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POSSIBLE FIELDS OF HARDWOOD APPLICATION

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ABSTRACT

One crucial result of the recent Swiss National Forest Inventory (NFI) from 2004-2006 is a volume increase of 10.4 % for hardwood. The softwood volume, in contrast, has decreased. Although other European countries confirm this tendency, Switzerland still uses the bulk (60 %) of the harvested hardwood directly for energetic purposes instead of adding value on it by other applications.

Besides the lower percentage of stem wood and the more complicated processing, the main problem in Switzerland is that the value chain from the round timber to an end product is not complete. Therefore the energetic use was and still is the most comfortable and profitable solution for unused assortments.

Hardwood use is possible as solid wood and wood composites, but it can even be used as a substance or chemical product. As a solid wood, hardwood has a long tradition (roof structures, stairs, furniture, flooring). Today, it is also employed for wood based materials (solid wood panels, plywood). Scientific analyses reveal that hardwoods nowadays even enter softwood domains such as particle boards, medium density fibreboards, oriented strand boards and structural timber (glued laminated timber, Duo/Trio beams). At the moment, manufacturers are restrained regarding the commercial production due to current standards or failing design bases. In the pulp production, domestic hardwood is more and more repressed as usage of fast-growing plantation lumber increases. To develop marketing channels away from energetic use, it is mainly necessary to build a processing industry in Switzerland. Semi-finished or finished goods should be produced on Swiss terrain and not imported from abroad.

KEYWORDS: Hardwood, processing, swiss saw industry, applications.

INTRODUCTION

Wood is one of the most important natural resources for mankind. It is used all over the world as energy source, building material, substance or chemical product. A sustainable forestry guarantees a balanced relation between second growth and the harvested wood. In the last years, softwoods and hardwoods show a different development of total volumes in Switzerland. The actual stock situation in Swiss forests is described by the Swiss National Forest Inventory (NFI). It was carried out three times so far - 1983/1985 (NFI 1), 1993/1995 (NFI 2) and 2004/2006 (NFI 3). The final results of the NFI 3 (Tab. 1) were published in 2010. They show a volume increase of 11.96 Mio. m^3 for hardwood compared to the NFI 2. Especially beech (+4.28 Mio. m^3) contributes to this trend. The softwood volume, in contrast, was reduced by about 2.4 Mio. m^3; the highest decrease was observed for spruce (-7.55 Mio. m^3).

Tab. 1: Volume change of softwoods and hardwoods from NFI 2 to NFI 3 (Brändli 2010)

Volume change	Softwoods						
	spruce	fir	pine	larch	Swiss stone pine	others	total
(Mio. m^3)	**-7.55**	2.96	-0.55	2.13	0.20	0.42	-2.40
(%)	-4.1	5.2	-4.1	11.0	9.2	41.5	-0.9
Volume change	Hardwoods						
	beech	maple	ash	oak	chestnut	others	total
(Mio. m^3)	**4.28**	2.06	2.87	0.59	0.18	1.98	11.96
(%)	6.2	21.8	24.4	7.1	3.8	18.0	10.4

In spite of the positive stock situation for hardwoods, processing is in a crisis. Not the use itself is a problem, but the distribution of the different branches. Almost 60 % are energetically used directly after harvesting.

The aim of this literature research is to analyse the processing technology and the background of the present situation. Furthermore different application areas are highlighted on the basis of previous and current scientific publications as well as product information and company enquiries. Finally some possible ways to change the situation are presented.

CHARACTERIZATION AND PROCESSING OF HARDWOOD

Anatomy of hardwood

Hardwood differs from softwood in anatomical structure, which influences the physical properties, durability, workability and bonding. The structure is more differentiated, because different types of cells fulfil the three main tasks: stabilisation, water conduit and storage. Most hardwood like beech, oak or ash have a higher density, which leads to better stiffness and strength, but also causes a lower form and dimensional stability due to the increased swelling and shrinking. Therefore drying and bonding is more complicated.

Bonding of hardwood

Although many investigations have been carried out, all of the existing test standards and performance requirements focus on softwood. Bonding of hardwood for structural purposes is still

problematic, because design bases are lacking. All of the existing test standards and performance requirements focus on softwood, although many investigation have been carried out.

