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ECO-EFFICIENT MANAGEMENT OF WOODY FOREST RESIDUES FROM THE EUCALYPTUS PLANTATION FORESTRY

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INTRODUCTION

An eucalyptus forest, when planted, is mostly oriented to produce wood. Except for situations where the forest is planted to the effect of soil or hillside protection or conservation, or when the purpose is to produce leaves for essential oil extraction, an eucalyptus forest is almost always intended to generate wood for miscellaneous uses. This wood is immediately associated with the stem or trunk wood, the wood that will be harvested and cut into logs for the most different industrial or domestic uses: firewood, charcoal, pulp and paper, poles, stakes, panels, furniture, etc.

Evidently, in economic terms, the most valuable planted forest product is the trunk or stem wood. The trees are improved in order to produce this wood in a very efficient way. This has been so effective that most photoassimilates by the trees are converted into trunk xylem cells. The modern eucalyptus forests manage to place in their trunks nearly 72 to 80% of their total net organic material. From this trunk, approximately 91 to 94% of the dry weight is wood, while 6 to 9% is bark. When reference is only made to the tree components above the soil, or to its aerial part (stem, bark, crown, branches, leaves, fruits, flowers), the stem wood represents from 78 to 85% of the total dry weight of the tree above the soil. However, it should be always remembered that there are still wood-containing plant compartments: the branches, the root, the tops of tree in the crown.

Sometimes the forest inventories try to quantify the availability of useful wood in these forest compartments. Nevertheless, in most cases they confine themselves to quantify the so-called commercial wood, which is the wood formed by the trunk, from the tree base to a minimum diameter on the top, a diameter predetermined by the user of the forest. We know that the whole tree utilization (or whole tree chipping) dream showed at last to be economically unfeasible and environmentally incorrect. Therefore, nowadays one would hardly think of clearing a forest soil from tree stubs, in order to make use of their roots. Using leaves and thin branches (less than 2 cm in diameter) is also considered to be environmentally improper due to their high content of nutrients, that they can return to the soil in order to restore its fertility. On the other hand, thick branches and stem tops are sources of wood that should not be neglected. They were produced by the tree and may be used by society.

For better clarity, we will define in the following a terminology intended to be valid for the rest of the present chapter of the **Eucalyptus Online Book**:

- Forest residues or forest harvesting residues: all organic forest material remaining in the forest after its harvesting;
- Woody forest residues: wood remainders, with or without bark, after harvesting the planted forest;
- Thick branches: branches above 2 cm in diameter;
- Thin branches: branches below 2 cm in diameter;
- Tops of trees: upper branchless stem part.

When the planted forest is harvested, the harvesters are oriented towards high productivity in the operations. They try to cut efficiently the trees, to delimb them, to cut their top (to cut the top of the tree), to debark them. They also drag them, section them into logs and stack these logs up in piles. In all these operations, large amounts of organic residues are generated, such as bark, leaves, branches, tops of trees, fruits, etc. Our **Eucalyptus Online Book** contains two chapters (chapters 01 and 02) showing the organic material generation by the different tree compartments. In those chapters we discoursed on the bark, on the forest harvesting remainders and on nutrient cycling. In case of interest, find both chapters by visiting **www.eucalyptus.com.br**.

Whenever the words "forest residues" are mentioned, large amounts of organic material remaining in the forest field, right after the forest harvesting, are referred to. That material mostly consists of the bark and the crown of the trees, although some entire thin trees and thin logs are also left, neglected by the tree harvesters. The residual material, which may remain on the soil, performs remarkable functions as to its protection and conservation, its biology, mineral richness, moisture and erosive process containment. Therefore, thinking of removing all this richness for industrial use is not fair to Nature, nor it is to the next planted forest intended to be developed in this same area. Some forest companies use to remove these forest harvesting rests (including the whole crown) as much as possible, in order to use them as biomass fuel. They obtain an apparently cheap fuel, but lose in terms of natural patrimony, as their soil will degrade faster.

Forest residues add quality to the soil, but make the operations of the next silvicultural activities difficult, when it is the case of reestablishing the forest or managing by coppicing to get a new forest generation. The thick branches, the residual logs forgotten by the log forwarding operators, the thin trees felled and not removed, all of them end up disturbing the motion of the soil preparation and plantation operation machines. For this reason, many companies use to put it into practice to bundle up the forest harvesting rests in lines, or else to remove the thick branches and short logs, to use them as biomass fuel. The small diameter forest rests, the leaves and the bark are no disturbing factors for the machines, if they are well-dispersed or correctly bundled up in lines.

Burning forest harvesting rests in the forest field is a forbidden and inadvisable practice. However, there are still some farmers or forest planters committing this type of environmental crime, simultaneously a crime against their patrimony. When the forest harvesting rests burn, they quickly mineralize the organic matter, transforming it into fertilizing mineral ashes. Notwithstanding, they lose the soil protecting layer and at the first heavy rain they end up losing these ashes as well, that will be ending up in the water streams. Therefore, burning the residues in the forest field is the worst of all situations, besides the illegality of the practice. Removing close to all forest harvesting rests to burn them later in a biomass boiler might be also considered to be as negative to Nature as burning them in the forest field, although it is less bad, since it does not impact so much on the biology of the soil.

Bundling up the forest harvesting rests in lines is expensive, as it depends on intense labor utilization, more and more scarce in agriculture. Aligned bundling up becomes necessary in most cases due to the presence of thick material, branches, short logs, thin trees, roots, etc. This thick and heavy woody material will undoubtedly disturb the motion of the machines that will be brought for the new forest activity stages.

An alternative to bundling up in lines is using a movable chipper for these heavier and thicker residues, removing them as chips to be used as biomass fuel. It is a simple and suitable practice, if the ground topography allows it. Just woody residues or thin firewood logs are removed, leaving leaves, thin branches, bark, etc., in the forest field.

Finally, the other alternative presenting itself to the forest producer is to separate these woody wood residues, to collect them, to section them and to sell them as firewood. The operations involved are labor-consuming and expensive. However, considering the increasing energy wood price, they become viable and generate working positions in the forest field.

In the present chapter of our virtual book we intend to comment on the main opportunities to recover wood losses wasted as residues in the forest area. We will discuss the alternatives for reusing this wood, as well as for reduction in its generation. We will see its characteristics, its potential uses and which are the forms of management and handling that can be adopted for maximum eco-efficiency.

Then, the first thing to be done is to clearly define which material we intend to recover and to avoid wasting. It should become altogether clear that we are not speaking of removing leaves, thin branches and bark from tree debarking, when it is done in the forest field. By woody forest residues we are just referring to the residual usable wood remaining in the forest field after forest harvesting. For different reasons, forest harvesting is not complete, there is always some useful wood getting lost at last. As the forest was planted to produce wood, if we lose some of it we are reducing our efficiency to use the goods generated by the forest. The mill may lack on wood, so that an additional forest area will have to be planted to make up for this loss.

The wood lost at forest harvesting may be in the form of:

- High harvested tree stubs;
- Thick harvested tree crown branches;
- Stem tops below a given diameter pre-settled for top cut;
- Thin trees discarded by the harvester operator;
- Lost or forgotten logs, or left inadvertently in the forest field;
- Sawdust generated when felling the tree and sectioning the logs.

The amount of woody residues remaining in the forest field depends on a series of causes associated with the forest quality, tree homogeneity, minimum limit pre-settled for log sectioning for industrial use, equipment available for the forest harvesting, forest operators' care, training and qualification and management intended to be adopted for woody residue collection and utilization. We will briefly discuss each of these causes and their implications for higher or lower woody residue generation.

- **Forest quality**

Forests of high increments, clonal, well-homogeneous, with well-developed trees of good shape and uniformity, tend to generate much less woody residues. Planted forests originated from seedlings produced by the use of seeds, with more dominated trees and higher irregularity, generate considerably larger amounts of residues. Second or higher rotation forests, with not a very careful sprouting management, may generate significant amounts of thin logs, which are at last discarded by the forest harvesting operator, when considering the user's quality requirements.

