

# **Supply of wood biomass for energy purpose: global trends and perspectives**

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## **1. Introduction**

Renewable energy pays, and that is a fact. One may argue about the best conversion route or the equitable distribution of the added value among all actors, but such discussions concern any field of human activity. Energy biomass presents a large potential for expansion and may grow faster and further than any other related sector. What's more, biomass is produced in forests and fields, and appeals to a rural world that has few other opportunities. In many European countries, forestry and agriculture are no longer competitive on the world market, and they have not been for many years. They have survived on subsidies, whose availability has kept shrinking over time. There is a will to make European forestry and agriculture more competitive on the global market, but that is made difficult by the falling production prices of most agricultural stocks. On the world market there is just one product whose price keeps climbing faster than we want: that is oil. Hence the interest in trying to produce a surrogate - biomass - whose value is necessary linked to the growing price of the stock it replaces.

Here the numbers are spectacular: biomass will never entirely replace oil, yet it may play an important role in a concerted strategy aiming at its substitution. That depends on the capacity of mobilizing very large amounts of raw material, exploiting a significant proportion of the quantities potentially available. The rural world is in the front line, because it controls the land, which is the ultimate source of biomass. Foresters and farmers have the keys to the large biomass stores of Europe, but they are not using them yet. They need to become aware of this opportunity and to learn how to exploit it correctly: only in this way they will be able to generate an offer of biomass that is competitive and sustainable. In turn, this will generate great opportunities for agriculture and forestry mechanization, which machine manufacturers must be ready to seize.

The renewable energy engagements of the EU require that the production of renewable energy is not just increased, but multiplied. That entails an explosive growth of the whole sector, including its agricultural and forest biomass branches.

## **2. Biomass availability**

Oversimplifying, we may consider three main sources of agricultural and forestry wood biomass: forest products, agricultural wood residues and dedicated plantations.

### *2.1. Forest by-products*

Forest by-products derive from commercial forest harvesting and consist of those tree portions that have no current commercial use. These are generally represented by branches, tops and eventually roots. In fact, the matter is somewhat trickier, and for at least two reasons. First, the definition does not only apply to tree parts, but also to whole trees, which lack the form or the size to make a conventional forest product, so that we have a distinction between forest residues (parts) and small trees (whole, non-merchantable trees). Second, these trees or tree parts could actually be used in some other manufacturing process, and especially particle-board manufacturing. Price is the key factor. If the price offered by conventional non-energy users cannot cover the cost of recovering this

material, then they are by-products. Yet, life is not as simple. The higher price offered by the new energy users not only may cover the cost of recovering non-merchantable trees and tree parts, but it can also exceed the price offered by conventional users for low-grade assortments. As a result, energy users may outcompete conventional users, and simply divert an existing wood product flow, without adding much to the overall balance. That is one of the main reasons why we want to improve forest harvesting technology, so that more forest biomass is actually mobilized, reducing the strain between competing users. The quantities are variable, and depend on stand type, silvicultural prescription and product strategy (i.e. who gets the low-grade assortments). The regeneration cut of mature forests yields about 0.2-0.3 fresh tons of residual biomass per each cubic meter of structural wood actually harvested. Hence a cut yielding 300 m<sup>3</sup> of sawlogs per hectare, will also offer an additional biomass harvest between 60 and 90 tons ha<sup>-1</sup>. Thinning operations yield between 50 and 80 tons ha<sup>-1</sup>, as most (or all) of the harvest is turned to biomass products.

The roots of harvested trees represent an additional source of wood biomass, and their recovery deserves special attention for the following reasons: first, the stump-root system represents a substantial portion of the tree mass (De Simiane 1977); second, root wood often has higher heating values than stem wood, and may prove to be a better fuel (Nurmi 1997); third, the removal of the root system in tree plantations is considered as a service rendered to the landowner. Therefore, harvesting tree roots does not require the payment of a concession, and may carry additional revenues in terms of landowner payments. Root recovery is becoming increasingly popular in the Nordic forests and has a long standing tradition in the Italian poplar plantations (Spinelli et al. 2005). The average yield varies between 20 and 40 tons ha<sup>-1</sup>, depending on stand type and conditions.