Bernasconi (2004) gives an overview of the gluability of different hardwoods for construction. Wetzig (2009) investigated, by varying the thickness of the joints, whether a polyurethane adhesive is able to compensate stresses in solid wood panels of ash and beech subjected to changing climate conditions. Stresses could be almost completely avoided with thick joints and a low elastic modulus of the adhesive. Pöhler et al. (2004) and also Aicher and Reinhardt (2007) reported on the bonding of beech with red heartwood. They assert that red heartwood has no influence on strength properties. Shear strength was occasionally even higher than in samples without red heartwood. Schmidt et al. (2009) demonstrated that an adaption of bonding parameters can lead to high delamination resistance of glued beech with and without red heartwood. Especially two melamine-urea-formaldehyde resins showed a delamination decrease when closed assembly time was extended.

Actual situation of standards for structural timber

Currently, the most-used raw materials for structural timber are softwood species, which is due to the actual situation of standards. Relevant standards of the European Union (EU), for example EN 14080, only permit the use of poplar and no mixture of different wood species. The reason behind this is that all design bases (bonding, strength classification of lamellas) are geared to softwoods. The transfer of results from softwoods to hardwoods is not directly possible, because hardwood has different mechanical properties as a consequence of its anatomical features.

The situation in Switzerland is similar, but not identical. Design bases are still missing as well. However, according to SIA 265, structural timber should be composed of softwoods, but other raw materials are also allowed, if the requirements are fulfilled. Companies can use both, hardwoods and wood combinations.

Timber construction companies, especially those in the EU, are constrained by this present situation. Swiss companies can use hardwood indeed, but they can offer their products only in Switzerland. A step in the right direction was done in Germany in October 2009, where glued laminated timber got the general technical approval.

REASONS FOR THE SITUATION

Influences of hardwood characteristics

Hardwoods are characterized by a more complicated processing and are not as profitable as softwoods. This is caused by differences in the wood anatomy and in the tree design. Hardwoods have a much lower percentage of useable stem wood. As shown in Fig. 1, it is almost half the value of softwoods (45 % vs. 80 %). Branches and leaves account for the rest.

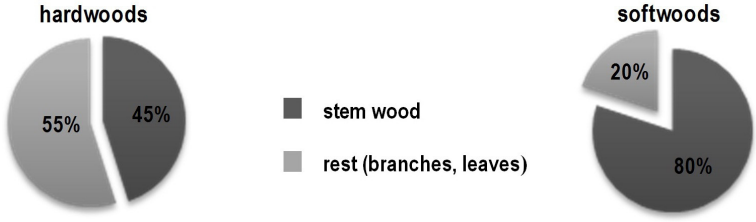

Fig.1: Useable percentage of stem wood (according to Thees 2009)

Certain characteristics of the hardwood anatomy (fibre structure, resin content) can cause complications during processing. In addition, (large) cracks can develop especially in beech and oak as a result of growth stresses released after harvesting.

Assortment distribution of the harvested hardwood

Depending on the quality, timber is divided into three assortments after harvesting (Fig. 2, data based on 2008). Most of the harvested hardwood (60 %) was directly used for energetic purposes instead of adding value on it by other applications. Only about 20 % of the hardwood was used either as stem wood or as pulpwood.

If no further steps are taken, this trend will persist or even rise, particularly since two new wood-fired power stations are currently built in the cantons Zurich and Bern. Acting this way is inconsistent with the political guidelines, which strive for cascade utilization. The reasons for the unequal distribution between softwoods and hardwoods are the energetic use of better hardwood qualities and of a larger amount of stem hardwood.