- **Minimum log diameter limit for industrial use**

Pulp mills are very cautious and demanding with regard to the minimum log diameter for their industrial processing. There are reasons for such a behavior. Too thin logs break easily into short logs in the debarking operations, when carried out at the mill. Thin logs are also very light and behave unsuitably at chipping for chip production. This is more serious with chippers of older technological models. In the ideal chipping situation, larger diameter logs are chipped one by one. If there are many thin logs, they are fed together as a bunch into the chipper. As these thin logs are light, they get crosswise and irregularly into the chipping operation. Thus, they generate more wood slivers and large over-thick chips. The chip classifying screens become at last overloaded and allow bad chips to follow to cooking. The re-chipping operation also becomes overloaded for re-chipping the excess amount of wood slivers and over-dimensioned chips.

Nevertheless, it should become very clear that the pulp mill requirements to solve these problems in the industrial area may cause significant woody residue generation in the forest field. Then, these requirements must be very well balanced, in order not to favor the mill side and impair the forest one. As the eucalyptus tree has a conical shape, it begins thick at the base and gradually tapers off as a function of its height. However, this tapering is not homogeneous. From the base to approximately 75% of the height, the conicity is much more pronounced than in the region near to the crown, because the tree knows that it cannot have too thin the trunk region that supports the crown, as otherwise the latter will easily break at any strong wind. For this reason, the last tree height quarter shows a much lower reduction in its diameter tapering. In case the pulp mill makes exaggerated demands as to the minimum diameter to be received in its wood preparation area, the treetop length to be discarded will increase too much. In the past, as technology was more antiquated in the pulp mill wood preparation area, demands were considerably stricter. The minimum diameters to be accepted ranged from 8 to 10 cm, including the bark. Nowadays, with more modern chipping technologies and debarking being carried out in the forest field by harvesters, the pulp mills became more flexible, accepting diameters between 4 and 6 cm. There are mills accepting even smaller minimum diameters (up to 2 to 3 cm), provided they correspond to logs debarked in the forest. This procedure causes a substantial reduction in residue generation in the forest field, proving to be more eco-efficient.

- **Forest harvesting equipment and harvesting methodology**

The forest harvesting can be carried out either in a mechanized (harvesters, feller bunchers) or a semi-mechanized (motor saws) way. Debarking can be performed either in the forest field or at the mill. At present the mills tend more and more to opt for forest field debarking, leaving the organic forest harvesting rests for soil protection and conservation. With the higher energetic efficiency of the kraft pulp mills, the bark fuel demands decreased much. If some bark is required, a part of the forest harvesting, with forest field debarking, may be combined with another part being debarked at the mill, so as to fulfill the biomass balance. What is definitively uninteresting for a mill is that the whole wood supply comes with bark to the mill and that a huge amount of bark remains after debarking, as it would be exceeding the energetic biomass balance demands.

To leave the bark in the forest field, even just a part of it, is very interesting for two major reasons:

- The awareness of the advantages that this practice brings for the sustainability of the productive capacity of the forest site;
- The high energetic efficiency of the modern pulp mills, capable of operating with minimum auxiliary power generation. As recovery boilers are burning black liquors with or over 80% of dry solids concentration, and due to the higher circuit closure and heat loss reduction, the amount of auxiliary fuel for steam or electric power generation is increasingly smaller. To take all trees with bark to the pulp mill and to debark them there means to generate an enormous amount of bark at the mill. The exceeding amount of bark will consume costs, will be left over in the form of residues and will require a final disposal or recycling action. In other words, the soil is impaired when the whole bark is taken to the mill and later a problem is created for the mill, as a great portion of the bark will be left over in enormous amounts that will have to be discarded on sanitary landfills or returned to the forest. There are mills composting the bark for sale as organic compost, but this is also an expensive operation. It is better to leave in the forest field the amount of bark that should be left there, where composting will be natural, and the beneficiary thereof will be the new forest that will develop in that area.

The more mechanized is the forest logging, the lesser is the attention the operators pay to the small logs, thin trees or thick branches. The mechanized operations are excellent for the clonal, uniform forests with individual trees with volumes varying from 0.25 to 0.5 m^3 per tree. The forest harvesting productivity grows exponentially with the average volume of the trees. A forest with trees of 0.5 m^3 each is much more easily and quickly harvested than another one with trees of 0.2 m^3. The woody residue generation in the second case tends to be definitively higher. A harvester operator, when finding a small, low volume and thin tree, of 0.05 to 0.10 m^3, for instance, may not be interested in it, he may simply push it to cut it down, leaving it in the forest field and going ahead to harvest a bigger one beside that small one. Furthermore, more voluminous trees have proportionally a smaller volume of tops of tree, since their base diameter is considerably larger and their height is greater too.

When the forest harvesting is semi-mechanized, it is easier to orient the thin log separation from the thick ones (above or equal to the minimum diameter imposed by the mill specifications). However, the sectioning, delimbing, segregation and stacking operations are much more difficult to be carried out. These operations are very labor-demanding and therefore expensive. It must be always evaluated whether the wood getting lost is more or less worth than the additional costs to recover it.

- **Forest harvesting and woody residue segregation management**

There are several ways of doing the management for maximum woody forest residue utilization. Unfortunately, most of these management forms try to solve problems instead of acting preventively for maximum eco-efficiency and minimum residue and wood loss generation. The woody residues represent a wood produced by the forest, which was not removed to be consumed. This additional wood availability from the woody residues may be substantial. There are cases and cases, but according to the previously mentioned factors the amount of residues may range from 2 to 8% of the harvested commercial wood volume. Well, my friends, this is a quantity that cannot be neglected by any means. The trees produce this wood for our use and after all we do not take advantage of it. Worse than that, the forest inventories carried out by the forest area often forget to consider these possible losses. Thus, a certain forest will offer a certain wood volume to the mill in the form of trees in the felling age. However, at forest harvesting a smaller than projected volume is harvested, as some wood is left in the forest field as residues. After all, the mill will lack on wood supply. The "search for the guilty parties" begins at once at the companies, with some "heads rolling" from their managerial positions. This is a well-known and routine fact at the forest companies, where justifications are extremely abundant, while they lack a positive action to quantify the wood losses, to prevent them from occurring and to recover the maximum possible amount thereof.

Now, I would like to briefly list the main types of management, in order to be able along this chapter to have a better understanding of the ways of preventing losses, both at the mills and in the forests.

The most usual procedure for the clonal high-productivity forests has been to harvest and to debark the whole tree in the forest field, availing oneself of the limit to which the harvester succeeds in processing it without productivity losses. Thus, the tree is felled, easily delimbed, debarked and top cut up to the limits of the minimum stem diameter, corresponding to about 2 to 3 cm. Branches, leaves, bark and thin tops of trees remain in the forest field, considerably disintegrated and scattered. The debarked trees are sectioned into 4.5 to 5.5 m long logs. The upper end logs of the trees will be thin but long, which will not cause any troubles for their handling, forwarding and transportation. The thin log problem will be transferred to the mills.

Nevertheless, many of these pulp mills will be already of new technological generations, with more efficient chippers and modern chip classifying units. They are capable of absorbing this potential inefficiency caused by the small diameter logs. The thick chips and the wood slivers, plus the rests of bark accompanying the logs, are separated and sent to burn in a biomass boiler. They become biomass generated by the wood chipping and preparation area. The forest area practically gets rid of the residue generation problem, having just to do a fine adjustment, gathering lost logs, thin trees discarded by the harvester operator, etc. Even thus, the forest manager can evaluate whether it is necessary to gather this wood or not. He must quantify these losses and evaluate the economics of the operation. Highly productive forests of 45 to 55 m^3/ha.year highly favor a forest harvesting as mentioned. The harvesting area is relatively clean from coarse residues, which will facilitate the activities of the silviculture that will get in to manage by coppicing or by replanting the area.

Another procedure of doing the management is by separating the thin logs in the forest field, segregating them from the thicker logs. Thin trees and thick branches, with diameters ranging from 2 to 6 through 8 cm are sectioned into wood for energy generation (firewood). This may be done so as to obtain 1 m long logs, stacked up for separate handling and transportation.

