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NEXT GENERATION WOOD-BASED MATERIALS: FROM IDEAS, TO RESEARCH, TO RESOURCE-EFFICIENT PRODUCTS

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Abstract:
The starting point for any innovation could be either a technology push or an existing market pull. For successful innovations a technological invention has to obtain approval by the marketplace, by technological institutions and also by society. Three criteria need to be met: (1) technological applicability, (2) economic profitability, and (3) social acceptability. The key technology model is seen as an efficient and effective way to achieve innovative results through research and development. An example on innovative industry-drive product development is given, addressing also resource efficient use of biomass. Materials using natural fibers include particle boards, fiberboards, oriented strand boards, a number of engineered wood products, and more recently polymers filled / reinforced with wood and other natural fibers. The latter are known but not limited to WPC (wood-plastic/polymer-composites). Many of these materials have fully developed industrial processes, such as the classical wood-based composite technologies, then injection molding, profile extrusion, pultrusion, or compression molding of non-woven mats. While virgin materials, i.e. wood, experience increasing prices and therefore reduced availability, a vast amount of cellulose-based waste materials have currently low-value usage. Multi-coated paper products, as used for e.g. milk and beverage packages, or other laminated waste paper fractions, need to be separately collected due to higher polymer contents. It is shown that products can be developed with these waste resources, with wood particles added, using advanced extrusion technology.

Key words: *innovation; research strategy; resource efficiency; biomass use; natural fibers; wood-based materials; industrial waste; paper sludge; extrusion technology; new materials.*

INTRODUCTION

Generating innovation

Science and technology is the engine for economic growth as international competition has greatly intensified in recent years. Many countries throughout the world have recognized the importance of innovation and have installed initiatives to develop national innovation systems. But how does innovation occur? There is the distinction between technology push and market pull. A technology push implies that a new invention is pushed through research and development (R&D), and through production and sales to enter markets. In contrast, an innovation based upon market pull has been developed by R&D in response to an identified market need. Therefore, starting point for any innovation could be either a technology push or an existing market pull (Fig. 1).

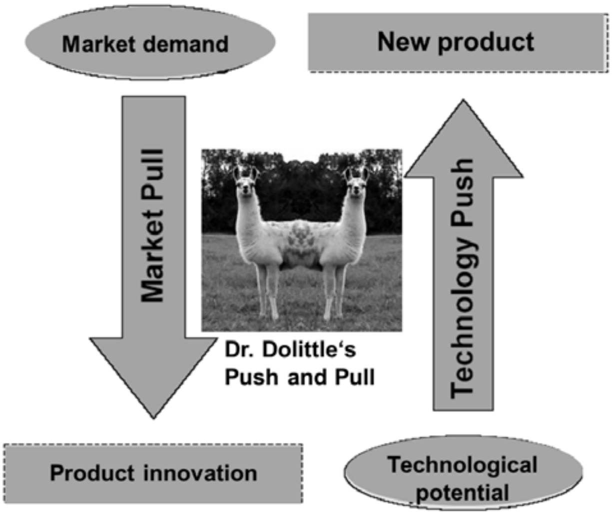

Fig. 1
Innovation starts in the changeover between technology push and market pull.

It is clear that essential forces behind social and economic changes are innovative technologies. New technology and products, whether generated at a research laboratory or somewhere in industry, is seen as the leading engine of economic growth (Marin 1994). Science-based innovations are traditionally based on inventions made in basic research. A prerequisite for such inventions is the overall knowledge about the research area, but with usually little understanding of marketing needs. For successful innovations a technological invention has to obtain approval by the marketplace, by technological institutions and also by society. In other words, an innovation has to meet three criteria (1) technological applicability, (2) economic profitability, and (3) social acceptability (Fig. 2).

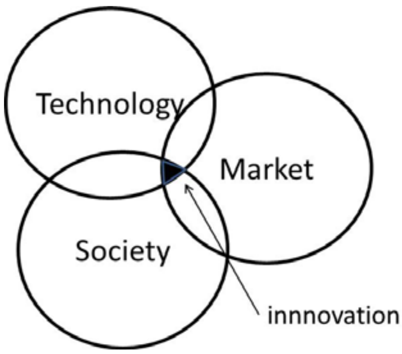

Fig. 2
Innovation as the acceptance by technology, market and society (adopted from Kairi 2005).