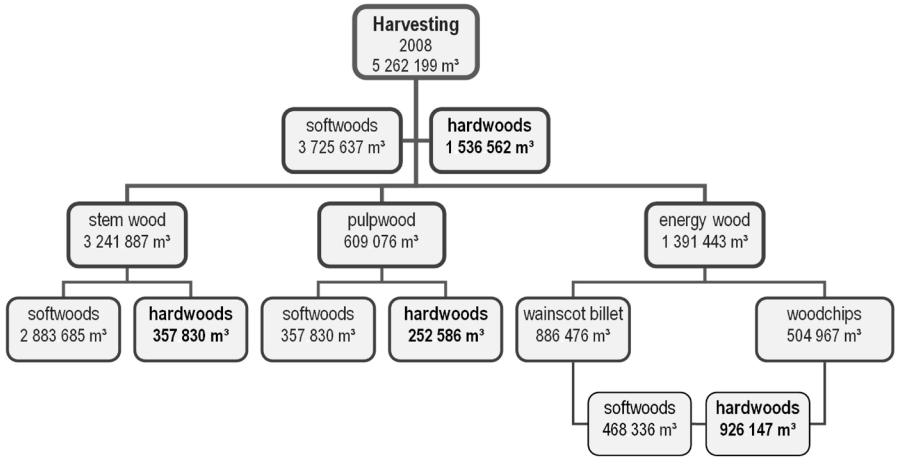

Fig. 2: Wood assortments after harvesting in Switzerland (according to Federal Statistical Office of Switzerland)

Structure of the Swiss saw industry

The Swiss wood industry has two main problems, which caused the unequal distribution on the different assortments. One problem is the missing market for hardwood products. The other is that the value chain from the round timber to an end product is not closed. Predominantly the processing from sawn timber to semi-finished or finished goods is lacking. Thus consumers have to buy imported goods, occasionally made of previously exported round or sawn timber. Swiss saw mills currently do not use their machines to full capacity. An actual analysis (Lüthi 2010) confirms that they are able to additionally process 85000 m^3 of hardwood each year. However, the energetic use was and still is the most comfortable and profitable solution for unused assortments, although in the meantime politics strives for cascade utilization.

POSSIBLE FIELDS OF APPLICATION

Hardwood use is possible in different ways and varies with shape and dimensions. To separate it clearly from each other, the applications can be divided into four areas:

- Solid wood products
- Wood-based materials
- Use after modification
- Supplemental services

Solid wood products

Building with timber

Hardwoods, especially oak, were a preferred raw material for joists, roof structures and timber frames. The use of solid hardwoods, however, decreased during the recent centuries, which can be ascribed to the development of wood-based materials that allow for constructions larger than the given dimensions of trees. Nowadays, some companies are specialized in solid timber construction and produce prefabricated elements for walls, roofs and floors. The material is mainly made of softwoods, some companies offer further types of wood. Only one company could be found in Switzerland offering hardwood like maple and walnut. Systems of softwood have proved themselves and are cheaper than hardwood. To achieve higher strength or smaller dimensions, hardwood could be used for single structural elements. The Swiss project "Woodstock" demonstrated the suitability of beech for wall and ceiling components of a multi-storey building.

Further fields of application are playgrounds, wood-facings, railway sleepers, noise barriers and bridges. Playgrounds have to be very durable (made of robinia, oak and sweet chestnut). Impregnations and modifications permit the use of less resistant wood species. Scheiding et al. (2007) showed that thermally modified beech and ash are (highly) durable and therefore suitable for playgrounds. This kind of modification is also an option for wood-facings and noise barriers, if the wood is not in contact with soil.

Furniture

81 % of the whole Swiss market is covered by 11 furniture dealers (Ikea, Migros, Märki, Pfister). They mostly work with professional marketing methods. High percentages of solid wood furniture were and are replaced by wood-based materials, particularly particle boards. Publicity and a label for Swiss hardwood products could help smaller companies to push their products onto the market.

There is only few furniture made of pure solid wood. Most elements such as table boards, shelves or cabinet doors belong to wood-based materials because their components are somehow glued. The boundary between the categories is not very strict. Taking this into account, solid wood can be used for:

- chairs, tables, stools, upholstery frames, beds, chests, shelves, sideboards, coat racks
- cabinets for kitchens, baths, children, offices and medicines; bath tubs and washbowls

Interior work

Fields of interior work are parquet flooring, doors and windows. Parquet flooring is one of the few areas, where hardwoods, especially those with a high density, dominate. The most popular wood species in Europe is oak. Beech has lost popularity over recent years and now dark species are currently preferred. Another trend is parquet with a "used-look". Thus companies add cavities, wormholes and other signs of use during processing. Thermally modified hardwood is able to

replace tropical species due to its dark colour.