## *2.2. Agricultural wood residues*

Agricultural residues from tree crops are another major source of wood biomass, which offers a strategic benefit wherever it is impractical to convert cropland to energy crop cultivation (Li et al. 2009) and the disposal of such residue is expensive or problematic (ARSIA 2009). Besides, agricultural residue does not accrue any growing costs and could be tapped at a relatively low price, if effective collection systems were deployed. Fruit growing represents a global business and generates substantial wealth. Grapes, apples and pears are some of the most common fruit crops in the temperate regions, and on a global scale they cover 7.4, 4.9 and 1.7 millions of hectares, respectively (FAOSTAT 2009). A further 9 millions hectares are represented by olive groves, whereas many other fruit crops exist and could be easily tapped for residue biomass. Finding some use for orchard pruning residues would allow converting a disposal problem into a collateral production, with a potential for revenues or reduced management cost. In fact, pruning residues could replace traditional wood assortments for energy and industrial use (Ntalos and Grigoriou, 2002), and they may play an important role in supplying bioenergy plants with renewable fuel (Bernetti et al., 2006). Again, yields vary with crop type and cropping system, but it ranges from 2 to over 4 green tons ha<sup>-1</sup>, for the annual pruning. The multi-year pruning intervals typical - for instance - of olive groves are bound to offer higher yields, often in the range of 5 or more tons ha<sup>-1</sup>.

## *2.3. Dedicated plantations*

Dedicated tree crops from surplus agricultural land have the highest potential for increasing the supply of energy biomass, and in the medium term they could account for three quarters of the total supply (Hoogwijk et al. 2003). Compared to other sources, dedicated crops offer the advantage of an extremely intense management that assures the highest surface yield and the shortest waiting time (Alig et al. 2000). As opposed to traditional agricultural crops, biomass plantations can accrue

further benefits such as groundwater protection, ecological planning, phyto-remediation etc. (Londo et al. 2004). This is especially the case with woody crops, including short rotation coppice (Heller et al. 2003). Among various cropping modules, short rotation coppice (SRC) seems to best reflect the expectations of farmers, who are used to short return times and generally show little enthusiasm for traditional wood plantations, harvested at 10-30 years intervals. However, SRC is an industrial crop, designed to produce large quantities of low-priced raw materials and its success requires that all operations be conducted with the utmost efficiency. Harvesting cost is estimated to be above 50 % of the total cost of biomass produced from wood plantations (Moiseyev and Ince 2000) which underscores the special needs for optimizing these operations. Main species are willow, poplar and eucalyptus, and the rotations range from 1 to 5 years. Annual yields are in the range of 30-35 green tons ha<sup>-1</sup> for willow and poplar in the temperate regions, but can be twice as high in the Brazilian eucalypt plantations.

### **3. Processing Technology**

#### *3.1. Chipping*

The recovery of forest residues for energy purposes generally requires some form of processing aimed at increasing the bulk density and the homogeneity of the feedstock, which is crucial to its effective handling. Such process must be performed as early as possible, in order to accrue its benefits all along the supply chain. In this respect, chipping and compaction are the main alternatives. Chipping is the most common, and today is generally performed by contractors equipped with powerful industrial chippers. Productivity varies most commonly between 15 and over 30 tons per hour. The cost of contract chipping generally ranges between 10 and 15 € t<sup>-1</sup>. Smaller operators can use tractor-powered chippers, which are cheaper to buy and run, but produce much less. If the self-employed small chipper owners did not use marginal resources, their chipping cost would be at least twice as high as the cost of contract chipping. In most cases they would be better off contracting the job rather than doing that themselves. However, small users generally handle small amounts, often too small for the contractor to offer a good price. A good chipping cost calculator is available for free from the following website: [www.biomassaforestale.org](http://www.biomassaforestale.org) (Spinelli and Hartsough 2001). This simple electronic tool was developed from over 100 tests and recently validated with an additional 45 independent tests (Spinelli and Magagnotti 2010).

