VINNOVA

WURC
Wood Ultrastructure Research Centre

# WURC

# Wood Ultrastructure Research Centre

## 1996-2007

## Final Report

SLU

Swedish University of
Agricultural Sciences

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*WURC*

*Wood Ultrastructural Research Centre*

*VINNOVA*

*The Swedish Agency for Innovation Systems*

*Uppsala, August 2008*

**Contents**

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## Foreword

WURC´s final report follows essentially the guidelines laid down by VINNOVA. The information therefore given refers primarily to how the Centre was organized through the almost 11 year period, how it functioned and its effects. Much of this information is of descriptive and of statistical character. The future direction and financing of the Centre after the competence centre era is also provided. Only an overview of WURC´s scientific achievements are provided within the report with the reader referred to *Appendices 1, 2* included providing details of publications, internal reports and presentations at national and international symposia etc.

**August 2008**

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## Executive summary

The Wood Ultrastructure Research Centre (WURC) (*http://www-wurc.slu.se*) at the Swedish University of Agricultural Sciences (SLU) was established July 1st 1996. The partners in the initial framework of WURC were STFI-Packforsk (STFI-Packforsk), the Royal Institute of Technology (KTH) and Chalmers University of Technology (CTH) together with seven forest industry-related companies including: AssiDomän, Korsnäs, Mo och Domsjö, SCA, StoraEnso Södra Cell and Eka Chemicals. Through various divisions and mergers two further companies (Holmen, KappaKraftliner) joined WURC in phase 3 making a total of 9 supporting industries that remained with the Centre throughout its duration. The number of Universities involved in WURC´s activities expanded during later phases and members from the Departments of Biochemistry and Quantum Chemistry, Uppsala University as well from the Division of Chemistry, Karlstad University and Department of Natural Sciences, Örebro University also participated in the Centre's activities.

WURC´s mission has been to significantly increase the basic knowledge on wood and pulp fibres regarding their morphological ultrastructure, chemical structure and physical properties and to determine how these properties change after different chemical, mechanical and enzymatic treatments. The research conducted has been primarily fundamental in character and long-term and based on cooperation between Universities, industrial research Institutes and the R & D units of forest industry-related industries. During phases 3 and 4, WURC added more applied projects in-line with the industries request and began applying the knowledge gathered and the experimental *toolbox* developed from the more fundamental projects to specific industrial problems associated with *Strength Delivery* and *Mechanical pulps*). The establishment of WURC in Sweden has provided the opportunity for specialists from a number of widely different disciplines to cooperate and build a united body to carry out research on wood fibre structure mainly at the micro- and nano-levels; a research area which at the start of WURC was insignificantly developed in the country, but also elsewhere in comparison to the economic importance of the industry. During later phases, the nucleus of WURC´s activities between the University partners was concentrated to the Uppsala-Stockholm area. During phase 3, the number of projects in WURC´s portfolio was twenty reflecting a quadrupling from phases 1 - 2 and the interest in this type of research from both academia and industry alike. During phase 4, the number of projects was progressively reduced *in-line* with the running down and completing of the Centre´s activities.

WURC has attained a high level of competence in the area of wood fibre ultrastructure during its *ca* 11 years existence. It has become internationally recognized (*e.g.* by annual international conferences, involvement in European COST actions, peer reviewed publications and symposium presentations, exchange of guest researchers etc) as a major *Centre of Excellence* interacting with the Swedish pulp and paper industry. By nature of its research, competence and critical mass (*e.g.* 50-60 people were involved wholly or part-time in WURC´s activities during years 2003/4) (phase 3), WURC was quite unique in the world. During the last 11 years, WURC scientists have been involved in over 300 scientific papers and symposia presentations and at closing, 17 PhD and 7 Licentiate graduates (wholly or partly financed) had successfully defended their theses within the Centre. The Centre has further organized 10 international, 11 major internal industry/academia interactive seminars and numerous other industry-academia project-group meetings through its era. The Centre has had an international advisory group of leading scientists that have further been active in advising WURC´s management, vetting project developments and directions during annual seminars.

WURC has used a working model based on interactions between industry and academia at all levels throughout its phases. Initially WURC´s board was comprised of representatives from member companies, VINNOVA, SLU and later on STFI-Packforsk. The chairman has been from STFI-Packforsk and the directors from StoraEnso (1996-1998), SLU (1998-2007) and vice-director from Sveaskog (2001-2007). WURC has had an Industrial Advisory (Reference) Group (IRG) comprised of representatives from all the supporting companies and together with WURC´s management team used to vet all project proposals for both academic and industrial possibilities. During phases 3/4, the group was very active in the establishment and running of industry orientated projects involving industry project leaders. The group has monitored the progress of the WURC projects and provided specialized fibre materials (*e.g.* chemical/mechanical pulps, wood samples) for the different projects.

WURC has had a primary focus on fundamental research on fibre ultrastructure, thus the major *major added benefits* of the Centre has been the creation and development of interdisciplinary interactions between the Swedish pulp and paper industry and WURC scientists in a research area of common interest. During its later phases, WURC revised its major research focus to include industrial orientated projects concerning *Pulp 2000*, *Strength Delivery* and *Mechanical pulps*. Research of the more applied nature comprised *ca* 35 % of WURC´s total budget in phases 3/4 and within this group; the majority of the *in-kind* contributions from WURC´s industrial partners (*ca* 36 %) were located. During later phases, the *in kind* contributions from industry/University also exceeded that contracted.

The challenge for WURC´s future has been to retain its academic standard at international level and at the same time further develop the industrial applications and significance of its knowledge. Great efforts were made to secure financing for continuation of the Centre after the VINNOVA Competence Centre era in 2007. This process was initiated already Autumn 05 and progressed through board activities, numerous management meetings, a writing of *gaps in our knowledge* document by WURC´s scientists and areas of research priority given by WURC´s member companies. This culminated in a successful application to VINNOVAs *"Branschforsknings fund"* February 08 for program entitled *Process and product developments through unique knowledge of wood fibre ultrastructure* (2008-2011) (WURC INNOVATION). The program will include strong collaboration between University/Institute partners SLU, STFI-Packforsk, KTH and Mid-Sweden University with member companies EkaChemicals, Holmen, SCA, SmurfitKraftliner, StoraEnso and Södra Cell. Securement of the new grant with continued industry support is a testimony to the success WURC has achieved.

# 1. WURC; Basic facts

This final report reflects contributions made from intermediate reports written for the three international evaluations of the WURC Centre carried out in 1998, 2001 and 2004. For detailed descriptions of the projects, results etc the readers are referred to the various scientific reports and publications given in *Appendices 1, 2* and to WURC´s homepage (*www-wurc-slu.se*). Summaries of project developments are also available in reports made for the three international evaluations 1998, 2001, 2004.

## 1.1 Partners and member companies

The Swedish University of Agricultural Sciences, STFI-Packforsk (STFI-PF), KTH, CTH (phases 1-3) and VINNOVA (Swedish Governmental Agency for Innovation Systems) and eight pulp and paper and one chemical industry have been the Centres contracted partners within the program (1996-2007) (*phase 1, 96-98; phase 2, 99-01; phase 3 02-04; phase 4, 05-07*). More specifically, NUTEK (Swedish National Board for Industrial and Technical Development), the predecessor of VINNOVA was the initial partner until the establishment of VINNOVA in 2001. SLU Uppsala has been the host of the Centre for the duration of the program. During the 11 year WURC program, additional research groups from SLU Umeå, Uppsala University (UU) Karlstad University, and Örebro University have also been involved as sub-contractors providing further complementary competences in fibre chemistry and physics, molecular biology and biochemistry areas. With the initiation of mechanical pulp projects in phases 2 and 3, the Mid Swedish University also became involved in WURC. While the main Centre of WURC´s activities have been at SLU, the *nucleus* measured in both total personnel and economy has been localized within the Uppsala-Stockholm area. During the later phases, it became highly apparent that WURC´s most important partners were STFI-PF and KTH where collaboration escalated compared with earlier phases.

The forest products industry forms an integral and important part of the Swedish economy and the sector produces net exports of the order 100 billion kronor. It is somewhat a dynamic industry and during WURC´s lifetime a number of major changes occurred with the member companies. Initially during phase 1, WURC had 7 industrial partners *viz:* the forest industry companies AssiDomän. Korsnäs, Mo och Domsjö, SCA, StoraEnso and Södra Cell and the chemical company Eka Chemicals. During phase 2, due to divisions and mergers, Holmen and M-real became partners and Mo och Domsjö left. The final contractual partners for phases 3 and 4 included: Eka Chemicals, Holmen, SmurfitKappa (formerly Kappa Kraftliner), Korsnäs, M-real, SCA, StoraEnso, Södra Cell and Sveaskog (formerly AssiDomän). All WURC´s companies have a policy of sustainable development, and sponsor research and developmental work on wide range of raw materials at Swedish Universities and research Institutes. Most of the companies are internationally based and therefore have significant activities, including production outside Sweden, primarily in Europe. Their interests are quite broad and variable and several sponsor research in other countries around the world with a policy of sponsoring development *where it is best* and most interesting for the company. The majority of the companies have relatively few research employees in relation to their annual turn over which obviously has restricted the possibility and mobility of WURC personal (*e.g.* employment of new doctors) for future employment out in industry (see later). Despite the acquisition of new mills and increased production capacity, the number of personnel employed by the larger companies seems to have remained stable if not reduced consistent with increased affectivity. The majority of the companies that have been involved with WURC are major actors on either the international or national scenes or both. *All the companies that joined WURC during phase 1 have remained wholly or partly (i.e. through mergers/divisions) throughout the lifetime of the Centre. Indeed six of them have also committed resources to WURC for a major post-WURC program (see later).*

**1.2 Economic overview of Centre**

The overall cash and natural contributions from WURC´s companies were calculated and agreed upon by the partners according to the size of the individual companies.

The financing of the four phases reflects negotiations made before each phase and that finalized in the contracts signed by all partners. Table 1 provides an outline of the financing of the WURC Centre by the Universities/STFI-PF, industries and VINNOVA partners for the entire program. In broad terms the contributions of the 3 partners were roughly equal as laid down in the original contract. The total cash intake from industry for the entire program with extra monies was 1.0 MSEK more than that originally budgeted resulting from extra payments during phases 1-3 by one of the major companies. The net result for the entire program was zero. The industry *in-kind* (*i.e.* natural) contributions final outcome was -0.2 MSEK which is *ca* only 1% less of the total expected. The University natural contributions were 2.7 MSEK more than that originally budgeted.

Concerning the balance between the natural and cash contributions, all WURC partners contributed with both. In total, the natural contributions by industry for the entire program was *ca* 33% and close to the 33.8% actually budgeted. The structure of WURC´s program and the many interactions in the projects (see later) at all levels facilitated use of the natural contributions by industry. The small minus occurred during phase 2 during a lag period when more applied projects were being established.

The extra contributions from University were provided in the form of natural contributions and the net extra came primarily from SLU. This was mainly through dedicated resources to positions given through the Forest Faculty TEMA program or from a special program introduced by SLU´s rector during phases 2-3.

Both the cash and natural resources were very valuable from a Centre´s point of view. The natural contributions from the industry partners provided the incentive for closer reactions not only with University but also between the University partners especially where larger applied projects were involved in phases 3 and 4. However, the cash from industry and VINNOVA provided the operational freedom to select and manage the projects as well as the additional joint Centre activities necessary for running a Centre. However, cash contributions to university staff were in some cases limiting (*i.e.* could not finance entire positions) and it was apparent in some cases that scientists financed wholly by the Centre (*e.g.* PhD students, post-docs) more closely followed the project work than persons financed by natural contributions from the University. Persons, particularly senior staff financed via natural contributions from the University often had other commitments and involvement in other projects that made total commitment to the program impossible. Thus it was more difficult to steer natural contributions from University (apart from the supervision of students) than when direct cash contributions were involved.

| ***i)*** | | **Budgeted income (MSEK)** | | | | |
|---|---|---|---|---|---|---|
| | | **Phase 1** | **Phase 2** | **Phase 3** | **Phase 4** | **Total** |
| **Year** | | **(96-98)** | **(99-01)** | **(02-04)** | **(05-07)** | |
| **VINNOVA** | **Cash** | 5,2 | 15,4 | 18,0 | 12,0 | **50,6** |
| | | | | | | |
| **Industry** | **Cash** | 4,6 | 9,7 | 11,7 | 7,8 | **33,8** |
| | **In kind** | 1,2 | 5,7 | 6,6 | 4,4 | **17,9** |
| | | | | | | |
| **University** | **In Kind** | 6,6 | 15,4 | 21,8 | 12,0 | **55,8** |
| | | | | | | |
| | | | | | | |
| | | **17,7** | **46,2** | **58,1** | **36,2** | **158,2** |
| | | | | | | |
| ***ii)*** | | **Income result (MSEK)** | | | | |
| | | **Phase 1** | **Phase 2** | **Phase 3** | **Phase 4** | **Total** |
| **Year** | | **(96-98)** | **(99-01)** | **(02-04)** | **(05-07)** | |
| **VINNOVA** | **Cash** | 5,2 | 15,4 | 18,0 | 12,0 | **50,6** |
| | | | | | | |
| **Industry** | **Cash** | 4,9 | 10,4 | 11,7 | 7,8 | **34,8** |
| | **In kind** | 1,2 | 5,1 | 6,7 | 4,7 | **17,7** |
| | | | | | | |
| **University** | **In kind** | 6,8 | 16,9 | 23,2 | 11,6 | **58,5** |
| | | | | | | |
| | | **18,2** | **47,8** | **59,6** | **36,1** | **161,7** |
| | | | | | | |
| ***iii)*** | | **Costs Result (MSEK)** | | | | |
| | | **Phase 1** | **Phase 2** | **Phase 3** | **Phase 4** | **Total** |
| **Year** | | **(96-98)** | **(99-01)** | **(02-04)** | **(05-07)** | |
| **Cash** | | 9,8 | 25,6 | 28,5 | 21,6 | **85,5** |
| | | | | | | |
| **Industry** | **In kind** | 1,2 | 5,1 | 6,7 | 4,7 | **17,7** |
| | | | | | | |
| **University** | **In kind** | 6,8 | 16,9 | 23,2 | 11,6 | **58,6** |
| | | | | | | |
| | | **17,8** | **47,6** | **58,4** | **37,9** | **161,7** |
| | | | | | | |

**Table 1.** ***Showing i) WURC´s overall budget for phases 1 – 4 (1996 - 2007) with breakdown of contributions for both cash and in-kind from member companies, VINNOVA and University; ii) the realized income; iii) The costs distributions with breakdown of contributions for both cash and in-kind from industry***

Table 2 outlines in broad terms how the costs have been distributed and realized within the entire program. It should be remembered that WURC was initiated with a small number (*i.e.* 5) of PhD projects in phase one and thereafter escalated in phases 2 and 3 to include a large number of projects included under an equal number of project areas (*see later*). In phase 4, where running down was necessary with the completion of the program, the projects were included under 5 project areas. To emphasize, during phase 3 there were over 20 projects running simultaneously.

The project areas given in Table 2 reflect on the whole the main areas through the program and those that were present on completion of the program.