Internal doors are predominantly made of wood-based panels. Solid wood is used for front doors and windows, but oak is the one and only European hardwood. Requirements for windows and front doors exposed to weathering are high. Beech, ash and maple are not durable and they also shrink and swell considerably. However, they can be used in composite structures where the wood is protected by a facing formwork of metal or a synthetic material.

Other applications

Most other applications are niche products. Beech with red heartwood, which is difficult to bring to market, could be used for individual furniture or coffins. Further applications are palettes, boxing, wooden toys, music instruments, sports equipment or small goods such as dowels, wooden handles, coat-hangers, handrails and cutting boards.

Wood-based materials

Solid wood materials

Solid wood-based materials can be used as beam or panels. The single-layer or multilayer solid wood panels are suited for nonstructural products (workbenches, table boards, steps). In contrast to other fields of application, hardwoods are common as raw material. Typical species are beech, oak, birch, alder and chestnut. Even the red heartwood of beech and the brown heartwood of ash enjoy an increasing popularity as each product has a unique design.

The most common bar-shaped products are glued laminated timber, Duo and Trio beams. The main raw material is still softwood due to the currently valid standards (paragraph Actual situation of standards for structural timber), the easier processing and the lower prize. A survey among 84 Swiss, German and Austrian companies showed that the hardwood ratio amounts to only 1 % of their production volume. However, many investigations have been carried out evaluating the applicability (Egner and Kolb 1966, Gehri 1980, Früwald et al. 2003, Blaß et al. 2005, Frese 2006, Blaß and Frese 2006, Ohnesorge 2009). Parameters were determined that help to improve and to simplify the processing. The most promising wood species are beech, ash and oak. Combined beams of beech and softwoods turned out to be as suitable as pure beech beams. This would lead to lower production costs. A bending strength up to 36 $N.mm^{-2}$ can be classified visually, higher values require a machine classification. Beech with red heartwood had no negative influence on bonding.

Ply materials

The situation of ply materials is similar to that of solid wood materials. Hardwoods are commonly used for nonstructural products such as plywood. Structural ones, however, such as cross laminated timber, laminated veneer lumber (LVL) and parallel strand lumber (PSL) are mainly composed of softwoods. An exception are so called knotpanels of the Swiss German company Hess. This is a kind of LVL made of veneer layers of beech with a thickness of 81 cm, a length up to 170 cm and a width up to 62 cm, which can be cut after production to different dimensions. Investigations of Gehri (1993) showed that beech LVL almost reaches twice the tensile strength of industrially produced softwood LVL. The type of joint plays also an important role, since strength properties were higher when scarf instead of butt joints were used. Densified laminated wood is one of the few materials, where hardwood is established. Rotary veneer sheets of beech are impregnated with resin and compressed to a material with high strength properties. It is very abrasion-resistant and its properties are similar to metal or stone.

Particle materials

Materials made of particles are ideal to use low-rate timber assortments and saw mill waste. The different types are particle board, mineral-bonded wood composites, oriented strand board (OSB), laminated strand lumber (LSL) and oriented strand lumber (OSL). The last-mentioned, LSL and OSL, are special OSB products. In contrast to the panel product OSB, both can be used either as board or as beam.

In Central Europe, softwoods are employed as main raw material. Hardwoods are also added, but in clearly lower quantities. In Switzerland, the percentage of hardwoods in particle boards accounts for 10-40 %. Previous and actual investigations on particle boards indicate that a higher percentage (up to 100 %) could be realized (Klauditz 1952, Buschbeck et al. 1961, Kehr and Schilling 1965, Grigoriou 1981, Vos and Kharazipour 2008). Particle boards made of hardwoods, especially beech, were already produced in Lower Saxony (Germany), in former Czechoslovakia and the former German Democratic Republic in the middle of the 20th century. In Eastern European countries (Hungary, Rumania, Slovakia), they are still produced due to the higher hardwood proportion in the forests.