#### *3.2. Residue bundling*

The alternative to chipping is compaction into units of set size and weight offers many benefits, especially for what concerns handling, transport and storage. To maximize such benefits, the residue can be processed into compact residue logs (CRLs), which resemble in shape and size conventional wood logs: this enables the complete integration of the supply chains of timber and forest fuels, with significant savings in overhead and fleet management costs (Asikainen 2004). Moreover, compacted residue stores much better than chips or loose slash, because the solid outer surface of CRLs greatly limits rewetting during storage, especially in case of snowfall (Pettersen and Nordfjell 2007). Even when rewetting of CRLs has been documented, moisture content has never returned to the original values recorded at the beginning of the storage period (Steele et al. 2008). Moreover, compaction into discrete, even-size units makes it easier to keep track of the stocks by simple visual assessment. Finally, the possibility of transporting CRLs on the same vehicles used for logs, allows resorting to cheaper backhaul trips, thus reducing transportation cost, especially in the case of long-distance deliveries Carlsson and Rönqvist 2007). In fact, these benefits are not limited to logging residue, but can be extended to small trees as well (Nordfjell and Liss 2000). Bundling productivity varies between 10 and 30 bundles h<sup>-1</sup>, corresponding to 5 to 12

fresh  $t h^{-1}$  (Cuchet et al. 2004). Bundling cost also ranges between 10 and 20 €  $t^{-1}$ , which may be recovered through more efficient handling, storage, transportation and comminution.

### 3.3. Root extraction

In the Nordic countries, pine and spruce roots are extracted using modified excavators, equipped with the a special claw-and-shear attachment, whose first example was the *Pallari* grapple, developed in the 1970s (Hakkila 1972). The tool consists in a three-pronged grapple, with sharp fingers and a projecting talon. The latter is used to lift the root, whereas the sharp fingers are used to shear flat stumps. Root cleaning is achieved by shaking the roots just after extraction and leaving the extracted root systems outdoors, so that the rain will wash out any soil still clinging to the wood.

In Italy, poplar root recovery has a long tradition, and relies on proven technology developed over 50 years ago. In 1960 an Italian manufacturer built an auger, designed to fit the rear end of a farm tractor and to receive power through the power take-off (FAO 1962). The auger was hollow inside, and large enough to contain the taproot of a mature poplar tree. It was lowered over the stump and driven into the ground to the depth of approximately 150 cm. Then the auger was raised with a soil "carrot" inside it, which contained the taproot. An ejection ram pushed the "carrot" out of the pipe, dropping it to the ground (Currò and Ghisi 1966). Over the years, this basic design has been improved through incorporation of newer technical elements, but the principle remains the same. The machines are available with either a mechanical or a hydraulic drive and widely used in Italy and abroad, especially in Hungary and in the Balkans – where poplar plantations are also very common (Marković 1973). The core-sampler system is ideal for trees with a strong taproot (poplar, pine etc.) but produces dirty "carrots" that needed cleaning. Active on-site cleaning is allows reducing storage time and transportation cost, and it is performed with chain-flail cleaners: these are mounted on a wheeled chassis and towed by a loader or a farm tractor. The two flail axles are powered by independent hydraulic motors, connected to the pump of the carrier. The loader picks up the "carrots" and dips each one for a few seconds between the rotating flails. It then throws the clean roots 5-6 m away, to form small heaps. Clean roots are loaded directly onto 3-axle trucks driven into the field, using the same loader that cleaned them. If the soil is wet, farm tractors are used instead of trucks.