The major cost areas through the program if grouped in descending order are: *Mechanical and physical properties of fibre materials, Cell wall ultrastructure, Fibre Chemistry of wood polymers, wood and pulp fibre models.* This is followed by WURC management and WURC jointly. The *mechanical and physical properties of fibre materials* program area corresponds to the area where the more applied interactive projects with industry were grouped and thus the combined cash and natural resources were necessarily the largest throughout the program. WURC jointly included diverse costs from WURC´s annual international seminars, the many national seminars/project meetings at Arlanda/SLU, guest researchers (*in/out*) to the program, joint publications, service and purchase of advanced equipment (SLU) and laboratory assistance at SLU. WURC management included funding of director, part-time vice director (phases 3, 4) and economic and secretary assistance at SLU.

| **Project Area** | **Phase 1 (96-98)** | | **Phase 2 (99-01)** | | **Phase 3 (02-04)** | | **Phase 4 (05-07)** | | **Total (96-07) % of total cash for period** | | **Total (96-07) % of total natural for period** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cash** | **Natural** | **Cash** | **Natural** | **Cash** | **Natural** | **Cash** | **Natural** | | | | |
| | | | | | | | | | | | | |
| Managerial Group | 1877 | 1 531 | 1940 | 1388 | 2112 | 2706 | 2654 | 2 277 | 8583 | 10% | 7 903 | 10% |
| I. Mech & phys props, | 2499 | 2 039 | 5820 | 6454 | 8238 | 10441 | 4970 | 6 231 | 21527 | 25% | 25 165 | 33% |
| II. Cell wall ultrastructure | 2018 | 1 647 | 5860 | 6562 | 8170 | 8167 | 5490 | 5 094 | 21538 | 25% | 21 470 | 28% |
| III. Fibre chem of wood poly. | 1000 | 816 | 3450 | 2860 | 5940 | 3348 | 2997 | 1 542 | 13387 | 16% | 8 566 | 11% |
| IV. Wood & pulp fibre models | 812 | 663 | 1700 | 2890 | 1960 | 4268 | | | 4472 | 5% | 7 820 | 10% |
| V. WURC Jointly | 1599 | 1 305 | 6820 | 1864 | 2003 | 896 | 5504 | 1198 | 15926 | 19% | 5 262 | 7% |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **TOTAL** | **9805** | **8000** | **25590** | **22018** | **28423** | **29826** | **21615** | **16342** | **85433** | | **76 186** | |

**Table 2.** ***Summary of the allocation of resources (cash and in-kind) within WURC for the entire program 96-07.***

### 1.3 Organization and management

Essentially the organisation (Figure 1) that was introduced at the end of phase 1 remained throughout the program. It was comprised of a *chairman* (Lennart Eriksson, STFI-PF), a *board* of company and SLU representatives, a *director* (Geoffrey Daniel, SLU), *managing*, *industrial advisory* (known earlier as *industrial reference group*) and *senior scientists* groups, *project leaders* and *PhD students* as well as *industrial contact persons* and the *international advisory group*; the latter initiated after the recommendation of WURC´s first international evaluation. During phase 3 the managing team was further strengthened by Lars Ödberg (then Assidomän, later Sveaskog).

Essentially the roles of the different groups/persons during were:

- *Board:* ultimately responsible for WURC´s research direction, economy, administration and strategic decisions. The composition of the board varied slightly through the phases. Typically it was composed of representatives from each of the member companies plus representatives from SLU and STFI-PF (phases 3, 4). An observer from VINNOVA also joined the meetings as did WURC´s director. The board met typically 2-4 times per year or more as circumstances

prevailed, meetings normally taking place at Arlanda. In the later stages, the board had strategic ambitions to find new funding after the completion of the Centre. During the entire

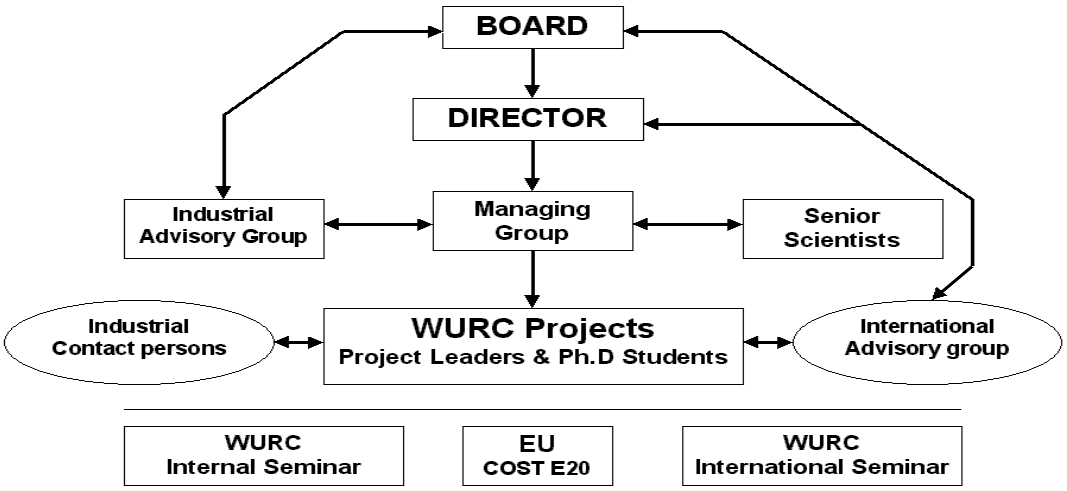


**Figure 1. WURC´s organization**

program, the board followed WURC´s development rather closely. Håkan Jöves (Korsnäs) was the interim chairman during the starting up of WURC being succeeded by Lennart Eriksson (STFI-PF) who remained the Centre chairman for the entire program. WURC´s board and director were appointed by SLU´s rector.

- *Director:* responsible to WURC´s board for enforcing WURC´s strategy and development regarding research direction, economy and administration as well as the daily running of the Centre. The Centre director implemented the board decisions and maintained the contact between the numerous groups within the Centre (see below) as well as the companies and participating Universities/Institute. Brita Swan (StoraEnso) was the director of WURC for phase 1 being succeeded by Geoffrey Daniel (SLU) who remained the Centre director for the rest of the program.
- *Managerial group*: responsible for the daily running and administration and following up the economy of the Centre. It was also responsible for following up on research projects, proposing new research areas, organizing meetings (*i.e.* seminars) and for recruiting and interviewing scientists and PhD students. This group met frequently (monthly) and had regular contacts with the chairman. It was led by the Centre director together with a secretary and economic advisors (Fredrik Gunnarsson, Per Jennische) from SLU. Lars Ödberg (Assidomän) (WURC´s vice director) strengthened the group during 2001 on a part-time basis and remained until the end of the program.
- *Industrial advisory (reference) group*: responsible for reviewing the applied research direction of WURC and prioritizing project proposals. In this role the group served as an expert panel to the board. *This group was very active throughout the WURC program having 6-8 meetings per year.* The group organized the production and extensive characterisation of special industrial pulps in several large industrial cooperative projects (*i.e.* all member companies were involved). They were also active in organizing industrial practice (periods up to 2 months) for WURC PhD students, seminars for discussion of WURC projects out in industry as well as industrial study trips for PhD/Lic. students. Advisory group members Karin Sjöström (Södra), Erik Persson (Holmen)/Peter Sandström (SCA), Anders Moberg (StoraEnso) also led large integrated industrial projects during phases 3 and 4.

- *Senior scientist group:* responsible for development of project ideas and discussing research possibilities. This group had meetings during the Centre´s annual seminars to discuss cooperative research possibilities. In retrospect, possibly the Centre could have benefited even more from these meetings if there had been the possibility to have organized them more regularly.
- *Project leaders* and *PhD students:* responsible for the detailed planning of individual projects conducting research and administrating economy at the project level. Project leaders (senior scientists, post-docs) were also responsible for the supervision of PhD students or actively involved themselves in research activities as some projects did not involve PhD students. A PhD/Lic. student group was also introduced during phase 2. Since the students were geographical dispersed between several universities, this provided a means for them to have contact, share ideas and experiences and basically help each other with research problems. The group met when we had our internal seminars and reported back to the managerial group concerning problems, requests or ideas etc.
- *Industrial contact persons:* functioned to give advice on the industrial relevance of research projects and maintain contact between students and companies. These company persons were introduced during phase 2 in order to provide additional help to PhD students independent to the normal University supervisors.
- *International advisory board:* functioning to provide strategic advice on the development of WURC´s overall research program to the board/management group as well as to project leaders/PhD students at the project level. The group comprised world leading experts in the area of wood fibre ultrastructure and was introduced during phase 2 and remained throughout the 10 year program. The group was composed of Prof. Malcolm Brown Jr., (University of Texas, USA) Prof. Bernard Monties (INRA, Institut National Agronomique, Thiveral-Grignon, FRANCE) and Prof. Keiji Takabe (Kyoto University, Kyoto, Japan). These persons regularly attended WURC´s international and spring seminars (held concurrently) providing advice and suggestions for strategy and project developments. They also provided advice and suggestions on how the Centre could exist after the 10 year program. Their introduction during phase 2 was stimulating for the Centre. Possibly the Centre could have benefited even more if it had been possible to have arranged a greater number of visits.

The persons involved in the different groups are shown in *Appendix 4.*

The functioning of WURC and the various roles of the different groups was laid down in WURC´s*"Arbetsordning*". Essentially, the above organisation developed from the experiences of WURC during its initial period. Because the organization functioned rather well, the board did not see any reason to change its structure during later phases.

## 2. Development of Centre through the program

### 2.1. Original concept

The highly complex structure of wood fibres, the industrial need for *new* knowledge, and the infrastructure of research on wood fibres in Sweden represent the basis for the original concept and long-term aims and strategies of WURC. The primary long-term objective of WURC has been to enhance the industrial utilization of wood fibres by significantly improving the understanding of their morphological and chemical ultrastructure including the interactions between the constituting wood components.

WURC´s *mission* was thus to conduct *focused basic research* on wood fibres of both immediate and long-term relevance. In addition, it was conceived that WURC should perform non-

competitive research that its industrial partners were unable, or did not find feasible to conduct themselves.

WURC´s research should serve as a basis for further R & D by its industrial partners and by research organizations that carry out more applied research *downstream* the process chain. Ultimately the knowledge created by WURC should support the development of resource-efficient and eco-balanced products fulfilling market demands. Therefore this included – *in addition to improvements in existing industrial processes and products* – ultimately the development of new industrial processes, new fibre-based materials and new consumer products. The improved knowledge of wood fibre ultrastructure should also be linked to research on the biology of cell wall formation (*i.e.* wood biosynthesis) and thus promote the understanding on how wood is formed in nature. Knowledge on cell wall formation is really a prerequisite for understanding all subsequent steps of processing and refinement to final products. With this in mind, WURC was a joint applicant for the grant and subsequent establishment of the FORMAS Centre of Excellence *"Funcfiber"* that was started in 2006.

*The original general objectives of WURC as a Competence Centre were defined as:*

- Provide an inventive and stimulating environment for high quality research and post graduate education. WURC should not however be similar to a research school for PhD students;
- Create a research environment where companies within the forest industry sector are actively participating;
- Become an internationally recognized research unit attracting foreign researchers;
- Promote interdisciplinary research and strong cooperation between the rather few, and geographically scattered scientists in Sweden working on aspects of wood fibre ultrastructure;
- Develop a competence profile and research program which gives WURC a clear identity within the Swedish and international research infrastructure.

It should be emphasized that before WURC was established, research on wood fibre ultrastructure was carried out by a number of diverse specialists geographically dispersed across Sweden. WURC therefore provided the first true opportunity for these specialists to work together and unify, and above all strengthen the research topic in Sweden.

### 2.2 Centre development in relation to original ideas

The general aims of WURC outlined above were to some extent already fulfilled by the end of phase 1 (96-98) but were subsequently further developed through the program especially its national and international profiles of the Centre. By the end of 1998, WURC had developed a clear research profile in the wood fibre ultrastructure area and industry was already actively engaged in its program of activities at all levels of organization. Industry engagement continued throughout the program and intensified in phases 3 and 4 where several industrial led projects were instigated.

Through the program the Centre continued to attract post-graduate students (primarily at SLU, KTH, STFI-PF) which reached its height during phase 3. None of the post-graduate students starting with WURC *dropped out* and all achieved as a minimal at the end of their studies, a Licentiate degree. Before the end of WURC, several PhD and Licentiate students were taking up positions in research but still remained associated with the WURC Centre in different ways.

By the end of the program WURC as a Centre was well known nationally and internationally by way of its research activities and achievements. WURC endeavoured to progressively develop its national and international reputation in number of ways. These included: *i*) annual *open*

international conferences at SLU, Uppsala; *ii*) acting as the initiator and driving force for the development of the European COST Action E20 "*Wood Fibre Cell Wall Structure*" involving many countries; *iii*) attracting guest researchers to the Centre and sending WURC scientists abroad for various periods of time; *iv*) by WURC scientists presenting research work at international symposia and publishing in peer reviewed scientific journals; *v*) setting up an international advisory group comprised of experts in the wood fibre field to advise on project developments, and *vi)* by its web page (*http://www-wurc.slu.se*). WURC scientists also actively participated in international projects particularly within EU.

Today research in WURC´s competence area is carried out by scientifically recognized groups in Finland, Canada, USA, France, Japan and New Zealand. However, it is apparent that the activities in these countries like previously in Sweden are very specialist orientated and research of critical mass does not currently exist like that developed by WURC. However, plans have been made for the establishment of Competence Centres on plant fibres in other European countries providing for the opportunities of a European network of Centres in the future. On hindsight, international networks and contacts have been essential for WURC´s successful development. One of the main reasons for arranging the International WURC seminars was to develop and strengthen the international network, an approach that has worked very well. It is worth further noting that practically all industrial partners in WURC have very significant international operations – particularly throughout Europe. So, from this point of view, the Centre automatically gained international penetration at the company level.

WURC also developed its national contact network through the program. In addition to STFI-PF, KTH, CTH, UU, KaU and Örebro University which participated in the Centres activities on a contracted basis, contacts and interactions were also established at project level with the *Research School on Wood and Fibre* (SJFR/FORMAS), Centre for Forest Biotechnology and Chemistry in Umeå (SSF, Stiftelsen för Strategisk Forskning), MISTRA (Stiftelsen för Miljöstrategisk forskning) project *Eco cyclic pulp mill* administered by STFI-PF and the Forest Products Industry Research College (FPIRC) (SSF). WURC also marketed itself domestically by interactive internal seminars with the pulp and paper industry *on-site*.

**2.3 Primary research aims**

The primary research objective of the Centre was to carryout research aimed at:

- Increasing knowledge on the morphological, chemical and physical ultrastructure of wood fibres. WURC´s main focus was on the ultra- and nanostructure of wood fibres from *ca* 500 nm to less than 1 nm;
- Determining the effects of chemical, physical and enzymatic treatments on the ultrastructure and the influence of such effects on wood fibre properties.

Research work was carried out on relevant fibre and wood materials and results obtained interpreted from both the academic and industrial points of view.

Specifically WURC´s main research encompassed the following areas:

- Ultrastructural morphology of wood and fibres *i.e.* fibre cell wall organization and nanostructure;
- Surface ultrastructural morphology and chemistry of wood and pulp fibres;
- Chemistry of wood polymers at supermolecular levels;
- Metals and extractives in wood – their location, nature and extractability;
- Ultrastructure and related physical properties of pulp fibres;
- Biotechnological, molecular and ultrastructural aspects of wood fibre biosynthesis;

- Molecular modelling of wood fibre formation and delignification.

*These primary research aims developed continually as can be seen from the wide range of projects subsequently accepted into the program in phases 2-4 (see below).*

**2.4 Competence profile**

In terms of competence profile, WURC´s research was focussed in the following disciplines involving both subject and technical expertise: plant and wood anatomy, polymer chemistry, material and polymer physics, biochemistry, microbiology, molecular biology and wood chemistry, spectroscopy and electron microscopy. During phase 2, molecular biology, biochemistry and quantum chemistry were introduced into WURC´s competence portfolio with the introduction of projects on wood biosynthesis, enzymes and molecular modelling. Thus, WURC comprised a broad spectrum of competences allowing a multidisciplinary approach to the understanding of the wood ultrastructure. Through its research WURC developed a diverse and specialized *toolbox* of techniques that were applicable to pulp and fibre research.

**2.5 Research and project structure, phases 1-4**

WURC was initiated in 1996 (phase 1) with only five wood fibre ultrastructure orientated projects *viz*: Projects 1-5, Fibre Models; The ultrastructure of wood fibre surfaces; Dislocations or nodes in wood fibres; Fibre chemistry: structure of cellulose and hemicellulose; Fibre strength of pulp fibres; and Ultrastructure modification of wood with respect to metal ions. Two more projects entitled: Lignin and hemicellulose structures in wood fibres; Mechanical interactions between wood polymers and their orientation in wood structure (financed by SJFR/FORMAS) joined the Centre shortly after. During phase 2, six major project areas were established in which the projects were organized as shown below giving the location (University/Institute) where the research was concentrated. Selection of suitable projects occurred by a process of: *i)* scientists being asked to submit research proposals; and *ii)* proposals vetted by WURC´s managerial and industrial reference group for suitability and/or industrial relevance.

