Project no. 518128

EFORWOOD

Tools for Sustainability Impact Assessment

Instrument: IP

Thematic Priority: 6.3 Global Change and Ecosystems

Deliverable D3.1.2
Key products of the forest-based industries and their demands on wood raw material properties

Due date of Deliverable: Month 17 (moved from Month 15)

Actual submission date: Month 22

Start date of project: 011105

Duration: 4 years

Organisation name of lead contractor for this deliverable: STFI-Packforsk

Final version

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	**PU**
PP	Restricted to other programme participants (including the Commission Services)	
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CO	Confidential, only for members of the consortium (including the Commission Services)	

Partners involved and acknowledgement

This report, deliverable D3.1.2, has been produced within the EFORWOOD workpackage 3.1 “Quality Assessment and Allocation”. The responsible organization has been STFI-Packforsk.

Editor of the report was Sven-Olof Lundqvist, STFI-Packforsk, who was also responsible for the part related to fibres, pulp and paper. Barry Gardiner, Forest Research, was responsible for the parts related to solid wood/wood-based panels and bio-energy.

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The editor wishes to acknowledge the Swedish-Finnish research programme “Wood Material Science and Engineering” and the funding parties of the Innovood project, from which parts of the background material regarding raw material demands of paper products have been obtained.

Thanks are also due to experts in the paper industry and at STFI-Packforsk who have contributed with valuable input.

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1. Summary

The scope of this report is to express the demands on wood and fibres for selected products from major production lines in terms of raw material properties. The major production lines are divided into solid wood chains, fibre chains and bio-energy chains. For each type of chains, sets of key product types have been identified.

Properties of importance for these product types have been listed. When possible, threshold values have been given. The plan is to revise the report later during the EFORWOOD project when more information on threshold values can be introduced.

In many cases, it is, however, not possible to state generally applicable threshold values, as there are alternatives. If the available raw material is not suitable, it may be possible to investment in order to make use of another material. In particular, these issues are very common for the fibre chains. In these cases, the demands have to be expressed in more qualitative terms and the text of the report is written to provide a background to the preference for certain raw materials. Preferred values are only indicated rather than stated.

The tables of key products have already proven to be useful, in connection with the establishment of the layout of the Iberian case.

2. Introduction

2.1 Objective

The objective of the deliverable D3.1.2 within the workpackage 3.1 “Quality Assessment and Allocation” of module 3 was defined as:

- To express the demands on wood and fibres for selected products in major production lines (solid wood to wood products, fibres to pulp and paper products, bio-energy) in terms of raw material properties.

To do this, it is obviously necessary to clearly define the products selected. Therefore, the deliverable has been expanded to include the task of:

- Defining the key products of the major production chains of forest based industries and the materials processed along each production chains.

2.2 Key products

The ambition has been to identify sets of **key products** for the major production chains, which are hereafter referred to as:

- solid wood chains
- fibre chains
- bio-energy chains

The ambition has not been to list all possible products produced in all countries, but rather the key products or types of products of the different production chains. The ambition has been to define product types covering at least 80 % of the production within Europe as a whole, so that the listed product types will cover at least 60-80 % of the production for the regions in which ToSIA, the Tool for Sustainability Impact Assessment, is foreseen to be used within the EFORWOOD project and afterwards. Another ambition has been to aggregate the types of products to a limited set which is possible to relate to available statistics on consumption, production, import, export, etc.

The selection of the key products has been performed in cooperation with experts engaged in related tasks within Modules 4 and 5. The starting point has been to identify the main types of converted products used by the end-user, such as books, sacks, outdoor furniture, pallets, floor systems, pellets, etc. and to follow the chains back to the raw material. For example a book (converted product in M5) is in most cases printed with offset or digital printing on printing paper (paper product in M4), which in turn is manufactured from bleached kraft (chemical) pulp (pulp product in M4) produced from hardwood and/or softwood (raw material from M3) or from thermo mechanical pulp (TMP) from spruce wood (M3) or from de-inked pulp (DIP) from paper collected in M5 and upgraded in M4.

The lists of key products have also proven useful in the preparation of the regional cases. The establishment of the general layout of the fibre chains of the Iberian case study, which applies a consumer perspective on the forestry wood chain, may be used as an example. We started by looking into the statistics for paper consumption in Spain and Portugal. 4 product types which constituted about 70 % of the consumption of paper were identified. We then concluded that most of these products were produced from wood harvested or recycled fibres collected on the Iberian peninsula. Only one type of paper and bleached long-fibre pulp were imported in substantial volumes. The sources of these imports were identified and it was concluded that only forest resources in Spain and Portugal and in regions representing these imports have to be dealt with in the study. In this way, the general layout was established.

2.3 Key properties

For each one of these key products, sets of key properties have been listed and property demands have been expressed. The key raw material properties which have to be considered have been listed and commented on below.

2.4 Quantitative and qualitative demands

Sometimes it is said that a mill can operate on any available wood raw materials. This may be true for some products with low added value or with large efforts made in the processes of the mill. Normally it is about optimization of product performance and costs, including costs for the raw material as well as for the processing in the mill. Less suitable materials may result in lower yield and higher operation costs. Sometimes, the properties of wood or fibres have to be tightly controlled. If the available raw material is not suitable, you may have to do an investment to make the material useful or to allow use of another material.

In some cases, it is possible to express property demands with specific values, for instance when the mechanical properties of wood materials for constructions have been standardised. Where it has been possible to define such threshold values these have been included.

In many cases, however, it is not possible to express the product demands in general terms because the same type of product may be possible to produce in production lines designed in alternative ways which are able to handle materials with different properties. However, it does not imply that the raw material properties in these cases are of less importance, but that alternatives may be developed to allow the use of materials that would otherwise be regarded as unacceptable or not economically feasible. Researchers may develop and producers invest in new processing equipment to deal with the problem. The associated costs for the investment and sustainability impacts of the modified operation (use of energy, chemicals, person-hours, etc.) have, of course, to be considered. Such development may also make it possible to offer the customer a better product or a good enough product at a lower cost or price provided that proper investment is made. Use of especially suitable materials may, on the other hand, increase product yield, quality, added value, customer satisfaction and reduce material use, transportation, etc. Innovations in new or improved products and processes as well as market supply and demand will continuously change the conditions and bring new possibilities or difficulties. Some of these optimisations can be performed gradually to adapt to the current situation, others will involve large investment and are performed stepwise after major decisions where it may also be an alternative to shutting down the operation.

Property variations in the processed materials may, thus, to some extent be dealt with through optimisation and investments in the long or medium time frame and through process adjustments based on assessment and measurements and process control in the short term. Even so, it is important to bear in mind that product quality and production efficiency are normally improved by use of materials with uniform properties.

From this insight, it has been concluded that the property demands in many cases can only be expressed in a qualitative way rather than quantitative and general terms. An obvious observation is that the more steps of conversion or processing that are involved in the manufacturing of a product, the more alternatives will be possible and the more difficult is it to define property demands on the initial wood raw material. It may be rather straight-forward for a board but less so for a wood-based construction element or a paper product in which the wood fibres have been totally restructured.

The more the materials have been converted, the more expertise is needed to make a realistic judgement on the property demands and how allocation and processing can be optimised when dealing with a specific forest resource, production facility and product. This is also to some extent reflected in the character of the chapters dealing with fibre chains, solid wood chains and bio-energy chains respectively. In the chapter related to production of pulp and paper, which is more complex and also assumed to be less familiar to most readers than the other production chains, a brief presentation of relationships between properties of fibres and paper has been added.

