POSSIBILITIES FOR THE USE OF THE DIFFERENT TYPES OF WOOD RESIDUES AS RAW MATERIAL

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Abstract: *Sawmill byproducts are a very important proportion of the recovered wood in Germany. Sawdust makes up about 37% of the total and is often relatively difficult make use of or to dispose. The main purpose of this paper, therefore, is to give a review of all the lesser known posibilities of using sawdust for products other than particle board or fibre board, pulp or energy. A survey of the literature and many websites points to an astonishingly broad spectrum of possibilities. Animal bedding and mushroom production are two examples of growing markets for sawdust as are wood plastic composites. In addition, there are many market niches such as food processing, environmental protection and some building products. It appears that although a great deal of research still needs to be done to quantify these uses, the potential for further development and optimisation of such products is certainly a given..*

Keywords: sawdust, material reycling, wood flour, mushroom production, wood plastic composites

1. INTRODUCTION AND OVERVIEW

The possibilities for utilizing recovered wood depends strongly on the grade of its contamination through wood preservatives and other chemicals. As long as one is dealing solely with pure wood material free of any foreign matter, the particle size and the wood species are the determining factors with regard to recycling options.

Foundation piles made from durable wood, which were previously used, e.g., in harbor construction, may be reused for the same purpose if they are in good condition[1]. Similarly, framework beams can be used after the demolition of an old house in the construction of a new one[2]. In Austria a company recently began offering doors made from boards recovered from old barns and farm houses[3]. How important this type of recycling has become is demonstrated by the fact that on the 2003 $LIGNA_{plus}$ fair one company presented a newly developed special edging saw for used timber[4]. The sale and reuse of such kinds of recovered wood have been substantially facilitated through the nowel possibilities of internet trade (Ebay), thus leading to a continual increase in its use.

Sawmill residues comprise a very important proportion of the recovered wood in Germany. With a total sawn timber output of 32.7 million m^3 in the year 2000 in Germany some 12.2 million m^3 of sawmill waste were produced; 0.9 million m^3 of this was used by the mills themselves as source of energy[5]. The average yield of products amounted to 62.3%. This varies depending on the type, dimensions and qualities of the wood, as well as by the sawing technology available.

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The sawmill by-products which enter the market in Germany can be broken down as follows[6]:

	m^3	%
Total softwood	**10.384.113**	**100**
Sawings / Sawdust	3.740.686	36
Slabs / Edgings	659.388	6
Chips	5.984.039	58
Total hardwood	**943.798**	**100**
Sawings / Sawdust	445.835	47
Slabs / Edgings	252.715	27
Chips	245.248	26

Table 1: Types of sawmill by-products in Germany.

The high proportion of chips stemming from the softwoods results from using modern profile chipper lines which are widely used in Germany.

As hardwood is obviously sawed into smaller units, a higher proportion of sawdust is produced as a consequence.

	Energy	Composite panels	Pulp & Paper	Trade	Export	Others
Total softwood	**%**	**%**	**%**	**%**	**%**	**%**
Sawings / Sawdust	0,2	56,7	0,7	39,0	1,3	2,1
Slabs / Edgings	0,3	22,7	10,5	63,5	2,2	1,0
Chips	0,3	21,6	30,5	37,3	10,2	0,1
Total hardwood						
Sawings / Sawdust	0,0	38,2	1,2	50,1	2,7	7,8
Slabs / Edgings	1,4	26,7	11,5	41,8	10,7	8,1
Chips	0,4	80,3	0,0	16,9	0,0	2,3

Table 2 The utilisation of sawmill by-products in Germany.

The principal purchaser of the sawmill by-products is obviously the wood-based panels industry, which also receives materials through the trade. Pulp mills have very high standards with respect to chip quality. They use a larger portion of the softwood chips, which should have a predefined shape and size.[7] Normally, the slabs and edgings are traded before they mostly are chipped and used accordingly. Also in "disposing" of materials with the lowest market value, the sawings and sawdust, trade plays a substantial role, particularly in the case of hardwood waste products, which are hardly usable in the wood based panel and pulp industry.

The main purpose of this paper is to investigate what possibilities are available for recycling sawings and sawdust apart from their common uses in the aforementioned industries or as source of energy. Sawdust is especially difficult to use in any of the ways described so far. For that reason, in many countries it is simply dumped or incinerated without any further application.