Fibre materials

This group includes fibreboards, insulating fibreboards, wood particle mouldings and wood plastic composites (WPC). The quality and processing of fibreboards and insulating fibreboards is crucially influenced by the fibre percentage, the geometrical structure of the fibre and the specific chemical composition of wood. The fibres of softwoods are long, slender and flexible, whereas those of hardwoods are short, smooth and thin. Hardwood fibres are ideally suited for the dry production process (medium density fibreboard), because they do not mat. In spite of this, almost no hardwood is used for fibreboards and insulating fibreboards, although investigations reveal that boards that conform to standards are possible (Krug and Mäbert 2007, Bartholme et al. 2009).

Use after modification

The aims of wood modification are dimensional stabilization, resistance increase an further property improvements. Possible modification ways are shown below:

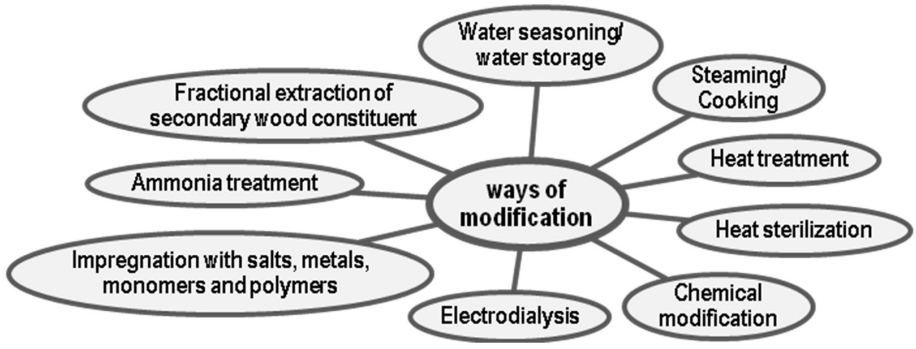

Fig. 3: Ways of wood modification

At the moment, chemical modification, heat treatment and impregnation are the prevalent methods. A very common way of chemical modification is acetylation with acetic acid anhydride. Research into acetylation of hardwood was performed (Tarkow et al. 1946, Militz 1991), but no

industrial application was derived from it.

Heat treatment and impregnation seemed more promising. Within the German joint project "Innovative modified products of beech" (coordination: Institute for Wood Biology and Wood Products/University of Göttingen), durability of beech could be risen to durability class 1 by a vacuum-pressure process with a water-based solution of DMDHEU (dimethyloldihydroxyethyleneurea). The practical capability is currently tested on some products. Investigations on thermally modified hardwood were carried out by Oelhafen (2005), Bächle and Schmutz (2006) and Wetzig (2010). It was shown that the red heartwood of beech can be compensated. The modification always leads to better dimensional stability, higher resistance and a dark colouration of wood.

Supplemental services

Use as a substance

Food production is one way to use wood as a substance. The sawdust of beech and oak is an ideal substratum to cultivate edible mushrooms. Oak, beech and maple are suitable hardwoods to cure meat or fish. Oak staves, chips and powder are used to add aroma to wine.

Another option is to use sawdust, especially of oak and robinia, to filter certain elements such as copper, nickel, zinc and cadmium (Šćiban and Klašnja 2004). Sawdust can also be a component or additive for plastics. Linoleum is a kind of flooring which consists up to 60 % of sawdust. "iwood" is a Swiss invention: sawdust and wood powder are mixed with water and starch to a paste and dried afterwards. The result is a wood-based material with a low density, good strength properties and a processing similar to wood.

Use as a chemical product

The pulp and paper industry using cellulose is still the most important field of wood chemistry. Properties of pulp and paper are greatly influenced by the anatomical features of wood. Softwood pulp leads to paper with high density, high strength and a smooth surface, whereas hardwood papers are abrasive, porous, bibulous and opaque. By mixing softwoods and hardwoods in certain ratios, the desired properties can be obtained. The most-used domestic hardwood is beech, although it is being more and more repressed by fast-growing plantation lumber. As a consequence, the Swiss company Borregaard was closed in 2008.

Cellulose is also a raw material for cellulose ester, cellulose ether and wood sugar. Regenerated cellulose is the base for so-called "natural synthetic fibres" (viscose) for which beech is a very suitable hardwood. Lignin processing was always unpopular due to the dark colour, the off odours and missing developments. Combustion was and still is the main application, although lignin can also be used for the production of vanillin, binders, fertilizers, emulsifiers and bio-materials. One of these materials is "Arboform" (TECNARO GmbH), a mixture of lignin, natural fibres and additives.