3. Fibre chains

3.1 Key products

The key products selected from the fibre chains and from what materials they are produced are structured in Table 1, and are divided into:

- Graphic products (1a - 1d)
- Packaging products (2a – 2e)
- Hygiene products (3a – 3b)

The list includes a total of 11 key types of converted products produced from 13 key paper types. In many cases the paper products are built up by mixing fibres with different properties and other materials, in order to optimize quality/functionality and cost/price. Higher cost materials or further processing (with associated costs) may be used to produce higher quality grades, and vice versa. Some of the paper types are multi-ply materials, where the different layers serve different purposes, for instance to enhance an important property or to reduce costs. The layers are often produced from different types of pulps, which are processed to optimise the material as a composite.

Some basic product properties are common for many of the key products of the fibre chains: printability, stiffness, runability on the paper machine, in printing presses and other converting, etc. The properties obtained in the paper depend both on the fibre raw materials used and the processing of the materials in the production line (equipment and conditions). As the fibres have similar influences on several properties important for many products, these relationships are commented on separately.

3.2 Key demands on wood and fibres

The properties of the fibres, pulp and paper used in the different parts of the production chains are very important for the product properties and the production efficiency. For paper products, no specific general threshold values can be defined for the materials used along the production chains. The properties need to be suitable for the product and the process and they also have to be uniform and predictable.

When the basic functionalities of a pulp or paper product are fulfilled, the uniformity is often said to be the most prominent “property”. Uniformity shall in this context be understood as constant property distributions in time, not as homogeneous. When a printer has adapted his press to a certain paper, he wants to get paper with the same properties all the time. And this constancy should preferably start with the wood raw material fed into the process. Some heterogeneity in fibre properties may, however, often be beneficial: Some long fibres in the pulp will provide good strength of the wet paper sheet on the paper machine and will improve the runability, but if they are too many, the fibres will start to form flocks and the formation of the paper will suffer. Suitable property distributions are, thus, needed and they should be reasonably constant in time. If suitable distributions can not be obtained from a single pulp, it is mixed with pulps or materials to match the specifications. A typical example of this is the addition in many products of some “reinforcement pulp”, longfibre kraft pulp, to increase strength.

Table 1: *Key products of fibre chains and fibre based materials used along each production chain*

Chain	Converted product (M5)	Paper (M4)	Pulp (M4)	Fibre raw material (M3)
	Graphic products			Suitable fibres from …
1a	Newspapers (cold-set web offset)	Newsprint	DIP (de-inked pulp)	Recycling (M5+M4)
			TMP	Spruce
1b	Catalogues, journals and magazines (gravure printing)	Magazine paper	TMP, CTMP, SGW (stone groundw.)	Spruce, aspen
			Kraft pulp, bleached	Softwood
1c	Books, brochures and folders (offset and digital printing)	Printing paper	Kraft pulp, bleached	Hardwood, softwood
			TMP, CTMP	Spruce, aspen
			DIP (de-inked pulp)	Recycling (M5+M4)
1d	Fine/Office paper (no conversion)	Woodfree paper	Kraft pulp, bleached	Hardwood, softwood,
			Office waste	Recycling (M5+M4)
	Packaging products			
2a	Corrugated boxes	Kraftliner	Kraft pulp, unbleached/bleached	Softwood, hardwood
		Testliner	OCC (Old Corrugated Containers)	Recycling (M5+M4)
		Fluting	DIP(de-inked pulp)	Recycling (M5+M4)
			NSSC	Hardwood
2b	Carton boards containers (flexographic/offset/digital printing)	Paper board (mainly)	Kraft pulp, bleached/unbleached	Softwood, hardwood
			Mid-layer: TMP, CTMP, DIP	Spruce, recycling
2c	Liquid carton board containers (flexographic/offset/digital printing)	Liquid carton board (mainly)	Kraft pulp, bleached/unbleached	Softwood, hardwood
			Mid-layer: CTMP	Spruce
2d	Sacks	Sack paper layers (mainly)	Kraft pulp, bleached/unbleached	Softwood
2e	Bags	Kraft paper	Kraft pulp, bleached/unbleached	Hardwood, softwood
	Hygiene products			
3a	Hygiene - Household	Tissue paper	Office waste	Recycling (M5+M4)
			Kraft pulp, bleached	Hardwood, softwood
3b	Sanitary goods	Absorbants	Kraft pulp, bleached	Softwood
			CTMP	Softwood

Basic properties common for several paper products

Paper is basically a network of fibres. The properties of a paper are determined by the properties of the fibres, the structure of the network and the character of the bonds between the fibres. It is also influenced by materials added to the network to improve specific properties or to reduce costs, such as starch and fillers. Very often, paper is produced from mixtures of pulps and other materials and often in multiple layers, where each layer shall have its specific properties to contribute to the properties of the engineered composite and to reduce costs. A good example of this is multi-ply paper board, which has to be stiff (shall not bend easily). The solution is to use two surface layers with high tensile stiffness and to separate these surfaces with material of lower density and cost. The materials of the different layers are selected and processed to fulfil the requirements for runability and other properties at the lowest possible cost.

For all types of paper, certain strength properties have to be fulfilled for acceptable runability on the paper machine, in printing presses and other converting equipments and for the expected functionality by the end user. Different levels of strength and types of mechanical and fracture properties (tensile, tear, delamination, puncture, etc.) are relevant depending on the final product. The stiffness and dimensional stability is important for many products. Surfaces need to stay flat and packaging materials need to remain rigid, even with reasonable humidity variations, while other products need to be somewhat elastic to absorb sudden loads.

The structure of the fibre network is also important and particularly its evenness/homogeneity. Only limited variations in sheet grammage, g/m^2, (formation) and thickness or density are acceptable. Otherwise the paper can not be optimally used. Local deviations may also initiate breaks. High bulk (low sheet density) is sometimes appreciated to save material (for instance in the mid-layer of paper board in the example above) and for porosity. Porosity and surface properties of the paper are also important, for instance for printing, absorption, coating, lamination and tactile properties.

Nowadays, most types of paper products carry printed information, which brings demands not only on surface properties as mentioned above but also on optical properties like light scattering, uniform appearance, etc.

Important properties of fibres in relation to paper properties

The dimensions of the fibres (length, width and wall thickness) are important in themselves, especially the fibre length and fibre wall thickness. A number of relationships between fibre length, width and wall thickness are also very important in papermaking and for the properties of the products. Below, some important fibre properties are listed. Their level of importance depends on the product and processes used:

- Fibre length
- Fibre wall thickness
- Fibre coarseness (g/km fibre), defined by fibre width and wall thickness (and process yield)
- Number of fibres/g, defined by fibre length, width and wall thickness (and process yield)

- Fibre stiffness (bending) , defined by fibre width, wall thickness and microfibril angle (and processing)
- Number and character of vessel elements (relevant for some hardwood species)

An important property closely related to fibre stiffness is fibre collapsibility; more about that below.

Other properties which may be of importance are:

- Wood density
- Chemical composition
- Microfibril angle

Effects on paper properties

The following HIGHLY SIMPLIFIED comments can be made about the influences of these fibre properties (the comments are valid in most but not all cases, depending on product, process, etc.):

- o Long fibres are normally positive for fracture properties and wet strength on the paper machine but negative for formation.
- o Thin-walled fibres are normally positive for surface properties (printability, smoothness) and optical properties.
- o Flexible fibres are normally positive for strength properties but negative for bulk.

It is not easy to generalise about the importance of each one of the fibre dimensions length, width and wall thickness. They are often to some extent correlated to each other. Shorter fibres are often also more thin-walled and slimmer (less wide). This is at least true for wood and fibres from the same wood species grown in regions with similar climate, etc. An important factor behind this correlation is the content of juvenile wood in the wood mix.

