Gianni Picchi, Jakub Sandak, Anna Sandak, Raffaele Spinelli

03-01: Introduction to supply of ligno-cellulosic fuels

As stated in chapter 02-01-00 fuel biomass can originate from a number of sources, being the main ones forest land, agriculture land, municipal wastes, wood and food industry. Each sector will have one or more possible supply chains, with a variable degree of complexity. In most cases, a short supply chain – both in terms of physical distance resource - plant and in terms of operations involved – will be more reliable and economical for all the actors involved.

Regardless its complexity, a woody biomass supply chain will generally include the following operations: harvest, extraction, transformation, comminution, transport, storage and energy conversion. It should be noted that according to the specific supply chain considered, the order of such operations may change and not necessarily all of them will be present.

Harvest or recovery is the operation of collecting the biomass. It can be a mere operation of collecting material produced as a residue of a main activity (e.g. timber production) or as the main product of the operations (e.g. thinning operations, energy crops). Harvest as a specific operation may be missing, for instance if the residues is piled up by a processor while delimbing whole trees at a landing, if the biomass is made available in an industrial process (e.g. sawmill, food processing industry, etc.) or in the case of municipal waste collection station.

Extraction is necessary when the biomass is harvested in forest stands or agricultural fields, where accessibility is poor and the resource is spread all over the area. With this operation the raw material is accumulated at roadside or other easily accessible facilities (landing, pads, etc.). Also this operation may be missing in the supply chain (see example above).

Transformation is generally required for facilitating the handling, transportation, storability or quality of the biomass. It generally involves compaction of the residues (i.e. by baling, compressing, comminuting, processing, etc.) and in some cases the removal of undesired parts (for instance when delimbing trees to be used for the production of high quality biomass).

Comminution is just one form of transformation, and it is the only operation that will be performed for sure at a certain point of the supply chain. In fact, as stated in paragraph 03-00-02d, regardless the energy conversion process, it will require to be fed with fragmented biomass.

Transport to the plant or the storage area may be performed with a variety of means (tractor and trailer, truck, train, boat, etc.). It may represent a major cost in the supply chain (over 50%) and thus should be carefully planned. Transformation is essential in most cases for keeping the transportation system cost efficient (see paragraph 03-00-02b). When the distance is short, extraction and transport may be a unique operation and can be accomplished with relatively inefficient systems.

Gianni Picchi, Jakub Sandak, Anna Sandak, Raffaele Spinelli

Storage is generally required for securing the procurement of fuel to the energy conversion plants, for improving the biomass quality (e.g. allowing natural drying and needles loss) and for optimizing the logistic system. Storage is unavoidable when the biomass resource is made available in season different than the period of consumption, as it happens on the Alps where trees are harvested in summertime and district heating operate – obviously – in wintertime.

Many aspects must be considered when analyzing the possible supply chains of fuel biomass for a certain area. It must be kept in mind that in a certain territory a variety of resources will coexist, but each of them should be considered separately for better understanding their potential and specific characteristics.

03-01-01: Supply of forest biomass

Many factors are involved in the definition of the possible supply chains from forests. When considering a specific territory the attention can be driven over some specific factor, which define the actual supply chains established or potentially applicable, namely they are: 1) type of forest management, 2) terrain characteristics, 3) common work systems, 4) market and local conditions.

03-01-01a: Forest management

Many models of forest management may coexist in the same area. Generally speaking biomass procurement will be drastically different according to the harvest intensity. Many silvicultural models could be adopted; here just the two extremes will be exposed:

- **Clearcut** – this term means that it is possible to harvest all the trees present in an area of variable size. According to local regulations this area may vary from few thousands squared metres to tens of hectares. Clearcut is generally applied to mature stands (end of production cycle) and is common in industrial silviculture, such as conifer stands in Nordic Countries or broadleaves coppice forests in Mediterranean Countries. As a rule of thumb harvesting with clearcuts reduces overall costs and the cost of residual biomass, which will be available in large amounts. The biomass availability is further increased in some countries, such as Finland, where also stumps are removed from the stand for facilitating the subsequent forest regeneration operations.
- **Selective cut** – this term means that single tree, or groups of trees are felled and extracted from the forest. This type of management is common in naturalistic silviculture for final cuts of mature trees (e.g. in many Alpine Countries). Because of the remaining standing trees, working in this condition is more expensive (less productive) and frequently the extraction of residual biomass can be limited for environmental or technical reasons.