***Phase 2 Project areas and projects***

***I. Wood and pulp fibre models:***
1. Fibre models (SLU)
14. Molecular modelling (UU)

***II. Cell wall ultrastructure:***
2. Fibre surface ultrastructure (SLU)
9. Ultrastructural studies of wood fibres using specific enzymes (SLU/UU)
10. Fibre cell wall biosynthesis (SLU)

***III. Fibre chemistry of wood polymers at the molecular level:***
4. Cellulose and hemicellulose structure (STFI-PF)
11. Fibre wall supermolecular chemistry (STFI-PF)
7. Lignin and hemicellulose structures in wood fibres (KTH)

***IV. Other subjects:***
6. Ultrastructural modelling of wood with respect to metal ions (CTH)
13. Influence of sulphate cooking on metals ions in wood (CTH)

***V. Physical properties of fibre materials:***
5. Fibre strength of pulp fibres (KTH)
8. Mechanical cooperation and orientation of wood polymers in the wood structure (STFI-PF)
12. Ultrastructural modifications after mechanical processing and drying of pulp (STFI-PF)

***VI. Fibre defects and structural changes:*** 3. Dislocations in wood fibres (SLU)

During phase 3, the number of projects escalated rapidly to 24 projects with also numerous sub-projects (*not shown*). Phase 3 included a number of projects remaining from phases 1, 2 as well as new projects creating a demand for good administration and organization. Thus for phase 3, WURC revised its research program and its project portfolio into four major areas namely: *i) Mechanical and physical properties of fibre materials; ii). Cell wall ultrastructure; iii) Fibre chemistry of wood polymers at the molecular level;* and *iv) Wood and pulp fibre models.*

***Phase 4 Project areas and projects***

***I. Mechanical & physical properties of fibre materials***

***IFP-0.*** Pulp 2000 (*i.e.* Massa 2000) *(StoraEnso plus most WURC companies, STFI-PF, SLU) (completed July 03);*

***IFP-1.*** Changes in fibre properties and morphological organization during processing, *"Strength Delivery" (Södra Cell plus most WURC companies, SLU, STFI-PF);*

***IFP-2.*** Effects of refining on wood fibre structure *(Stora Enso, Kappa Kraftliner, Sveaskog, SLU, STFI-PF);*

***3.*** Dislocations in wood fibres *(SLU, M-real);*

***5.*** Fibre strength of pulp fibres *(KTH, plus most WURC companies)*

***8.*** Mechanical cooperation & orientation of wood polymers in the wood structure *(STFI-PF)(PhD)(Completed Nov. 03);*

***12.*** Ultrastructural modifications after mechanical processing and drying of pulp (*STFI-PF, Eka Chemicals)(PhD);*

***15.*** Mechanical pulp fibres *(SLU, SCA, Mid-Swedish Univ., Holmen, Stora Enso)(PhD);*

***Project 15;*** Mechanical pulp fibres has major sub-projects including: *Ultrastructural studies on mechanical pulp fibre surfaces (SLU, SCA)(PhD)*; *Pectins and mechanical pulp fibre surfaces (SLU, SCA)*; and *Mechanical pulp fibre collapsibility (SLU, SCA);*

***20.*** Mechanical properties of hemicelluloses within the fibre cell wall matrix *(STFI-PF, Stora Enso, Eka Chemicals);*

***33.*** Ultrastructural studies of post harvest changes in wood *(SLU, Holmen).*

***New projects May/June 04***

***IFP-3.*** The variation in surface properties of bleached hardwood kraft pulp fibres: Influence of wood raw material, bleaching sequence and storage *(Karlstad Univ., Stora Enso, Eka Chemicals);*

***16.*** Physical properties of wood fibre outer wall layers (*STFI-PF, Holmen, SCA) (PhD);*

***34.*** Transfer of hygromechanical properties: From the wood cell-wall ultrastructure to composite materials for engineering applications *(STFI-PF, Sveaskog)(PhD);*

***IFP-4.*** Morphological differences between *Pinus sylvestris* and *Picea abies* for mechanical pulp *(Holmen, Stora Enso, STFI-PF, SCA, Mid Sweden Univ., SLU).*

***II. Cell wall ultrastructure***

***2.*** Fibre surface ultrastructure Part II *(SLU, SCA, Eka Chemicals);*

***9.*** Ultrastructural studies of wood fibres using specific enzymes *(SLU, UU, Stora Enso)(PhD);*

***10.*** Fibre cell wall biosynthesis *(SLU, Sveaskog);*

***30.*** Carbohydrate binding modules as analytical tools for fibre structure *(KTH, SLU, StoraEnso, Sveaskog)(PhD);*

***25.*** Metals ions in wood and pulp *(CTH, Eka Chemicals, Södra).*

***III. Fibre chemistry of wood polymers at the molecular level***

***7.*** Lignin and hemicellulose structures in wood fibres *(KTH, Holmen) (completed July 02);*

***19.*** Fibre chemistry of supramolecular nano-aggregates *(STFI-PF, SCA, StoraEnso) (PhD);*

***32.*** Characterization of lignin from surface cell wall layers *(KTH, Holmen)(PhD).*

***IV. Wood and pulp fibre models***

***1.*** Pulp Fibre models Part II – 3D modeling and visualization *(SLU, Sveaskog, SCA);*

***14.*** Molecular modeling *(UU, Örebro Univ., Eka Chemicals)(PhD).*

The main purpose was to establish a major research area *"Mechanical and physical properties of fibre materials"* that included industrially orientated projects (some industrial formulated) that could be supported by the other areas containing more fundamental (academic) projects.

In terms of economic expenditure in phase 3, these major project areas reflected *ca* 35, 30, 20 and 15 % respectively of the total budgeted finance representing an important shift to more practical aspects within the program (not shown). The number of WURC´s projects quadrupled from 5 projects in 1997 during phase 1, to 14 projects at the end of phase 2 (2001), to 24 projects towards the end of phase 3 in 2004. During the initial stage of phase 4, the number of project areas remained the same and the number of projects progressively decreased from 17.

During phase 4, the project areas and project structure was essentially similar that shown above for phase 3 and changed only as the number of projects decreased through completion in compliance with the running down of the program.

Together, the projects in WURC may be considered as constituting a network of research tasks that are more or less integrated depending on the specific aspect studied and that are carried out by experts in a cross-disciplinary approach. For example, in two large cooperative projects, industry selected and carefully produced a range of well characterised unbleached and bleached kraft pulps using a variety of cooking and bleaching methods to be used in WURC projects thus creating standard materials and synergy between the projects.

### 2.6 Some research trends over the 10 years

In brief, there are a number of trends that occurred over the 10 year period. In summary these included:

- A general shift from small PhD/supervisor projects to larger more integrated projects; Although all projects were integrated into the program throughout, there was a general trend towards larger projects;
- A great escalation in number of projects in phases 2-3 and even 4 compared to phase 1; These were the phases during which WURC research was intensified and most people involved;
- More active involvement of senior researchers in projects at the bench level;
- Larger more applied projects with all the industry partners involved with industry project leaders;
- From the beginning to the end a change in focus from concentration on chemical pulps (*kraft pulps*) to a major focus on mechanical pulps;
- A trend from a research concentration on spruce to including other commercially important wood species like pine;
- A greater input of ideas from industry of specific problems and problem areas that the Centre scientists could apply their experiences and diverse *toolbox* of techniques.

## 3. International evaluations

WURC was subjected to three international evaluations during 23/24$^{th}$ June 1998, 26/27$^{th}$ September 2001 and 20/21$^{st}$ September 2004. On each occasion a panel of international reviewers (2 specialists, 2 generalists specific for the entire VINNOVA program) chosen by VINNOVA were invited to WURC to carryout an evaluation of the activities and progress of the Centre. On each occasion a *WURC Evaluation Report* was compiled summarizing activities and progress of the Centre. The evaluation proceeded on the first day with a review of scientific progress of the projects –academic/applied followed the next day by a main review meeting on the research and general issues concerning the Centre. The 1998 review (2 years after the start) was slightly

different than subsequent evaluations as it was primarily orientated towards determining if the Centre had developed the infrastructure necessary for the successful development and operation of a Centre of Excellence. ***WURC received a very good evaluation on each of these occasions (Appendix 3).***

WURC found the international evaluations to be very stimulating and valuable for its subsequent development. Each written evaluation came with a number of recommendations that WURC later discussed at Board and management meetings and implemented changes to its working structure. For example, from the 1998 evaluation WURC introduced an international advisory board and slightly changed its organizational structure. From the 2001 evaluation, WURC extended its range of activities to the study of mechanical pulp fibres an area that subsequently became one of its major areas of focus in phases 3 and 4 including a large industrial project. WURC also introduced studies on pine as a raw material and intensified its efforts to secure industrial PhD/Licentiate students.

In summary, the international evaluations had a very good impact on WURC´s progress. The occasions provided a stimulus for our activities, forcing us to write a comprehensive report and thus to see over our progress. Naturally with such long-term programs it is highly beneficial and really a prerequisite to have periodic assessments to ensure success.

# 4. Scientific results

## 4.1 Effect of WURC for the scientists

Essentially WURC provided a great opportunity and very importantly the financial means for scientists and research groups working on different aspects of wood fibres in Sweden to unite and work together in a common forum. Before the Centre, research groups and scientists had contact and there was some cooperation but this was more on a sporadic level. For SLU scientists, the Centre provided totally new opportunities to collaborate particularly with STFI-PF and KTH and later other Universities on aspects of wood fibre ultrastructure. Similarly the Centre provided the opportunity to work and interact together with industry. Certainly for SLU scientists this was a completely new direction. One can not however over emphasize the importance of the financial possibilities the Centre provided giving long-term possibilities and security for positions within the University. The Swedish University system has very few tenure track positions for researchers and the finance for most positions must be secured partly, if not wholly from external sources; either from competitive grants (*i.e.* national/EU) or industry; much of it being on a short-term basis (*i.e.* 2-3 years/project). For senior scientists this can sometimes be extremely problematic. Thus WURC provided security for many persons for long periods of time. The consequences of such long-term financing became readily apparent towards the latter stages of the Centre when new avenues of finances needed to be sought, but at the same time there was a need to complete obligations for the work already financed by WURC.

### 4.1.1 Examinations and eventual employment of students

On completion of WURC June 2007, seventeen PhD, seven Licentiate and six Diploma theses originating from WURC´s activities (*i.e.* 11 year period) have been successfully defended (Tables 3-5 below). All the examinations have originated from students from the different Universities. Throughout the program great efforts were made to establish industrial PhD and Licentiate students. However this proved to be quite difficult. Important reasons included that candidates were not able to take time away from their daily industrial duties and also a general feeling of the possibility of loosing status within the company. Nevertheless during Phase 3 three WURC Licentiates were enrolled between StoraEnso-KTH (2) and StoraEnso-Karlstad University. These students are still working on their theses and are expected to finish during the latter part of 2008.

Thus in this case a total of 10 Licentiate theses will have been completed within entire WURC program. Of the 7 Licentiate students, 5 continued to PhD and 2 left to take up employment outside the Forest Industry fields. Of the 17 completed PhD students, 4 have employment in industries not related and one related to the Forest industries. Five have continued employment and research orientated towards the Forest Industries within Institutes in Sweden or Norway and the others have continued to research positions within the University system. Several (4) of the students have also carried out post-doctoral work abroad.

Working within the Centre has shown to be a good way of securing subsequent employment. One of the early ideas of the Centre was that it should provide a stepping stone for students to find employment in the Forest Industry following completion of their education. While there is little doubt that WURC Centre participation helped students to obtain valuable contacts for such a possibility as was conceived initially, the changes in the employment situation and general cut-backs and re-organizations within the Forest Industry –especially pulp and paper- meant that industry was employing far fewer persons. The continuation of students as researchers within the Forest Industries research environment at Universities and Institutes has nevertheless helped to secure and maintain networks within the industry. Employment after PhD within an Institute is very often the first step before entering into industry anyway. It is quite surprising however therefore that the pulping industry is expressing currently concern in that it is having problems in securing young talented workers.

| ***Name*** | ***Title of Thesis*** | ***Employer*** | ***Curr. Employ.*** |
|---|---|---|---|
| K. Wickholm<br>March 2001 | Structural elements in native celluloses | STFI-PF | STFI-PF |
| E-L. Hult<br>April 2001 | CP/MAS$^{13}$C-NMR Spectroscopy applied to structure and interaction studies on wood and pulp fibres. | STFI-PF | Japan/now PFI, Norway |
| **I. Duchesne**<br>Nov. 2001 | Electron microscopic and spectroscopic studies on the surface ultrastructure of kraft pulp fibres. | ***SLU*** | *Forintek, Canada* |
| **U. Molin**<br>March 2002 | Pulp strength properties – influence of carbohydrate composition, molar mass and crystalline structure | KTH | AGA, Stockholm |
| J. Brändström<br>Feb. 2002 | Morphology of Norway spruce tracheids with emphasis on cell wall organization | SLU | SLU, France, now VINNOVA |
| P. Väljamäe<br>Dec 2002 | The kinetics of cellulose enzymatic hydrolysis | UU | Univ. Latvia |
| H. Önnerud<br>May 2002 | On the structure of native softwood and hardwood lignins | KTH | AstraZenca |
| R. Berggren<br>April 2003 | Cellulose degradation in pulp fibers studied as changes in molar mass distributions | STFI-PF | STFI-PF |
| M. Åkerholm<br>Oct. 2003 | Ultrastructural aspects of pulp fibers as studied by dynamic FT-IR spectroscopy | STFI-PF | STFI-PF |
| P. Persson<br>April 2004 | Strategies for cellulose fiber modification | STFI-PF | Consulting Co |

| | | | |
|---|---|---|---|
| Lars Hilden Oct. 2004 | The characterization of wood and wood fibre ultrastructure using specific enzymes | SLU | SLU/Holmen |
| B. Durbeej Sept 2004. | Quantum chemical studies of protein-bound chromophores, UV-light induced DNA damages, and lignin formation | UU | *No curr. info. available* |
| J. Fahlén Febr. 2005 | The cell wall ultrastructure of wood fibres – effects of the chemical pulp fibre line | STFI-PF | Perstorp AB |
| Å. Kallas 2006 | Heterologous expression, characterization and applications of carbohydrate active enzymes and binding modules | KTH | Karolinska Institute |
| M. Christiernin June 2006 | Composition of lignin in outer cell-wall layers | KTH | AstraZeneca |
| R.C. Neagu Oct. 2006 | Hygroelastic behaviour of wood-fibre based materials on the composite, fibre and ultrastructural level. | KTH | EPFL, Lausanne, Switzerland |
| D. Fernando April 2007 | Ultrastructural characterization (morphological and topochemical) of wood pulp fibres; effects of mechanical and kraft processing | SLU | SLU |
| J. Stevanic *(In progress)* | Ultrastructure of the primary cell wall of softwood fibres during studies Using dynamic FT-IR spectroscopy | STFI-PF | |

***Table 4. PhD theses within the Centre***

| ***Name*** | ***Title of Thesis*** | ***Employer*** | ***Current Employer*** |
|---|---|---|---|
| A. Berglund Oct. 1999 | Morphological investigations of metal ions in spruce wood | CTH | Telecompany, Goteborg |
| I. Duchesne Nov. 1999 | Surface ultrastructure of Norway spruce kraft pulp fibres | SLU | *Cont. to PhD* |
| K. Nyholm May 2001 | Dislocations in wood and pulp fibres of Norway spruce | SLU | Biotech. Company, Uppsala |
| M. Åkerholm March 2001. | Dynamic FT-IR spectroscopy applied to studies on wood polymers | STFI-PF | *Cont. to PhD* |
| J. Fahlén Nov. 2001. | Ultrastructural arrangement of the polymers in the wood fiber wall | STFI-PF | *Cont. to PhD* |
| Å. Kallas March 2004. | Heterologous expression, characterization and applications of carbohydrate active enzymes and binding modules. | STFI-PF | *Cont. to PhD* |
| J. Stevanic Feb. 2008 | Ultrastructure of the primary Cell Wall of Softwood Fibres during Studies Using Dynamic FT-IR Spectroscopy | STFI-PF | *Cont. to PhD* |