The key technology model

In a traditional innovation chain model, R&D is viewed as a process comprising a number of stages from basic research to finished product. In the 1990s, large technology programs in Finland have pushed the "key technology model". This model integrates not only product and process development, but also basic and applied research, and business objectives (Fig. 3). The key technology model refers to a procedure, which combines the industry's business objectives and the required research and development activities to achieve the defined objectives (Kairi 2005).

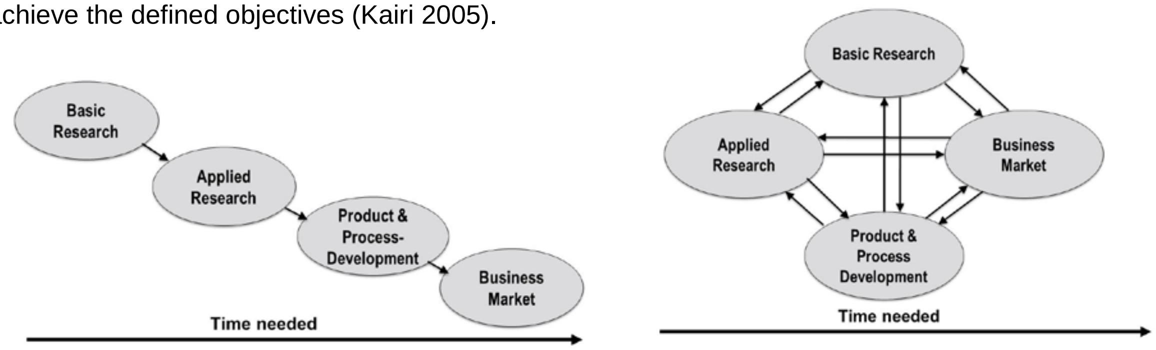

Fig. 3

Classical innovation chain starting with basic research, with ideas carried on to next stages, eventually arriving at the market (left); Implementation of the key technology model, with basic research, applied research, and product/process development, integrated with customer-based solutions (right).

The key technology model is an efficient and effective way to achieve innovative results through R&D in industry. Many European countries have now implemented funding systems that are in accordance with the proposed "key technology model". Within the context of basic research, applied research and development work, this operating model focuses on finding customer-based solutions.

RESOURCE-EFFICIENT BIO-BASED PRODUCT DEVELOPMENT – A SHOWCASE

The use of reinforcements and fillers in thermoplastic materials has been a long and well-documented practice in industry. In general, filled thermoplastic materials are stiffer, stronger, and more stable than unfilled materials. In contrast, other properties such as impact bending strength may decline. Fillers are typically inorganic such as talcum, or glass fibers. The use of wood fibers as a replacement for traditional, inorganic fillers has been practiced for some time. A number of materials use a considerable amount of natural fibers as the main component, as filler or reinforcing component. These materials range from particle boards, fiberboards, oriented strand boards, to a number of engineered wood products, and also to polymers reinforced with wood or other natural fibers (e.g. hemp, flax, coir, kenaf). These materials are known but not limited to WPC (wood-plastic/polymer-composites). The largest commercial applications for WPC are decking, but also furniture, packaging, housing goods, and selected interior components for automotives are produced. Today, WPC represent a relatively small but rapidly growing material class. One significant argument to use wood instead of inorganic fillers are the lower costs. However, this situation seems to be changing. Since wood is favored and greatly pushed as a key resource for energy production ("bioenergy"), prices for low-quality wood stocks have significantly gone up. According to Mantau (2010) 46% of the European wood consumption go into energy use. This share will continue to rise up to 53% by the year 2030, as predicted. Saw log prices in Germany have risen by 30% between the years 2005 and 2008, and wood residues are up even by 70% during the same period (Sauerwein, personal information). Alternative natural fibers may be seen as substitutes to wood fibres in WPC. However, fibers such as hemp, flax or sisal are much higher in price, and since their fiber length is in the centimeter range, these fibers also need to be cut to become processable in an extruder or injection molding machine.

The search for alternative fibers that are resource and eco-efficient has led us to the question if cellulose-containing wastes can be utilized for composite material development. At the Institute of Natural Materials Technology, IFA Tulln, Universität für Bodenkultur Vienna, research has been initiated looking at different cellulosic-type waste sources, with the goal to develop and ultimately manufacture 3D shaped materials (Mundigler 2004, Bittermann and Sykacek 2007). This research effort has been steadily growing over the past years, indicating that industry is increasingly concerned about resource efficient production. The key question is how these cellulose-containing wastes perform as polymer-filling materials. If suitable materials properties are determined, a number of applications can be developed.