A part of the removal of mature trees, silviculture works generally include many harvest operations, most of those being thinnings. With this practice the density of young trees is reduced in order to enhance the growth of the remaining trees and the quality (market value) of the final timber assortments.

Gianni Picchi, Jakub Sandak, Anna Sandak, Raffaele Spinelli

Thinnings have an approach similar to selective cuts (also in forests that will be clearcut-harvested at maturity), meaning that parts of the standing trees are removed from the area, and parts are left to produce the future valuable trees. Thinnings are expensive operations because of the difficult work conditions (the remaining trees must not be damaged) and the low market value of the extracted trees (generally small diameters). Fuel biomass is often the main or the only merchantable product obtained from thinning operations.

Figure 03-01 1: Example of supply chain integrating timber (main product) and forest residues such as slash and stumps (source: Forest Energy Portal)

Main type of forest operation	Main assortments	Biomass details
Clearcut (*final cut*)	• Timber (*or whole trees*) • Slash (*branches and tops*) • Stumps	• Potentially large amounts • Poor quality (*high share of bark, needles if conifer*), wet or dry according to the adopted technique
Selective cut (*final cut*)	• Timber • Slash (*rarely*)	• Low amounts • Poor quality
Selective cut (thinning)	• Small diameter timber • Energy wood (small whole trees)	• Low to large amount, according to the share of energy wood • Good quality (large share of wood), wet or dry according to storage time

Table 03-01 1: Biomass resources related to type of forest operation

Gianni Picchi, Jakub Sandak, Anna Sandak, Raffaele Spinelli

03-01-01b: Terrain

Terrain conditions do have a strong influence on the cost of harvesting operations and the final cost or availability of residues for biomass fuel. Generally speaking flat terrain are more accessible, and mechanization can be fully deployed leading to lower costs and higher output of low value products, such as biomass. In steep terrain working conditions are clearly more difficult, full mechanization is not always applicable (part or the whole of operations must be done manually) and in some cases only the valuable assortments are extracted from the forest, leaving the residual biomass on the stand.

03-01-01c: Work system

Many working systems could be distinguished according to the local custom, the type and degree of mechanization, the market requirements and the working conditions (season, terrain, forest type and age, etc.). Trying to condense the whole matter in a short synthesis, the main difference can be pinpointed in the size of the material extracted from the forest stand:

- **Cut-to-length system** – means that the trees are felled and processed (delimbed and cross-cut) into the forest. The material extracted is already at the final length, generally as 2-4 metres logs. This system is very common in Nordic Countries and generally performed with harvesters and forwarders (but a variety of equipment could be used, to the extreme that the whole work is done manually with chainsaw). Residues are separated from the timber at an early stage and normally just after felling, thus biomass will be spread all over the forest or roughly accumulated in small piles. The collection and extraction of residues is separated from timber extraction – thus it represents a separate cost – can be done with different equipment and can be postponed in time (e.g. for organizational reasons or for allowing natural drying).

Figure 03-01 2: Forwarder (left side) loaded with processed logs, on the right side is visible the harvester used for felling and processing the trees (source: Gianni Picchi).

- **Tree length system** – means that after felling the whole trees or the entire stem are extracted from the forest. Processing is accomplished in a second phase, generally at a landing or at roadside. With this working method residues and valuable assortments are extracted in a unique operation, thus with no additional cost for biomass. Processing will generate both timber (sawn timber, pulpwood, poles, etc.) and residues (tops, branches, parts of defected stems) accumulated in large piles easily accessible. This system is common on the Alps (associated with cable yarder extraction) but can be found in other areas of Europe (France, Germany) when extraction is done with skidders in areas with moderate slope. Because of the lower manoeuvrability of whole-tree loads, this system is easier to apply on clearcuts (where it has a higher productivity than the cut-to-length system), while in selective harvesting or thinning operations the dragged trees could damage the remaining trees.

Figure 03-01 3: Skidder extracting manual felled and delimbed tree-length stems (left) and extraction of whole trees by mean of cable yarder on steep terrain (right) (source: Carolina Lombardini).