### 3.4. Pruning residue harvesting

Since a few years, a number of machine manufacturers have been offering dedicated implements for collecting pruning residue. These technologies can be divided according to the processing technique between shredding technologies and baling technologies. A further subdivision can be made between small-scale and industrial technology. Small-scale machines designed to pick up, shred and collect the residue derive from conventional shredders, which have been equipped with a storage bin or a blower, the latter designed to direct the flow of shredded residue towards an accompanying trailer. Small-scale balers are developed starting from conventional hay-balers or built anew. They compact the residues into units of regular size and shape, tie the bale and drop it on the ground for later collection. Baling represents an extra step in the fuel production chain, but it offers the benefit of easier storage: bales can keep for months, whereas fresh chips tend to decay very quickly. Unfortunately, the productivity of small-scale pruning residue harvesters is very low, and in the range of 1-2 fresh  $t h^{-1}$  (Spinelli et al. 2010). Small-scale recovery makes sense especially if the residue is used within the farm boundaries, to satisfy the internal heat or power demand. However, the quality of shredded pruning residue is not ideal for feeding small-scale boilers. Hence the development of industrial units, derived from modified foragers or industrial chippers. There are at least two such units, developed in Germany and Spain, respectively. Their productive potential is

much higher, between 4 and 9 fresh t h<sup>-1</sup> (Spinelli and Picchi 2010). Harvesting cost is proportionally low, and in the range of 15 to 35 € t<sup>-1</sup>, delivered at the farm yard.

### *3.5. Dedicated plantations*

The harvesting of dedicated short rotation tree plantations is dominated by modified foragers, equipped with dedicated SRC headers (Manzone et al. 2009). All main forager manufacturers have developed their own SRC version, including: Austoft, Claas, Krone, John Deere and New Holland. The current trend is towards powerful units fitted with the heavier and stronger headers, which are best suited to plantations harvested every second or third year (Spinelli et al. 2011). However, the effective harvesting of large-size stems requires more than just a powerful forager: plantation design must adapt by allowing for an accordingly large spacing, so that the tops of cut stems can sneak between the standing crop ahead and the stems can be laid horizontal. Modified foragers cannot harvest stems that are too big and too close (Spinelli et al. 2009). Top performance is obtained only when several factors concur, and namely: good terrain conditions, adequate machine choice, high crop density and appropriate row spacing. If harvesting conditions are appropriate, modified foragers can reach a very high productivity, with average values in excess of 30 fresh t h<sup>-1</sup>, including turns and delays. Depending on field stocking and machine type, the total harvesting cost ranges from 10 to 35 fresh t h<sup>-1</sup>, including forwarding to a collection site, preparation and relocation. Harvesting cost is kept below 15 € t<sup>-1</sup> only if field stocking exceeds 40 fresh t ha<sup>-1</sup> and a very powerful forager (> 300 kW) is used.

Over the years, a number of small-scale tractor-powered harvesters have been developed and tested, and much work is still being conducted in this direction. The general idea behind small-scale harvesting units is that their lower investment cost will allow part-time operations, while their higher mobility will bring within economical reach even the smallest holdings. In fact, one of the pillars of modern agriculture is the specialised industrial contractor, and it is very unlikely that SRF will make exception. Small-scale units are relatively cheap to operate, by they are far less productive and reliable than modified foragers, so that their use results in a significantly higher harvesting cost: their most likely role is that of supporting a main industrial fleet, with mop-up work.

## **4. Up and coming**

New technology cannot solve all problems, but it can certainly give a main contribution to the further development of the biomass sector. Researchers and manufacturers are working at new machines, which may make biomass harvesting more effective and competitive. Some innovation is simple and incremental, other is somewhat more daring and creative. Both types are needed, and the examples are so many that it would be difficult to list them all. Below are just some examples. The selection is inevitably based on subjective judgement and could be debated, so that I apologize to all those whom I had to omit, for dearth of space.