Raw materials and processing

Different types of paper-based wastes have been collected: TetraPak® (beverage) packages, poster paper, cardboard-type paper, other polymer-coated waste paper. Due to multiple polymer-coating most of these paper types are not collectable in standard paper recycling pins. The material of a e.g. juice package consists of a cardboard layer that has been foliated with 2-3 polyethylene layers, as well as an aluminium layers, to achieve sufficient mechanical stability and liquid-tightness. In the recycled fraction the polyethylene content of coated paper wastes might be as high as 20%. The paper-based materials were cut in sieve-mills at mesh-sizes between 3 and 10mm. During processing special care had to be taken due to metal or mineral inclusions.

Wood plastic composites (WPC) are usually processed in two steps. First, a granulation step is done, using a co-rotating, conical double screw extruder with a granulator mounted at the exit nozzle. Second, the compounded granules are then fed into the profile-extruder. For the paper-waste materials direct extrusion was tried, since sufficient homogenisation seemed to be achievable. The paper particles were mixed with polypropylene and polyethylene granules as well as additives, before the mixture was fed into an extruder. The geometry of this conical twin screw extruder was especially suitable for low density materials. With a special extruder screw configuration the material was homogenized, densified, and heated to obtain an endless viscous polymer strand, which was then shaped through the mounted form die into different profile shapes (Fig. 4).

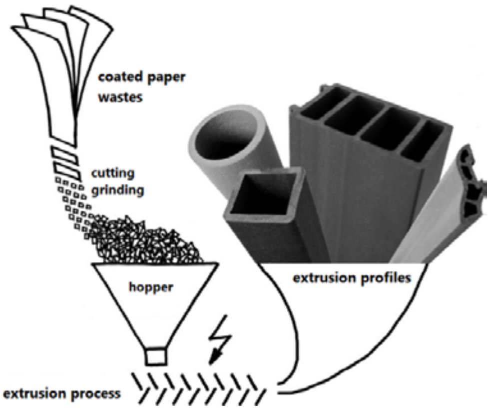

Fig. 4
Simplified process scheme - from coated paper wastes to extruded profile materials.

Preliminary research on de-inking paper sludge (DPS) as a special filling material was also included in the study. This material is a major waste product resulting from the paper recycling process. De-inking paper sludge is about 60% inorganic, additional pre-processing is necessary prior to profile-extrusion. We partially replaced the wood component in standard WPC recipes, with polypropylene used as the matrix polymer. A standard two-step process was applied, which means materials went into the extruder with a mounted granulator, before the granules were fed into the hopper for the actual profile extrusion. The extruded profiles were characterized for mechanical-physical properties using standard material testing procedures.

Thermoplastic materials from coated waste paper

Different recipes were tested, having various proportions of waste paper, thermoplastic polymers, and additives. Wood fibres as reinforcing components were also used. The waste paper content went up to maximally 70%. After optimizing processing conditions, extrusion profiles were produced and then tested. The surfaces of the produced profiles appeared homogeneous and smooth, profile edges were to size and accurate. Examples of the different profiles are shown in Fig. 5.

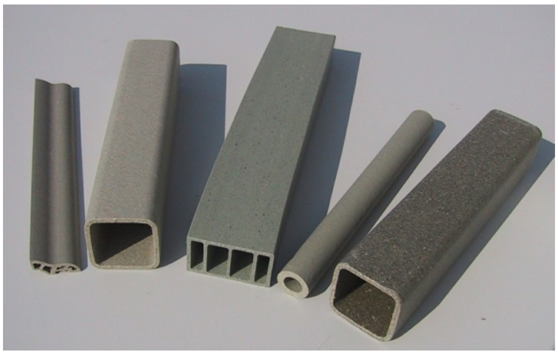

Fig. 5
Different profiles of extruded paper-based polymer composites.