The adoption of one of those alternative work systems depends, among other factors, on the availability of machinery, the market requirements and the local regulation in terms of forest works. Generally speaking, if the goal is to maximize the residual biomass output, the whole tree system should be preferred, because it reduces the overall costs.

Nevertheless the risk of nutrient depletion caused by an excessive extraction of biomass should be carefully considered. Each forest stand will have a specific aptitude to provide assortments, including biomass, without reducing the soil fertility: in some cases the extraction of biomass should be avoided allowing the nutrient rich slash to decompose on the site.

Figure 03-01 4: Schematic comparison of cut-to-length and tree-length systems (source: Forest Energy Portal).

Figure 03-01 5: Extraction of tree section from the forest. Trees are processed on the spot, piling commercial timber and slash in different heaps. In order to clear up the landing it is important to promptly remove the piled material, this is the optimal point for residues transformation by chipping or bundling (source: Gianni Picchi).

03-01-02: Agricultural biomass

In many European countries, mostly located in the Mediterranean area, agricultural woody biomass residues have a higher potential contribution than forest material. For instance in Italy the biomass still unused accounts to 2.2 Mt year^{-1} from forest residues and over 5.0 Mt year^{-1} from agricultural residues (just considering woody biomass).

This source of biomass, similarly to most forest material, should be regarded as a by-product of the common management activity of agricultural crops such as orchards, vineyards and olive groves.

We can distinguish pruning residues, with a constant yearly production of a low amounts of biomass per hectare (1-6 green t ha^{-1}), and uprooting residues obtained at the end of the commercial life of the plantation (up to 50 green t ha^{-1}). Both residues must be disposed of, but different possible options lead to different biomass market costs.

03-01-02a: Pruning residues

Pruning residues (composed totally or mostly by small branches or twigs), are traditionally disposed of by mulching it on the inter-row area or by open-air combustion. Both of them represent a cost and the latter is forbidden in most European regions due to pollution and fire hazards. Integrating residues to the soil can contribute to enhance the organic matter content, but on the other hand can facilitate the spread of diseases, thus the collection for energy purposes is getting more and more common.

Many dedicated equipment have been developed for the recovery and conditioning of pruning residues. The final output can be either bales or comminuted biomass. Biomass cost depends highly on the working conditions (residue density, row width, extraction and delivery system) and the chosen machine.

Figure 03-01 6: Dedicated harvesting equipment for agricultural pruning residues (source: Marco Fellin).

With harvest-and-chipping units (figure 03-01 6 left) one operation accomplishes too many tasks: residues picking up, shredding, loading, extraction and transfer to a shuttle unit (an agricultural trailer, a roll off container, etc.).

With balers (figure 03-01 6 right) the whole supply chain is composed by a number of separated operations:

- residues recovery and baling
- bales extraction, transport and/or storage
- chipping

Biomass from bales results more expensive because of the involvement of many machines at different stages, but allows for operating in difficult conditions (narrow plantations) and for storing and drying of biomass.

The fuel quality of this material is generally low. Because of the small size of the branches and twigs pruned the bark/wood ratio is rather high, leading to high ash content (more than 2-4 %). This aspect is further increased by the fact that residues are usually windrowed on the ground for a variable period (few days to several weeks) with risks of soil contamination or grass development within the residues before harvest. Both are increasing the final ash content of the fuel. Moisture content at harvest of this biomass will be similar to that of forest residues (45-50 %), but can be effectively reduced by postponing harvest and comminution after the pruning operations. As an example, olive residues left a few weeks windrowed in the field can reduce their original moisture content from about 45 % to 30-35 % (a value perfectly suitable for direct combustion). Finally, most of the harvesting equipment use shredders or crushers as comminution tools, providing biomass with an irregular and rather large size distribution.

Because of these characteristics agricultural residues are generally to be regarded as a source of fuel for medium to large energy plants, which can easily adapt to fuel with such quality standards.