Such correlations are illustrated in Figure 1 and 2, based on data for Scots pine in Sweden. The wood samples represent pulpwood logs from the top of the tree and from the mid part of the-stem, sawmill chips and root logs from slow-grown small trees. Figure 1 shows large differences in fibre length and fibre wall thickness among the wood of different origins. These wood types are extremes. The wood delivered to a pulp mill is normally a mixture of these, but a variable mixture which will bring variations in property averages and distributions. At the mill, materials are often blended to improve the uniformity of the chips fed into the process. The figure illustrates the spectrum of wood raw materials which could be offered to a mill from the pine forest in a region, if it was economically feasible.

The figure also shows that there is some correlation between fibre length and wall thickness, but also large systematic deviations from this. Such correlations sometimes make it difficult to understand the real origin of problems with paper quality and to act properly. And, seen from another angle, when it has become possible to efficiently analyse a property, for instance fibre length or fibre coarseness, it has been used to predict pulp and paper properties, and sometimes quite successfully for a certain species and product, even if other more hard-to-measure fibre properties like collapsibility or stiffness would explain more of the variation.

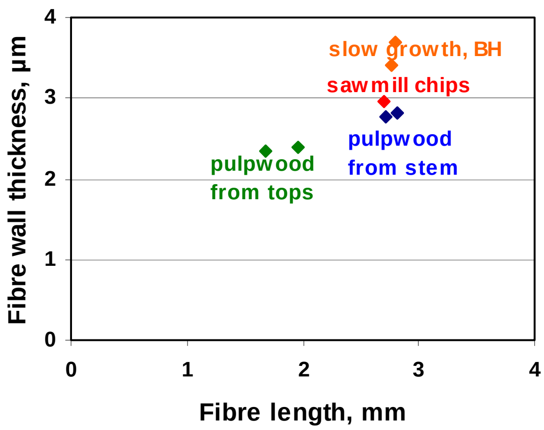

Figure 1: Fibre length (STFI FiberMaster, length-weighted) and fibre wall thickness (SilviScan). Wood representing different parts of Scots pine trees. (Lundqvist et al, 2007)

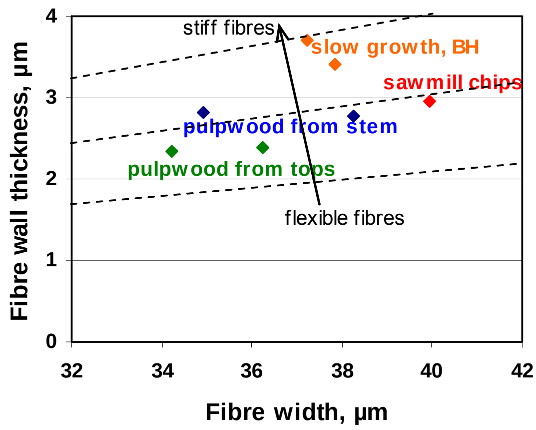

Figure 2: Fibre width (STFI FibreMaster) and fibre wall thickness (SilviScan). Wood representing different parts of Scots pine trees. The broken lines indicate different levels of fibre collapsibility. (Lundqvist et al, 2007)

As said above, the effects on paper properties are often related to combinations of dimensions rather than to one single dimension. The ability of the individual fibres to collapse has a strong influence on several paper properties. Collapsible fibres will turn into flexible bands in the paper structure, whereas those which do not collapse will become stiff rods in the structure. Collapsibility is largely related to the relationship between fibre wall thickness and fibre width. This is illustrated in Figure 2 with data from the same samples as Figure 1. The broken lines indicate different wall thickness to width ratio. In this case, the fibre width shows a rather small variation and, therefore, the collapsibility is mostly influenced by the wall thickness. But this is not a general truth. Fibres with thin walls may also be hard to collapse if they also are slim, for instance fibres from hardwood species like eucalypts. (Hardwood fibres are, however, too slim to match the width scale in Figure 2.) And looking at distributions rather than at averages, all the samples of the figure have fibres with both high and low collapsibility but in different proportions.

The angle of the microfibrils in the fibres (in relation to the fibre axis) is also important for the collapsibility of the fibres and influences also other mechanical properties. Fibres with a large angle tend to be less collapsible at the same width and wall thickness. This issue is more relevant for wood raw materials from fast-grown plantations than for slow-grown Nordic trees.

The size or mass of the fibres (length, width and wall thickness) will determine the number of fibres per gram and also properties of paper. In sheets specified to have the same grammage, the use of fibres with lower coarseness and shorter fibres, for instance from hardwoods like eucalypts, will mean a longer total length of fibres in the sheet, a larger number of fibres and more bonds, which will influence the sheet structure. Again this is an example that it is important to be concerned with individual fibre dimensions but also the combination of fibre dimensions.

During processing in the mill, the properties of the fibres are modified to match the properties needed in the product, as far as possible. It is not always possible and the cost will depend on the properties of the fibres of the raw material. An example is given in Figure 3, showing sheet densities and air permeability (porosity) of sheets produced in the laboratory in the same way. Refining of pulp, an energy-consuming mechanical treatment, is a powerful tool to adapt the fibres. For each wood material of Figures 1 and 2, sheets have been produced from unrefined pulp and from pulps refined to two energy levels. The figure shows that there are large differences between the raw materials. It also shows that the fibres can be modified for the specific product by refining, at least to a considerable extent, but of course at a cost and a related sustainability impact. The sheets from fibres of top logs have a high density and low porosity even if the pulps are not refined. The sheets from the most slow-grown wood have a high porosity and low density even if produced from refined pulp. (Lundqvist et al, 2007)

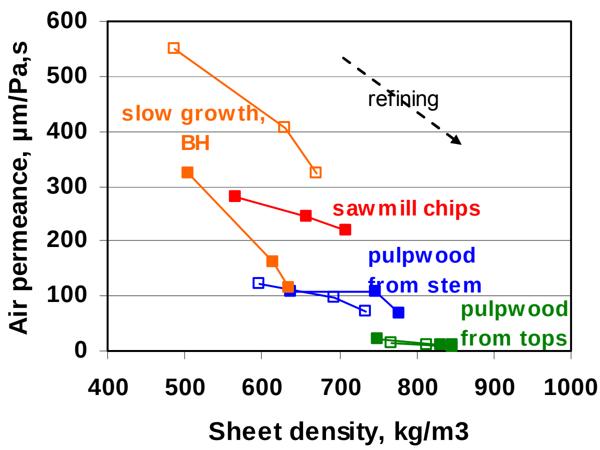

Figure 3: *Density and air permeance (porosity) of laboratory sheets produced from pulps of various origin and refining (PFI mill). The pulps are produced with laboratory kraft cooking from wood representing different parts of Scots pine trees. The sheets from fibres of top logs have a high density and low porosity even if the pulps are not refined. The sheets from the most slow-grown wood have a high porosity and low density even if produced from refined pulp. (Lundqvist et al, 2007)*

(Figures 1-3 were produced within the Innovood project of the Swedish-Finnish research program "Wood Material Science and Engineering". More information is available at www.stfi.se/innovood)

Wood density is also to a major extent defined by the fibre width and wall thickness. In hardwood species there is also an effect due to the number and size of vessel elements. A high wood density is beneficial to reduce the wood volumes per ton of pulp and paper being transported and for production capacity (if the process equipment is designed for it), but it may be good or bad for quality and production efficiency depending on the particular product and process. Different fibre cross-sections can result in the same wood density so wood density cannot be used as a general measure of fibre properties. However, for a specific mill with given products and processes such general considerations are most often not relevant. The alternatives in wood supply regarding wood species and origin are normally quite well established. Then, the wood density may be a useful property to monitor and stabilise the fibre properties, and possibly also to differentiate wood with different properties for specific production lines and products.