*Ongoing: A. Moberg, StoraEnso/KTH; G. Wäne StoraEnso/Karlstad Univ. J. Stevanic continues to PhD at STFI-PF.*

***Table 5. Licentiate theses within the Centre***

| ***Name*** | ***Title of Diploma*** | ***Employer*** |
|---|---|---|
| E. Sjöblom 1999 | A comparative study between two-phase and single stage oxygen delignification using experimental design (MoDo/WURC) (Degree project in Chemical Engineering | Umeå Univ./MoDo/WURC |
| C. Östmark 1999 | Enzymer av *Trichoderma reesi* och dess påverkan på fluffmassa (Degree project in Chemical Engineering) (In Swedish) | Mälardalens Högskola Korsnäs/WURC |
| A. Gouget 2000 | Characterization of expression of PttXyn10, a putative xylan hydrolase from poplar wood-forming tissues | SLU, Umeå/WURC |
| J. Risén 2002 | ESCA analysis of soft- and hardwoods from the same bleaching sequences (Degree project in Chemical Engineering) | CTH/Eka/Södra/WURC |
| S. Eriksson 2004 | Prediction of wood content in bark with NIR spectroscopy (Degree project in Chemical Engineering) | Korsnas/Umeå Univ./WURC |
| H. Andersson & T. Thalib 2002 | Comparison of different methods for characterization of pulp fibre surfaces | CTH/Eka Chemicals, Södra, WURC |
| D. Wihlemsson 2006 | Finite element modelling of mechanical properties of geometrically characterized wood fibres. (Degree project) | KTH/WURC now Volvo, Gothenburg |

***Table 6. WURC Industry and University Diploma work within the Centre***

### 4.1.2 Publications and presentations

WURC´s scientific publications, symposium and conference presentations and internal reports from 1997-2007 are given in *Appendix 1*. The oral and poster presentations that have been given at WURC´s ten international seminars and interactive seminars provided by the Centre industry representatives and WURC scientists *on-site* or during the annual internal seminars are given in *Appendix 2*. Altogether, WURC scientists have produced over 300 scientific publications/ symposium presentations (oral/poster) at international and national conferences. This is in addition to all the presentations made at WURC´s own international seminars and its own internal report series *Appendix 2*). The publications highlight the wide variety of multilateral interactions that has occurred between the various groups and large number of projects that have occurred within the WURC program. Specifically, publications have basically been of four kinds: *i)* in peer reviewed journals; *ii)* Symposium presentations with proceedings; *iii)* Popular presentations in the media – this has been done by WURC´s management group to publicise WURC and VINNOVA´s Competence Centre Program as a whole; and *iv)* More technical internal reports on specific projects conducted together within industry. These technical reports (12 in all) were published in WURC´s own internal report series and were restricted to persons involved WURC´s projects and the supporting companies. In only a few cases over the entire Competence era were any publications/internal reports made in Swedish as it was a requirement by industry that English

should be used in order for them to circulate the information within the entire company which in some cases part was abroad. All the companies also received DVDs of WURC and its projects that were prepared for the international evaluations in 2001 and 2004. In addition, industry received six-monthly reports outlining the progress of the projects throughout the program. No patents were sought however within the WURC program (*see later*).

### 4.1.3 Training and academic-industry interactions within the Centre

Naturally these were very numerous at many levels and it is difficult to estimate their impact in quantitative terms. They however were the basis for providing the stimulus and opportunities for the multilateral interactions and cross-fertilization of ideas as well as new project ideas. Concrete examples nevertheless include: *i)* joint internal seminars (normally 2 per year); *ii)* WURC´s annual international seminars; *iii)* specific seminars out in industry, *iv)* industrial practice for PhD students; *v)* diploma work in industry; *vi)* six monthly reports of project work to the companies; and the teaching of specific techniques to industrial R & D persons. This is in addition to the publications. Numerous examples of joint publications from the research work between academia and industry have also been published in peer refereed journals (*Appendix 1*) in addition to the technical reports.

Within the Centre, the obligatory internal seminars –*located either at SLU, Arlanda or at Industry during spring and autumn*- in particular provided an excellent way for bringing scientists together from both industry and academia. As the Centre had a number of geographically spread industrial and academic partners, these two day workshops provided an excellent forum for cementing interactions between all member parties not only industry - academia but also between the different project groups. It also provided the forum for discussing projects in detail as well as providing information within the Centre on the different project developments. This gave great *added value* to the program. Different approaches were tried ranging from *normal project reviews* to more interactive seminars. At some seminars, specific guest speakers were also invited. WURC internal seminars were not restricted for its member companies and normally the companies sent additional scientists than those actually involved in the project work. The seminars grew in size and during phase 3 at the height of the Centre, meetings of *ca* 50 persons were normal. The spring seminars (usually March/April) were also attended by the international advisory board after its formation in 1998 allowing these persons to also interact with the Centre activities.

## 4.2. Effect of WURC for SLU

### 4.2.1 Effect of WURC activities within the University system - SLU

There is little doubt that WURC brought together a great academic and industrial competence in the wood fibre pulp and paper related areas to SLU. This still remains true today and even though a number of additional Centres with new applications and orientations of wood fibres have been established (*see later under future possibilities*), none of these Centres have taken over WURC´s niche, but rather they compliment WURC´s research orientation. WURC was further successfully involved in its latter phases within joint applications for establishment of the Centre for *"Bioengineering of Wood Materials"* (KTH, SLU, CTH) (Wallenberg supported; 2006-2008) and the FORMAS Centre of Excellence *"Funcfiber"* (www.funcfiber.se) (SLU, UmU, KTH; 2006-2011). With the Bioengineering Centre WURC was able to obtain important financing for new equipment to be used in the Funcfiber Centre and in the new WURC project financed from the VINNOVA-BFP program.

Within SLU, the Centre despite not having employment rights was treated very much like a Department with its own economy set up and ID etc. In addition it was privy to much of the same

information as Departments. Possibly this status was achieved by nature of the Director and Centre Board being appointed by the Rector in agreement with the contract.

### 4.2.2 Impact on the research infrastructure within SLU and Department of Wood Science

WURC allowed the development of a national and internationally known Centre of excellence on *Wood fibre ultrastructure* to be developed at SLU linking for the first time the nanostructure of wood fibres to final products encompassing both fundamental and technically motivated research on one of Sweden's most important natural resource, the wood fibre. The WURC Centre was unique within SLU regarding its cross-disciplinary approach linking several Universities and Departments, strong dependence/interactions with the Swedish pulp and paper companies and nature of financing. Furthermore, WURC was the only Centre under the first generation of NUTEK/VINNOVA Competence Centre program that was specifically orientated towards the pulp and paper industry, not only within SLU. More recently the Berzelius Centre at SLU/UmU has been established in the second generation of VINNOVA Centres although it does not encompass WURC´s niche. Currently there are no other large projects within SLU´s forest faculty linking wood fibres and the pulp and paper industry. Within the Forest Faculty, WURC complemented the genetic, physiological and molecular biology research performed at the Umeå Plant Science Centre (SLU/UmU), as well as the more traditional types of research within the Faculty (*e.g.* silviculture) providing a further dimension and potential that did not exist before.

WURC´s initiation in 1996 allowed for the establishment of the Department of Wood Sciences within the Faculty and provided *financial incentives* for the development of close ties and cooperation particularly with STFI-PF and KTH; an interaction that will now continue under the next WURC program under the VINNOVA-BFP program. Without WURC, it is unlikely that the Department of Wood Science would ever have been established, thus emphasizing the important nature of the Centre and its financial stimulus. The equipment sponsored by WURC or obtained -*via its research*- at the Department has also been utilized in many other projects at the University campus in addition to those in WURC´s portfolio further emphasizing a core asset for the University as a whole. At the end of 2006 the Departments of Wood Science and Forest Products and Markets in the Forest Faculty and located at Ultuna were amalgamated. The amalgamation while affording a greater *total* critical mass includes 5 major research areas (*i.e.* Wood Science, Forest Economy, Wood Products, Forest Policy, Silviculture) will not however provide any greater focus or resources on wood fibre research.

Throughout its four phases, WURC has received support and help from the Forest Faculty and SLU´s rectors. This has been reflected not only through already established *"in-kind"* help, but also through economic support in positions to match the industrial partners and VINNOVA under the contract. As outlined above, SLU´s financial contributions have dominated the program reflecting the earlier commitment of the Forest Faculty and SLU to WURC.

An aspect of considerable importance concerns the fundamental nature of the WURC Centre. WURC has had a more widespread geographical distribution than other Centres in the VINNOVA program that had a more devoted one University emphasis. In this respect, WURC probably would have had an even greater impact on the infrastructure at SLU if this had been the situation. However in contrast, WURC has had a much greater impact on multilateral collaborations with the other Universities and STFI-PF than would have been expected if the Centre had been solely localized at SLU.

### 4.2.3 Impact of WURC on education

WURC has not been formally involved as a unit in the education of undergraduate or post-graduate students within SLU. WURC scientists at SLU Uppsala and Umeå have nevertheless organized undergraduate and PhD courses on *Wood biology* involving fibre ultrastructure and processing during phases 3, 4. The Department of Wood Science initiated in 2004 and now hosts annually an international PhD course including aspects from WURC´s research on wood-fibre ultrastructure. It should be noted that within the Forest Faculty the *in-take* of undergraduates and the majority of post-graduate courses are held at SLU Umeå and the possibilities for WURC to break into teaching have been limited. It should be noted however, that all scientists participating from the Universities within WURC have normally as part of their employment profile a commitment to teaching at their respective Departments in both undergraduate and post-graduate (national and international) courses**.**

*Despite WURC´s success, SLU was unable to continue financing the Centre after its completion summer 2007.*

## 5. Effect of WURC activities for the companies

### 5.1 Some general aspects and reflections

Seven companies from the pulp and paper, forestry and chemical industries supported WURC during its initiation and early phases and via various mergers and separations, 9 companies including those from the beginning and two new companies (Holmen, Kappa Kraftliner (now Smurfit Kraftliner) were active in supporting the Centre in its final phases. These companies vary from large international conglomerates to small-medium sized companies and can be seen as representative of the majority of the pulp and paper companies in Sweden. No companies have withdrawn from WURC during its lifetime. WURC´s industrial partners contributed significantly to the early establishment and development of WURC during its *ca* 11 year existence. During the establishment of WURC, the chairman (Håkan Jöves, Korsnäs, 1995/6) was from industry and the Director (Brita Swan, Stora Enso, 1996-1999) during phase 1 and the vice-director during phases 3/4 (Lars Ödberg, Sveaskog, 2001-) were all from industry.

The effects of WURC for the individual companies have as expected varied considerably over the life of the Centre and also have differed between companies. These effects are naturally very difficult to measure in quantitative terms but rather should be seen more in terms of *added benefits*. Specifically, experience showed within WURC that the greater the industry involvement/commitment in the Centre activities the greater was the *added value*. This was to some extent also reflected in the different industry comments to the importance and benefits of WURC during the international evaluations.

*In hindsight; is there a recipe and how positive effects be achieved/guaranteed* ?

Experience through the competence centre era showed that in general terms the best effects were achieved when company personnel were very active to participate in the actual collaboration and particularly within individual projects. This would seem obvious but nevertheless was a focal point of importance for success. In retrospect, great credit should therefore be given to NUTEK for their “requirement” for “active” participation of industry in projects in the form of “registered natural contributions from the companies”. This single, but obligatory requirement ensured that industry/university had to find ways of working together in order for WURC´s program to be acceptable to NUTEK. Prior to the beginning of WURC, it was not obvious however, how this could be achieved since both the way of working was new for the Forest Industries and also the program was primarily orientated towards basic research and thus differed significantly from all

other Centres within the Competence Centre program. On reflection however this requirement did not turn out to be a problem, but rather acted as a stimulus !

For successful industry/University collaboration, the following factors were apparent: *i)* Company management (*i.e.* board) and other personal working with the centre should have a vested interest in the work and Centre outcomes as well as its success; *ii)* Company personal should be encouraged by their respective organizations to participate and the necessary time needed allocated –*it should not be seen as extra work involving time that is not compensated at home that can give rise for the lack of interest for industrial Licentiates and PhD students; iii)* Emphasis should be on designing suitable interactive Centre-Company projects with distinct milestones rather than just silent and general industry participation as a whole; *iv)* Interesting and important results (new information/approaches, techniques, know how) (*very important for companies that are reducing research personal*) for participants to *show off* at the company level thereby strengthening the bond and commitment of the company in the Centre; *v)* Mobility exchanges through students working out in industry (*i.e.* industrial practice); *vi)* Continuous information spreading through six monthly reports, internal seminars, project meetings etc; and *vii)* Access for company personal to University courses and facilities as well as possibilities for individual tuition on new techniques.

**5.2 Ways of working with industry within the Centre**

During the program the industrial partners were actively involved at all levels within the Centre. This included the involvement in influential strategic decisions of WURC´s Board and Industrial Advisory Group to the involvement in project proposals and research work, supply of fibre materials and provision of industrial practice for students.

Specific examples of company involvement in the Centre´s activities include:

*1) Involvement in applied projects during phases 2-4:*

- During phases 2-4 project leaders from industry led joint industry-University projects including: *Strength Delivery* (K. Sjöström, Södra), *Pulp Refining and beating* (A. Moberg, StoraEnso), *Mechanical pulping of pine* (E. Persson, Holmen/P Sandström, SCA) and the *Pulp 2000* project (B. Swan/G. Söderstam/B. Mao StoraEnso). Each project had an established project group including persons from the different companies plus University/Institute personal reflecting both industry-industry and industry-University interactions from the project formulation, development and the carrying out of actual work;
- Companies were also directly involved in specific projects of both industrial and more academic character; *e.g.* dislocations in fibres (M-real), molecular modelling of bleaching processes (Eka Chemicals); post-harvest discolouration of stored lumber (Holmen); pitch problems (Kappa Kraftliner);
- WURC established a major project group of industrial and University personal including PhD students on mechanical pulping of pine and spruce (phases 3, 4).

*2) Examples of the provision of specialized raw materials for WURC projects included:*

- Representative spruce wood samples and pulps for experimental purposes in the different projects; (*e.g.* fibre modelling);
- Provision during phases 1, 2 of unbleached and bleached kraft pulps produced by a cooperative company effort. This included all stages from tree selection, felling, chipping, cooking, bleaching, paper characterization etc and provided unique experimental material subsequently used in the majority of the WURC projects. WURC scientists carried out an interactive project to characterize these special pulps that was completed in phase 3. The

project was the basis for several international publications and popular articles by scientists as well as an internal WURC report for industry;
- Specialized and well characterized mechanical pulps of pine and spruce from pilot trials at Metso were produced during phases 3, 4;
- Provision of specialized pulps for enzymatic and molecular characterization of fibre surfaces;
- Provision of specialized pulps aimed at improved utilization of the inherent strength properties of fibre materials;
- Provision of experimental facilities for studies on fibre damage related to dislocations and other fibre anomalies;
- Provision of specialized mechanical pulp samples;
- Provision of round wood samples for studies on wood discolouration;
- Provision of pulp samples for studies on metal distribution;
- Experimental facilities made available for WURC scientists to conduct work out in industry.

*3) Educational:*
- Reviews written on the industrial implications and recommendations of research work (*Brita Swan*, previous WURC director/StoraEnso) following the completion of PhD and Licientiate projects concerning changes in the chemistry, morphology and physical properties of fibres during kraft pulping. This provided member companies with important details on how WURC´s research findings could be interpreted from an industrial perspective;
- Provision of industrial Licentiates;
- Provision for industrial practice for PhD students *on-site* (sometimes abroad);
- Organization of study trips by industry for PhD students and scientists;
- Involvement in the supervision of diploma studies at the company sites;
- Organization of WURC internal seminars and project seminar *on-site* in industry;
- Industry has also been involved in WURC´s internal seminars presenting results of their *on-going* research etc as well as giving advice to WURC´s researchers;
- WURC scientists have instructed industrial colleagues with specialized techniques to be used *on-site*.