03-01-02b: Uprooting residues

This raw material, mostly stumps, is generally made available by farmers at roadside after removal by mean of excavators. After a variable storage period the stumps are collected by specialized contractors, comminute by mean of a grinder or crusher and transported to the end user. The storage period is extremely important for enhancing the fuel quality of this raw material since it allows for natural drying and a partial reduction of soil contamination. If storage period is long enough (at least two months) the final moisture content can be lower than 30%, while contamination will depend on the soil texture (higher in clay soils).

The uprooting operation is generally expensive, but the recent interest towards this material as a biomass feedstock is stimulating the development of several dedicated machines for stumps removal

Gianni Picchi, Jakub Sandak, Anna Sandak, Raffaele Spinelli

Figure 03-01 7: Common uprooting procedure by mean of excavator (left) and stump comminution by mean of grinder (right) (source: Gianni Picchi).

Figure 03-01 8: Examples of dedicated equipment for orchards uprooting by removal of the stumps (left) and one passage removal of the whole tree (right) (source: Gianni Picchi).

03-01-03: Woody energy crops

Woody energy crops are an actual agricultural crop grown solely for the production of biomass. Fast growing tree species (usually poplar, willow and eucalyptus) are grown on arable land with an intensive management including fertilizing, irrigation and weed/pest/disease control. Because of the highly favourable conditions the growth potential is fully expressed and the yearly yield of biomass can exceed 15 oven dry tonnes per hectare (poplar plantations in Italy). The high productivity and the possibility to establish plantations close to the conversion plants make regard energy crops as a valuable and strategic resource of biomass in highly populated agricultural-urban areas.

This type of plantations is commonly known as Short Rotation Forestry or Short Rotation Coppice. Two types of plantations can be roughly distinguished according to the recent trends: actual short rotation coppice and medium rotation coppice.

- **Short Rotation Forestry (SRF)**, this type of plantations closely resembles a common agricultural crop. Trees are planted with a density ranging from about 5 500 to 14 000 plants per hectare and harvested by mean of a modified forager with a rotation of 1-2 years.
  The stumps produce new sprouts as a consequence of the harvest, naturally renovating the trees for a variable number of rotations (approximately 5-7).
  Biomass is extracted from the field already in the form of wood chips in large trailer-dumpers towed by tractors. Those can deliver directly the fuel biomass to the end user if the distance is less than 15-20 km.
  Otherwise the load is accumulated on a pad and reloaded on trucks for transportation to the end user. Biomass obtained from SRC has generally a high moisture content (up to 60% for poplars, about 45% for eucalyptus), and its market value is generally low.

Figure 03-01 9: Harvest of poplar short rotation coppice by mean of agricultural equipment (source: Gianni Picchi).

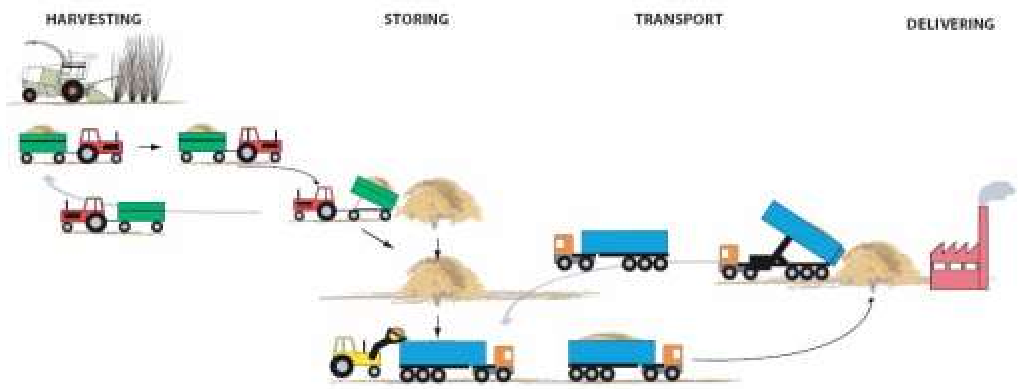

Figure 03-01 10: Sequence of the operations during SRC harvesting (source: Intelligent Energy for Europe project Biomass Trade Centres).