### *4.1. Intelligent mountain chippers*

Mountain forests are still largely unexploited because they are difficult to access with industrial machinery. The cost of infrastructure is particularly high, so that road-building is kept to a minimum. The same accounts for landings, which are often rather narrow. In many cases, the space is too small for parking both a chipper and a truck to receive the chips. That often rules out side-loading, with the chipper and the truck parked side by side. Some manufacturers have equipped their machines with upsized blowers, so that trucks can be parked in line, against the front or the

rear end of the chipper. Here the game is to reduce chipper weight and size, while increasing its power and manoeuvrability. Hence the new chipper trucks, designed to replace clumsier truck-mounted chipper. While a truck-mounted chipper has its own independent engine, additional to the truck engine, the new chipper-truck runs the chipper with the truck engine, through a robust power take-off. Often, the loader cab is removed and the truck cab is modified to accommodate for the loader seat and controls. The result is a powerful chipper, which is much more compact and lighter than a conventional truck-mounted unit. The extra space can also be used for installing a high-dumping chip container, to be used as a buffer when the trucks are late, or as solution to those cases where it is impossible to work together with a truck, for lack of space. In that case, the chipper truck can fill its own bin and then dump it into the truck, wherever they find enough space to park alongside. The “intelligent” bit comes through the application of advanced sensors, including: GPS, moisture content meter, flow meter, metal detector. Most of this technology is already available on foragers and tractors, and its application to forestry technology is just an example of incremental innovation. Nothing that will make us jump on our chairs, but something quite useful to commercial operators in the field.

#### *4.2. Convertible grinders*

Within the large family of comminution machinery, there is a sharp distinction between chippers and grinders. The former use sharp tools (knives) to cut or slice the wood, whereas the latter use blunt tools (hammers) to smash or crush the wood (Pottie and Guimier 1985). The two types of machines are generally used to process different materials. In particular, grinders are used when dealing with contaminated wood, as their blunt tools are less sensitive to the wearing effect of contaminants (Goldstein and Diaz 2005). However, grinders offer a rather coarse product, unsuitable for use in some plants (Strelher 2000). In contrast, chippers are exclusively applied to clean wood and offer a finer and better product. These brief considerations represent the main criteria used by wood processing companies, when discriminating between alternative comminution technologies in the event of a purchase. Today, several manufacturers are offering new versatile horizontal grinders that can be temporarily converted into chippers by replacing the standard hammers with sharp knives or chisels. That requires removing the hammers from the drum and inserting special mounts to support the knives. The specifics of tool replacement vary with the manufacturer, but the result is always very similar. The solution is very interesting, as it can add flexibility to most chipping operations, and increase their resiliency to contamination. In the future, one may improve the conversion package by developing a tighter-set anvil, so that the chipper version can develop a better shearing action. Current models often use a very loosely-set anvil (or no anvil at all) and their knife conversion still works much as a grinder.

#### *4.3. Swathe chippers and chipper-balers*

Swathe machines are the ideal harvesting tool for brush, understory or shrubs – so abundant in most regions. Such stands have pioneer character and colonize bare land after a fire or abandonment. Shrub is periodically cleaned for fire prevention, using masticators. Recently, some manufacturers have added to their product lines a “harvester” version, which can recover masticated wood instead of spreading it around. That is the case of German Ahwi, Italian FAE and US Fecon. Their developments are similar and consist of adding some recovery system (a propeller or a blower) to a heavy masticator, so as to drive the wood particles through a spout and eventually into a container. A similar solution is offered by Biobaler AB, where the masticator directs the flow of coarsely broken stems to a round baler. That removes the need for an accompanying container, as the biomass is baled and dropped on the ground, for later recovery. The advantage with this system is that no attempt is made to produce small, even-size fragments, which would be very difficult for a

masticator. On the contrary, fragments are kept as coarse as possible, to facilitate baling and limiting access to microbial attack. Hence, the better storage properties of biobales, which – however – need to be comminuted before feeding to a boiler. These machines are still at the stage of commercial prototype, under advanced testing. If they worked effectively (which we shall soon know) they would offer an ideal solution for tapping the vast resource represented by shrubland.