The chemical composition of the wood influences the yield of the pulping processes.

Predictable differences between and within wood species, stands and trees

There are large variations in the wood and fibre properties between and within wood species, stands and trees. Part of these differences is known and predictable. This part may sometimes be exploited through allocation of particularly suitable fibre materials to specific mills and products, if economically feasible. The rest of the variations are stochastic and negative for the uniformity of the properties (as defined above). Its effects may, however, be reduced though blending of the material.

Some HIGHLY SIMPLIFIED comments on differences between fibres in various types of wood:

Hardwoods species (broad-leaves) have normally shorter and slimmer fibres with thinner walls than **softwoods**. They also have vessel elements, special cells to conduct water, and these can cause problems in paper grades for printing.

In both hardwoods and softwoods there is a successive change from **juvenile wood** in the centre of the stem to mature wood formed further out from the pith. Juvenile wood has typically shorter, slimmer and more thin-walled fibres, as well as fibres with a higher microfibril angle, than mature wood fibres in the same stem cross-section. As a consequence, the properties of logs will differ with their number and structure of growth rings. Pulpwood will typically have shorter fibres, lower wood density and higher microfibril angle than sawmill chips from the outer part of the higher diameter sawlogs from the same tree.

Another structural variation within softwood trees is the difference between **earlywood and latewood.** Latewood is formed towards the end of the growing season and has typically more thick-walled and slimmer fibres. Thus, latewood has a higher wood density and its fibres are less collapsible and stiffer than the earlywood fibres. These differences explain why we can see annual rings in stem cross-sections. (The differences are normally smaller for hardwoods than for softwoods.) All parts of the tree show this mixture of fibres with different properties, but the proportions of earlywood and latewood, as well as their specific properties, vary between and within stands and trees in a quite systematic way.

The proportions of earlywood and latewood on the one hand and juvenile wood and mature wood on the other hand have a strong influence on the wood and fibre properties in the different parts of an individual tree. This fact is also a reason why it is often possible to predict wood and fibre properties reasonably well from readily available data and to implement practical systems for proper wood and fibre allocation. Such systems are in operations at many mills around the world.

Qualitative relationships between properties of wood raw materials and key paper products

As stated above, it is not possible to state generally applicable threshold values for wood raw material properties in relation to paper products and processes. To clarify some important relationships, some general qualitative influences of the basic properties, the fibre dimensions, and the combined variables listed above have been compiled in Table 2a and 2b. The table differentiates between various types of pulps typically used in the different key products to enhance special qualities of paper grades or in different layers of multi-ply products. Hopefully, this qualitative information can be of help, when alternatives in the allocation of wood and fibre raw materials are discussed. Please, note that even if no preferred value is indicated, the property distribution should be reasonably constant in time.

Table 2a: *Important relationships between properties of fibres and key properties of paper products, part a*

Paper and pulp	Type of pulp	Fibre dimensions		Combined fibre properties				Wood
		fibre length	Fibre wall thickness	Fibre coarseness	Number of fibres per gram	Fibre stiffness (bending)	No of large vessel elements	Wood density
1a Newsprint								
1a.1 Pulp for printability	DIP, TMP	-	- [1)]	- [1)]	+	-	-	-
1a.2 Pulp for strength	TMP, SBK	+			+			+
1b Magazine paper								
1b.1 Pulp for printability	TMP, SGW	-	- [1)]	- [1)]	+	-	-	-
1b.2 Pulp for strength	TMP, SBK	+						+
1c Catalogues, brochures, folders								
1c.1 Pulp for printability	HBK,TMP,DIP	-	-	-	+	+	-	
1c.2 Pulp for strength	SBK	+	-	-				
1d Fine / Office paper	HBK, SBK, Office waste	-	-	-	+		-	

Continued

+ = relatively high (and stable) value preferred; - = relatively low (and stable) value preferred

S=softwood; H=hardwood; B=bleached; U=unbleached; K=kraft pulp; TMP=thermomechanical pulp; CTMP=chemi-thermomechanical pulp; SGW=stone groundwood pulp; NSSC=Neutral Sulfite Semi Chemical pulp; DIP=de-inked pulp

[1)] For a specific wood source, the fibre wall thickness is often positively correlated with the fibre length, see figure 1. Fibre wall thickness and tear strength will correlate, but the surface and printability properties will suffer from too thick-walled fibres. If fibres with the same length but thinner walls can be obtained at a comparable cost, for instance from another wood species, these fibres would normally be preferred, as they result in sheets with more fibre layers at the same grammage.

Table 2b: *Important relationships between properties of fibres and key properties of paper products, part b*

Paper and pulp	Type of pulp	Fibre dimensions		Combined fibre properties				Wood
		fibre length	Fibre wall thickness	Fibre coarseness	Number of fibres per gram	Fibre stiffness (bending)	No of large vessel elements	Wood density
2a Corrugated boxes								
2a.1 Kraftliner (surface, new fibr.)	USK, SBK, UHK, HBK		+ [1)]	+ [1)]	+			+
2a.2 Testliner (surface,recycl.fibr)	Recycled containers							
2a.3 Fluting (corrugated)	DIP, NSSC					+		
2b Carton board containers								
2b.1 Pulp for surface and print	SBK, HBK	-	-	-	+	-	-	
2b.2 Pulp for mid-layers	TMP, CTMP	-	+	+		+		+
2c Liquid carton board containers								
2c.1 Pulp for surface and print	SBK, HBK	-	-		+	-	-	
2c.2 Pulp for mid-layers	CTMP, SBK		+	+		+		+
2d Sacks	USK, SBK	+			-			-
2e Bags	USK, SBK, UHK, HBK	+				+		
3a Hygiene Household / Tissue	BKHW, BKSW, Office waste	+	- [2)]	-	+	-		-
3b Sanitary goods / Absorbants	BKSW, CTMP	+	+ [2)]	+		+		+

+ = relatively high (and stable) value preferred;   - = relatively low (and stable) value preferred

S=softwood; H=hardwood; B=bleached; U=unbleached; K=kraft pulp; TMP=thermomechanical pulp; CTMP=chemi-thermomechanical pulp; SGW=stone groundwood pulp; NSSC=Neutral Sulfite Semi Chemical pulp; DIP=de-inked pulp

[1)] For a specific wood source, the fibre wall thickness is often positively correlated with the fibre length, see figure 1, and also coarseness. If fibres with the same length but thinner walls can be obtained at a comparable cost, these fibres would normally be preferred, as they result in sheets with more fibre layers at the same grammage.

[2)] - if tactile properties like softness are emphasised, + if absorption has priority

3.3 CPA codes

It has been an ambition that the aggregated types of products would be possible to relate to available statistics on consumption, production, import, export, etc. For the fibre chains, we have in the first place related to statistics of CEPI, the Confederation of European Paper Industries, but statistics for some European countries has also been looked upon.

Other sources of data are structured according to the Classification of Products by Activity (CPA) codes used within the European Union. Table 3 describes the connection between the aggregated types of products of table 1 and 2 and these codes. The CPA codes are partly difficult to apply. Difficulties exist for instance when grades of different product types are summed up in the same CPA category: the CPA code 22.13.11 probably includes grades of both product type of 1a and 1b and products of the categories 22.11.xx could belong to either 1c or 1b according to the CEPI statistics. Code 22.21.15 covers both product type 2b and 2c. In the table, the most probably CPA codes are given for each key product of the fibre chains.