- **Medium rotation coppice (MRC)** is a hybrid concept between the former and the fast growing timber plantations common in some countries (e.g. poplar plantations in Southern Europe). Trees are still planted in arable land but at a lower density (about 1 400 plants per hectare) and harvested with a rotation of 5-6 years.
  Renovation still relies on coppice management, but harvesting is performed with forest equipment due to the larger size of the trees (diameter at breast height exceeds 20-25 cm). The advantage of this type of plantations is the higher market adaptability (biomass is just one of the possible assortments, such as pulp-wood logs or sawn timber) and the possibility to postpone chipping after a storage period for naturally drying the biomass, enhancing the fuel quality and its market value.

Figure 03-01 11: Harvest of poplar medium rotation forestry on arable land (source: Fabio De Francesco).

03-01-04: Industrial residues

Presently industrial residues are the main source of woody biomass fuel in many countries. A variety of manufacturing and transformation industries can produce untreated biomass residues, namely the main ones are:

- Sawmills and wood based manufacture (e.g. furniture industry) produce a large amount of wood residues in form of solid material (butts, shavings, etc.) or loose material (bark, wood chips, sawdust, etc.). Solid residues are relatively easy to store, dry and comminute, and can be regarded as a source of high quality biomass. Bark and wood chips are generally separated by debarking the incoming timber, thus the final quality in terms of ash content is very homogeneous (low for chips, high for bark). When produced by sawmills they are generally wet since timber is generally processed without drying, while industries working with dry wood such as carpentries and joineries will provide dry biomass. Sawdust is the main raw material used for the production of wood pellets or briquettes.

- Pulp industry can provide bark, black liquor and other processing residues. Generally these residues are used for energy conversion within the same industrial process.
- Food industry can produce a large variety of woody fuels such as kernels (hazelnut, almonds, etc.) or stones (olive). These residues are often ready to use without any further transformation, and in some cases they can be used even as a substitute of wood pellets. More details in relation to such biomasses are described in chapter 01-02.

The main advantage of industrial biomass fuel is the high reliability, the homogeneous quality, and the ease to programme the fuel procurement (i.e. there is no influence of weather conditions or other external factors). Also contracting is facilitated, since one or few suppliers can provide most of the required fuel along the year.

03-01-05: Waste wood from householders

Domestic or household wastes (as presented briefly in chapter 01-04) are composed of garbage and rubbish, which normally originated from private homes or apartment houses. It can also be considered as a valuable source of ligno-cellulosic biomasses. Such waste wood usually comes from old furniture, do-it-yourself construction, wood packaging and discarded wood materials from home renovations. In the last stage of its life cycle it arrives at a municipal waste collection station. You may refer to 03-04 in order to find some more details in regard to handling of such waists (collection, transportation, comminution and processing). The important, from the supply chain point of view is to consider additional operations related to sorting of the waste wood both on the waste collection station and/or after chipping/milling.

Figure 03-01 12: Wood wastes collected from householders and stored in municipal waste collection station (source: Marco Fellin).

03-01-06: Waste wood from construction sites

Construction waste comes from waste materials generated during the construction, alteration, or repair of structures. Demolition waste comes from buildings and other structures that are torn down. The characteristic of such wastes are in general similar to that of householders, the difference lay however in the collection of materials; in case of waste wood it is usually collected directly at the construction site. Material sorting is also a typical operation related to utilization of waste wood from construction sites.

03-01-07: Transformation, storage and transport of biomass

Biomass can be made available in different forms according to its origin. Branches and twigs are very common as forest (slash) and agricultural (prunings) residues. Whole trees or stems are mostly produced with silvicultural activities; as well as bark (e.g. when using debarking rolls on timber processors) and stumps. This raw material can be further transformed along the supply chain, originating a variety of final assortments delivered to the end users (Table 03-01 2). Transformation is generally required as early as possible during the production process in order to enhance the handling and transport efficiency (see also 03-00-02b).

Some forms of transformation also improve the storability of the residues. This is particularly true when dealing with forest slash, which is generally difficult to handle and bulky, making handling operations inefficient and expensive compared to other biomass assortments. For this reason the extraction distance of loose material alone (not associated to other timber assortments) should be kept the shortest possible.

Figure 03-01 13: Extraction of loose residues by mean of forwarder (source Raffaele Spinelli).