#### *4.4. Alpine forwarders*

Forestry forwarders are a mature product with limited potential for improvement. Modern forwarders are high-tech, productive and reliable machines, resulting from over 40 years of continuous development: it would be hard to make them better than they already are. However, these machines are designed for introduction to a classic Nordic system, and especially for extraction under relatively short distances (about 500 m). Not that they cannot operate successfully over longer distances, but certainly they were not designed for combined forwarding and transportation over several kilometres. Unfortunately, that is the common procedure under mountain conditions, where the lack of large landing areas often imposes intermediate transportation on narrow forest roads. Hence the enduring success of forestry fitted farm tractors, which are much less efficient than forwarders in the specific extraction task, but offer a superior performance with intermediate transportation. Today, some manufacturers are offering dedicated forwarders with improved transmission boxes, for best performances in both tasks. The machines are also registered for traffic on public roads, reducing the cost of relocation between worksites, which is a main problem when woodlots are small and scattered. Many such machines are also fitted with synchronised auxiliary winches for steep terrain extraction. This is a fully commercial development, which could expand from fringe to mainstream product within few years.

#### *4.5 SRC harvesters*

Within this field there are two main developments, both at the prototype stage. The first concerns new modified foragers designed to cope with larger trees than handled by the machines in current use. One such prototype is the New Holland SRC harvester, whose header combines the main elements of a conventional SRC header and of a sugar cane harvester, to the benefit of a better through flow, even with relatively large and tall stems. This machine is going through an intense test programme and should be ready in its final commercial version within a short time.

Further work is being done in a completely different direction, by developing a two-pass system, where one machine first fells and windrows the stems, and a second picks them up and chips them, blowing the chip into conventional silage trailers. The expected benefits are the capacity to concentrate felling within a short period of time (thus exploiting good weather windows) and the possibility to leave the stems in the field for some time, so as to favour natural drying. Several prototypes have already been built, making significant progress.

#### *4.6. Root extraction in thinning operations*

So, far root wood is only recovered after clear-cutting. That because the excavator-base technology used in Scandinavia is too aggressive for using in thinning operations, and would result in the extensive damage of residual trees. The Italian core-sampler system is much less aggressive, but it has never been used in thinning operations because it is only applied to poplar plantations, which are established at final density and never thinned. Hence the interest in adapting the Italian technology to Nordic conditions, for deployment in thinning operations. This could be achieved by removing the later wings from the auger-pipe, in order to avoid any disturbance outside the pipe

bore. The machine could then be installed on a tracked excavator in order to reach the stumps in selection thinning. A similar unit has already been developed in Italy for stump grinding, and a version for stump extraction should not be too difficult to obtain.

#### *4.7. Hybrid electric forwarders*

Forestry is also exploring the use of hybrid electric transmissions, which is increasingly popular in the automotive sector. A commercial forwarder model has already been presented in Sweden. The machine has a 40 kW diesel engine powering six electric wheel motors and an accumulator. The manufacturer claims that the new transmission has an efficiency of about 80 %, whereas the standard hydrostatic transmissions adopted by conventional forwarders only reach a 50% efficiency. Furthermore, the adoption of independent wheel motors greatly simplifies the transmission chain and allows for a higher independence of wheels. Hence, the machine has steering front and rear wheels, a central articulation and a turning bunk plate, so that all wheels feel exactly the same path. Compared to standard forwarders, the new machine should use 50% less fuel and emit 80% less carbon dioxide. Nitric oxide emissions are also reduced by 50%. release a great simplification of the transmission. Due to its simpler transmission and smaller engine, the forwarder has a lower tare weight compared to conventional models. A 12 t capacity hybrid forwarder has an empty weight of 9500 kg, versus 14000 kg of the equivalent conventional forwarder. This can compare with forwarders today, which have a hydraulic and mechanical power transmission with efficiency around 50 %.