Use as energy source

The application of wood as energy source is reasonable when sawmill waste and low-rate timber can be used. However, this should not be the standard way to process high-quality wood assortments as currently usual in Switzerland. There are three different ways hardwood can be used: combustion, wood gasification and production of bioethanol (Fig.4).

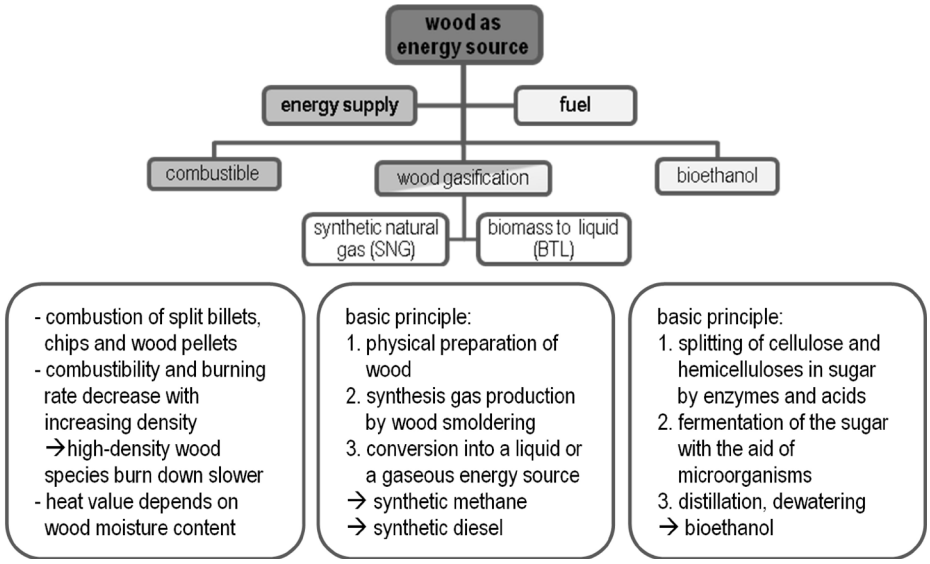

Fig. 4: Ways of wood as energy source

CONLUSIONS

This survey summarizes the present situation of hardwood processing in Switzerland, but also the diversity of possible applications. Solving the current problems and entering further fields besides energetic purposes requires the initiative of different parties. Forestry, wood industry and politics have to cooperate to develop joint solutions. But each of them also has to be willing to change the current situation in his respective field of activity. The most important aspects will be to develop marketing channels, to build up a processing industry, to realize further research projects and to provide information for the end customer as shown in Fig. 5.

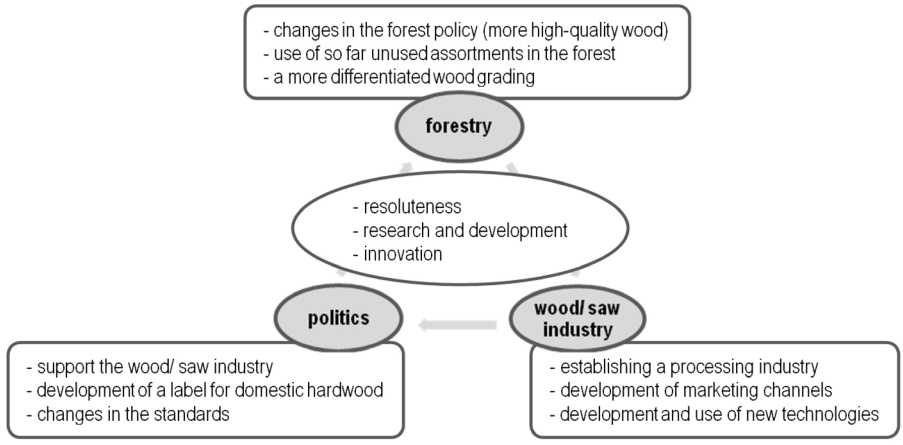

Fig. 5: Ideas to solve the crisis

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