The above interactions expanded considerably during the latter phases of WURC with the broad and integrated projects bringing together close ties between the industry and University.

**5.3 Commercialization, technology transfer and patents**

WURC´s primary focus has been on fundamental research on wood fibre ultrastructure research that the member companies were interested, but unable to conduct themselves. Thus, WURC´s research should be *recognized in a broad and long-term perspective at present and not in commercialization*. It was explicitly stated at the beginning of WURC that the Centre should provide fundamental knowledge on fibre structure and ultrastructure while the companies themselves would perform subsequent product development. *Application for patents from the Centre´s research has therefore never been a priority.* Similarly, the Centre did not contribute to any *start-up* companies. Nevertheless WURC had legistration (*i.e. forskareavtal*) in place in the event of possible patenting and commercialization. All scientists receiving financing from WURC signed an official agreement that the research conducted under WURC´s mantle was own by the Centre and that member companies had the first right of exploration. To this end all scientific papers produced by WURC scientists intended for publication were vetted by members of the Industrial Advisory Board who had the right to delay submission for six months should they consider the information of commercial interest and/or relevant for patenting. As indicated earlier, no patents were sought within the WURC program. In hindsight, this was possibly one of the greatest mistakes (as recognized after) made within the Centre in that at least University scientists

did not/or felt they could not further developed their own findings and seek their own patents. In this respect, some loss in stimulation no doubt occurred particularly with the more senior staff involved.

**5.4 Particular success stories**

WURC´s focus has been primarily on pre-competitive fundamental research. Therefore the success of WURC can not be given as *Success Stories* in terms of *new products* but rather the very significant advances in useful understanding of fibre ultrastructure that has been generated (*Appendix 1; scientific output*). WURC can be regarded as a focused effort on fibre ultrastructure research with strong industry involvement and thus in itself be regarded as a *Success Story*.

Particular examples together with industry that we regard as *"success stories"* include:

- In general an improved knowledge on the changes (*e.g.* chemical, morphological, physical, microstructural, nanostructural) that take place during spruce kraft pulping. The information obtained here has lead to *new ways of thinking* regarding this process and the events taking place;
- *Pulp 2000* project completed in 2003; This project involved most WURC´s member partners collaborating to produce unique and highly characterized bleached pulps that were used by the University/Institute WURC scientists in an array of different projects. The pulps were industrially characterized by the member companies and characterized using more sophisticated tools of WURC´s *toolbox*. The project lead to increased cooperation between SLU and STFI-PF, joint international and internal publications and a much greater insight on how fibre ultrastructure can influence mechanical and physical properties of final products;
- *Strength Delivery* project. Here, the majority of WURC´s member companies were involved with a specific aim to determine reasons for the loss in strength of pulp fibres along the industrial process chain during cooking, washing and bleaching etc. Strength loss leads to impaired and non-optimal final products and economic loss. Member companies supplied unique fibre materials and the project produced some unexpected results. From the project work, a novel method was developed for the quantitative determination of fibre damage along the process chain that was subsequently tested for industrial usage;
- *Mechanical pulping of pine and spruce.* Attention was given to the reasons why pine wood requires considerable more energy and therefore costs much more during refining of thermomechanical pulps than spruce. Pilot plant trials were conducted by industry and specific studies carried out using WURC´s *toolbox*. Important reasons for the difference in energy costs between the two softwood species were found associated with variations in the ultrastructure of the fibre cell walls providing important clues for how improvements could be attained.

The significance of the results in the industrial projects within WURC can not be over emphasized and the projects represent a basis for new projects in the area in the new VINNOVA-BFP finance program of WURC 2008-2011.

**5.5 WURC´s impact on its industrial partners; their own comments**

Prior to the international evaluations of WURC in 2001 and 2004, the member companies were asked concerning their expectations and benefits from the Centre. Prior to the 2001 the consensus was:

- Access to up to date scientific knowledge on wood fibre ultrastructure;

- The possibility together with representatives from other companies and scientists from University/Institutes to influence the orientation of research within an important commercial field;
- Possibility to interact with academia and further develop contacts with University;
- Opportunity to create and develop new ideas on wood fibres;
- A possibility to solve specific industrial problems on fibres by new approaches;
- Through cooperation between participants in the Centre at many levels and fronts, an improved general impression and awareness is created in the companies regarding the importance for their products of fibre ultrastructure;
- Opportunity to interact with the international scientific community on aspects of wood fibre ultrastructure;
- The establishment of a platform for recruitment of personnel with industry relevant research education.

*Prior to the 2004 international evaluation the main interests (and to some extent expectations) of the companies for WURC were:*

- To obtain a more in-depth knowledge of wood and fibre ultrastructure, that will stimulate and contribute to the further development of their industrial processes and products leading to an improved utilization of wood fibre. Example: Higher selectivity in the kraft chemical process may be realized by a better knowledge of wood fibre cell wall ultrastructure and the influence of the different events and chemical processes on wood fibre structure.
- Obtain knowledge from ultrastructure that can provide important clues for savings in energy during the mechanical pulping process and as well as the optimal use of pine as a raw material in this process;
- To have available a cooperating leading research body within the field of wood ultrastructure which can be both consulted and conduct contract work;
- To improve interaction with academic research and facilitate greater contact between industry and academia;
- To increase the companies own competence by involving its own staff in WURC research and by allowing WURC personnel to work in their industries.

*For phase 4 (i.e. final phase) of WURC and for its future, the industry partners had the following expectations:*

- WURC must represent and maintain a clear competence profile in the Swedish research infrastructure as well as retain a sufficient critical mass for its research;
- WURC should further develop its international status;
- Continue its main theme of fundamental research on wood fibre ultrastructure;
- Perform a reduced number of carefully selected industrially orientated projects;
- Transfer of knowledge from academia to industry should develop via direct participation of industry personnel in WURC projects; and
- WURC scientists should write a *"State of the art/gaps in our knowledge"* report on wood fibre ultrastructure outlining important breakthroughs and their potential implications for the pulp and paper industry regarding process changes and use of the information in product development.

*WURC´s competence profile should further be developed via:*

- Continued generation of new knowledge on wood fibre ultrastructure through application of the most recently available techniques;
- Further recruitment of post-doctoral scientists in order to increase research efficiency;
- Further develop its international and national networks and increase the number of visits to member companies;
- Coordinate research with other research groups in Sweden;
- Integrate further the project portfolio and the interactions between the unique set of competences existing in WURC.

The expectations of WURC by the companies increased through its duration but the companies had a full understanding that fundamental knowledge on wood fibre ultrastructure was extremely important if not imperative for any eventual improvement in pulping processes and paper products. The need for an international basis for the research of the Centre was also fundamental in their thinking. Nevertheless, the importance of orientating the research more *down-stream* towards products and processes (*i.e.* in an eventual industry financing of any new WURC) was emphasized and formed the basis for the subsequent project application within the VINNOVA-BFP program. It should also be realized that since the initiation of WURC in 1996, considerable changes have occurred within the Pulp and Paper Industries in Sweden. The climate has hardened and there have been considerable cut-backs in R & D at the company level and thus research collaboration with Universities *down-stream* nearer to product generation and modifications are likely to intensify rather than be reduced in the future.

# 6. Future possibilities for WURC

## 6.1 International perspective

WURC has represented a unique niche in the Swedish research competence spectrum and is still one of the few bridges between forestry research and the industrial utilisation of wood. A number of other Centres have also been established during the later phases of WURC including *BiMAC* (KTH), *BiMAC Innovation* (KTH), *BioMIME* (KTH) and *Funcfiber* (SLU, UmU, KTH), *Bioengineering of Materials* (KTH, SLU, CTH). None of these Centres have research focussed within WURC´s special field of interest. Instead partition of competence has inspired collaboration. Besides the close research cooperation, WURC´s research serves as an important link to industry for *Funcfiber* and *Bioengineering of Fibre Materials* Centres. It is clear that the field where WURC is working is rapidly expanding in USA, Japan and some countries in Europe. This indicates its importance and that the field is not sufficiently researched and exploited. In its later phases, WURC represented a world-leading competence base, but strong investments were needed for Sweden to keep this position. To date, Work Programmes in FP 7 have not provided many possibilities for WURC-oriented research and this is not likely to change very much although the Forest-based Sector Technology Platform (FTP) is trying to influence the situation. WURC participated in a proposal addressing plant cell walls in the first call for proposals under FP7. However, this proposal was not selected.

On the European level, WURC managed COST Action E20 (Wood fibre cell wall structure, 2000-2004) and is participated in several follow-up actions including COST E50 and E54. However, such participation builds on national funding. A (continued) ERA Net on forest-based materials science is very probable (opening in next FP7 NMP call). This could fit WURC, but again participation builds on national funding.

WURC has provided the basis for future University and industrial development in the further refinement of processes and products. Over the *ca* 11 year period that WURC has existed countless contacts and fruitful collaborations have been initiated at many levels not only between scientists at the member Universities (SLU, KTH, STFI-PF, Örebro, Karlstad, CTH) but also between the industrial partners themselves. This has provided a strong impetus for seeking further finance to maintain the organisation after the Competence Centre era so as to preserve WURC in the future. WURC´s member companies and scientists all considered that the Centre had been an outstanding success in an area that badly needed base knowledge. It was also firmly agreed that without the WURC Centre, the majority of the research and collaborations would never have been carried out. This is particularly so for SLU that before WURC had little research on pulp and paper and collaboration with the Swedish industries involved in fibre processing. Similarly, WURC has provided the possibility for new constellations between SLU scientists and those at STFI-PF and KTH. The major issue was however, how WURC could not only be preserved in the future but also be able to flourish with likely decrease financial possibilities. All these issues were discussed at various levels within WURC´s organization including the Board, the Industrial Advisory Group and leading scientists. In particular, a working group was formed (VD, Director, vice director) and the process initiated as early as late spring 2005. Against the background given above, WURC´s board and Industrial Advisory Group expressed a strong interest for a continuation of fibre ultrastructural research.

The consensus of opinion was that WURC must establish a new orientation since industry had already indicated that any new WURC must be further *down-stream* and that the tools developed should be utilized for improving processes and products. At the start of WURC, research in the field of fibre ultrastructure was insignificantly developed. In the initial phases, WURC was mainly conducting fundamental research and with chemical pulps as *testbeds*. Gradually, applied projects have been introduced and even industry led. In the last two phases, WURC also conducted research on mechanical pulp fibres.

At the end of 2005, the board therefore initiated a process for developing a strategic research program for the years to come. This planning was done with the aim to develop two separate but strongly interacting programmes:

- An **applied program** where ideas for solution from researchers would meet industrial needs and tackle unsolved industrial questions of high relevance;
- A **fundamental (base) program** moving the knowledge front forward and also providing a continued basis for applied projects.

### 6.2 Financing model for the future

The total future program of WURC should include both applied and fundamental projects, although it was realised that it was unlikely that only one funding agency could give money for both directions. A sufficient financing of a continued and supporting fundamental program (Figure 3) was judged (also by industry) as necessary. Such financing will be sought from sources including SLU´s forest faculty money, EU-FP7, FORMAS and foundations.

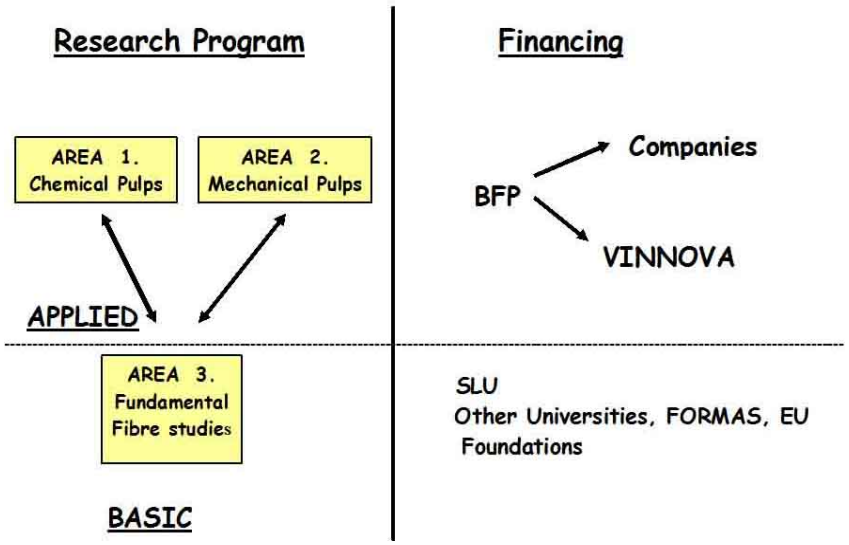


***Figure 3. Future structure of total WURC***

An important feature of the new program is that participating companies have the possibility to allocate a major part of their financial input to the projects they find most important. Thus, WURC´s member companies were invited to give their views on the most industrially relevant issues for the application of new knowledge on fibre ultrastructure. The inputs were discussed in detail during two industrial advisory group meetings; and a synopsis of priorities made. In parallel, WURC senior scientists were invited to contribute to a "*gaps in knowledge document*". In order to discuss this in detail and create an overall synthesis, a meeting including WURC´s senior scientists, industry representatives, WURC`s chairman and managerial group members was organised. This resulted in a project portfolio that was then used in further discussions with companies and eventually lead to a proposal to the VINNOVA *"Branschforskningsprogram"* (BFP) called *"Process and product developments through unique knowledge of wood fibre ultrastructure"* The *"Branschforskningsprogram" program* was introduced in order to further research of an applied nature within the Swedish pulp and paper an other forest industries.

In this process a set of *knowledge gap*s on the ultrastructural level were identified including:

- Surface properties: variations in hemicelluloses, surface aggregation and spatial distribution – chemistry and morphology (topochemical);
- Fibre defects (dislocations) and 3D structure – cellulose I and II;
- Internal fibril aggregation/de-aggregation and pore structure in fibres;
- Internal delamination and surface fibrillation under mechanical action;
- Cell wall structure – cellulose/hemicellulose and lignin supermolecular 3D structure;
- Effect of fibre microfibril angle and raw material – $S_1$, $S_2$ layers;
- Water interactions with pore structures;
- Influence of supermolecular structure and ultrastructure on mechanisms of fibre fragmentation in relation to temperature and softening of cell wall components;
- Influence of extractives and lignin on fibre development;
- Influence of cellulose degradation (molecular weight) and lignin carbohydrate complexes on fibre collapsability.

The priorities were sorted under three research areas namely:

***- Chemical fibres (applied);***

***- Mechanical fibres (applied);***
***- Supporting fundamental research on fibre ultrastructure.***

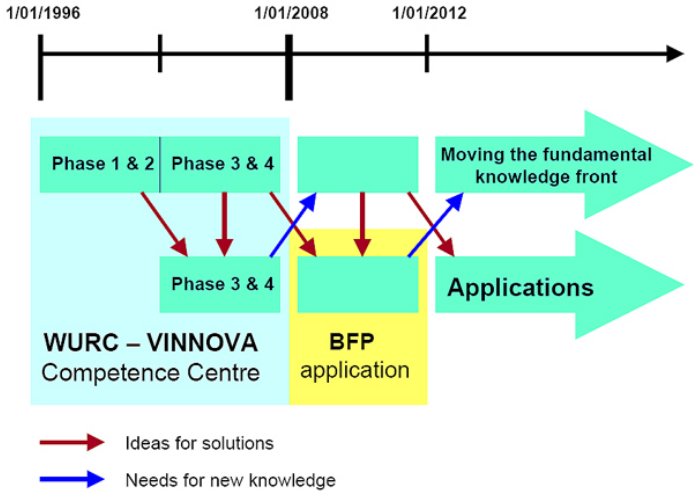


***Figure 4. Illustrates the interactions (in the past and in the future) within the WURC structure between the building of new knowledge and its use in applications***

**6.3 A new consortium and organization**

On the basis of the above structure outlined in Figure 4 the following companies indicated that they would participate in the new program: Eka Chemical, Holmen, SCA, SmurfitKappa, StoraEnso, Södra Cell. Additional discussions were also made with a couple other companies. The participating research organisations are SLU (host), KTH, Mid Sweden University and STFI-PF.