However, one should be aware that the thinner the wood the worse is the stacking factor (ratio between solid cubic meters of wood per stere cubic meter of stacked up wood). On the other hand, this loss in stacking factor is minimized when cutting the logs shorter. The shorter the logs, the better they can be stacked up and the better will be the stacking factor. A loss is made up for with a gain. With this type of management it is possible to obtain something like 92 to 98% of pulp wood and from 2 to 8% of thin wood for energy. As the basic densities of the pulpwood and fuelwood are close to each other, the percentages mentioned are valid both for quantification's expressed in solid wood volume and in dry weight. Care should only be taken in order not to compare the stacked volumes measured in stere for these two types of woods: thin and normal diameter logs. We know already that the stacking factors vary considerably. We will see this later on. This type of management is interesting, as it even involves separate transportation and industrial processing at the mill. More labor is required, but more wood is recovered and each type of wood is processed in a more suitable way and more compatible with its characteristics. Even thus, there occur wood losses, as separation is difficult: there are situations where it is so difficult to remove the residue that the forest worker chooses to leave it in the forest field. The losses concerning wood difficult to harvest or to collect may represent from 0.5 to 1.5% of the volume produced by the forest stand. However, it is obviously better to lose 1% than 4 to 5%, do you agree?

Some companies opt to harvest this fuel wood (biomass) with own human resources. Other ones wisely go into partnerships with the community, developing legalized cooperatives of small diameter firewood gatherers in the forests after harvesting. These cooperatives are oriented to gather, section, segregate and stack up the thin firewood logs on the roadside. They have as guarantee of sale the purchase by the forest company itself, who should pay a fair price and will be able to use this firewood as biomass in its power boilers.

We have already mentioned that there is a form of management consisting in gathering the whole amount of generated organic forest residue, chipping it in movable chippers and producing mixed biomass chips. These chips are transported in bulk to the mills and will feed the power boilers. They carry energy, but also carry large amounts of important nutrients, such as nitrogen, potassium, phosphorus, etc. In Chapter 02 of our **Eucalyptus Online Book** we have discussed the little economical validity and the environmental mistake of such a procedure. A poor biomass is obtained, considering its low apparent density, while much energy and human effort are spent for this all. The economical and environmental balances do not justify this form of management.

There is still another form of management, which is wasteful, but is being put into practice by some companies. They shoulder this loss of wood remaining in the forest field as if it were normal, letting good wood to decay in the forest field. Partly this is good for the environment, as the wood will putrefy and release carbon and nutrients to the soil. However, the forest-based company will lose a significant fraction of wood that was produced by the forest and will not be used. It should be born in mind that the concept of eco-efficiency is to produce more and better with less use of natural resources. Besides leaving a percentage of good wood – a ready raw material – in the forest field, new forest areas will have to be planted in order to compensate this lost wood. If for instance 3% of wood is being left in the forest field, susceptible to be recovered, an additional of 3% of forest area will have to be planted to make up for this loss. It means that a company handling a total of 100,000 hectares of forests will have to plant 3,000 additional hectares to make up for this loss. Therefore, a larger area of effective plantation, a larger total area of land, a higher involvement of resources, a higher environmental impact. And this all due to an inefficiency in recovering ready wood that the planted forest is offering us. For this reason, eco-efficiency is wisely acting when it recommends us a better use of the resources offered us by Nature. And in the present case Nature offers us the wood from the planted forest in order to meet requirements of society. In addition, Nature offers us the bark, the thin branches, the leaves, the roots and the planted forest understorey, in order to serve as soil protectors, enriching it and protecting it against erosion, compaction and drying up. This all is magnificent. Knowing to use what should be used and to save what needs to be preserved we will add happiness to society and environmental richness to Nature.

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QUANTIFYING FOREST HARVESTING WOOD LOSSES

We have just shown that wood losses at a planted forest harvesting may be significant. We have discoursed a great deal on wood considered to be thin, reduced in diameter, as well as on the wood losses in the form of logs, short logs, tops of trees and branches. Nevertheless, these are not the only wood losses in the forest. Unsuitable forest harvesting or inattention with regard to the specifications made for cutting and sectioning the logs may also represent an additional amount of lost wood. These quantities may also be significant.

Following are the main forms of losing wood at a forest harvesting:

- **High stub**

When the motor saw, or the harvester, or the feller buncher cut the tree, they leave a stump or stub in the forest field. The recommendation made by the forest research and planning areas is to cut the eucalyptus tree at a maximum height between 5 and 10 cm from the soil surface. With this height, the future sprouting, if handled and conduced, will be more vigorous and will form a tree less influenced by the residual stub of the just felled tree. The new tree will grow more rectilinear and when it is grown-up it will not even be noted that it is originated from a sprouting of the stump. Nor will this low stub height disturb the motion of machines in the subsequent forest operations.

The problem occurring in general is that the motor saw operators do not feel ergonomically comfortable to cut the tree at such a low stub height, whereas the harvester operators, due to the fact of being in the machine, do not have such a clear notion of the cutting height. There is always a false soil level, caused by leaf, bark and branch deposition; or else by the ground unevenness, among other possible causes. Then, the operator has a false sight of the base of the tree, as it becomes unclear where is the soil and where the base of the tree (transition region between tree stem and roots). If the cutting equipment does not set a low height limit, in order that this cut really occurs at so low a point as specified, the stub height may be excessive. An additional problem is that many of these robust forest harvesters set too large bases to protect the chain cutting device (saw), which may set the cutting height at about 15 – 20 cm or even higher. Undoubtedly an additional amount of wood remaining in the forest field. There are even cases requiring onerous operations of stub reduction on height, to allow silviculture machinery to get in for reestablishing a new forest in the same area.

As a result of this high cut and of the compaction of the organic tree litter deposited on the soil surface after forest harvesting, in many cases it is possible to have a clear sight of the rests of protuberant stubs in the soil, aligned and showing the waste we had generated by our poor operation. It is even very common to note, a short time after forest harvesting and after the whole "straw" has settled, that the stubs are about 15 to 20 cm high with regard to the ground level or from the transition region between tree stem and roots. This means waste and inattention, or mismanagement.

We will calculate in the following table the wood losses based on cutting 5, 10, 15 and 20 cm high stubs. We will do this for trees with distinct individual volumes, both for small and more voluminous trees. At eucalyptus harvesting, trees with individual volumes ranging from 0.15 to 0.6 m^3, mainly as a function of the cutting age and the average forest increment, are common.

Table 01: Loss of wood left in the stub or in the stump (in percentage of the commercial wood volume of the tree)

Tree volume without bark (m^3)	**Stub height (cm)**			
	5	**10**	**15**	**20**
0.15 (12.5 cm BHD* - 25 m H**)	0.45	0.85	1.30	1.70
0.30 (16.5 cm BHD - 28 m H)	0.40	0.75	1.15	1.50
0.45 (19.5 cm BHD - 30 m H)	0.35	0.65	1.00	1.30
0.60 (21 cm BHD - 35 m H)	0.32	0.60	0.90	1.20

* BHD = Diameter at Breast Height
** H = Commercial Height

This table motivates us to reflections. Due to operational carelessness or to non-fulfillment or even lack of cutting specifications, an amount between 0.5 and 1% of wood may be lost in the forest field, if the cut for felling the tree is done at a point higher than required. It also indicates that the better the trees, the higher is the harvesting efficiency. In case of more productive forests, the forest harvesting performance is better in many requisites, including wood losses.

- **At log sectioning, due to the rotors or the cutting blades thicknesses**

The modern harvesting machines have cutting devices ranging from 0.8 to 3 cm thick, according to their design and operating concept. The motor saws have approximately 0.9 cm wide cutting blades. When a tree is sectioned into logs, at each cutting equipment pass this average wood width is lost and transformed into sawdust, falling to the ground. The shorter the logs, the more cuts are required. More energy is spent and more wood is lost in the form of sawdust.

If a tree is 30 m high and is sectioned into 2 m long logs, a cut is made at the base and further 15 cuts are made to log the tree into 2 m logs. In case a motor saw is concerned, 14.4 cm will be cut from the height, to turn into sawdust by means of this procedure. This corresponds to approximately 0.45% of the tree that is lost, only considering this operation. The shorter the logs, the higher will be these losses, which is completely natural, it is pure mathematics.

If a harvester is used, which will log this same tree into 5 m long logs, calculations will have to be changed, to see whether there are advantages involved and which they are. The cutting blade of a harvester is approximately 0.8 cm wide. Seven cuts will be made, one at the base and six sectioning cuts. This corresponds to 0.18% of wood loss, a considerably better figure, but even thus it is a significant loss.