Samples were cut from sides of the profiles, to determine mechanical properties as well as water uptake percentages. Table 1 shows a comparison of three typical examples. *TetraPak*® represents a blend of 40% *TetraPak*® paper particles (3mm), 20% writing paper particles (3mm), 25% polypropylene, and the additives talcum filler and coupling agent. The "*Poster paper*" type consisted of 60% poster waste paper, 28% polypropylene, and also talcum and a coupling agent. WPC was a standard wood-plastic-composite with 60% wood filled in polypropylene. Results show that the *Tetra-pak*® as well as the *poster paper* versions are having high impact bending strengths compared to the standard WPC, which was due to the existing polyethylene content. The other properties bending strength (MOR) and bending stiffness (MOE), including water uptake, are at comparable levels. The conclusion is that waste-paper based polymer composites deliver materials with a very acceptable property profile.

Table 1

Selected properties of WPC (Wood-PP (60/40)), Poster Paper – PP, and TetraPak®-PP (MOR modulus of rupture, MOE modulus of elasticity, IBS Impact Bending strength, and water uptake after 24h immersion

	WPC	Poster Paper	TetraPak®
MOR [MPa]	51	30-40	35
MOE [MPa]	4430	2500-3000	2240
IBS [kJ/m^2]	8,2	8-9	13
Water uptake 24h [%]	1,5	1,5-2	1,6

The waste-paper filled polymer composites have further advantages, compared to wood-plastic composites (WPC). Since lignin and resins are almost absent in paper, the processed composites are less prone to UV degradation. This results to higher weathering resistance, as proved in various outdoor tests. Further, the lack of lignin allows higher processing temperatures at the extruder, making the production more versatile and better adjustable to desired properties. In can be concluded, that polypropylene filled with special waste-paper types results in a new type of material, which is named called Paper-Polymer-Composite, or PPC.

Continued research and development at the Institute of Natural Materials Technololgy, resulted to products jointly developed with industry, as in the case with UPM-Kymmene. Decking products filled with recycled laminated papers have been developed and they are now successfully established on the market, as UPM ProFi Deck. This new decking type has proven as a durable and new outdoor solution used as garden decks, patios, terraces, marina or boardwalks.

Thermoplastic materials made from de-inking paper sludge (DPS)

From the different test mixtures using DPS two results are presented in Table 2. A WPC recipe was chosen, having 70% wood and 30% PP (plus additives). In the first trial, half of the wood was replaced by DPS. The second trial refers to a full replacement of wood by DPS. Bending strength and stiffness show considerably higher levels, compared to standard WPC (see Table 1 for WPC values).

Table 2

Modulus of rupture (MOR), modulus of elasticity (MOE) and impact bending strength (IBS) of extruded Wood – DeInking Paper Sludge (DPS) – polypropylene composites

	Wood/DPS 35%/35%	Wood / DPS 0%/70%
MOR [MPa]	52	56
MOE [MPa]	7511	6648
IBS [kJ/m^2]	4,7	3,6

Different processing conditions with wet and dry DPS were tested, which are not reported here. The conclusion is that added-value materials can be manufactured from DPS. There is a considerable amount of paper sludge, which the paper industry generates during papermaking. About 3 million tons p.a. paper sludge is discharged in Japan, 8 million ton in the United States, and 6 million tons per year in Western Europe. De-Inking paper sludge contains good quality reusable fibres, and the high inorganic portion gives rise to additional characteristics such as fire resistance, or higher surface hardness. These residues are usually disposed as landfills or are used as a low-quality additive in the cement industry, all at significant costs for the paper industry (Yamashita *et al*. 2010). With new material applications the overall resource efficiency for cellulosic waste material can be greatly improved. Advanced material development with DPS will be a focus of future research.

CONCLUSIONS

New product developments in the wood industry need to consider resource efficiency at much higher levels. While virgin materials, i.e. wood, experience increasing prices and therefore reduced availability, a vast amount of cellulose-based waste materials have currently low-value usage. Multi-coated paper products, as used for e.g. milk and beverage packages, or other laminated waste paper fractions, need to be separately collected due to higher polymer contents. However, the higher polyolefine-content is making them suitable for thermoplastic processing. It was possible to extrude paper particles with polypropylene/polyethylene to profiles showing superior material characteristics. The other material tested was de-inking paper sludge, a highly inorganic matter that is currently discharged at high costs. It was possible to demonstrate that added-value materials can be made, which gives rise to great improvements of resource efficiency. Future developments will most likely demonstrate that manufactured materials can be commercialized.

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