Type of biomass assortment	Bulk density	Storability (at landing/roadside)	Fuel quality
Loose residues (*slash, pruning residues*)	Very low	Low to Medium (*if covered*)	Low
Energy wood (*small diameter whole trees or logs*)	Medium to High	High	Medium to High
Bundles	High	High	Low to High
Stumps	Low to Medium	High	Low
Chips/hog fuel	High	Low	Low to High (*depending on the raw material*)

Table 03-01 2: Main characteristics of forest biomass assortments

Prior to transportation, or even before extraction the residues should be transformed by chipping or bundling, both operations aiming to increase the bulk density of the raw material. The benefits of biomass compaction are quite evident in every step of the supply chain, but can be easily visualized for the transportation phase (Figure 03-01 13). Residues transformation can increase the efficiency (payload in this case) threefold by increasing the mass of material that can be loaded in the same loading volume.

Figure 03-01 14: Bulk density of different assortments of forest biomass products compared to solid wood density (100%) and its influence on load efficiency.

Chippers and crushers are available in a large variety of configurations (see also 03-00-02d). This operation can be performed at the very beginning of the supply chain or just prior to energy conversion. In Nordic Countries it is common to use of chip-forwarders, which enter the forest area, collect the residues, chip and load them on a bin. When the bin is full, chips are extracted at roadside and transferred to a container for road transportation.

On the opposite, whole trees or stems can be extracted from the forest, transported to the end user and stored as a strategic resource of high quality dry biomass to be chipped with a stationary crusher/chipper just before combustion.

- Generally chippers are lighter units than crushers, more mobile and flexible to use and capable of providing a higher quality fuel.
- Crushers are deployed when the raw material is expected to be contaminated (soil, stones, etc.) and a tough, reliable comminuting device is required.

Figure 03-01 15: Chipping of whole trees loading the biomass directly on a high volume truck (source: Gianni Picchi).

If from an operational point of view chipping (or crushing) should be done as early as possible in the supply chain, it is opposite from a quality point of view. Chipping should be done just before addressing the biomass to the energy conversion process. This is due to the fact that whole trees, stems or even branches are protected by the bark against microbial attack, and their exposed surface is rather small (just the crosscut sections), while it is extremely large for comminuted woody biomass. As a consequence, when storing whole residues the natural drying process is much more evident than biomass deterioration due to biological activity. A further benefit is that residues of evergreen species (conifers, olive, eucalyptus, etc.) will tend to lose their leaves and needles. This improves the biomass quality and returns in the forest/field the nutrients contained in those parts. On the opposite wood chips are quickly attacked by fungi, which can cause severe biomass losses in large piles of wet material (up to 30% of the original biomass). Bark protection also prevents the whole material to adsorb meteoric water (snow, rain), while the exposed wood fibre of chips tends to be highly hygroscopic and gaining humidity if stored uncovered. A high moisture content (MC) is basic for fungi multiplication, thus the best condition for preserving wood chips is to get them dry (30-35 % MC or less) and store them in a covered and ventilated area, possibly with paved surface. Also pile size is important, being the risk of deterioration or even self-ignition related to the mass of wood stored in it. In some countries the pile size is considered as risk-bearing factor and bigger masses (5000 m^3 for the case of Italy) require the presence of fire-control appliance and permanent control, with obvious extra costs.

Factor	**How does the factor influence?**	
Moisture content	High	Low
Pile size	Great	Small
Biomass size distribution	Fine	Coarse
Biomass loss	**High**	**Low**

Table 03-01 3: Main factors influencing the storability of wood chips

In Sweden, insurance companies have agreed to set upper limits to pile height and storage time according to the following table where the main division is between piles that have been compacted (i.e. tractors have been driven onto the top of the pile) and piles that are loosely packed. The numbers presented here are the maximum heights in meters and the maximum storage times in months for chips from various assortments and, the two bottom lines, industrial residues. The limiting factor is the risk for self-ignition and it should be noted that this risk becomes greater the warmer the climate. Thus, in Southern Europe, heights and times should be reduced from the values presented in this table.