Now, if a feller buncher is concerned, having a 3 cm wide cutting rotor to fell the tree, the situation will be different. The tree is dragged to the roadside and sectioned into 5 m long logs, this time with a 0.9 cm wide blade. The wood loss will be equivalent to 0.3%, which is also impressive. This means that we are always speaking about wastes, which added up along the whole operation may amount to an enormous value. It should be born in mind that the forest inventories including these losses are just a few. Just to cut the trees and to section them into logs we will be losing 0.2% or more of the forest stand wood volume. If the forest stand is yielding 300 m^3/hectare in the cutting operation, 0.6 m^3 of wood will be lost only in this sectioning operation. Adding this to further 0.5 to 1 m^3, which was left in the high stub, there will be already a yield of 1 to 1.5 m^3 minus in the forest productivity. Huge wastes, if we do not take ourselves to doing everything well-done and paying much attention to these details.

- **At forest field debarking**

The forest field debarking operation is violent and brutal. There will be always trees that do not resist and break. Furthermore, always when scraping the tree to remove the bark, some wood is scraped along with it. These added losses have already been computed in some experiments and correspond to 0.1 to 0.15% of the total wood.

- **At tops of trees, thick branches and thin trees left after forest harvesting**

These values correspond to 2 to 8% of the total solid volume of the commercial wood of the forest stand. This broad range varies as a function of the forest quality, the specifications of the minimum diameter to be harvested, the harvesting equipment used and the machine operators' abilities and care.

It was also already proven that the clonal forests, of excellent quality, homogeneity and productivity, generate lower percentage values of woody residues. Then let's suppose that an excellent forest, with a commercial wood increment of 50 m^3/hectare.year, generates 2% of woody forest residues i.e. of good but neglected wood. Comparatively, a worse forest, with 30 m^3/hectare.year, may generate, for instance, 7%. At the age of felling, when it is 7 years old, the excellent forest would yield 350 m^3 of commercial wood, 7 m^3 of which of woody forest residues, while the worse quality forest would have a potential production of 210 m^3, of which the woody residue generation would amount to 14.7 m^3. In both cases, a considerable amount of useful woody material produced by the forest and that is possibly being wasted.

We have also seen that even with careful wood residue hand-gathering an approximate amount of 0.5 to 1.5% of wood potentially usable as firewood or energetic biomass still remains as residue in the forest. Anyway, removing tops of trees, thick branches and short logs is an eco-efficient way of using well the planted forest. Even if this removal is not complete, the remaining residues in the forest field will fulfill an environmental role, decomposing in the long run and adding carbon and nutrients to the soil.

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TRAPS EXISTING IN WOODY FOREST RESIDUE QUANTIFICATION

When referring to recovered woody forest residues, we are mostly referring to woods with bark in the form of thin, relatively irregular short logs. Evidently, there are also larger diameter materials, like the normal logs inadvertently "forgotten" in the forest field by the cutting and log forwarding operators. These logs may be thick logs laid on the ground to form a cushion for log stack deposition, which get very dirty with sand and soil after some time. They may be also logs dropping from the transporting vehicles, that fail to be collected. They may also originate from thin or defective trees that the harvester operator rejected and has not harvested, just having thrown them to the ground.

It should be born in mind that when we refer to residue volumes we are almost always referring to wood with bark. The thin logs, small in diameter, are very difficult to debark by mechanical means, not to speak of the manual debarking. Thin short logs, under 6 to 8 cm in diameter, have a rather significant bark proportion, considerably higher than logs larger in diameter. It can be surely stated that these thin logs have a bark proportion ranging from 15 to 25% of their total volume.

The optimum manner to quantify woody residues would be based on their dry weight. However, this measuring is difficult to make in the forest field. In addition, as thin short logs are concerned, the residues dry faster than the logs, having therefore higher consistencies than the regular logs larger in diameter.

The most usual way of quantifying woody residues is based on their stacked up volume, or stere cubic meter, or stacked cubic meter. This measuring is very easy to make, but involves some traps. The first one is that it does not measure the "actual solid volume" of logs, but the volume of a log stack. If the forest increments are being followed in solid cubic meters, while those of the residues are measured in stere, we will be speaking about rather different units. There exists a factor that relates the actual log volume to the stacked up volume and is called stacking factor. The higher this factor, the higher the actual wood volume existing in the log stack.

This stacking factor (S.F.) is affected by a series of parameters, the most important of which are as follows:

- Log diameter: the smaller the average log diameter, the lower the stacking factor, since more logs will be required to be stacked up in order to compose one cubic meter of stacked up logs. As they form "cages", this favors stacking factor reduction.
  For example:
  16 to 18 cm in diameter: Stacking factor of 0.70
  13 to 16 cm in diameter: Stacking factor of 0.67
  4 to 7 cm in diameter: Stacking factor of 0.52
- Log length: the shorter the logs, the higher will be the stacking factor. Longer logs tend to form more "cages" or empty spaces in the stack.
  For example:
  15 cm in diameter and 2.3 m long logs: S.F. = 0.67
  15 cm in diameter and 1 m long logs: S.F. = 0.72
- Short log form: the more rectilinear the short logs, the higher will be the stacking factor.
- Short log dryness: the drier the logs, the higher will be the stacking factor, since when drying the wood it suffers a contraction in its volume. Thus, more short logs will be placed in one cubic meter of stack. The volumetric contraction, depending on the drying intensity, can range from 3 to 5%.
- Operators' care when stacking up the wood

The commonest procedure in residual woody material collection, sorting and segregation operations is to cut and stack up one meter long short logs with bark. These short logs are considerably dry, as this whole residue collecting operation occurs at least 15 to 30 days after felling the forest. As the material is quite dry and cut into one meter long short logs, the stacking factor reduction occurring due to the smaller diameter of these short logs will be partially made up for. Even thus, the thin and short log stacking factor will be approximately 10 to 20% lower.

For the above-mentioned reasons, I would like to make a recommendation to everyone measuring stacked up forest residue wood volumes. Try to make a good gauging and control of your stacking factor, in order to avoid paying for "empty spaces" rather than for wood, when paying for it. Establish reliable values for the thin short log stacking factors according to their quality (moisture, crookedness, length, diameter). This all is necessary, because one cubic meter of stacked up wood may contain from 0.5 to 0.7 solid cubic meter, which is a fair difference. Besides, sometimes thick logs without bark and thin short logs with bark may be referred to. If these thin short logs are intended to be used for coal or biomass fuel production, this is not so important, although bark has a lower calorific power than wood. However, if it is the wood, not the bark, the residue purchaser is interested in, he should pay attention to the high proportion of bark present on these thin short logs.

All these traps help reinforce the suggestion of negotiating woody forest residues based on their dry weight, not on their volumes. It is much simpler and the work of persons cutting 1 meter long short logs, stacking them up and cubing the stacks can be minimized. It should be also remembered that the simple operation of sectioning a 2 meter long log into two one meter long each corresponds to a loss of 0.4% of wood turning into sawdust. Stacking up these thin residue logs requires a considerable manual work. It is practically impossible to carry out this work using machines. Small diameter log handling is enormous. To have an idea of the increase in the number of logs due to the differences in diameters, it is enough to mention that in a cross section of one square meter of a log stacked pile there are from 2.5 to 3.5 times more logs when the residue short logs are counted than when counting the number of normal logs. While there are 40 to 65 logs ranging from 12 to 18 cm in average diameter per square meter of cross section of the stack, there will be from 120 to 150 logs of thin wood residues. The stacking difficulties result in low stacking factor values. Carefully this thin and short log stacking operation is done, it is inevitable: the stacking factor is still low. Low stacking factors are absolutely favorable to the wood seller, not to the wood buyer.

This all stresses the importance of purchasing wood based on its weight. Considering that the basic densities of the thin and of the thicker log woods are relatively close to each other for eucalyptus trees, the relationships that will establish themselves between dry weights and between solid wood volumes will be very similar. Let's explain it better: if the ratio of the solid residue volume to the total solid volume of wood produced in the forest stand is 3%, the ratio of the residue dry weight to the total wood dry weight should be also around 3%.

Another important aspect that may be a measurement trap refers to the basis the generated residues should be referred to: whether to the effectively harvested useful wood or to the total harvested wood plus residues. Let's give the example of a forest of 50 solid cubic meters of commercial wood/hectare.year of growth rate. When it is 7 years old it has potential to generate 350 m³ of commercial wood. However, at forest harvesting the volume is measured and 340 cubic meters of debarked wood are thus obtained. When collecting and measuring the forest harvesting woody residues, the measurement resulted in 18 solid cubic meters of thin wood logs with bark (after equalization by the corresponding stacking factor). Then how to express the residue percentage? If this is done based on the useful production of harvested commercial wood, the figure obtained is 5.29%. If based on the total wood production plus residues, the percentage ratio drops to 5.03 %. If the residue bark is deducted (15% of bark), just to speak in terms of wood, these proportions would be 4.5 % and 4.3 %, respectively. This all must be very clear when the results are reported and presented on the managerial and production planning meetings, as otherwise there may be unpleasant surprises.