An evaluation of a wide variety of literature and internet sources resulted in a surprisingly high number of possibilities with regard to the use of sawings and sawdust. These will be presented and discussed here with respect to their development potentials.

2. ANIMAL HUSBANDRY

In both livestock husbandry as in the care of pets sawings find numerous applications.

In central Europe **cattle** are usually kept in stalls with slatted floors. In comparison with straw sawings offer definite advantages as bedding material. They can be easily be disposed as part of liquid manure, moreover, the do not block the spaces between the slots. Certain disadvantages have been reported: especially as far as dairy cows are concerned. Sharp pointed sawings can cause injury to cows´ teats and lead to streptococcal infections[8]. It is therefore recommended that only softwood sawings/shavings may be used, which is dry and lacking splinters[9]. If more straw is not replaced by wood by-products, a drop in the demand for sawings can be expected, because within the 15 older European Union countries the total number of cattle has decreased since 1995 by nearly 8% to 78.281 million head (2002)[10]. New market potentials may, however, develop as new members are admitted to the EU and who then modernise their cattle raising practices.

83% of the approximately 123 million **pigs** in the European Union are raised on farms with large herds of 400 or more animals[11]. In most cases no bedding materials are used, although sometimes the use of straw is observed. In a few cases sawings are also used. They have the advantage that they reduce the strong ammonia odor, in addition, as layers of waste increase microbiological processes germinate warmth. On the whole, sawings may contribute to the general health of the animals, but not without relatively intensive labour[12].

Like straw, sawings are also widely used in **horse** stables. Of particular importance is the high level of absorbency provided by dry shavings; furthermore as they can be pressed into bundels, they require less storage space than straw. They are, however, somewhat more expensive and the waste disposal can cause problems since farmers and mushroom growers are often hesitant to accept such "wooden" manure. In riding schools large chips are often used[13]. Today, in addition to the usual shawings, softwood pellets with increased absorbancy are being offered as an attractive alternative. They reduce the amount of cleaning necessary and facilitate the decomposition process .[14]

Woodchips or sawings have also proved useful on **sheep and rabbit** farms[15] as well as on **poultry** farms[16]. Shavings may cause problems with chicken with respect to plumage cleaning[17]. On the other hand when shavings are used in new floor management systems for hens, relatively small nitrogen losses occur[18].

Pet litter is a product of special importance on the German market. In addition to straw, both sawings and shavings are used. The number of small mammals (guinea pigs, rabbit etc.) in German households rose from 4 million in 1996 to 5.7 million in 2000. 59% of these households have children. Current demographic trends show that these numbers can decrease. They might be compensated for through a rising interest for pets among elder people. In Germany in 2001 there were a total of 6.9 million cats, making them the most popular pet. This number is still growing. In the year 2002 cat litter with its 189 million € in sales holds the largest market share among "commodities" for pets[19]. This market is dominanated by mineral based materials, however manufacturers have noted a tendency toward the use of wood based products which are said to be more "ecological"[20].

3. MUSHROOM PRODUCTION

Through the production of edible fungi low value wood material (sawdust, small pieces of stems) can be transformed into high value food. This can be done in a very efficient way: When growing shiitake (*Lentinula edodes*) intensively under controlled conditions (defined substrate composition, temperature, humidity, light) the fresh weight of mushrooms produced can reach 70 – 100 % of the dry mass of the wood comsumed.[21]

Shiitake has been grown in Asia for 2000 years. The older method of drilling holes into small logs and then injecting mycelium into them is mostly used today by hobby mushroom growers. Since about 1974 intensive production systems use sawdust-based substrates in plastic bags. These substrates consist of a variety of different mixtures of wheat or rice bran, straw and gypsum, sucrose or other additives. The individual mixtures are inoculated with selected shiitake-strains. The size of the wooden particles is important for aeration and should therefore not be smaller than 0.95 mm. The kind of wood also plays an important role. Hardwoods like oak and beech are commonly used[22]. "Low-value" species may be upgraded by fermentation as is done in Australia with sawdust from *Eucalyptus*.

Through mushroom production low value wood can be transformed into high value food.