Raw material for the chips	**Loose packing**		**Packed material**	
	Max.height	*Max. time*	*Max.height*	*Max. time*
De-barked stem wood in general	20	12	16	9
Stem wood with bark in general	15	9	12	6
Whole trees, broadleaf	12	9	9	6
Whole trees, conifers	10	9	7	6
Felling residues	7	6	PROHIBITED	
Bark	7	3	4	3
Saw dust	15	6	12	4
Cutter shavings	8	6	6	4

Table 03-01 4: Swedish insurance company limits for storage of wood chips


Figure 03-01 16: Forest residues piled at roadside and covered with biomass paper (left, Sweden), this cover type can be chipped directly with the woody biomass and delivered as fuel (right, Finland), facilitating the comminuting operation. (source: Gianni Picchi).

Storage of biomass is crucial for securing the supply of fuel, particularly to larger consumers, and to enhance the fuel quality by naturally reducing the moisture content. Nevertheless the consequences of storage should be carefully evaluated, see text section 03-00-02e. In figure 03-01 17 is shown the dynamics of biomass drying in terms of energy content and total weight changes.

Starting with a defined amount of product with a moisture content of 50% (over green weight), the reduction in merchantable weight is about three-fold higher than the gain in terms of energy content. This is a natural and obvious dynamic, but it should be carefully considered when planning a biomass procurement system.

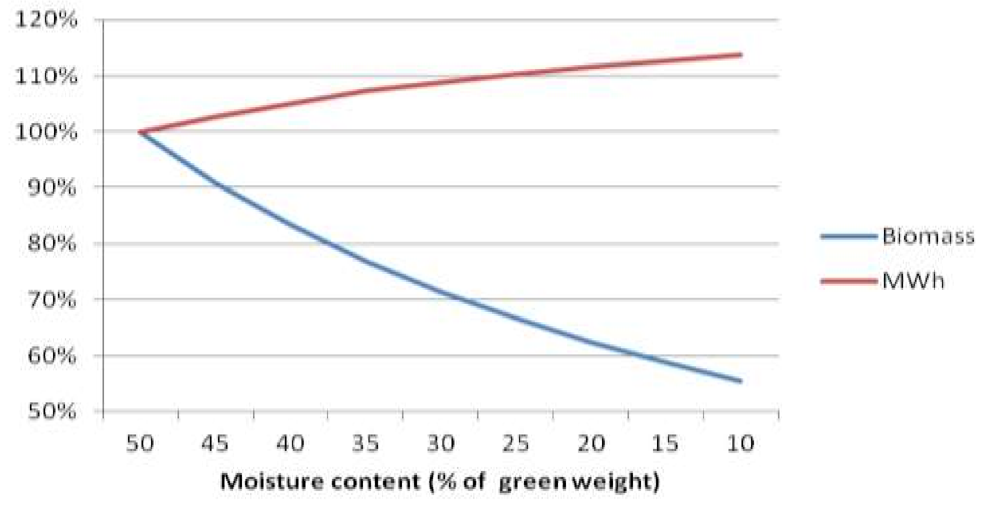

Figure 03-01 17: Biomass weight and energy content changes during natural drying

As an alternative to chipping, the bulk density of woody residues can be increased with the bundling technology. This solution is common in the agricultural sector, but rather new for forest biomass. It permits to compact the residues in "reconstructed logs" (about 3 m long and 70 cm diameter), which can be handled with common timber equipment (cranes, forwarders and trucks). Generally bundling is performed in the forest, optimizing all the subsequent operations. For instance, the chipping operation performed on bundles has a productivity double compared to the same operation on the original loose residues. The use of bundles reduces the required storage area, being those compact and easy to pile in high heaps.

Microbial activity inside the bales is limited since the raw material is relatively intact, but the high compaction limits the natural drying process, which tends to require longer storage periods compared to loose residues. For this reason the final quality of baled biomass tends to be rather low.

Since bundling represents a further step (and cost) along the supply chain, the opportunity to include such system should be carefully evaluated. In most cases the benefits of bundling can be better appreciated in large industrial supply chains, where logistics play a major role.

Figure 03-01 18: Baling of loose residues in Northern Spain (left). Bales are then extracted with a forwarder to the roadside where a common timber-truck (right) can autonomously complete the delivery process (source: Gianni Picchi).