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RECOVERING AND MINIMIZING OUR WOODY FOREST RESIDUE LOSSES

We have already discussed the appreciable volumes that may be left in the forest field after forest harvesting. It is the forest manager's role to minimize these losses. To minimize and optimize, the manager must quantify very well and value these residues in economical terms.

The residue recovery begins by preventing their generation. It is necessary to understand the reasons and causes for their generation and work thereupon. The necessary fulfillment of the specifications established for forest logging by the operators distinguishes itself among these causes. These specifications include: cutting height or stub height, collection of logs lost during handling, respect for the minimum treetop sectioning diameter, etc.

Even with strict fulfillment of the specifications there may be significant woody residue volumes, potentially capable of being converted into raw material, especially for energy.

The leverage of social community programs starting from collection, segregation, sectioning, stacking up and commercialization of residues is an interesting alternative for the companies. Regardless of the labor legislation problems that this may provoke, the forest businessmen have managing skill and intelligence to find juridical solutions to minimize these risks. They must also consider this as a program of social responsibility. It is very different from just allowing "residue pickers" to appear there to remove residues, often in situations that are not quite fair in social terms. With a practice based on social justice and potential for economical results for both sides, the forest manager can generate working positions and make possible an income to be earned by a destitute population of low educational qualification, who is in need of opportunities. It consists in one more practice of social responsibility that may become important for our forest-based sector.

In the following, we will make a little and simple economical valuation for residue utilization and what these residues may generate for both parties – company and community. The manager should always bear in mind that when recovering a certain percentage of wood coming from the residues he will be needing less planted area proportionally to the amount of recovered residue wood. This is definitively very important. It means less land to plant, lower costs and lower environmental impacts.

Let's give the example of a planted forest having a yearly average increment of 45 m^3/hectare.year of commercial solid wood without bark. When it is harvested as it is 7 years old, this forest would yield 315 solid cubic meters of solid commercial wood in the form of logs for the pulp mill. The forest harvesting is supposedly done by using harvester type machines, with debarking carried out in the forest. The operator of our harvester was given instructions for 10 cm as maximum stub height to be left and to cut the tree between 5 and 10 cm from the transition region between tree stem and roots (average of 7.5 cm). However, due to deficiencies of his training and care, as well as the harvester's, the average stub height resulted to be 15 cm. In addition, the discarded thin trees, thick branches and tops of trees under 7 cm in diameter, which was the minimum diameter specified for top cutting the trees, remained in the forest field. In the log forwarding operation, some wood logs fell to the ground and at last were forgotten in the forest field.

All these quantities were measured by the forest research personnel and the average values expressed in solid cubic meters of woody residues per hectare. The results are exemplified in the following:

- Thick branches (above 2 cm) : 3.05 m^3/ha
- Wood with bark from tops of trees under 7 cm in diameter: 8.7 m^3/ha
- Thin trees: 4.7 m^3/ha
- Wood forgotten in the forest: 1.6 m^3/ha
- Wood lost in the stub, as the average of 7.5 cm was not observed: 0.63 m^3/ha.

These measurements have already incorporated the stacking factor value differences and all of them are referred to solid cubic meters.

The loss of wood corresponding to the higher stub is irreversible, there is nothing to do unless to regret. This means that due to bad operation 0.63 m^3 of wood is lost per hectare. It remains to offer a better training to the operator and to orient him to observe the specification better at the next forest harvesting operations. Sometimes it is a harvester equipment problem, something that should be also ascertained.

The estimated potential commercial wood production was 315 solid cubic meters. Nevertheless, 0.63 cubic meter was lost in the stub, 1.6 m^3 of good logs was forgotten in the forest and 4.7 m^3 of thin trees, that have been inventoried and helped us estimate the amount of 315 m^3 of wood at the forest harvesting, were neglected. Just deducting the thin tree bark represents already a loss of 3.9 m^3 of wood. The result of this all is that our production, that should amount to 315 m^3, was restricted to 309 m^3. A volume of 6 cubic meters "vanished". A mistake of inventory? Certainly not. How could we call this phenomenon, commonplace at our forest companies?

These losses of thin trees, forgotten wood, thick branches and treetop wood may be recovered by cooperatives of woody residue gatherers. We know that a total collection of this material is practically impossible. In addition, when sectioning the logs into 1 m long short logs an additional percentage of about 0.4% of wood will be lost, converted into sawdust by the motor saw action. For this reason we will adopt a 90% recovery of this material susceptible to be recovered. Following is considered therein: thick branches, tops of trees, thin trees, "forgotten" wood. The sum of these volumes corresponds to 18.05 m^3/ha. In percentage terms, the amount of generated residues for this hypothetical case was 5.8%, related to the useful production of 309 m^3.

Recovering 90% of this material will correspond to 16 m^3/ha of energetic firewood, made available in the form of 1 m long short logs stacked up on roadsides. It can be purchased by the company owning the forest itself, at firewood market price. If a value of US$ 15.00 per solid cubic meter of firewood under the offered conditions is admitted, there will be a gross income of US$ 240.00 per hectare for the cooperative. Something economically very interesting, besides environmentally correct and socially fair.

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MAIN WOODY FOREST RESIDUE WOOD CHARACTERISTICS

The bibliographic references about chemical composition and properties of eucalyptus tree woody residue woods are not very abundant. Moreover, in general they do not clearly show the sampling processes, whether characterization is based on wood with or without bark and which is the variability of the results obtained. Considering the enormous dimension of the potential supply of these materials, more stress should be laid on these studies. On the other hand, there exist many studies of the variability of eucalyptus wood lengthwise to the trunk, from the base to the top of the trees (root → crown direction). The branches and treetops characteristics are connected with the greater presence of bark, besides being aerial parts of the trees, very active in mineral utilization. For this reason, the analyses of chemical composition of these materials have revealed higher contents of mineral ashes and lower contents of pentosans and holocellulose. The analyses are often performed on material with bark, which affects considerably the results. The treetop residues, for instance, may represent from 2 to 5% of the total wood of the tree, but they have from 3 to 6 % of the total bark of that same tree.

Regardless of the presence or absence of bark, these tops of trees consist of irregular wood, with a high frequency of knots from the insertion of still live branches of the trees. The knot wood is responsible for the higher content of lignin and extractives of that wood, as well as for the increase in its basic density. Even when the knot influence is isolated, this treetop wood is denser, richer in lignin, in extractives and has a higher ash content than the average wood of the tree. Hence, its good fitness for energetic firewood. There are many evaluations available in literature, regarding calorific powers of these residues, much more than the volume found for their chemical characterization.

Under normal conditions, it can be surely stated that the treetop wood, where the crown fits in, has a basic density approximately 10% higher than the average basic density of the tree. The contents of extractives and lignin are 4 to 8% higher. If in the trunk the lignin content participates in the wood composition with about 26%, in the tops of trees it reaches e.g. 27.5%. The high calcium and magnesium contents in the high parts, as well as in the bark of the trees, convey to these tops of trees about 30 to 50% higher ash contents than those found in the average wood of the tree.

As a reflection of these properties, the fibers of these woods have thicker walls, with higher wall fraction and higher coarseness.

The branch woods are very similar to those of tops of trees. They are very mineral rich, their ash contents are high (about 1% of their dry weight). The lignin contents are approximately 10% higher and those of extractives are 20 to 30% higher than those of the trunk normal wood. As to the basic density, it is very similar to that of tops of trees. An interesting anatomical characteristic of the branch wood is the smaller length of its fibers, showing the juvenility of this wood.

With regard to the eucalyptus tree root wood, there is surprisingly very little information in literature. In general, this wood has little utilization, except when some soil clearing from tree stubs is carried out. This root wood, due to its characteristics and irregularity, is much more useful as firewood, for artisan craft works or for charcoal manufacturing, than for industrial uses. It is a dense wood, with high contents of extractives, lignin and minerals. Its ash content is rather high due to the presence of concentrated mineral sap, which must be like that in order to favor absorption of water and minerals from the soil by osmotic pressure differential. The plant manages to do this due to the higher ionic concentration required in the internal solution of its root cells, compared to the soil solution.