The program will be headed by a director (Geoffrey Daniel) and the organization will have much of the same structure built and successful during the WURC Competence Centre era with an Industrial Advisory Group, project leaders and project groups composed of senior scientists, company representatives and other researchers engaged in the work.

In the early stage of developing the new program WURC was also in contact with FORMAS several times regarding financing possibilities. Additional efforts have also been made to SLU Forest Faculty for TEMA-research monies for a project entitled WURC–Innovation that would also be tied to the VINNOVA-BFP project. During 2008 the research possibilities for the project was further strengthened at SLU by the installation of advanced microscopy (cryo-transmission electron microscope TEM) and ancillary preparation equipment (donation from the Knut and Alice Wallenberg Foundation).

**6.4 A future horisont**

***There is little doubt that the knowledge-base developed within WURC has widespread applications not only within the pulp and the paper industry but within the forestry industry as a whole. For example, an increased knowledge of wood fibre ultrastructure and its components still represents the basis for improved biofuels and energy production (e.g. how to optimize component/cellulose/hemicellulose removal), major energy savings during fibre refining for mechanical and chemical pulps, the development of improved genetic clones – genotype/phenotypes- for increased raw material production and no less for the establishment of new bio(nano)composites in future materials. We still have very much to learn and those that finally unravel the knowledge on the exact nanostructure of wood fibre cell walls will allow for a new green revolution and basis for sustainability.***

## 7. Acknowledgements

The WURC competence centre has provided "*a one in a life-time"* opportunity for people to come together from wildly different disciplines and work very successfully on one of natures most remarkable engineering feats the *wood fibre* ! I would like to extend my sincere thanks to all of you who have been involved over the years from the very initiation of the program, all the students, supervisors, visiting scientists, staff within the University, the member company scientists, project leaders, company managers and of course the supervisors (*Staffan Hjorth, Susanne Andersson*) from NUTEK and VINNOVA. Very special thanks to all the company representatives on the board and those within our very active Industrial Advisory Group. Many thanks are also given to our International Advisory board members Malcolm, Bernard and Keiji!. Finally the financial support –*whether in cash or in-kind* - provided by NUTEK, VINNOVA, SLU, STFI-PF, KTH, CTH, UU, Karlstad's and Örebro Universities and the member companies: Eka Chemicals, Holmen, Korsnäs, M-real, SCA, StoraEnso, Södra, SveaSkog, SmurfitKappa is gratefully acknowledged.

# *Appendix 1.*

## *Scientific Output:*

## *Publications, Symposia Presentations, Proceedings etc*

# *Scientific output:*

## *Conference presentations and publications 1997-2007*

(*Presentations at WURC-Industry interactive seminars and International Seminars are given in Appendix 2)*

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Sjöström, K., R. Berggren, P. Ander, G. Daniel, L. Salmén, J. Hornatowska, F. Thuvander. 2004. Strength delivery. Changes in fiber properties and morphological organization during industrial processing. Internal report nr 8. WURC, SLU, Inst f. Trävetenskap, Uppsala. (Limited dissemination).

Marklund, A. 2007. The effect of chip compression on softwood kraft pulp quality. Internal report nr 9. WURC, SLU, Inst f. Skogens Produkter, Uppsala. (Limited dissemination).

Sjöström, K., L. Salmén, P. Ander, G. Daniel, A. Marklund, P. Sandström, A. Bergmark, G. Wäne, A. Heijnesson-Hultén H. Tufvesson. 2007. Strength delivery – Part 2 Changes in fiber properties and morphological organization during industrial processing. Internal report nr 10. WURC, SLU, Inst f. Skogens Produkter, Uppsala.

Ander, P., S. Bardage, D. Fernando, J. Hafrén, G. Daniel, L-Å Hammar, Ö. Hedenberg, J. Hornatowska, L. Salmén. 2007. Mechanical Pulps II Differencies between *Pinus sylvestris*, *Pinus contorta* and *Picea abies* for mechanical pulp: Changes in fiber properties and morphological organization during industrial processing. Internal report nr 11. WURC, SLU, Inst f. Skogens Produkter, Uppsala.

Sandström, P., K. Wilhelmsson, M. Paulsson, J. Gustafsson, O. Ferritius, E. Persson, J. Brändström, G. Daniel. 2007. Differencies between *Pinus sylvstris*, *Pinus contorta* and *Picea abies* as raw material in mechanical pulping. Internal report nr 12. WURC, SLU, Inst f. Skogens Produkter, Uppsala.

## ***Project conference presentations and peer reviewed publications***

## ***Phase 1 – 2: 1997 – 31 Dec. 2001; Phase 3: 1 January 2002 – 31 Dec. 2004; Phase 4: 1 January 2005 – 30 June 2007.***

### ***Project 1, Phase 1-2: 1997 – 2001***

| | |
|---|---|
| **Author** | Bardage, S.L. 2000. |
| **Title of paper** | Three-dimensional visualisation of wood fibres: 3D modelling. |
| **Journal/conference** | Proc. Workshop Fibre Wall & Microfibril Angle, COST Action E20 Wood Fibre Cell Wall Structure, 11-13 May, 2000, Athens, Greece. Printed by NTUA, Athens, and MC/WG of COST Action E20, p. 20. |
| **Author** | Nilsson, T. 2000. |
| **Title of paper** | Microfibril angle in spruce wood. |
| **Journal/conference** | IAWS conference. Reading, U.K., July 2000 |
| **Author** | Bardage, S.L. 2001. |
| **Title of paper** | Three-dimensional modeling and visualization of whole Norway spruce latewood tracheids. |
| **Journal/conference** | Wood and Fibre Science 33(4): 627-638 |
| **Author** | Bergander, A., J. Brändström, G. Daniel & L. Salmén. 2000. |
| **Title of paper** | Fibril angle variability in earlywood of Norway spruce using soft rot cavities and polarization confocal microscopy. |
| **Journal/conference** | J. Wood Science, 48(4): 255-263. |

| | |
|---|---|
| **Author** | Singh, A.P. & G. Daniel. 2001. |
| **Title of paper** | The S2 layer in the tracheid walls of *Picea abies*: inhomogeneity in lignin distribution and cell wall microstructure. |
| **Journal/conference** | Holzforschung 55(4) 373-378. |

| | |
|---|---|
| **Author** | Brändström, J. 2001. |
| **Title of paper** | Micro- and ultrastructural aspects of Norway spruce tracheids: A review. |
| **Journal/conference** | IAWA J, 22(4): 333-353 |

***<u>Project 1</u>, Phase 3: 2002 - 2004***

| | |
|---|---|
| **Author** | Bardage, S.L., G. Daniel & A. Singh. 2002. |
| **Title of paper** | Collapse behaviour of kraft cooked Norway spruce fibers. |
| **Journal/Conference** | Proc. Workshop Cell Wall and Stress, COST Action E20 Wood Fibre Cell Wall Structure, 30th May – 1st June, Reims, France, p. L15 (Lecture). |

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|---|---|
| **Author** | Brändström, J., G. Daniel & T. Nilsson. 2002. |
| **Title of paper** | Use of soft rot cavities to determine microfibril angles in wood; advantages, disadvantages and possibilities. |
| **Journal/conference** | Holzforschung 56(5): 468-472. |

| | |
|---|---|
| **Author** | Bardage, S. L., G. Daniel & A. Singh. 2002. |
| **Title of paper** | Three-dimensional analysis of the collapse behavior of Kraft cooked Norway spruce fibers. |
| **Journal/conference** | Wood and Fibre Science 34(4): 382-390. |

| | |
|---|---|
| **Author** | Brändström, J., S.L. Bardage, G. Daniel & T. Nilsson, T. 2003. |
| **Title of paper** | The structural organization of the S1 wall layer of Norway spruce tracheid. |
| **Journal/conference** | IAWA Journal 24(2): 27-40. |

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|---|---|
| **Author** | Bardage, S.L., L. Donaldson, C. Tokoh & G. Daniel. 2003. |
| **Title of paper** | Application of high resolution electron microscopy and image analysis for characterising pulp fibre surfaces. |
| **Journal/conference** | Proc. Workshop Building a Cell Wall, COST Action E20 Wood Fibre Cell Wall Structure, September 4-6, 2003, Helsinki, Finland (Lecture). |

| | |
|---|---|
| **Author** | Bardage, S.L. & G. Daniel. 2004. |
| **Title of paper** | Three-dimensional morphological aspects of wood and pulp fibres |
| **Journal/conference** | COST Action E20 "Wood Fibre Cell Walls: Methods to Study Their Formation, Structure and Properties". Eds.: U. Schmitt, P. Ander, J. Barnett, A.M. Emons, G. Jeronimidis, P. Saranpää and S. Stanzl-Tschegg. Swedish University of Agricultural Sciences, Uppsala, Sweden. ISBN 91-576-6803-5, p. 217-230. |

| | |
|---|---|
| **Author** | Bardage, S.L., L. Donaldson, C. Tokoh & G. Daniel. 2004. |
| **Title of paper** | Ultrastructure of the cell wall of unbeaten Norway spruce pulp fibre surfaces. |
| **Journal/conference** | Nordic Pulp Paper Res. J. 19: 448-452. |

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|---|---|
| **Author** | Mayr, S., S. Bardage & J. Brändström. 2005. |
| **Title of paper** | Hydraulic and anatomical properties of light bands in Norway spruce compression wood. |
| **Journal/conference** | Tree Physiology 26, 17-23. |

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|---|---|
| **Author** | Donaldson, L., S. Bardage & G. Daniel. 2007 |
| **Title of paper** | Three-dimensional imaging of a saw surface: a comparison of confocal microscopy, and light microscopy combined with serial sectioning. |
| **Journal/conference** | Wood Science & Technology vol DOI 10. 1007/s00226-007-0132-y 132-226 |

| | |
|---|---|
| **Author** | Wilhelmsson, D., R.C. Neagu & S. Bardage. 2006. |
| **Title of paper** | Finite element modeling of mechanical properties of geometrically characterized wood fibres. |
| **Journal/conference** | Proc. 5th Plant Biomechanics Conf., Stockholm, August 28-September 1, 2006. p. 181-186. |

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|---|---|
| **Author** | Gamstedt, E.K., S.L. Bardage, & R.C. Neagu. 2006. |
| **Title of paper** | Hygroelastic behaviour of compression wood tracheids based on analytical composite mechanics. |
| **Journal/conference** | COST Action E50, Cell Wall Macromolecules and Reaction Wood (CEMARE). Warsaw Agricultural University, October 19-21, 2006. |

| | |
|---|---|
| **Author** | Chun, Y., S.L. Bardage, & A. Vilenius. 2007. |
| **Title of paper** | Determination of the microfibril angle of wood fibres using spectroscopic transmission ellipsometry. |
| **Journal/conference** | 14th ISWFPC, Durban, South Africa, 25-28 June 2007. |

***<u>Project 2</u>, Phase 1-2: 1997 – 2001***

| | |
|---|---|
| **Author** | Daniel, G. 1997. |
| **Title of paper** | Use of HR-Cryo-FE-SEM for studies on wood and pulp fibre ultrastructure. |
| **Journal/conference** | International Cryo-Electron Microscopical Meeting, York, UK, June 1997. |

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|---|---|
| **Author** | Daniel, G. 1997. |
| **Title of paper** | Studies on wood and pulp fibre ultrastructure using HR-Cryo-FE-SEM. |
| **Journal/conference** | Proc. Tappi Biological Sciences Symposium, San Francisco, USA, p. 447. |

| | |
|---|---|
| **Author** | Awano, T., K. Takabe, M. Fujita & G. Daniel. 1998. |
| **Title of paper** | Immuno-FE-SEM reveals distribution of xylan in beech. |
| **Journal/conference** | 49th Annual meeting of the Japanese Wood Research Society, April 1998. |

| | |
|---|---|
| **Author** | Daniel, G. & I. Duchesne. 1998. |
| **Title of paper** | Revealing the surface ultrastructure of spruce fibres using Field Emission SEM. |
| **Journal/conference** | 7th Int. Conf. Biotechnology Pulp Paper Industry, Vancouver BC, June, 1998, pp 81-84. |

| | |
|---|---|
| **Author** | Daniel, G., K. Takabe, & I. Duchesne. 1999. |
| **Title of paper** | Visualization of the Surface Ultrastructure of Spruce Pulp Fibres Using Field Emission-SEM and TEM-Replica Techniques. |
| **Journal/conference** | In "Microscopy as a Tool in Pulp and Paper Research and Development, June 21-22, STFI, Stockholm, p. 18-27. |

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|---|---|
| **Author** | Daniel, G., 1999. |
| **Title of paper** | Processing samples for light and electron microscopy. |
| **Journal/conference** | In "Microscopy as a tool in the pulp and paper industry - Workshop on sample preparation" (EC Fair -98-3681), KCL, Espoo, Finland, 28-29/10 1999, p. 1-31. |

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|---|---|
| **Author** | Duchesne, I. & G. Daniel. 1999. |
| **Title of paper** | The ultrastructure of wood fibre surfaces as shown by a variety of microscopical methods. |
| **Journal/conference** | In "Microscopy as a tool in Pulp and Paper Research and Development" (EC Fair -98-3681), STFI, Stockholm, June 21-22, 1999. |

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|---|---|
| **Author** | Duchesne, I. & G. Daniel. 1999. |
| **Title of paper** | The ultrastructure of wood fibre surfaces as shown by a variety of microscopical methods - a review. |
| **Journal/conference** | Nordic Pulp Paper Res. J. 14: 129-139. |

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|---|---|
| **Author** | Duchesne, I. & G. Daniel. 1999. |
| **Title of paper** | Changes in spruce fibre surface ultrastructure during kraft pulping – A Field Emission SEM study. |
| **Journal/conference** | In "Microscopy as a tool in the pulp and paper industry - Workshop on sample preparation", (EC Fair -98-3681). KCL, Espoo, Finland, 28-29/10-1999, p. 165 |

| | |
|---|---|
| **Author** | Awano, T., K. Takabe, M. Fujita & G. Daniel. 2000. |
| **Title of paper** | Deposition and localization of glucuronoxylans in the secondary cell wall of Japanese beech as observed using immuno FE-SEM. |
| **Journal/conference** | Protoplasma, 212: 72-79. |
| **Author** | Duchesne, I. & G. Daniel. 2000. |
| **Title of paper** | Changes in surface ultrastructure of Norway spruce fibres during kraft pulping – Visualization by Field-Emission-SEM. |
| **Journal/conference** | Nordic Pulp Paper Res J. 15: 54-61. |
| **Author** | Duchesne, I., E.-L. Hult, U. Molin, G. Daniel, T. Iversen & H. Lennholm. 2001. |
| **Title of paper** | The influence of hemicellulose on fibril aggregation of kraft pulp fibres as revealed by FE-SEM and CP/MAS $^{13}$C-NMR. |
| **Journal/conference** | Cellulose 8: 103-111. |
| **Author** | Daniel, G., U. Molin, I. Duchesne & S. Bardage. 2001. |
| **Title of paper** | Ultrastructural (FE-SEM, TEM) observations on PFI refined novel spruce kraft pulp fibres of varying molecular weight. |
| **Journal/conference** | 8th Int. Conf. Biotechnology Pulp Paper Industry, June 4-8, 2001, Helsinki, Finland, PII/92, p 253-254. (Poster). |
| **Author** | Daniel, G., J. Volc, & M-L. Niku-Paavola. 2001. |
| **Title of paper** | TEM immunocytochemical and HR-Cryo FE-SEM studies on white rot decay of lignocellulose. |
| **Journal/conference** | 8th Int. Conf. Biotechnology Pulp Paper Industry, June 4-8, 2001, Helsinki, Finland, O4/17, p 42 - 43. |
| **Author** | Duchesne, I., G.C. van Leerdam, G. Daniel & J. Basta. 2001. |
| **Title of paper** | Characterisation of pulp fibre surfaces using X-ray photoelectron spectroscopy and field emission-scanning electron microscopy. |
| **Journal/conference** | Proc. Workshop on advanced methods for lignocellulosics and paper products characterisation. June 18-19, Grenoble, France. |
| **Author** | van Leerdam, G.C., J. Basta, I. Duchesne & G. Daniel. 2001. |
| **Title of paper** | The use of micro-analytical techniques for the characterization of pulp. |
| **Journal/conference** | 9th European conference on applications of surface and interface analysis, 30 September - 5 October 2001, Avignon, France. |
| **Author** | Daniel, G. 2001. |
| **Title of paper** | FE-SEM and TEM methods in the pulp and paper industry. “Microscopy as a Tool in Pulp and Paper Research and Development”: synthesis of future problems and needs of microscopy in pulp and paper. |
| **Journal/conference** | Concerted Action FAIR 98-3681, 26-28 September 2000, UCM Madrid, Spain. |
| **Author** | Molin, U. & G. Daniel. 2001. |
| **Title of paper** | Changes in cell wall structure during refining of pulps with different molecular weights. |
| **Journal/conference** | Proc. "Research Techniques for Tomorrow’s Papermaking" Characterization Methods for Fibres and Paper. COST Action E11, Hanansaar, Finland. |
| **Author** | Singh, A.P. & G. Daniel. 2001. |
| **Title of paper** | The S2 layer in the tracheid walls of *Picea abies*: inhomogeneity in lignin distribution and cell wall microstructure. |
| **Journal/conference** | Holzforschung 55: 373-378. |