***Table 3**: CPA Codes for the key products of fibre chains listed in Table 1.*

Chain	Converted products (M5)	CPA Code	CPA definition
Graphics products			
1a	Newspapers (cold-set web offset)	22.12.11	Newspapers, journals and periodicals, appearing at least four times a week; printed
		22.13.11	Newspapers, journals and periodicals, appearing less than four times a week; printed
1b	Catalogues, journals and magazines (gravure printing)	22.22.12	Trade advertising material, commercial catalogues and the like
1c	Books, brochures and folders (offset and digital printing)	22.11.10	Printed books, brochures, leaflets and similar printed matter, in single sheets
		22.11.21	Books, brochures, leaflets and the like; printed
		22.11.31	Dictionaries and encyclopaedia, and serial instalments thereof; printed
		22.11.41	Atlases and other books of maps or charts; printed
		22.11.51	Maps and hydrographic or similar charts, globes, other than in book form; printed
		22.22.11	New stamps; stamp-impressed paper; cheque forms; banknotes and the like
		22.22.13	Other printed matter n.e.c.
		22.22.20	Registers, account books, binders, forms and other articles of stationery, of paper or paperboard
1d	Fine/Office paper (no conversion)	21.23.13	Other paper and paperboard, of a kind used for writing or printing or other graphic purposes, printed, embossed or perforated
Packaging products			
2a	Corrugated boxes	21.21.13	Cartons, boxes and cases, of corrugated paper or paperboard
2b	Carton boards containers (flexographic/offset/ digital printing)	21.21.14	Folding cartons, boxes and cases, of non-corrugated paper or paperboard
		21.21.15	Box files, letter trays, storage boxes and similar articles of a kind used in offices, shops or the like, of paper
2c	Liquid carton board containers (flexographic/offset/ digital printing)	21.21.14	Folding cartons, boxes and cases, of non-corrugated paper or paperboard x
		21.21.15	Box files, letter trays, storage boxes and similar articles of a kind used in offices, shops or the like, of paper
2d	Sacs	21.21.12	Sacks and bags of paper
2d	Bags	21.21.12	Sacks and bags of paper
Hygiene products			
3a	Hygiene - Household	21.22.11	Toilet paper, handkerchiefs, cleansing or facial tissues and towels, tablecloths and serviettes, of paper
3b	Sanitary goods	21.22.12	Sanitary or hospital articles, articles of apparel and clothing accessories, of paper pulp, paper, cellulose wadding or webs of cellulose fibres

4. Solid wood and wood-based panels chains

4.1 Key products

In this section the term solid wood is used to describe both solid wood and wood-based panel products. The key products selected from these chains and the materials from which they are produced are displayed in Table 4a, and are divided into:

- Solid-wood furniture (4a – 4c)
- Solid-wood joinery (5a – 5b)
- Solid-wood packaging (5a – 5b)
- Solid-wood construction (7a - 7d)
- Panel Products (8a – 8d)

The list includes a total of 25 key types of converted products (M5) produced from a range of softwood and hardwood species including species grown outside Europe. These converted products are secondary products in M4 that are derived from M4 primary products. It is impossible to cover the enormous range of solid-wood/wood-based panel secondary and primary products used in Europe in their entirety so we have placed them into broad categories. The lists in Table 4a are intended as an agreed list to allow easy exchange between Modules in EFORWOOD and to simplify modelling within ToSIA. Table 4b describes the connection between these products and the Classification of Products by Activity (CPA) codes used within the European Union. Due to the broad categories used it is impossible to ascribe absolute values to the wood properties and so these must be ascribed at an individual case level. Instead we have given general indications of the relationship between wood properties and solid-wood products in Table 4c. Furthermore, the properties of the logs used in primary processing can only be divided into broad categories because the capabilities of each sawmill will vary as will the demand of the final customer. Therefore, we have proposed a set of 5 broad log categories (with sub categories) that cover the basic range of requirements for different end-products and these are given in Table 4d.

4.2 Key demands on solid wood

The key demands on solid wood vary according to the final product but can be broken down into a number of categories:

- Density (kg/m^3). The basic density of wood varies enormously depending on species, growth rate and position the wood has been cut from in the tree. Values vary from around 100 kg/m^3 for balsa wood to 1300 kg/m^3 for lignum vitae. However, most softwoods in use in Europe will vary between 300-500 kg/m^3 and most hardwoods from 500-900 kg/m^3. The density of wood is correlated to its strength and toughness.

- Knot size and status: The size of knots, the area they occupy as a ratio of the area of the solid timber (KAR) and their status (dead or alive) have important consequences for the usability of timber. Knots are a key characteristic that defines the visual grading of timber into different categories. Knots also have important consequences for wood strength because the presence of knots leads to grain distortion and strength reduction (clear wood with no knots can be twice as strong as a typical piece of sawn timber). Dead knots which may fall out of sawn timber will disqualify its use in joinery, cladding, veneer, parquet etc.

- Grain angle: The fibres in timber are approximately aligned along the tree axis. However, deviation from this axis reduces the stiffness of the timber and increases its tendency to twist during drying. Grain angle varies from pith to bark usually increasing rapidly in the first few years of growth and then decreasing slowly and, if the tree is old enough, reversing direction. Grain angle is a function of species, growth rate and exposure to the wind. Trees planted at wider spacings or in windy locations will generally have higher grain angles.

- Microfibril Angle (MFA): The middle layer of the secondary cell wall of wood cells is dominated by cellulose microfibrils wound in a helix. The angle of these microfibrils in relation to the long axis of the cell has profound consequences for the stiffness of the wood, with angles close to zero giving the stiffest wood. Microfibril angle varies from pith to bark with generally higher values close to the pith and lower values in the more mature wood towards the bark. Microfibril angle is also affected by the presence of reaction wood with compression wood in gymnosperms having higher values and tension wood in angiosperms having very low values.

- Reaction wood: In gymnosperms compression wood is produced to direct stems and branches into the desired orientation to access light. Compression wood is highly lignified with rounded, thick walled cells and high microfibril angles. Typically it is denser and more brittle than normal wood. The presence of compression wood in a piece of timber can lead to bow and spring during distortion due to the lignified cells having higher longitudinal shrinkage during drying. Tension wood is the equivalent form of reaction wood in angiosperms. It is characterised by lower lignin content and higher cellulose levels than normal wood and a gelatinous G-layer forms in the centre of the cells. Microfibril angles are generally lower than in normal wood. Due to its high longitudinal shrinkage it is also liable to lead to distortion in drying timber.

- Hardness: The hardness of the wood (i.e. its ability to take punishment) can be a very critical requirement in uses with high wear and tear such as flooring. Hardness will be primarily a function of species and growth rate and is related to wood density.

- Appearance: The visual appearance is important for a number of applications, particularly those with high value. The characteristics of importance for appearance vary with the application but will be a function of knot size and status, grain angle, location within the stem (sapwood/heartwood) and the presence of any stain. In some circumstances a property such as wavy grain will be highly desirable in one application but not in another.

- Durability/Permeability to Preservatives: For outdoor applications in particular, the natural durability (resistance to pathogens and environmental degradation) is crucial. The presence of high levels of extractives, especially phenols, enhances the durability of wood and heartwood is generally more durable than sapwood. Furthermore, heartwood formed in mature wood is more durable than heartwood formed in juvenile wood. If a timber is not durable it can still be of value for outdoor applications if the wood is amenable to preservative impregnation. Some species such as spruce can be very difficult to impregnate with preservatives and may have limited outdoor use.
- Moisture content: The moisture content of wood is generally <18% following processing. The moisture content of the wood will change in service and typically might be around 12% in sheltered outdoor locations and 8% in indoor use. Any changes in moisture content can lead to potentially undesirable timber movement. Also if the moisture content becomes too high then rot can be a problem. For panel products it is desirable to have low moisture contents of the raw material being used in order to keep the energy requirements in manufacturing to a minimum.