Another very difficult and contradictory material, as far as its chemical compositions and the basic density of its wood are concerned, consists in the so-called thin, small diameter or dominated trees of a forest stand. The expectation for dominated trees is a slow rate of growth, under some kind of stress, as for lack of light, water and nutrients, or due to some attack of disease or plague. This may be also partially due to their inferior genetics. The wood quality primer reads that this wood should have a higher basic density, as well as lower lignin content and higher holocellulose content. However, there are several literature references indicating that dominated trees have lower basic density, especially at clonal forest stands. This has been explained by the selection of superior trees, often based on the concomitant selection of trees of higher basic density and higher volumetric increment. In other words, the high intensity of genetic improvement may be affecting the traditional wood quality concepts, developed for eucalyptus trees growing at forest stands obtained from seeds, still with a low level of tree breeding. As in general the forest geneticist selects at the same time volumetric growth and basic density of the wood, the trees growing more have also in their genome the genes for higher wood density. This is evident for species like *Eucalyptus grandis*, *Eucalyptus saligna* and for the hybrid *E.urograndis*, which in Brazil are the materials presenting the most intense level of genetic improvement.

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GENERATING EXTRA WOOD FOR PULP PRODUCTION BY USING EUCALYPTUS WOODY FOREST RESIDUES

Whenever wood becomes scarce or more expensive, the consumer's and the producer's eyes turn attentively towards the wood losses of the forest harvesting operation. It was already seen and repeated that these volumes are representative, reaching values ranging from 2 to 8% of the volume of harvested wood.

There are several options for utilization of this material by the pulp mills, thus increasing the wood supply for the chippers and digesters.

The simplest way of having more wood supplied is by reducing the minimum log diameter limiting specifications. For example, if the limitation was 7 cm with bark, it might be reduced to 4 cm with bark. Thus, we will be able to supply an additional wood volume of 2 to 4% to the mill. Debarking this thinner material is very difficult. If debarking is carried out at the mill, the debarking efficiency decreases, so that more bark will go to the digesters. Also, a greater log breaking occurs inside the debarking drums, generating more short logs for energy. This all impairs the industrial operations, making them more difficult, since chip quality and purity decrease. Many mill managers, even working with lack of wood, do not like this option of using very thin wood logs.

The other option would be to debark in the forest field, using machines, since manual debarking for this material cannot be thought of, it is unfeasible. The present processing harvesters can do this job reasonably, even because they are designed to debark the whole tree, from one end to the other. In practical terms, when reducing the minimum diameter to a lower value, we just lengthen the trees a little more. If these elongated trees with thin end resist well the harvester operation, this is a rather viable and economical option. It is also well-known that harvester debarking is not very efficient. Much bark, from 10 to 20%, still remains together with or adhered to the logs. When these logs are subsequently dried, the bark gets looser and its removal in the log washing and cleaning operations is easier. The removed bark will either remain as a residue at the mills or will have to be burned in the biomass boilers. Thus, a cleaner chip will be guaranteed. Thin and long logs may provide good quality chips in horizontally fed chippers. Therefore, there exists a reasonable technology that makes it possible to consume a larger portion of the wood that at present is lost as woody residue in many forest logging operations.

When the forest-based company will have at its disposal suitable technologies to prevent too much bark from getting into the digesters, to reduce wood sliver and irregular chip generation, which increases with the thin logs, and also to prevent thin logs from breaking into short logs in the wood preparation yard operations, this option will definitively become an excellent alternative.

In case the company does not have these technologies available, a more troublesome but efficient option consists in segregating these residues in the forest field and in processing them separately for pulpwood chips. Mechanical debarkers can be used for this thin wood logs in the forest field itself, as well as chippers specially designed for lighter small diameter logs.

Branches, thin short logs and tops of trees are sources of additional wood for the industrial processes, both for energy and for pulp. It is up to the technicians and managers to find the best solutions. If the main line is impaired by residue incorporation, there is always the alternative of processing them separately, giving them conditions optimized for their realities.

Due to the chemical and anatomical characteristics of these residual materials, they will behave distinctly at separate pulp production. They will consume more active alkali, will have slightly lower screened yields and the pulp quality may be slightly poorer in terms of strengths and cleanliness, due to the greater presence of bark and differences in wood quality. However, this material corresponds to small proportions with regard to the total mill wood and should not affect significantly the pulp quality after mixing both types of pulps. These differences can be minimized by suitable forest and industrial operations and technologies, in the wood yard and in the chip preparation and selection area. If the bark is carefully separated and good quality chips are produced, differences will be minimal and the woods will be even able to be processed concomitantly.

The cooking operations of the woods from branches, tops of trees and thin logs have shown some differences with regard to the normal stem wood. This is understandable, since the woods are somewhat different in their chemical and anatomical compositions. There is also the bark factor that influences still more the negative aspects. These differences result in lower yields at the conversion into screened pulp (from 2 to 5% less, based on dry wood), higher active alkali consumption's (about 1.5 to 2% more active alkali, % NaOH wood basis) and higher TDS (Total Dry Solids) generations in the black liquor to the recovery boiler (about 0.15 to 0.2 tons of TDS/adt of pulp in the digester). These are disadvantages of these materials, if separately processed. In case they are processed after being mixed with normal wood, they will also exert an effect on these pulping properties. These pulping differences are caused by differences in terms of lignin content, basic density, presence of knots, extractives and mineral ashes, in addition to the influence of a larger percentage of bark, which increases this effects, too.

There is a whole chapter in our **Eucalyptus Online Book**, where we describe eucalyptus bark and its effects on the forest area and pulp production. (**http://www.eucalyptus.com.br**).

For this reason, one should try to optimize the woody residue processing starting from the forest area, by means of procedures such as:

- To work with debarked material as well as possible;
- To work with best quality chips, avoiding the presence of wood slivers, over-thick chips, bark, sand, soil, stones, etc.;
- To have a low proportion of these residues in the wood mix (5% at most);
- To have a good mixture of this material in the wood mix, in order to avoid pockets of different materials inside the digesters;
- To have a constant follow-up of the bark content, rejects leaving the digester, dirt specks in the pulp, "pitch", and TDS/adt of pulp ratio;

- To have a detailed evaluation of the cost effectiveness involved, always trying to distinguish and to balance the advantages and disadvantages of the operation.

It is also well-known that the kraft pulps produced from these residues are slightly weaker in terms of strengths (tear, folds, tensile, elongation), but they have better apparent bulk, absorption capacity and porosity. These are absolutely common conditions for woods of these qualities, with higher basic densities and greater presence of thick-walled fibers.

Therefore, my friends, viability exists, but it must deserve continuous monitoring. The reason for this is easy to understand. We may believe that we are using this wood and earning a lot, but in fact we may be losing production, quality and economic results. It is very common that this occurs at mills having a production bottleneck, with no capacity to feed any more chips to their digesters due to limitations in the digester itself, in the recovery boiler or in the white liquor preparation. If the mill has capacity to absorb these residues as an extra wood capacity, above the level it was already consuming, and does not have any limitation, this would be the great advantage for using woody residues. For example, if a mill has production limitations for lacking of wood, it surely will produce more and earn more by using residues. Now, if it goes on feeding the same amount of wood, just replacing a better wood with residue wood, it may meet with production and result losses. In these cases, it is better to supply the wood residues to the biomass boiler, as fuel wood.

We will see these two cases in two case studies shown in Tables 2 and 3.

Table 2: **Case A** – A kraft pulp mill consumes 8,000 solid cubic meters of standard quality wood per day and proposes replacing a part of this wood with woody residues (4 and 8% in the wood mix, in two steps) – Results estimated in the unbleached pulp production

	% Woody Residues (on dry weight)		
	0	**4**	**8**
Screened kraft pulp yield - %	53	52.5	52
Alkaline charge applied - % NaOH	18	18.5	19
Wood mix basic density (dry t/m³)	0.500	0.502	0.504
Daily wood consumption (solid cubic meters)	8,000	8,000	8,000
Daily pulp production in the digester (odt/day)	2,120	2,108	2,096
TDS/adt (for 80% activity in white liquor)	1.31	1.34	1.38

This is a very well-known situation. As a function of the quality loss of the wood getting into the digester, due to the presence of residues with more bark, the mill of **case A** will consume more active alkali, will generate more TDS to the recovery system and its daily pulp production will be reduced to the same volume of the supplied wood. The losses may be even higher if the boiler does not endure this additional TDS load or if causticising does not cope with the additional amount of white liquor. This situation of case A is very common to happen, differently from the situation of case B.