#### *4.8 Unmanned machines*

A Swedish manufacturer has recently presented an unmanned harvester, consisting of a tracked carrier, fitted with parallel loader boom and harvester head. The machine is not a robot and is not capable of independent work, but it is operated remotely by the forwarder operator. The whole concept is based on two forwarders and an unmanned harvester (named “Beast”). Control of the beast is assumed by the forwarder being loaded, whose operator steers the “Beast”, getting it to fell the trees, process them into logs and drop the logs on the forwarder bunk. Once the forwarder is fully loaded, the “Beast” is idled and the forwarder leaves for the landing. If the machine system is in balance, the second forwarder shows up when the first is about to leave, so that the second operator can take control of the “Beast” and make it fill his own forwarder’s bunk. The system was first designed in 2002 and the advanced prototype was field tested in 2006. This system offers lower fuel consumption than the conventional two-machine system ( $1 \text{ l m}^{-3}$  vs.  $1.4 \text{ l m}^{-3}$ ) and is economically competitive over distances shorter than 3-400 m (Bergkvist 2006). The difference is made by system balance. If system balance is achieved, the “Beast” system is the most competitive: otherwise, unproductive waiting time begins eroding its competitive edge.

### **5. On the horizon**

Readers will have noticed that none of the technology solutions listed above have ground-breaking character. They are specialised applications of innovative solutions already developed in other sectors. Forestry is the “poor” relative of other more profitable businesses, like agriculture, mining and the automotive industry. It is logical that new solutions are first developed within these sectors, and then transferred to other secondary activities. The possibility of success is higher, since the proposed innovation already works in some other application. Failure may depend of a lack of compatibility between the specific technology and forestry use, but it is not inherent to the technological solution itself, which is already proven. Here, the merit of forest engineers is mostly

in scoping and selecting the most promising technologies, and adapting them to the specific needs of forestry use. That is no little thing, and takes much imagination and audacity.

Nevertheless, there are still some possible developments that would be specific to forestry and have haunted forest engineers for decades. The current exponential progress in sensor and data processing technology may soon offer a solution to these problems. Once realized, these new ideas may truly revolutionize forest technology.

### *5.1. Loader boom automation*

Interest in the automation of forestry tasks dates back few decades, and yet experts are skeptic that a fully automated forest machine will appear any time soon (Hartsough et. al 2010). However, partial solutions like “smart” boom controls may be nearer than we think. Development started in the mid 90s and has slowly continued until present. The idea is to automate boom coordination. Under current manual control, the operator uses a set of levers or joysticks, with each motion controlling one of several cylinders or motors to activate a particular joint on the boom or the implement attached to the boom-tip. “Smart” control would allow automating most sequences, through emulation, path recording and replication or reverse-activation. That would mean that once the boom has been led to a wood stack and the path memorized, the following cycles leading the boom to the same wood stack could be repeated autonomously by the machine. Similarly, the computer could launch an activation sequence to effect more movements otherwise controlled separately, once a proper command has been issued and recognized. That could rely on a mix of sensors and data processors, which would take over much of the repetitive tasks currently performed by the operator, thus relieving his/her effort and allowing him/her to focus on taking decisions, rather than on moving levers. In turn, this would allow one operator to handle more machines or more booms at a time, making it possible to develop multi-task multi-boom machines.