For any product a combination of desirable properties is usually required and a general description of desirable properties is set out in Table 4c.

4.3 Key demands on logs

In a similar way to the properties of the wood we can define a set of log properties of importance in the manufacturing of solid-wood products. These are:

- Stem Size: The size of the stem is one of the most important considerations for primary processing. Sawmills will have very tightly defined upper and lower limits for the size of logs they are able to handle. Specialised mills are built to deal with small and oversize logs.
- Straightness and roundness: The straightness of the log is a key filter for different products. Construction timber and timber used in laminated products such as veneer wood or glulam will generally require straighter and rounder logs than other products. However, it is not possible to completely generalise because some sawmills are able to curve saw and some veneer mills are able to deal with out of round logs.
- Grain Angle: As in the discussion above the grain angle of wood has to be small enough to be acceptable for a number of converted products. Logs with external grain angles greater than certain values could be rejected for these end-uses and converted into other less demanding products.
- Knot Size and Status: Knot size and status is a key requirement for a number of products as discussed above. If the external knots on logs are too large or numerous or dead the log may be rejected for a particular end-use (e.g. joinery). Unfortunately, sometimes it is not possible to determine the knot extent and status until the log has been first sawn.

- Appearance: Log appearance is important for directing the log for primary processing. Logs with obvious external damage or rot will be separated and sent to a low-value end product such as the manufacture of panel products. If the symptoms are too severe the logs may not be suitable for any solid-wood product end-use.
- Hardness: The hardness of wood is most directly associated with the species. Therefore, for certain end products such as parquet only certain species will be acceptable.

As for the wood properties different products will require a number of log properties to be met. In Table 4d we have grouped these properties into 5 log categories for simplification. Particular products will require logs meeting the requirements of a particular log category.

Table 4a: *Key products of solid wood and wood-based panel chains and materials used along each production chain. (Values in red are preliminary estimate of **minimum** requirements. Needs expert advice and updating)*

Chain	Converted product (M5) Secondary product (M4)	Primary product (M4)	Species Choice (M3/M2)	Desired Wood Properties	Log Properties (M3/M2) (see Table 4c below)
	Solid-wood furniture:		**Suitable species**	**e.g. appearance, strength, knots (number, size, status), stiffness, slope of grain, compression wood, dimension stability, wane, cracks, splits, hardness, permeability, resin pockets, durability, ring width**	**species, dimension, taper, knots (number, size, status), straightness, colour, percentage of heartwood, density, slope of grain, compression wood, shakes, rot, stains, cracks, resin pockets, ring width, internode length**
4a	Home and office furniture	Solid Wood	Pine, Beech, Oak	Clear wood, Tight knots if present. Knots <2.5cm. No stain. Good visual appearance	Log Type II
		Laminated Sheet	Birch, beech + spruce/pine	Clear wood. Knots <1cm. No stain, straight grain.	Log Type I
4b	Kitchen / Bathroom furniture	Solid Wood	Pine, Beech, Oak	Clear wood, Tight knots if present. Knots <2.5cm. No stain.	Log Type II
		Laminated Sheet	Birch, beech + spruce/pine	Clear wood. Knots <1cm. No stain, straight grain.	Log Type I
4c	Outdoor furniture	Decking	Cedar, larch	Natural durability (heartwood) at least durable or permeability to preservatives. Long clear wood sections, no resin pockets.	Log Type II+
		Furniture Components	Tropical hardwoods, treated softwoods	Natural durability (heartwood) at least durable or permeability to preservatives. Long clear wood sections, no resin pockets.	Log Type II+
	Solid-wood joinery:				
5a	Floor covering	Parquet	Hardwoods, pine	Long clear wood sections. Knots <1cm. High hardness. No stain.	Log Type III
		Laminated sheet	Hardwood + spruce	Long clear wood sections. Knots <2.5cm. high hardness. No stain.	Log Type III-
5b	Doors & windows	Solid wood components	Pine, oak, beech	Natural durability (heartwood) at least moderate durability or permeability to preservatives.	Log Type IV

				Long clear wood sections. Knots <2.5cm. No resin pockets.	
		Finger jointed components	Pine	Long clear wood sections. Knots <1cm. No stain.	Log Type IV-
	Solid-wood packaging				
6a	Pallets	Solid wood boards	Spruce	High stiffness. High strength. High impact resistance	Log Type V
6b	Boxes	Solid wood boards	Softwoods	High stiffness. High strength. High impact resistance	Log Type V
		Veneer sheets	Hardwoods (oak, cherry, walnut, maple, etc, etc..)	Clear wood, straight log, No stain, straight grain. Knots <1cm	Log Type III+
		Plywood solid sheets	Birch, spruce, tropical hardwoods	Clear wood, straight log, No stain, straight grain. Knots <1cm	Log Type III+
	Solid-wood construction:				
7a	External & internal wall (incl. timber frame)	Cladding	Douglas fir, cedar, larch, treated spruce & pine	Natural durability (heartwood) at least moderate durability or permeability to preservatives. Long clear wood sections, no resin pockets.	Log Type IV
		Construction timber	Spruce, pine	High strength, High stiffness (□C16), low longitudinal shrinkage, small knots (<2.5 cm).	Log Type I
7b	Floor systems	Solid wood joist	Spruce, pine	High strength, High stiffness (□C24), low longitudinal shrinkage, small knots (<2.5 cm).	Log Type I
		Engineered wood joist Parallel Strand Lumber	Spruce, pine	Wood fibres (often recycled)	Log Type V-
		Engineered wood joist Laminated Strand Lumber	Birch, aspen, poplar	Long clear wood sections. Knots <1cm	Log Type V+
		Solid floor boards	Spruce, pine	High strength, high stiffness	Log Type I
		Laminated Veneer Lumber	Softwoods (pine, hemlock, Douglas fir)	High stiffness, long clear wood sections	Log Type I-
		Glulam	Douglas fir, pine	High stiffness (□C30), long clear wood sections. Knots <1cm	Log Type I-
7c	Roof	Solid wood joist	Spruce, pine	High strength, High stiffness (□C24), low longitudinal	Log Type I

				shrinkage, small knots (<2.5 cm).	
		Engineered wood joist Parallel Strand Lumber	Spruce, pine	Wood fibres (often recycled)	Log Type V-
		Engineered wood joist Laminated Strand Lumber	Birch, aspen, poplar	Long clear wood sections. Knots <1cm	Log Type V+
		Laminated Veneer Lumber	Softwoods (pine, hemlock, Douglas fir)	High stiffness, long clear wood sections. Knots <1cm	Log Type I-
		Glulam	Douglas fir, pine	High stiffness (□C30), long clear wood sections. Knots <1cm	Log Type I-
		Roof shingles	Cedar	Natural durability (heartwood) at least moderate durability or permeability to preservatives. Long clear wood sections, no resin pockets.	Log Type IV
7d	Complete house	Floor system	See above		
		Roof systems	See above		
		External & internal wall	See above		
	Wood-based panels:				
8a	Veneer sheets	Veneer sheets	Hardwoods (oak, cherry, walnut, maple, etc, etc..)	Clear wood, straight log, No stain, straight grain. Knots <1cm	Log Type III+
8b	Plywood	Plywood solid sheets	Birch, spruce, tropical hardwoods	Clear wood, straight log, No stain, straight grain. Knots <1cm	Log Type III+
8c	Particle board	OSB	Softwood chips	High density. Low levels of Compression Wood. No rot.	Log Type V- and some recycled material
		Chipboard	Softwood chips, sawdust, shavings	No rot. Low MC <18%	Mainly recycled + Log Type V-
8d	Fibreboard	MDF	Spruce & pine fibres	No rot. Low MC <18%	Mainly recycled + Log Type V-
		Softboard	Spruce & pine fibres	No rot. Low MC <18%	Mainly recycled + Log Type V-
		Hardboard	Spruce & pine fibres	No rot. Low MC <18%	Mainly recycled + Log Type V-