World wide, commercial mushroom production was about 5 mio. tons (fresh weight) with a value of approximately U.S.-$ 9.8 billion in 1994. Large increases can be expected because it has only been possible to cultivate a few basidiomycetes (mainly *Agaricus, Lentinus, Pleurotus, Auricularia, Volvariella, Flammulina* and *Tremella*) up to now. In many cases it is still not known how the fruiting body development can be induced. When this question is solved, more species can be used and the overall production will further increase. Not only wood but also agricultural by-products can be very efficiently transformed into high value protein. As mushrooms are low in calories, sodium, fat and cholesterol, but rich in protein, carbohydrates, fibre and minerals, they are a very good dietary food. Some species even contain medicinal substances.[23]

4. WOOD AS FOOD AND FEED

About 200 years ago it was found that the large molecular carbohydrates in wood, namely cellulose and hemicellulose, can be fractionised by acid treatment into simple sugars (glucose, hexose and pentose) and thus converted to food. Because of the huge investments necessary to build production facilities, this has only made sense economically in times of need[24]. But as ruminants are able to utilise cellulose through encymatic solubilisation, studies have been carried out to establish whether wood products could be used in addition to grass and other feeds. Experiments with fermented or acidified wood flour (see 8.) have been successful. In India, for example, a suitable solid state fermentation process has been developed to enhance the biological composition and nutrition value of sawdust using *Pleurotus sajor-caju*.[25] Cellulose made from sawdust can possibly be used as feed if it is carefully derived and finely ground[26].

Among the wood flour products shown in Table 3 a feed extender is mentioned. This is a fine wood meal obtained from so called fat trees (softwoods and "smooth" hardwoods which contain a fatty oil, e.g. birch (1.5 – 3.3%) and lime (6.3- 9.2%)). In times of need this has been added to normal feed, it is partially digestable.

For human consumption wood meal can be used as an extender in cereal flours; in addition, spruce meal can be used to coat baking trays to prevent the dough from sticking.

5. FOOD PROCESSING

Sawmill by-products have not only been used directly and indirectly for the production of food stuffs but have, for centuries, also been used to help conserve them and to improve their taste.

Fumigation is a traditional method of food conservation for meat and fish. This is usually done by smouldering of hardwoods such as beech, oak and maple or juniper in the form of sawings, shavings or split wood. The smoke has a germicidal and drying effect on the fumigated food. Depending on the temperature it can be categorized as cold, warm or hot smoke[27].

Oak wood chips from wood barrel production are used to **improve the taste of red wine** during fermentation in steel containers. Just as wooden barrels are toasted so too are the chips. This makes them an important factor in the development of aromatic substances in red wine which determine its taste and color[28].

6. BUILDING PRODUCTS

The use of **shavings for thermal insulation** is basically not a new thing; however, only since 1993 has their use in construction been officially permitted in Germany. In 1997 CLIMATE CHIPS® were given an official seal of approval. These shavings undergo a special treatment process and are then covered with a very thin layer of cement[29]. A study at the University of Munich established a thermal conductivity value (λ_R) for shavings of 0.050 – 0.060, and a somewhat less effective value of 0.060 – 0.070 for sawings. It proved necessary to fill this material to a degree of density which would keep it from settling. The requirements of building material class B2 can be fulfilled even without fire protection chemicals[30]. Further results are expected in June 2004 when a new cooperation project is completed which focuses on the optimal production and processing of shavings[31].

An interesting use of wood by-products in construction is demonstrated by **wall form units made of low-density cement-bonded wood fiber composite**. This is composed of specially graded recycled waste wood (100% clean, natural softwood lumber) that is neutralized and mineralized and then bonded together with Portland cement. This material is lightweight with an adequate carrying capacity, porous, thermal insolating and very durable. It does not rot nor decay. It is vermine, termite and insect proof and does not support fungus growth. It is accepted as environmentally friendly and does not contain nor emit any toxic elements[32]. When producing this material it care has to be taken that the wood being used is compatible with cement. If its sugar content is too high, it can be reduced by first subjecting the sawdust to fermentation[33].

The Forestry Research Institute of Nigeria (FRIN) has developed **ceiling boards and floor tiles from saw dust** which were presented at the World Exposition EXPO 2000 in Hannover[34].