***Project 2, Phase 3: 2002 - 2004***

| | |
|---|---|
| **Author** | Singh, A., G. Daniel & T. Nilsson. 2002. |
| **Title of paper** | Ultrastructure of the S2 layer in relation to lignin distribution in *Pinus radiata* tracheids. |
| **Journal/conference** | J. Wood Science 48(2), 95-98. |

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|---|---|
| **Author** | Singh, A., G. Daniel & T. Nilsson. 2002. |
| **Title of paper** | High variability in the thickness of the S3 layer in *Pinus radiata* tracheids. |
| **Journal/conference** | Holzforschung 56, 111-116 |

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|---|---|
| **Author** | Duchesne, I., K. Takabe, & G. Daniel. 2003. |
| **Title of paper** | Ultrastructural localization of glucomannan in kraft pulp fibres. |
| **Journal/conference** | Holzforschung 57(1), 62-68. |

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|---|---|
| **Author** | Duchesne, I., G. Daniel, G.C. van Leerdam & J. Basta. 2003 |
| **Title of paper** | Surface chemical composition and morphology of ITC kraft fibres as determined by XPS and FE-SEM. |
| **Journal/conference** | J. Pulp Paper Sci. 29 (3): 71-76 MAR 2003. |

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|---|---|
| **Author** | Daniel, G. 2003. |
| **Title of paper** | Microview of wood under degradation by bacteria and fungi. |
| **Journal/conference** | In: Wood Deterioration and Preservation.: Advances in our changing world. (Eds B. Goodell, D.D. Nicholas, T.P. Schultz). ACS Symp. Ser. 845, Washington DC, pp. 34-72. (peer reviewed). |

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|---|---|
| **Author** | Daniel, G. 2003 |
| **Title of paper** | Fibre micro- and nanostructure. |
| **Journal/conference** | Biofibre-research towards products. Conference 27 March 2003, STFI, Stockholm. |

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|---|---|
| **Author** | Daniel, G. 2003. |
| **Title of paper** | Cellulose aggregates an integral part of pulp fibre structure. |
| **Journal/conference** | Proc. Workshop Building a Cell Wall, COST Action E20 Wood Fibre Cell Wall Structure, September 4-6, 2003, Helsinki, Finland (Lecture). |

| | |
|---|---|
| **Author** | Thygesen, A., A.B. Thomsen, H. Lilholt & G. Daniel. 2003. |
| **Title of paper** | Microscopical and cytochemical observation on hemp stems with emphasis on fibers. |
| **Journal/conference** | Proc. Workshop Building a Cell Wall, COST Action E20 Wood Fibre Cell Wall Structure, September 4-6, 2003, Helsinki, Finland (Poster prize). |

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|---|---|
| **Author** | Daniel, G., I. Duchesne, C. Tokoh & S. Bardage. 2004. |
| **Title of paper** | The surface and intracellular nanostructure of wood fibre fibres: Electron microscope methods and applications. |
| **Journal/conference** | COST Action E20, "Wood Fibre Cell Walls: Methods to study their formation, structure and properties". Eds.: Schmitt, U., P. Ander, J.R. Barnett, A.M.C. Emons, G. Jeronimidis, P. Saranpää & S. Tschegg. Swedish University of Agricultural Sciences, Uppsala, Sweden. ISBN 91-576-6803-5. p. 87-104. |

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|---|---|
| **Author** | Molin, U. & G. Daniel. 2004. |
| **Title of paper** | Effects of refining on the fibre structure of kraft pulps as revealed by FE-SEM and TEM: Influence of alkaline degradation. |
| **Journal/conference** | Holzforschung 58:3, 226-232. |

| | |
|---|---|
| **Author** | Daniel, G., J. Volc & M-L. Niku-Pavola. 2004. |
| **Title of paper** | Cryo-FE-Sem & TEM Immuno-Techniques reveal new details for understanding white rot decay of lignocellulose. |
| **Journal/conference** | Comptes Rendus 327, 861-871. |

***Project 2, Phase 4: 2005-2007***

| | |
|---|---|
| **Author** | Thygesen, A., G. Daniel, H. Lilholt & A.B. Thomsen. 2005. |
| **Title of paper** | Hemp fibre microstructure and fungal defibration used to obtain fibres useful as reinforcement of composite materials. |
| **Journal/conference** | J. Natural Fibers 2:4, 19-37. |
| **Author** | Daniel, G. & L. Ödberg 2005 |
| **Title of paper** | Fibern avslöjad. |
| **Journal/conference** | SPCI/Svensk Papperstidning nr 5, 2005. |
| **Author** | Daniel, G. 2005. |
| **Title of paper** | Wood and pulp fibre research at the Wood Ultrastructure Research Centre (WURC), Uppsala, Sweden. |
| **Journal/conference** | Int. Symp. Wood Science & Technology (IAWPS), Yokohama, Japan, November 27-30, p. 241. |
| **Author** | Thygesen A., Thomsen, A.B., Daniel G., Lilholt H. 2006 |
| **Title of paper** | Comparison of composites made from fungal defibrated hemp with composites of traditional hemp yarn. |
| **Journal/conference** | Industrial crops and products 10, 45-55. |
| **Author** | Thygesen A., Daniel G., Lilholt H., Thomsen A.B. 2006. |
| **Title of paper** | Hemp fiber microstructure and use of fungal defibration to obtain fibres for composite material. |
| **Journal/conference** | J. of Natural Fibers 2:4, 19-37. |
| **Author** | Daniel G. 2006. |
| **Title of paper** | WURC's impact on our understanding of wood fibre nanostructure. |
| **Journal/conference** | Proc. 5th Plant Biomechanics Conference, Stockholm, Sweden, August 28-September 1, 2006. ISBN 91-86018-12-4, p. 129-138. |
| **Author** | Thygesen A., A. B. Thomsen, G. Daniel & H. Lilholt 2006. |
| **Title of paper** | Comparison of hemp fibres with glass fibres for windpower composite density. |
| **Journal/conference** | Proc. 27th Risø Int. Symp. on Material Science; Polymer Composites for Power Turbines, Roskilde, Denmark, September 4-7, 2006, p. 329-336. |
| **Author** | Goodell B., X. Xie , Y. Qian, G. Daniel, M Peterson, & J. Jellison J. 2008. |
| **Title of paper** | Carbon nanotubes produced from natural cellulosic materials |
| **Journal/conference** | J. Nanoscience and Nanotechnology, 8 (5) 1-3. |

***<u>Project 3</u>, Phase 1-2: 1997 – 2001***

| | |
|---|---|
| **Author** | Ander, P., K. Grabner, G. Kandioller, E. Srebotnik, K. Poppius-Levlin, S. Semar, H. Anke, M.-L. Niku-Paavola, L. Viikari & K. Messner. 1998. |
| **Title of paper** | The in vitro $^{14}$C-labelled kraft pulp assay as used for evaluation of laccases and mediators intended for pulp bleaching. |
| **Journal/conference** | 7th Int. Conf. Biotechnology Pulp Paper Industry, Vancouver BC, June 1998, Vol. A, pp A111-A115. Lecture. |
| **Author** | Ander, P., K. Grabner & K. Messner. 1999. |
| **Title of paper** | Coupling of phenols to lignin in pulp fibres and potential of the fibre product. |
| **Journal/conference** | Natural Fibres Performance Forum. Royal Vet. & Agric. University, Copenhagen, Denmark, 27-28 May 1999. Poster. |
| **Author** | Nyholm, K. & P. Ander. 1999. |
| **Title of paper** | Dislocations in wood fibres. |
| **Journal/conference** | SPCI´ 99 June 1-4, Stockholm. Poster. |

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|---|---|
| **Author** | Nyholm, K. & P. Ander. 1999. |
| **Title of paper** | Dislocations in wood fibres. |
| **Journal/conference** | Skogskonferensen "Trädets variationsrikedom - problem och möjligheter", SLU, Uppsala, 30 November-1 Dec. 1999. Poster. |

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|---|---|
| **Author** | Nyholm, K. & P. Ander. 2000. |
| **Title of paper** | Dislocations in wood fibres. |
| **Journal/conference** | Proc. Workshop Fibre Wall & Microfibril Angle. COST Action E20 Wood Fibre Cell Wall Structure, 11-13 May, 2000, Athens, Greece. Printed by NTUA, Athens, Greece and MC/WG of COST Action E20, p. 58. Poster. |

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| **Author** | Ander, P. & K. Nyholm. 2000. |
| **Title of paper** | Deformations in wood and spruce pulp fibres: Their importance for wood and pulp properties. |
| **Journal/conference** | Proc. Int. Symp. on Wood Machining, Properties of wood and wood composites related to wood machining. 27-29 September, Vienna, Austria, p. 3-19, ISBN 3-9501315-0-7. |

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|---|---|
| **Author** | Ander, P. & K. Nyholm. 2001. |
| **Title of paper** | The effect of cellulases, hemicellulases and laccase/HBT on spruce pulp fibre deformations. |
| **Journal/conference** | Proc. 8th Int. Conf. Biotechnol. Pulp Paper Ind., June 4-8, 2001, Helsinki, Finland, O6/33, p.71-73. |

| | |
|---|---|
| **Author** | Nyholm, K. & P. Ander. 2001. |
| **Title of paper** | The connection between spruce pulp fibre dislocations and balloon swelling. |
| **Journal/conference** | Proc. 8th Int. Conf. Biotechnol. Pulp Paper Ind., June 4-8, 2001, Helsinki, Finland, PI/5, p. 95. (Poster). |

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|---|---|
| **Author** | Nyholm, K., P. Ander, S. Bardage, & G. Daniel. 2001. |
| **Title of paper** | Dislocations in pulp fibres - their origin, characteristics and importance - a review. |
| **Journal/conference** | Nordic Pulp Paper Res. J. 16: 4. |

***<u>Project 3</u>, Phase 3: 2002 – 2004***

| | |
|---|---|
| **Author** | Ander, P. 2002. |
| **Title of paper** | Dislocations and balloon swelling in spruce pulp fibres – Effect of cellulases, xylanase and lacase/HTB. |
| **Journal/conference** | Progress in Biotechnology 21, Biotechnology in the Pulp and Paper Industry: 8th ICBPPI. Eds: L. Viikari and R. Lantto, Elsevier Science B.V., pp. 49-59. ISBN 0-444-5107. |

| | |
|---|---|
| **Author** | Ander, P. 2002. |
| **Title of paper** | Dislocations, polarized light colour patterns and acid cleavage of spruce pulp fibres. |
| **Journal/conference** | Proc. Workshop Cell Wall and Stress. COST Action E20 Wood Fibre Cell Wall Structure, 30 May-1 June, 2002, INRA, Reims, France. Printed by INRA and MC/WG of COST Action E20, p. P24 (Poster). |

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|---|---|
| **Author** | Ander, P. 2003. |
| **Title of paper** | Project 3: Dislocations in wood fibres |
| **Journal/conference** | Poster at COST Action E20 Workshop Building a Cell Wall, Helsinki 4-6 September 2003. |

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|---|---|
| **Author** | Ander, P., I. Burgert, & K. Frühmann. 2003 *and* 2004. |
| **Title of paper** | The possible relationship between dislocations and mechanical properties of different spuce fibres: A single fibre study. |
| **Journal/conference** | Poster & Proc. from Second Int. Conf. Europ. Soc. Wood Mechanics, Stockholm, Sweden, May 25th-28th , 2003, and at COST Action E20 Workshop Building a Cell Wall, Helsinki 4-6 September 2003. Proc. published 2004 by STFI-Packforsk AB. Ed: L. Salmén, pp. 63-66. ISBN 91-86018-10-8. |

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|---|---|
| **Author** | Terziev, N., G. Daniel & A. Marklund.2004. |
| **Title of paper** | Effect of dislocations in Norway spruce fibres on the mechanical properties of paper. |
| **Journal/conference** | Proc. Second Int. Conf. Europ. Soc. Wood Mechanics, Stockholm, Sweden, May 25th-28th , 2003. Proc. published 2004 by STFI-Packforsk AB. Ed: L. Salmén, pp. 351-356. ISBN 91-86018-10-8. |

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| **Author** | Schmitt, U., P. Ander, J. Barnett, A.M. Emons, G. Jeronimidis, P. Saranpää, and S. Stanzl-Tschegg. 2004. |
| **Title of book** | COST Action E20 "Wood Fibre Cell Walls: Methods to Study their Formation, Structure and Properties". Printed by Swedish University of Agricultural Sciences, Uppsala, Sweden. ISBN 91-576- 6803-5, pp. 308 |

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|---|---|
| **Author** | Ander, P. & G. Daniel. 2004. |
| **Title of paper** | Morphology of spruce fibre dislocations as studied by balloon swelling and acid cleavage – light and electron microscope observations. |
| **Journal/conference** | COST Action E20 "Wood Fibre Cell Walls: Methods to Study their Formation, Structure and Properties". Eds.: U. Schmitt, P. Ander, J. Barnett, A.M. Emons, G. Jeronimidis, P. Saranpää, and S. Stanzl-Tschegg. Swedish University of Agricultural Sciences, Uppsala, Sweden. ISBN 91-576-6803-5, p. 203-215. |

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|---|---|
| **Author** | Ander, P. & G. Daniel. 2004. |
| **Title of paper** | Effects of HCl, Cellulase and Sulphuric Acid on Dislocations in Wood and Wood Fibres. |
| **Journal/conference** | Proc. 2nd Int. Symp. Wood Machining Properties of Wood and Wood Composites Related to Wood Machining. July 5-7, 2004, Vienna, Austria. Eds: S.E. Stanzl-Tschegg, M. Gindl, G. Sinn. BOKU, University of Natural Resources and Applied Life Sciences, Vienna, pp. 247-254. ISBN 3-9501315-2-3. (Oral presentation). |

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| **Author** | Ander, P. & G. Daniel. 2004. |
| **Title of paper** | A novel method to compare industrial and laboratory pulp fibres using hydrogen chloride and FibreMaster analyses. |
| **Journal/conference** | Proc. 8th European Workshop on Lignocellulosics and Pulp. August 22-25, 2004, Riga/Latvia. (Oral presentation). |

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| **Author:** | Ander, P. & G. Daniel. 2004. |
| **Title of paper** | Characterization and Comparison of Industrial and Laboratory Pulp Fibres using HCl, Cellulase and Fibermaster Analaysis. |
| **Journal/conference** | Proc. 9th Int. Conf. Biotechnol. Pulp Paper Ind. 10-14 October 2004, Durban, South Africa. O13.4. |

***Project 3, Phase 4: 2005-2007***

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| **Author** | Terziev, N., G. Daniel & A. Marklund. 2005. |
| **Title of paper** | Dislocations in Norway spruce fibres and their effect on properties of pulp and paper. |
| **Journal/conference** | Holzforschung 59, 163-169. |