***Table 4b**:CPA Codes for Converted Products (M5)*

Chain	M5 products	CPA Code	CPA definition
Furniture:			
4a	Home and office furniture	36.14.12	Wooden furniture of a kind used in the bedroom, in the dining room and in the living room
		36.12.12	Wooden furniture of a kind used in offices
		36.12.13	Wooden furniture for shops
4b	Kitchen / Bathroom furniture	36.13.10	Kitchen furniture
		36.14.13	Wooden furniture n.e.c.
4c	Outdoor furniture		
Joinery:			
5a	Floor covering	20.30.12	Parquet panels, shuttering for concrete constructional work, shingles and shakes, of wood
5b	Doors & windows	20.30.11	Windows, French windows and their frames, doors and their frames and thresholds, of wood
Packaging			
6a	Pallets	20.40.11	Pallets, box pallets and other load boards of wood
6b	Boxes	20.40.12	Other wooden containers and parts thereof
Construction:			
7a	External & internal wall (incl. timber frame)	20.30.12	Parquet panels, shuttering for concrete constructional work, shingles and shakes, of wood
		20.30.13	Builders' joinery and carpentry, of wood, n.e.c
7b	Floor systems	20.30.12	Parquet panels, shuttering for concrete constructional work, shingles and shakes, of wood
		20.30.13	Builders' joinery and carpentry, of wood, n.e.c
7c	Roof	20.30.12	Parquet panels, shuttering for concrete constructional work, shingles and shakes, of wood
		20.30.13	Builders' joinery and carpentry, of wood, n.e.c
7d	Complete house	20.30.20	Prefabricated wooden buildings
Wood-based panels:			
8a	Veneer sheets	20.20.21	Veneer sheets and sheets for plywood and other wood sawn lengthwise, sliced or peeled, of a thickness ≤ 6 mm
8b	Plywood	20.20.11	Plywood consisting solely of sheets of wood
		20.20.12	Other plywood, veneered panels and similar laminated wood
8c	Particle board	20.20.13	Particle boards and similar boards of wood or other ligneous materials
8d	Fibreboard	20.20.14	Fibreboard of wood or other ligneous materials

Table 4c: *Important relationships between properties of wood and solid-wood products (**NEEDS COMPLETING AND CHECKING**)*

	Reaction Wood		Knot size	Knot area ratio	Dead knots	Resin*	Density	Stiffness	Strength	Appearance	Dimensional Stability	Durability	Internal Bond	Surface Soundness
Product														
Batten	-		-	-	?	-	+	+	+	+	+	+		
Fencing	-		-	-	-	=	=	+	+	=	+	+		
Pallet	-		=	=	=	=	=	=	+	=	=	=		
OSB	N		N	N	N	N	+	+	+		+	=	+	
Particleboard	N		N	N	N	N	+	+	+		+	=	+	+
Veneer	?		-	-	-	-	?	?	?	?	?	?		
Joinery (Furniture)	-	+	=	=	-	-	=	=	=	+	+	=		
Joinery (Windows/Doors)	-		=	=	-	-	=	=	=	+	+	+		
LVL	-		=	-	=	?	+	+	+	=	+	=		
Glulam	-		=	-	=	?	+			=	+	=		
Cladding	-		=	=	-	-	=	=	=	+	+	+		
Rail Ties (Sleepers)	=		=	=	=	=	+	=	+	=	=	+		
Piling	=		-	-	-	=		+	+	=	=	+		
MDF	N	N	N	N	N	N	+	+	+	+	+	=	+	+

Legend

Correlation	**Code**
Strong positive	+
Weak positive	
Neutral	=
Weak negative	-
Strong negative	-
Not Applicable	N
?	Needs defining

* "Resin" relates to natural tree resin

Table 4d: *Log Types by Properties for Solid-Wood Chain (values in red are preliminary assessment of **minimum** requirements. This needs updating with expert advice from everyone and particularly to avoid inconsistencies with Table 4a)*

Log Type:	**Properties: No absolute values.** Need to be decided for each case
I	Stem Size > 16 cm top diameter Straightness < 1cm in 1m deviation Grain Angle < 5 degs Knot Size < 5cm Appearance
I-	As for I but 50 cm top diameter >stem size> 16cm top diameter
II	Stem Size > 20 cm top diameter 3cm in 1m deviation < Straightness < 1cm in 1m deviation Knot Size < 5cm Live Knots Appearance
II+	All II plus Permeable to treatment or Durability □ moderate durability
III	Knot Size < 1cm Appearance Hardness
III+	III plus 50 cm >Stem Size> 20 cm
III-	III but 1cm < Knot Size < 2.5cm
IV	Live Knots Permeable or Durability □ moderately durable Grain Angle < 5 degs Reaction Wood < Appearance
IV-	All IV but No criteria for knots
V	Stem size< 16cm > Straightness > Reaction Wood<
V+	All V and knots<
V-	All V but no straightness requirements

5. Bio-energy chains

5.1 Key products

The final Converted Products in the bio-energy chain can be broken down into:

- Heat (9a)
- Electricity (9b)
- Pellets and Briquettes for small scale users (9c)
- Wood chips for small scale users (9d)
- Firewood for small scale users (9e)

Products likely to appear on the market within the time span of the scenario analysis (2015 & 2025) but which are not considered further here include the following:

- Liquid Biofuel (substituting traffic fuel or heating oil) (9f)
- Synthetic Gas (substituting & supplementing natural gas) (9g)

The distinction between M5 and M4 products is less clear in the bio-energy chain than the other chains. For example, a local district heating plant, a power plant or a CHP-plant may also use wood chips or pellets/briquettes for producing the final product in M5 such as heat and electricity. Therefore, we have identified a list of Intermediate Products that sit between M3 and M4 and Final Products that sit between M4 and M5. Waste liquors such as black liquor and other liquid industrial by-products used for energy production are assumed to be dealt within Module 4 and the heat or electricity produced mainly used within M4, but electricity and/or heat produced from these may appear as a market product in M5. Process steam is assumed to NOT be a final product as it is mainly used within M4 industrial processes.

The Converted Products in the chain (Table 4a) can be derived from 6 Intermediate Products:

- Wood Briquettes
- Wood Pellets
- Wood Chip/Hog Fuel
- Log Wood
- Charcoal
- Composite Residue Logs (CRL)

As noted above some of these Intermediate Products (Wood Briquettes, Wood Pellets and Wood Chips) are also final Converted Products. The Intermediate Products themselves are derived from 4 primary sources of raw materials (Table 4a):

- Solid Wood Processing By-products (Chemically untreated wood fractions from pulp and paper industry and mechanical processing, i.e. sawdust, bark and chips)
- Forest Residue (Tops, branches, stubs or whole tree chips from thinnings, small-sized trees or rejected logs)
- Refuse Derived Wood (Construction and Demolition Wood, Packing or Paper Waste, Wood as a Municipal Waste Fraction, Chemically Treated Wood Residue
- Biomass from energy forestry
- Blends and mixtures of the above

For further information on the conversion of these primary sources of raw material to final products it is recommended to visit:

http://www.forestresearch.gov.uk/woodfuel or http://www.biomassenergycentre.org.uk

5.2 Key demands on manufactured products in bio-energy chain

The requirements of the intermediate products in the bio-energy chain are regulated by CEN/TC 335, which is the technical committee developing the draft standard to describe all forms of solid biofuels within the European Union (EU), including wood chips, wood pellets and briquettes, logs, sawdust and straw bales. The requirements of each product are set out in Table 4b in terms of the origin of the material, moisture content, density, dimensions, ash content, additives, net calorific value, mechanical durability, percentage of fines, and percentage sulphur content where applicable.