7. ENVIRONMENTAL PROTECTION

One possibility for using sawings and sawdust for environmental protection purposes is to mix it with materials which are to be composted, e.g. manure. In the composting of sewage sludge wooden particles serve as structural material. Its main function is to help adjust the water content of the rotting mixture to an optimal value and to increase the volume and stability of the pores[35].

Modified sawdust can be used for **filtering**:

Chemical modification of sawdusts with fatty acylazides was carried out in order to obtain new materials for the removal of organic pollutants, e.g., fats, among others, from water. The wood thus modified presented higher affinities than unmodified wood for oleic acid and olive-oil chosen as representative compounds of fats and allowed their elimination from water[36].
In another case the reaction of succinic anhydride with wood meal from *Picea abies* was studied in a search for low cost materials usable in the removal of heavy metals. Three more or less modified sawdust samples were used after activation with $NaHCO_3$ for the removal of cadmium(II) from water[37].
In contrast, trials with untreated sawdust from different tree species resulted in a relatively low degree of filtering of Cd (II), but displayd much higher rates for copper (II) and zinc (II). In these trials sawdust from hardwood species such as oak and black locust was more efficient as an absorbent than sawdust from the poplar, willow and fir[38].

Researchers in Iowa (U.S.A.) have found that lining underground drainage tiles with wood chips can **filter out** about 70 percent of the **nitrates** stemming from dead plants, human waste and crop fertilizers. As the wood decomposes, bacteria transform the nitrates into nitrogen gas. Lab tests have shown that all nitrates could be effectively removed if the water is held within the system long enough[39].

8. WOOD FLOUR PRODUCTS

For approximately 100 years wood flour has been being produced by either sieving sawdust and/or finely grinding sawings, shaving or pieces of wood. Because of the very high standards which have to be met in the production of wood flour products, the raw material must be carefully selected and processed according to strict guidelines.

A fundamental factor with regard to the quality of wood flour is the original tree species; the size and form of the grit also plays a role although with decreasing size the influence of the species and the form becomes less relevant. Other important properties include the degree of purity, moisture and resin content, colour, type of chemical reaction, ash content and the iodine-potassium-starchgrade.

Activated carbon	Filler for batteries	Putty and adhesive
Artificial wood	Filler for paper and cardboard	Sandpaper discs
Cleaning and polishing agents	Filter paper	Sweeping powder
Cleaning products	Glue extender	Wallpaper coating
Coating for baking trays	Kneadable wood	Wood plastic composites
Desiccant	Linoleum	Woodstone (Xyolith)
Explosives and fuses	Medical dressing materials	
Feed extender	Powder fuel	

Table 3 Variety of possible uses for wood flour as described by Vorreiter (1960)[40].

In Germany in 1960 half of the total ammount of wood flour was consumed in the production of **linoleum**. Following a strong decrease in the production after1929 (42.9 mio. m^2) this floor covering, made purely of natural ingredients (mainly wood flour, linseed oil, colophony and jute) has experienced a come back over the past few decades. Currently 10 – 12 mio. m^2 are sold annually in Germany[41]. This is only 2.3% of the entire flooring market. From 1994 to 2003 the consumption of prefabricated linoleum floor covering increased from 0.06 mio. m^2 to 2.38 mio. m^2. This growth has

mainly resulted from the fact that prefabricated flooring materials have largely replaced rolled linoleum[42].

Somewhat more recent than linoleum is the practice of mixing **wood flour with plastics**. Dr. Leo Hendrik Baekelund´s research led to the construction of the first factory for synthetic plastics (thermosets, made of phenol and formaldehyd) near Berlin in 1910. This material was called Bakelite and was used in the production of many household items. Very fine wood flour was used as a filler (up to 50%) sometimes with aesthetic effects[43].

For several decades now **Wood Plastic Composites (WPC)** based on thermoplastics have been produced, especially in the U.S.A.. Although activity in the WPC industry has increased dramatically since the mid-1990´s, it only represents a fraction of a percent of the total wood products industry; nevertheless, it has made significant inroads into certain markets. Current endproduct manufacturers are an interesting mix of large and small manufacturers from both the plastics and forest products industries. According to a recent market study, the WPC market was 320,000 metric tons in 2001, and this volume is expected to more than double by 2005. One factor behind this growth may be the phasing-out of the once widely used wood preservative CCA (chromated copper arsenate). Besides WPCs are regarded "as a way to increase the durability of wood with little maintenance on the consumer's part (one of the greatest selling points)."