03-01-08: Destination for ligno-cellulosic biomass

The processes to which the fuel shall ultimately be delivered are usually:

- combustion plant; might be of any scale from single household, up to a 500 MW CHP-plant
- gasification plant

It should be noticed that for the moment combustions plants seems to be much more relevant than gasification industries. However, undergoing intensive research in the field of ligno-cellulosic biomass processing provided very promising results in industrialization of gasification technology.

As described in chapter 04-01, even if cellulose degrades very slowly (and lignin is almost non-degradable) several new biochemical treatments have been developed recently. Apparently, today technologies are not ready for industrialization. However it is expected in the close future to mature such and implement as an alternative to combustion.

03-01-09: Planning aspects

Planning for ligno-cellulose to be a major fuel in a sustainable energy system will always start from identification and mapping of the local and regional resources:

- Wood waste from households, together with demolition wood, (see 03-01-05 and -06) can be found in any region regardless of the actual presence of forests, but may be scarce resource. The disadvantages may be that old furniture or wall panelling – for example – may contain paint or impregnating agents to render the fuel fraction qualify not as clean biomass but demands that it is burned in waste combustion plants.
- Residues from forest- and wood based industry (03-01-04) may sometimes be ready to use as a fuel without any further processing and they would also be composed mainly of stem wood, they would typically be dry, easy to store and comminute and can be regarded as a source of high quality fuel biomass. Sawdust, together with cutter shavings – in case they are available in large enough quantities – are a main resource for production of wood pellets and wood briquettes and may provide an extra income for wood-based industries as well as an “export income” for the region. Industrial residues will usually be available at relatively stable amounts from year to year and the reliability, the homogenous quality and the ease to arrange collection and procurement with commercial actors are also factors making this a very attractive assortment.
- In densely forested regions, a main resource will be felling residues and residues from forest operations such as thinnings. The quality of the fuel thus obtained will be strongly affected by the integration of fuel production into the forest operations as described in sections 03-01-01a and -01c while the total cost will also be strongly affected by the geographical constraints as described in 03-01-01b. For thinnings, the biomass extracted usually has no commercial value other than as a fuel. In case of large-scale utilisation of forest biomass, competition between the energy sector needs and the needs of other forest-based industry sectors must also be taken into account. Finally, the risk for nutrient depletion must be carefully considered and measures to maintain the productivity of the forest land included already in the planning stage. In case the extraction of forest residues is planned and co-ordinated in a proper way, they may well be used in large-scale biomass-fired plants up to or exceeding 500 MWth.
- In some regions, plantations of fast-growing tree species (poplar, willow, eucalyptus …) is an interesting alternative for the production of ligno-cellulose for the energy sector. The high productivity and the possibility to establish plantations close to the conversion plants make regard energy crops as a valuable and strategic resource of biomass in highly populated agricultural-urban areas. This technique is described in some detail in section 03-01-03 and may yield more than 15 tonnes of oven-dry biomass per hectare and year even in states where the natural growth-rate of forest biomass is only less than 4 tonnes per hectare and year, such as Italy, Spain and Greece. These fuels should, from a logistic point of view be classified as agricultural fuels.

- Other ligno-cellulosic fuels from agriculture are prunings and stumps/roots from fruit plantations such as apple plantations, olive plantations and alike, including vineyards. Since some of these materials will be thin, with a high bark-to-stem ratio (see 03-01-02) while others may be extracted from the ground, one will have to assume that the ash content will be high and these fuel fractions may require special attendance. These resources may be of a great regional importance but generally speaking, the amounts will be limited and suitable to supply medium sized energy plants rather than the large-scale. Some of the materials originating from agricultural activities may be bundled of baled to improve transport economy. However, the benefits of bundling are best appreciated in large industrial supply chains, where logistics play a major role. Hence, the co-ordination of supplies is crucial to arrive at large enough total annual amounts for rationalization.

Generally speaking, any upgrading process such as drying, baling or bundling – with one exception – should take place as early as possible in the production process in order to enhance the handling and transport efficiency.

The exception is comminution (crushing/shredding/chipping) of moist material. As pointed out in 03-01-07, storage is an essential prat of a biofuel supply chain. The storage can be planned for comminuted wood (chips), for storage of round timber or for storage of the material as extracted.

Storing of wood chips for any prolonged time should be avoided because of several factors, described in some detail in text section 03-01-07 and summarized in table 03-01 3.