In **case B** the mill was facing wood supplying difficulties and was only consuming 7,500 cubic meters/day of wood. With the addition of 4% of woody residues to its present demand (7,500 x 0.04 = 300 m³/day), it would be adding further 300 m³ of wood to process at the mill. Applying 8%, the new consumption would be then 8,100 m³/day (7,500 + 600= 8,100 m³/day). It is admitted that the mill has no digester feeding limitations, nor does it have any in the recovery boiler or in terms of causticising. In short, the residues will come in order to increase production. Then let's see how the situation of our case B would become:

Table 3: **Case B** – A kraft pulp mill manages to increase the wood supply (which was scarce) by using woody residues (4 and 8% in the wood mix, in two steps) – Results estimated in the unbleached pulp production

	% Woody Residues (on dry weight)		
	0	**4**	**8**
Screened kraft pulp yield - %	53	52.5	52
Alkaline charge applied - % NaOH	18	18.5	19
Wood mix basic density (dry t/m³)	0.500	0.502	0.504
Daily wood consumption (solid cubic meters)	7,500	7,800	8,100
Daily pulp production in the digester (odt/day)	1,987.5	2,055.7	2,122.8
TDS/adt (for 80% activity in white liquor)	1.31	1.345	1.38

Definitively, case B deserves to be celebrated. The mill consumes residues and increases its production, its wood limitations finish and happiness is general. These are two hypothetical situations, but they may perfectly fit into the situation of some company facing difficulties, be it like that of case A, or that of case B.

Besides these physical evaluations it is also important to make economic evaluations and valuations for the various cases studied, simple calculations, fundamental for any manager wanting to introduce so substantial changes to their wood supply for pulp production.

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GENERATING EXTRA WOOD FOR ENERGETIC PURPOSES BY USING EUCALYPTUS WOODY FOREST RESIDUES

The qualitative requirements for woody forest residues for energetic use are rather distinct from those for pulp production. For energetic purposes one is interested in higher contents of lignin, extractives, organic carbon and higher basic density of the wood. The presence of bark, although it is not completely welcome, does not require any removal, either. Bark burns and carbonizes in the same way as wood, though with less efficiency and results. As related to the contents of ashes and volatile extractives, it would be better if they were low, because volatile extractives tend to release and to get lost in the wood carbonizing processes. Using woody residues, not only as firewood fuel, but as raw material for charcoal manufacturing, is very common. Ashes are always undesirable when using residues, as well for pulp as for firewood or charcoal. They are only interesting as fertilizing residue after wood combustion and can return to the forests for soil fertility improvement.

The presence of bark on the residues helps supply more biomass, but reduces the calorific power per biomass dry weight unit. Bark is mineral rich and has lower basic density than wood. It contains less organic carbon per dry weight unit. Therefore, it is bulkier and brings about a worse quality coal, more friable after carbonization. However, it is a renewable fuel and may be a source of energy to society or to the mills.

Among all qualitative characteristics defining a good woody forest residue as energetic biomass, the most important one is the moisture content thereof. The drier the residue, the less energy will be lost in heating and evaporating the water contained in the residue, when burning this material. For this reason, it is good practice to let the residues dry very well before sending them to the power boilers or the charcoal-making furnaces. As these residues are small in diameter, they get dry easily, reaching moistures from 25 to 40% after a short natural drying time in the forest field.

Therefore, a good woody residue for energetic purposes must present a high basic density, a high lignin content, a high organic carbon content, a low ash content and the lowest possible moisture. Lignin presents a higher carbon content in its molecular composition than carbohydrates. For this reason, lignin is desirable in the energetic biomass, as it increases the calorific power of materials rich in its content. Softwoods have a higher lignin content than hardwoods. They also show the presence of a resin that is an excellent fuel. For these reasons, calorific values of softwoods are higher than those of hardwoods. One limitation for many softwoods is the potentially lower wood basic density they may have.

Wood intended for energy generation has a lower selling price than that having suitable quality for pulp production. Requirements in terms of cleanliness, density, form and quality are considerably higher for pulp processing woods.

When an eucalyptus forest plantation is established to supply a pulp mill with wood, all wood good for pulp production migrating to energy generation will be destroying value and yielding a lower result to the forest producer.

Let’s give the example of a planted forest that should yield in its harvesting 280 m³ of wood logs for pulp production and 20 m³ of firewood for energy generation. In case harvesting is carelessly done and more residues are generated, there may be the case, for instance, of getting 270 m³ of wood for pulp production and 30 m³ for energy generation. Based on these data we will be able to analyze the value destruction per hectare by means of rather simple calculations.

Let the value of the cubic meter of pulp production logs be for instance US$ 25.00 (cut, debarked and loaded on the truck). The price of the same cubic meter sold as energetic firewood could be assumed as US$ 15.00, for example. Moreover, the residue segregation adds costs when gathering these residues. Let the additional value for residue gathering and handling be US$ 5.00. This will result in a net value of US$ 10.00/m³ for the residues. Based on these data we can establish a comparative table.

Table 4: Valuing the “value destruction” as a function of “wood status” change

Basis: one hectare	Situation	
	1 (expected firewood generation)	2 (more firewood generation)
Pulp wood production - m³	280	270
Firewood generation (woody residues)– m³	20	30
Pulp wood sale result - US$	7,000	6,750
Net energy firewood sale result – US$	200	300
Income generated per hectare – US$	7,200	7,050
Value destruction by wood “status” change – US$		150

Imagine that US$ 150.00 were lost for only one hectare, even selling the residues. For an area of 5,000 hectares, there would be a destruction of US$ 750,000.00, which is an enormity, don't you agree? In other words, the solution consists not only in finding a use for the residues, gathering them and managing them. The best solution is to minimize their generation, avoiding losing good wood. The ultimate destination of the wood should be serving as a recycled residue. This is acceptable only in the cases the prevention is not achieved. This is the great teaching of the eco-efficiency science. The raw materials are not to be lost, they have to be used as much as possible at the origin. Losses are losses of money, raw materials, and they generate inefficiencies.

These situations are very common, the purpose of a wood or a tree is changed for the most different reasons, most of them already referred to in this chapter. Whichever the cause, the solution may have a very quick payback, since value destruction exists and the destroyed values involved are high.

On the other hand, the value destruction would be even higher if the residues remain in the forest field without being gathered. In this example of ours, the net incomes from the residue sale reached US$ 200.00 to US$ 300.00 per hectare, so that it is definitively no good to be left in the forest field without being gathered.

Another usual way of presenting the results of an energetic valuation of the woody residues for use as energetic biomass is by means of the expressions of their energetic potential, e.g. in Mcal/ha or Gcal/ha.

Starting from the calorific values of the residues, thus considering the energy loss due to the moisture and to its hydrogen content (which turns into water during burning and requires energy), it is possible to calculate how much energy will be made available by the residues per forest area, just from the energetic woody residues. This valuation clearly indicates the net energy differences as a function of the moisture contents of the residues. For this reason, the companies purchasing energetic wood should establish as form of acquisition the weight of the material associated with its moisture content. If they fail to do this, purchasing residues just based on their measured weight as such, they will be making the serious mistakes of spending more money and not stimulating the residue producers to have them drier for sale. On the contrary, they will even be stimulating unscrupulous producers to wet the residues in order to increase their wet weight. I even suggest a differentiated price i.e. the drier the residue the higher the price, thus favoring energy savings in the productive chain. We will spend less to transport a lower residue weight and the useful calories released in the biomass boilers will increase.

In the following we will try to exemplify an energetic balance for a planted eucalyptus forest, evaluating the net energetic potential of its forest residues.