Despite the demonstrable success of WPC´s in the USA, market development in Europe has been slow. About 31,500 tons of wood plastic composite are used in only a small number of cases in the automotive and building industries. Little is manufactured in Europe; most composite is produced elsewhere (e.g. USA) and then sold through European distributors. Activity is also evident in Japan where one of the leading companies in the WPC market is Ein Engineering Company. There is high acceptance of WPC material within the region, with over 22,000 tons of WPC produced in 2000. This represents an increase of 50% over the 1999 figure of 14,000 tons.

Wood Plastic Composite from Japan made from 55% (wt) wood powder and 45% recycled PP.

"Because of the limited thermal stability of wood, only thermoplastics that melt or can be processed at temperatures below 200° C are commonly used in WPCs. Currently, most WPCs are made with polyethylene, both recycled and virgin, for use in exterior building components. However, WPCs made with wood- polypropylene (PP) are typically used in automotive applications and consumer products, and these composites have recently been investigated for use in building profiles. Wood-PVC composites typically used in window manufacture are now being used in decking as well. Polystyrene and acrylonitrile-butadiene-styrene (ABS) are also being used. The plastic is often selected based on its inherent properties, product need, availability, cost, and the manufacturer's familiarity with the material. Small amounts of thermoset resins such as phenolformaldehyde or diphenyl methane diisocyanate are also sometimes used in composites with a high wood content.

The wood used in WPCs is most often in particulate form (e.g., wood flour) or very short fibers, rather than longer individual wood fibers. Products typically contain approximately 50 percent wood, although some composites contain very little wood and others as much as 70 percent. The relatively high bulk density and free-flowing nature of wood flour compared with wood fibers or other longer natural fibers, as well as its low cost, familiarity, and availability, is attractive to WPC manufacturers and users. Common species used include pine, maple, and oak. Typical particle sizes are 10 to 80 mesh." [44] Cleanliness is a priority and the wood should be free of any non-wood contaminants. Small amounts of glue, paint or laminates can generally be tolerated as long as the amount does not exceed 5%. Feedstock consistency is one of the most important factors[45].

There is also a continual optimisation with regard to tool technologies and raw material properties. The proportion of wood in the various mixtures may range from 1% to 95%.[46] With the development of plastic foam comprised of wood and other fibres, the variety of materials made from sawings continues to increase thus expanding their utilization[47]. Optimisation efforts can also have the reverse effect. In some cases sawmill by-products may no longer be good enough for the production processes making it necessary to use roundwood or even pure cellulose.

Unlike for WPC´s for the production of **fasalex®** natural starch such as maize is used as the main bonding agent. The wood component makes up to 70% sawings and can be processed with 15% moisture content. Fasalex® ("liquid wood") is a recyclable and biologically degradable material with the characteristics of wood. It promises dimension stability, as well as a higher resistance to damp and a higher rigidity and resistance to bending than chipboard or MDF. It belongs to fire protection class B2 and can be laminated and veneered with convential hot melt lamination systems and can be powder coated. It can also be extruded into a whole range of shapes: profiles, pipes or panels as well as window frames and door elements[48].

A new development of a somewhat different kind is being offered by a Swiss startup company. *Innovation wood* ("iwood" for short) was founded on the idea of developing a marketable, new, biotechnological process for the production of environmentally friendly and affordable panels for the furniture and building industries. Panels and mouldings are produced from sawdust and wood flour through a process in which micro-organisms (mainly yeast) are used to release the wood starch in the wood and convert it into a foam wood paste comparable to bread dough. The wood paste is then dried, resulting in a hard material (like crackers or crispbread) with properties comparable to chipboard and similar products. **Starch-bound Low-density wood-based Panel** (SLP) as a material weighs half as much as current conventional materials (250 – 300 kg/m^3) and can easily be ground, sawed, planed and drilled with common tools, fastened with screws and glued[49].

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