See
http://www.biomassenergycentre.org.uk/portal/page?_pageid=77,19836&_dad=portal&_schema=PORTAL for further information.

***Table 4a**: Key products of biofuel chains and materials used*

Biofuel Chain	Final product (M5/M4)	Intermediate Product (M4/M3) (see Table below for properties)	Wood raw material (M3)
	9a Heat 9b Electricity 9c Pellets 9d Wood chip 9e Fire wood Future option 9f Liquid Biofuel 9g Synthetic Gas	**Forest and Plantation Wood:**	
		Logs, chips, pellets, Hog fuel *(i.e. rough chips/larger chips)*, briquettes, charcoal and composite residue logs (CRL)	Whole Tree *(hardwood, softwood, SRC, scrub, blends and mixtures)*
		Logs, chips, pellets, charcoal and composite residue logs (CRL)	Stem wood *(hardwood, softwood and blends and mixtures)*
		Composite residue logs (CRL) and Hog fuel	Logging residues *(Wet inc leaves/needles, dry and blends and mixture)*
		Chips and Hog fuel	Stumps *(hardwood, softwood, SRC, scrub, blends and mixtures)*
		Chips and Hog fuel	Bark
		Logs, chips some CRL and Hog fuel	Arboricultural arisings
		Wood processing industry, by-products and residues:	
		Chips, Hog fuel, pellets and briquettes	Chemically untreated wood residues *(wood without bark, wood with bark, Bark from industry ops and blends and mixtures)*
		Chips, Hog fuel and briquettes	Chemically treated wood residues *(wood without bark, wood with bark, Bark from industry ops and blends and mixtures)*
		Hog fuel, pellets…	Fibrous waste from the pulp and paper industry *(chemical treated and untreated)*
		Used Wood:	
		Chips, Hog fuel, pellets and briquettes	Chemically untreated wood *(wood without bark, bark and blends and mixtures)*
		Hog fuel, pellets…	Chemically treated wood *(wood without bark, bark and blends and mixtures)*
		Blends and mixtures:	
		Chips, Hog fuel, pellets and briquettes	

***Table 4b**: Key properties of biofuel intermediate products (STANDARDS REF: CEN335)*

Material	Origin	Moisture Content	Density	Dimensions	Ash Content	Additives	Net calorific value	Mechanical durability	% of fines	Sulphur Content %
Wood Briquettes:	Origin required	<10 w-%	1.00 – 1.09 kg/dm^3	diameter mm, length mm	<0.7 w-% of dry matter	<2 w-% dry basis. Only products from primary forestry biomass, not chemically modified are approved as additives for pressing	≥ 4.7 kWh/kg = 16.9 MJ/kg	97.5 w-% of a pellet batch of 100g uncrushed after testing		
Wood Pellets:	Chemically untreated wood without bark	< 10 w-%		6mm ± 0.5 mm and length < 5 x diameter. 8mm ± 0.5 mm and length < 4 x diameter. Max 20 w-% of pellets may have a length of 7.5 x diameter	<0.7 w-% dry matter	<2 w-% dry matter and may consist of bio-based chemically material			% after sieving through > 3.15 mm. Shall not exceed 1 or 2 w- %	<0.05 w-% 0f dry matter (sulphur is normative only for chemically treated biomass and if sulphur containing additives are used)
Wood Chip /Hog Fuel:	Origin of stem wood required	Range expressed as w-%		Expressed as main, fine and coarse fractions –w%. Range 16 mm, 45mm, 63mm, 100mm and 300mm			> 900 kWh/bulk m^3			
Log Wood:	Origin of stem wood required	< 20 w-%		diameter and length mm. Range <200, 200, 250, 330, 500 and 1000 mm with tolerances						
Charcoal: No CEN standard			800 grams favoured for high quality UK charcoal	Large fairly evenly sized pieces. This can only be produced from timber that has been cut to consistent sizes and generally is no smaller than 4 inches diameter.					Charcoal out of the kiln has to be run over a sieve before it can be bagged. This removes the smallest pieces (known as fines) which are then bagged off and utilised in mulches.	
CRL: No CEN standard	Stem wood, branch, needle and leaves	Moisture content important but no standard		Diameter and length (m)	Ash content important but no standard		Net calorific value important but no standard			

6. Quality-based allocation of wood raw materials to key products and analysis of sustainability effects

Even though it is in most cases difficult to define specific general threshold values for the product and process demands on the raw material properties, it will be possible to investigate effects of various allocation alternatives with the tools developed in the EFORWOOD project. It can be done from a total sustainability perspective or broken down into effects on different types of indicators. The ToSIA model, the Tool for Sustainability Impact Assessment, will be a unique and useful tool to do this.

Alternatives with a broad perspective

The solution is to combine expertise from modules M3, M4 and M5 and to define alternatives from a broad perspective, including all effects of allocation from harvesting via transportation to processing in different product chains, distribution and use. These broad perspective alternatives are then simulated as “scenarios” with ToSIA and compared. (It will of course also be possible to simulate parts of the full chain.)

The standard way to do this would be to start with a “Regional Resource Databases” and to use it to define a number of segregation alternatives for the available resource. Each alternative is obtained by application of a set of search criteria on the database. Each selection can be based on properties of stands, trees, logs, knots, wood or fibres included in the database. (The approach may be further developed to include optimisation of log lengths, consideration of transportation costs, etc, when analysing segregation alternatives.) The result of each selection will be a set of raw material classes, which may be dedicated to the production of different key products, including all the three types of chains (fibres, solid wood, bio-energy). For each class, the volume (or dry mass) and the key properties are known. The volumes and properties may serve as the basis for allocation of wood flows to different production chains. The properties define how the material may be processed in the processes that follow, the costs involved, etc..

Simulation with ToSIA and comparison of product yields, properties and sustainability indicators

A reference case is defined and simulated within ToSIA. The reference case is evaluated to see to it that the result is reasonable. The experts define what products can be produced if the wood classes of the reference case are allocated in an other way and what the consequences are regarding changes in yield, consumption of energy, chemicals and person-hours, in terms of product quality, the need for transportation, etc. Also these cases are simulated within ToSIA to clarify how sensitive the sustainability measures are to proper allocation, for individual indicators and as a whole.

This initial step will also provide information about what changes in allocation (flows to various chains), efforts in processing, product properties and uses, etc. will have the strongest effects and should be given most attention in the investigation of various alternatives.

The different segregation alternatives are then looked at by the experts in a similar way and are simulated within ToSIA. The results are compared with regard to the quantity of products produced and their properties as well as effects on various sustainability indicators (environmental, social and economic). It is then concluded which alternatives are optimal, depending on which indicators are emphasised in the optimisation criterion.

In this way, the different demands on raw material properties of various key products of the forest-based industries may be dealt with in an integrated way.

Future update of the report

Many comments on the report are expected from project partners and other experts. It is already decided that the report will be updated at a later stage of the project. To support this, please forward your comments on the report and suggested modifications to Sven-Olof Lundqvist, STFI-Packforsk, regarding overall issues and issues related to the fibre chains and their products and to Barry Gardiner, Forest Commission, regarding solid wood and bio-energy chains and their products.