Be it again that forest of ours, that when harvested should yield 315 m^3/hectare, due to the fact that its yearly average growth rate of commercial debarked wood has been 45 m^3/ha.year. Remember that it generated in fact just 309 m^3/ha of useful commercial wood at harvesting, plus 16 m^3/ha of woody forest residues that were effectively recovered. Let's suppose that the average basic density of these woody forest residues has been 0.55 t/m^3 (or 0.55 g/cm^3). The moisture content of these residues may vary according to the climate and the waiting time for these residues to be removed from the forest field. We may have moisture values ranging from 25 to 50%. Thus, the total wet weights, the costs of transportation and the energetic valuation of this material in Mcal/dry ton will change. In order to visualize these effects, let's consider in this example of ours the following situations: residues removed and commercialized with moistures of 25, 35, 45 and 50 %. For comparison purposes, the expected results in case the residue could have 0% of moisture i.e. with 100% of consistency and at their maximum energetic potential and minimum weight for transportation, are also presented.

Table 5: Energetic valuation of woody eucalyptus forest residues (residues showing different moisture contents)

Basis: one hectare	Woody Forest Residue Moisture Content (%)				
	0	**25**	**35**	**45**	**50**
Useful volume of commercial and saleable residues after equalizing to solid cubic meter	16	16	16	16	16
Dry weight of generated residues - tons (for average Db* = 0.55 t/m³)	8.8	8.8	8.8	8.8	8.8
Residue weight as such in the pre-settled moisture value – tons as such	8.8	11.7	13.5	16.0	17.6
Weight of water present in the residues as such – tons	0	2.9	4.7	7.2	8.8
Net lower calorific value** or heating power at the pre-settled moisture content – Mcal/t as such	4,100	2,930	2,480	2,030	1,800
Total net energy availability per hectare - Mcal	36,080	34,281	33,480	32,480	31,680
Net unit energetic availability expressed in Mcal/dry ton of residue	4,100	3,895	3,804	3,690	3,600
Net unit Mcal difference with regard to the absolutely dry residue	0	- 205	- 296	- 410	- 500

* Db = Basic density of the wood

**The efficiency of using the calorific power of each biomass fuel admitted to be 96%

Based on the data of table 5 it is clear that when increasing the forest residue moisture content there will be much more weight to transport and less net energy will be made available in our biomass boilers. An important energy part will be destined to heat and to evaporate the residue moisture water. These values are significant and should not be forgotten by any means by the energetic biomass producers and consumers.

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SOME REAL LIFE CASE REPORTS EXEMPLIFYING EUCALYPTUS WOODY FOREST RESIDUE SITUATIONS

In this section, I intend to show in a simple way some situations happened to me in real life, showing opportunities that may be dealt with in the theme "woody forest residues". In some cases, the situations show wastes or lost opportunities due to non-fulfillment of specifications, or for lack of orientation or knowledge, or even due to inattention. In some situations the cause is in the machinery, in other ones is the procedure, and other ones are due to the persons' commitment. Favorable opportunities and examples of residue utilization are also shown.

Eight situations will be presented, containing many photos and concomitantly some comments. I hope that you will appreciate them and amuse yourselves at them.

<table>
<tr><td colspan="3">Example number 01</td></tr>
<tr><td colspan="3">The case of organic residues from forest plantations favorable for nutrient cycling and soil and environment improvement</td></tr>
<tr><td></td><td></td><td rowspan="2">The organic forest residues remaining on the soil after forest harvesting contribute to the physical, chemical and biological soil improvement, prevent erosion and help develop the new forest that will grow on this forest site. This material consists of leaves, bark, thin branches, fruits, flowers, besides the understorey material consisting of weeds, bushes, etc. For greater eco-efficiency, only the wood rich woody residues should be removed, in order that they are used for the purpose the forest was planted for.</td></tr>
<tr><td></td><td></td></tr>
</table>

Example number 02

The case of the eco-efficient wood and nutrient rich treetop recovery

Treetops contain much wood that can be still taken advantage of, but they have also many thin branches, leaves and fruits, very nutrient rich materials, mainly nitrogen, potassium, phosphorus, calcium and magnesium, besides many micro-nutrients. For this reason, we recommend to remove only the treetop stem wood, as well as that of thick branches, leaving the rest of the material to be incorporated into the soil, for nutrient cycling purposes.

<table>
<tr><td colspan="3">Example number 03</td></tr>
<tr><td colspan="3">The case of tree cutting at the correct height, leaving a low stub and reducing wood losses</td></tr>
<tr><td></td><td></td><td rowspan="2">It is obvious that the wood loss may be high if the trees are cut at a height above the specified one. After all, this is the part of the tree which is the largest one in diameter. Any additional 5 centimeters in stub height may represent about 0.3% of wood left in the forest field, without being destined for consumption.</td></tr>
<tr><td></td><td></td></tr>
</table>

<table>
<tr><td colspan="3">Example number 04</td></tr>
<tr><td colspan="3">The case of improper harvesting, leaving very high stubs and requiring the operation of stub reduction on height to facilitate forest stand reestablishment</td></tr>
<tr><td></td><td></td><td rowspan="2">Extremely high stubs may represent losses of 3 to 5% of the volume of the trees felled in this way. In case of second or third rotation forest harvesting, if sprouting and coppicing management are improper, cutting the tree in the lowest possible position becomes very difficult. Therefore, my friends, proper sprouting management is essential to produce better forests and to facilitate forest harvesting, thus losing less wood.</td></tr>
<tr><td></td><td></td></tr>
</table>

<table>
<tr><td colspan="3">Example number 05</td></tr>
<tr><td colspan="3">The case of wood losses due to the cutting instruments at forest harvesting</td></tr>
<tr><td></td><td></td><td rowspan="2">Motor saws, feller bunchers and harvesters consume and waste wood to saw the trees. The harvester design may also result in a high stub cut (about 20 cm), which means losing wood that turns into sawdust in the cutting area, as well as losing wood due to the remaining stub height.</td></tr>
<tr><td></td><td></td></tr>
</table>

Example number 06

The strange case of wood loss due to the thick short logs that remained in the forest field.

I saw a curious situation when visiting an eucalyptus forest harvesting area. There was an enormity of short thick logs left in the forest after harvesting. I asked for the reason of such a great waste and was informed by the supervisor that the mill did not accept logs larger than 35 cm in diameter. Then they removed the thick part of the tree, which remained as residue in the forest field. Just imagine, my friends, what a monstrous loss of the thickest part of the tree! There are things difficult to understand and to accept. Out of ingenuousness or due to mismanagement, such things do happen, believe me.

Example number 07

The case of the wood "forgotten" by the forest harvesting and log forwarding operators

One of the commonest wood losses in the forest logging operations consists of logs and even log stacks "forgotten" by the forest harvesting, log forwarding and transportation personnel.

A typical loss due to mismanagement and failure to monitor the quality of operations.

<table>
<tr><td colspan="3">Example number 08</td></tr>
<tr><td colspan="3">The case of residue gathering and segregation by forest residue gatherers, providing extra work for the community and more wood for the industrial operations</td></tr>
<tr><td></td><td></td><td rowspan="2">One of the good opportunities to put social responsibility into practice is by sharing the planted forest richness with the people of local communities. By creating cooperatives of woody residue gatherers, working under worthy, safe and healthier conditions, it is possible to provide more wood for the mills and more jobs to the communities where the forest undertakings are inserted in.</td></tr>
<tr><td></td><td></td></tr>
</table>

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FINAL REMARKS

In this chapter we addressed a very important theme, that often does not deserve due consideration or attention at many forest companies. Sometimes, due to characteristics of mankind itself, it is easy to understand why. When production is abundant, when the eucalyptus forest grows fast, forming wood in record time, this all conveys a feeling that some wood produced may be even wasted. After all, wood is abundant and "cheap". However, the world changed and more responsibility, evaluations, quantification's and care are required. In the present chapter we tried to demonstrate where are the opportunities and how much they represent for the companies and the communities, which may be involved in the solutions.

The key to the whole residue generation lies in the comprehension of its generating causes. We must work on them first of all, trying to prevent generation. Thereafter, if the whole residue generation has not a completely satisfactory solution by combating the causes, ways of recovery, reuse, recycling and miscellaneous utilization's may be looked for. These are basic eco-efficiency teachings, which we are sharing with you in the most practical way applicable to our forest operations.

We wish you success in your forestry activities, always remembering to try to prevent losses from occurring, whichever they are. This is something vital to our society and to Nature.

"The line separating the plus world from the minus world is very tenuous. All of us want a better world, without so many wastes. To a great extent this depends on ourselves.

I hope that this chapter has contributed to a better understanding of this point in our world so full of challenges, where our forest and industrial sectors are inserted in".

Celso Foelkel

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