### *5.2. Continuous vs. step-wise collection*

Forest harvesting involves handling rather large objects, so that step-wise processing is almost exclusive. Most forest machines are fitted with a boom for handling one or few pieces at a time. A felling machine – for instance – reaches for one or few trees, cuts them and then lays them on the ground, to resume a new cycle with the same procedure. Similarly, a forwarder will pick up a grapple load of logs, lift them, place them on the tractor bunk and then start a new cycle, reaching out to pick up a new grapple load. In brief, forest work is generally cyclic. In contrast, the harvesting of agricultural produce is generally continuous, with a forager – for instances – running in the field and cutting, collecting and chopping corn stalks at the same time. In fact, continuous feller-bunchers were studied and prototyped already in the 1980s, in Canada and in the US. Among them, the best known are the Hyd-Mech FB7 and FB12 units, as well as the MTDC feller-forwarder (Twaddle et al. 1989). The machines worked well, despite the simple technology then available. Similar machines are being developed today for short-rotation forestry, and this might be the future of plantation harvesting, in general. On a similar note, one may automate log stack collection by forwarders, a bit like already done in agriculture for the collection of hay bales (Hartsough et al. 2010). Site conditions offered by forest sites are certainly more challenging than those found in agriculture, but appropriate sensors are likely to overcome most difficulties.

### 5.3. Stand-alone bundlers

The Swedish “Beast” concept could be applied to compact bundlers for the compaction of forest residues. From a logistic viewpoint, residue bundling is an ideal solution. The main obstacle is cost, which is still too high. Current bundlers are expensive and relatively large, being carried by a heavy forwarder or a 6X6 truck. If one removed the carrier and its loader, the cost and the size of the bundler would be substantially reduced. The idea is to develop a compact stand-alone bundler for parking at a yarder landing and bundling residues as they fall off the processor. Processors used at yarder landings have excess capacity, because they are generally much more productive than the yarders they serve. Hence, the same processor could be used to process the trees, feed the bundler and pile the bundles, ready for transport. If the processor carrier was strong enough, it could also be used to power the bundler, which is essentially a hydraulic machine. This would allow a dramatic reduction of bundler size and cost, thus favouring widespread adoption.

### 5.4. Long distance booms

Forest owners are suspicious of in-stand traffic, fearing that it may cause soil compaction and a consequent forest decline. There is a strong interest in confining machine traffic on designated trails: in some countries, this interest has already materialized into a specific legislation channelling all in-stand traffic over designated permanent trails, and prohibiting free in-stand traffic. At the same time, some owners would like to increase the space between permanent trails in order to minimize the unproductive land area reserved for traffic. Hence the adoption of long reach booms, supported by massive carriers. Standard carriers cannot handle an adult tree at a 15 m distance without tipping, and the carriers used for this purpose are heavy excavators in the 40 tons class. That makes relocation particularly difficult and expensive. In the past, special long reach booms have been the object of a few studies. In all cases, the prospected solution was that of equipping the boom with an intermediate support, either a folding prop placed at mid length (Parker 1999), or a castor wheel under the boom tip (Hartsough et al. 2010). A further idea in this direction is a new German project for a walking harvester, operating on a folding sliding base.

## 6. Conclusions

Forest engineering is evolving rapidly, and the recent interest for forest biomass is accelerating this process, as the booming bioenergy market is attracting new capitals and customers. Innovative technology is badly needed, and this need opens many business opportunities to innovative machine manufacturers. Innovation is required at all levels, from incremental to fundamental. In this respect, well-organized multidisciplinary research would have the highest potential. Many of the solutions sought by forest engineers have already been implemented in agricultural engineering. Although akin, agricultural and forest engineering are different disciplines. Yet, their similarity may facilitate interfacing and lead to rapid progress. I firmly believe that increased cooperation between agricultural and forest engineers would be greatly beneficial to both disciplines, and to the related sectors.

## 7. References

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**Figure 1 -** Chipping operation at a roadside landing



**Figure 2 -** Bundling logging residues at a yarder landing



**Figure 3 -** Root wood extraction



**Figure 4 -** Harvesting SRC



**Figure 5 -** Integrated tower yarder, full suspension carriage, processor and chipper



**Figure 6 -** “Intelligent” mountain chipper



**Figure 7 -** The electric forwarder



**Figure 8 -** The unmanned harvester