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| **Author** | Thygesen, L.G. & P. Ander. 2005. |
| **Title of paper** | Quantification of dislocations in spruce pulp and hemp fibres using polarized light microscopy and image analysis. |
| **Journal/conference** | Nordic Pulp and Paper Res. J. 20(1), 64-71. |

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| **Author** | Ander, P., G. Daniel, C. Garcia-Lindgren & A. Marklund. 2005. |
| **Title of paper** | Characterization of industrial and laboratory pulp fibres using HCl, Cellulase and FibreMaster analyses. |
| **Journal/conference** | Nordic Pulp and Paper Res. J. 20(1), 115-120. |

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| **Author** | Ander, P., & G. Daniel. 2005. |
| **Title of paper** | Comparison of spruce fibre cleavage using HCl and cellulase. |
| **Journal/conference** | Proc. COST Action E23 " Biotechnology for pulp and paper industry" Conf. "Biotechnology for Pulp and Paper Manufacture: From Tailor-Made Biocatalysts to Mill Application", Baiona (Pontevedra, Spain), 26-29 April 2005, p. 101-104. |
| **Author** | Ander, P., & G. Daniel. 2005. |
| **Title of paper** | Abstract: "Effect of HCl and dislocations on properties of spruce pulp fibres"; Poster: " The HCl-method for determination of dislocations and spruce pulp fibres". |
| **Journal/conference** | COST Action E50 "Cell wall macromolecules and reaction wood", LMGC, Montpellier, France, 3-4 November 2005. |
| **Author** | Ander, P., & G. Daniel. 2006. |
| **Title of paper** | Dislocation counting and comparison of pulp fibre properties after HCl-treatment and fibre length determination. |
| **Journal/conference** | Proc. 5th Plant Biomechanics Conference, Stockholm, Sweden, August 28-September 1, 2006. ISBN 91-86018-12-4, p. 169-174. |
| **Author** | Ander, P., & G. Daniel. 2006. |
| **Title of paper** | Recent developments in fibre testing with the HCl-method. |
| **Journal/conference** | COST Action E50 "Cell wall macromolecules and reaction wood", Warsaw 19-21 October 2006. |
| **Author** | Ander, P., & G. Daniel. 2007. |
| **Title of paper** | Pulp fibre testing with the HCl-method and comparison with cellulase activity and phosphoric acid swelling. |
| **Journal/conference** | COST Action E54 "Characterisation of the fine structure and properties of papermaking fibres using new technologies". April 25-27, 2007. Riga, Latvia. |
| **Author** | Ander, P., Hildén, L. & G. Daniel. 2007. |
| **Title of paper** | Differencies in Cleavage of Softwood Kraft Pulp Fibres by HCl and Cellulases as Determined by Fibre Length Measurements, Sugar Analyses, Polarized Light and Scanning Electron Microscopy. |
| **Journal/conference** | Proc. 10th Int. Congress Biotechnol. Pulp Paper Industry, Madison, Wisconsin, USA, June 10-15, 2007, p. 71-73. Poster. |
| **Author** | Ander, P. & G. Daniel. 2007. |
| **Title of paper** | Degradation of softwood pulp fibres by HCl and Cellulases reflects different action on the fibre cell walls. |
| **Journal/conference** | Proc. COST Action E50 CEMARE, Workshop "Structure and function of primary and secondary cell walls", Max-Planck-Institute, Potsdam, Berlin, September 26-28. Poster. |
| **Author** | Ander, P. & G. Daniel. 2007. |
| **Title of paper** | Degradation of softwood pulp fibres by HCl and Cellulases reflects different action on cellulose and hemicelluloses. |
| **Journal/conference** | The Third Workshop on Cellulose, Regenerated Cellulose and Cellulose Derivatives. Karlstad University, Karlstad, November 13-14, 2007, p.36-40. Poster. |
| **Author** | Ander, P., Hildén, L., & G. Daniel. 2008. |
| **Title of paper** | Cleavage of softwood kraft pulp fibres by HCl and Cellulases. |
| **Journal/conference** | Bioresources 3(2), 477-490. |
| **Author** | Eder, M., Terziev, N., Daniel, G., & I. Burgert. 2008. |
| **Title of paper** | The effect of (induced) dislocations on the tensile properties of individual Norway spruce fibres. |
| **Journal/conference** | Holzforschung 62, 77-81. |
| **Author** | Terziev, N., Daniel, G. & A. Marklund. 2008. |
| **Title of paper** | Effect of abnormal fibres on the mechanical properties of paper made from Norway spruce, *Picea abies* (L.) Karst. |
| **Journal/conference** | Holzforschung 62, 149-153. |

***Project 4, Phase 1-2: 1997 - 2001***

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| **Author** | Larsson, P.T., K. Wickholm & T. Iversen. 1999. |
| **Title of paper** | Structural elements in cellulose I. |
| **Journal/conference** | 10th ISWPC, Yokohama, Japan, June 7-10, 1999, Vol. 1, 602-606 |
| **Author** | Iversen, T., E.-L. Hult, P.T. Larsson & K. Wickholm. 2000. |
| **Title of paper** | CP/MAS 13C NMR spectroscopy applied to structure studies on cellulose I. |
| **Journal/conference** | 219th ACS National Meeting, San Francisco, CA (2000) CELL 145. |
| **Author** | Wickholm, K., E.-L. Hult, P.T. Larsson & T. Iversen. 2000. |
| **Title of paper** | Quantification of cellulose forms in complex cellulose materials. |
| **Journal/conference** | Proc. 6th European Workshop on Lignocellulosics and Pulp (EWLP), Bourdeaux, France, September 3-6, 2000, p. 19-22. |
| **Author** | Hult, E-L., P.T. Larsson & T. Iversen. 2000. |
| **Title of paper** | A comparative CP/MAS 13C-NMR study of cellulose structure in spruce wood and kraft pulp. |
| **Journal/conference** | Cellulose 7 (1): 35-55. |
| **Author** | Hult, E-L., P.T. Larsson & T. Iversen. 2000. |
| **Title of paper** | Determination of the supermolecular structure of polysaccharides in unbleached sulphite pulps by CP/MAS $^{13}$C-NMR. |
| **Journal/conference** | Holzforschung 56: 179-184. |
| **Author** | Duchesne, I., E.-L. Hult, U. Molin, G. Daniel, T. Iversen & H. Lennholm. 2001. |
| **Title of paper** | The influence of hemicellulose on fibril aggregation of kraft pulp fibres as revealed by FE-SEM and CP/MAS $^{13}$C-NMR |
| **Journal/conference** | Cellulose 8: 103-111. |
| **Author** | Wickholm, K., E-L. Hult, P.T. Larsson & T. Iversen. T. 2001. |
| **Title of paper** | Quantification of cellulose forms in complex cellulose materials: A chemometric model. |
| **Journal/conference** | Cellulose 8:139-148. |
| **Author** | Hult, E.-L. 2001. |
| **Title of paper** | Ultrastructure of wood and pulp fibers. |
| **Journal/conference** | Ekmandagarna, SPCI, 5-7 January, 2001, Stockholm, Sweden |
| **Author** | Hult, E.-L., T. Iversen, P.T. Larsson & K. Wickholm. 2001. |
| **Title of paper** | CP/MAS $^{13}$C NMR spectroscopy applied to structure and interaction studies on cellulose. |
| **Journal/conference** | EUROCARB XI, Lisboa, Portugal. |
| **Author** | Hult, E-L., P. T. Larsson & T. Iversen. 2001. |
| **Title of paper** | A study of supermolecular changes in the cellulose and hemicellulose structure during kraft pulping. |
| **Journal/conference** | Nordic Pulp Paper Res. J. 16 (1): 46-52. |
| **Author** | Hult, E-L., T. Larsson & T. Iversen. 2001. |
| **Title of paper** | Cellulose fibril aggregation – An inherent property of kraft pulps. |
| **Journal/conference** | Polymer 42 (8): 3309-3314. |
| **Author** | Hult, E.-L., T. Liitiä, S.L. Maunu, B. Hortling & T. Iversen. 2001. |
| **Title of paper** | A CP/MAS $^{13}$C NMR study of cellulose structure on the surface of refined kraft pulp fibers. |
| **Journal/conference** | Carbohydr. Polym. 49: 231-234. |

***<u>Project 5</u>, Phase 1-2: 1997 – 2001***

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| **Author** | Molin, U. 1999. |
| **Title of paper** | Hemicellulosa/cellulosa och styrka. |
| **Journal/conference** | Ekmandagarna, SPCI, 19-20 January, 1999, Stockholm, Sweden |

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| **Author** | Molin, U, & H. Lennholm. 2000. |
| **Title of paper** | The influence of molecular weight on mechanical properties of pulp fibres. |
| **Journal/conference** | Proc. 54th Appita Annual Conf., Vol. 2, 615-621. |

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| **Author** | Berggren, R., Molin, U., Berthold, F. & Lennholm, H. 2001. |
| **Title of paper** | Alkalisk nedbrytning av cellulosa i björk och gran. Är tid och alkalihalt utbytbara? |
| **Journal/conference** | Ekmandagarna, SPCI, 5-7 February, Stockholm, Sweden |

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| **Author** | Daniel, G., U. Molin, I. Duchesne & S. Bardage. 2001. |
| **Title of paper** | Ultrastructural (FE-SEM, TEM) observations on PFI refined novel spruce kraft pulp fibres of varying molecular weight. |
| **Journal/conference** | Proc. 8th Int. Conf. Biotchnol. Pulp Paper Industry, June 4-8, 2001. Helsinki, Finland, p. 253-254. |

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| **Author** | Molin, U. & H. Lennholm. 2001. |
| **Title of Paper** | The influence of alkaline degradation on mechanical properties of pulp fibres. |
| **Journal/conference** | APPITA J. 54(6): 540-546. |

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| **Author** | Duchesne, I., E.-L. Hult, U. Molin, G. Daniel, T. Iversen & H. Lennholm. 2001. |
| **Title of paper** | The influence of hemicellulose on fibril aggregation of kraft pulp fibres as revealed by FE-SEM and CP/MAS $^{13}$C-NMR. |
| **Journal/conference** | Cellulose 8**:** 103-111 |

***<u>Project 5</u>, Phase 3: 2002 – 2004***

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| **Author** | Molin, U. & A. Teder. 2002. |
| **Title of paper** | Importance of cellulose/hemicellulose-ratio for pulp strength |
| **Journal/conference** | Nordic Pulp Paper Res. J. 17(1): 14-19. |

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| **Author** | Berggren, R., U. Molin, F. Berthold, H. Lennholm & M. Lindström. 2003. |
| **Title of paper** | Alkaline degradation – influence of degradation conditions on molecular mass distributions and fibre strength. |
| **Journal/conference** | Carbohydrate Polymers 51:3, 255-264 |

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| **Author** | Molin, U., M. Hallberg, H. Lennholm & M. Lindström. 2002. |
| **Title of paper** | Mercerization of spruce kraft pulps – The effect on cellulose II content, refining and mechanical properties. |
| **Journal/conference** | Manuscript. (Paper VI in thesis). |

***<u>Projects No 6 & 13</u>, Phase 1-2: 1997-2001 & <u>Project No 25</u>, Phase 3: 2002-2004***

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| **Author** | Berglund, A., H. Brelid & R. Simonson. 1999. |
| **Title of paper** | Spatial distribution and chemical attachments of metal ions in spruce wood. |
| **Journal/conference** | Proc. 10th Int. Symp. Wood Pulping Chemistry (ISWPC), Yokohama, Japan, 7-10 June, 1999, Vol. 1, p. 90-94. |

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| **Author** | Berglund, A., H. Brelid, A. Rindby & P. Engström. 1999. |
| **Title of paper** | Spatial distribution of metal ions in spruce wood by synchrotron radiation microbeam X-ray Fluorescence Analysis. |
| **Journal/conference** | Holzforschung 53: 474-480. |

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| **Author** | Berglund, A., H. Brelid, A. Rindby & P. Engström. 2000. |
| **Title of paper** | Spatial distribution and chemical attachments of metal ions in spruce wood. |
| **Journal/conference** | J. Pulp Paper Science 26: 352-357. |

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| **Author:** | Brelid, H., K. Nåhem & A. Sundén. 2001. |
| **Title of paper** | The behaviour of Ca and Mn in spruce wood chips during kraft pulping. |
| **Journal/conference** | 11th Int. Symp. Wood Pulping Chemistry, Nice, France, June 11-14, 2001, Oral 7.3. |

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| **Author:** | Brelid, H., A. Rindby & L. Vincze. 2003. |
| **Title of paper** | Analysis of the redistribution of metal ions in softwood kraft pulp |
| **Journal/conference** | 12th Int. Symp. Wood Pulping Chem., Madison, WI, USA, June 9-12, 2003. Vol. I, p. 135-1 |

***<u>Project 7</u>, Phase 1-2: 1997-2001 & Phase 3: 2002-2004.***

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| **Author** | Önnerud, H., M. Palmblad, T. Eriksson & G. Gellerstedt. 1999. |
| **Title of paper** | Analysis of the native lignin structure using FT-ICR-MS |
| **Journal/conference** | 10th Int. Symp. Wood Pulping Chemistry, Yokohama, Japan (1999), Vol. I: 166-171. |

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| **Author** | Önnerud, H. & G. Gellerstedt. 2001. |
| **Title of paper** | Inhomogeneities in the chemical structure of spruce lignin. |
| **Journal/conference** | 11th Int. Symp. Wood Pulping Chemistry, Nice, France (2001), Vol. (Oral 5.2). |

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| **Author:** | Önnerud, H., M. Palmblad & G. Gellerstedt. 2003. |
| **Title of paper** | Investigation of lignin oligmers using electrospray ionisation mass spectrometry. |
| **Journal/conference** | Holzforschung 57, 37-43. |

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| **Author:** | Önnerud, H. & G. Gellerstedt. 2003. |
| **Title of paper** | Inhomogeneities in the chemical structure of spruce lignin. |
| **Journal/conference** | Holzforschung 57, 165-170. |

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| **Author:** | Önnerud, H. & G. Gellerstedt. 2003. |
| **Title of paper** | Inhomogeneities in the chemical structure of hardwood lignins. |
| **Journal/conference** | Holzforschung 57, 255-265. |

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| **Author:** | Önnerud, H. 2003 |
| **Title of paper** | Lignin structures in normal and compression wood. Evaluation by thioacidolysis using ethanethiol and methanethiol. |
| **Journal/conference** | Holzforschung 57, 377-384. |

***<u>Project 8</u>, Phase 1-2: 1997 – 2001***

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| **Author** | Vickes, M. 1999. |
| **Title of paper** | Tvådimensionell FT-IR korrelationsspektroskopi, exempel på samverkan mellan cellulosa och hemicellulosa studerad med denna teknik. |
| **Journal/conference** | Poster at Svenska Kemistsamfundets Analysdagar, Uppsala 14-17 maj 1999. |

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| **Author** | Hinterstoisser, B. & L. Salmén. 1999. |
| **Title of paper** | Two-dimensional step-scan FTIR: A tool to unravel the OH-valency range of cellulose. |
| **Journal/conference** | Cellulose 6: 251-263 |

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| **Author:** | Åkerholm, M. & L. Salmén. 1999. |
| **Title of paper** | Interactions between wood polymers studied by dynamic FT-IR spectroscopy. |
| **Journal/conference** | Polymer 42: 963-969. |

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| **Author** | Hinterstoisser, B. & L. Salmén. 2000. |
| **Title of paper** | Application of dynamic 2D-FTIR to cellulose. |
| **Journal/conference** | Vibrational Spectroscopy 22: 111-118. |

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| **Author** | Åkerholm, M. & L. Salmén. 2001. |
| **Title of paper** | Kolhydratsamverkan studerad med dynamisk FTIR-spektroskopi. |
| **Journal/conference** | Ekmandagarna, SPCI, 5-7 February, 2001, Stockholm, Sweden. |

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| **Author** | Åkerholm, M. & L. Salmén. 2001. |
| **Title of paper** | Interactions between wood polymers studied by dynamic FT-IR spectroscopy. |
| **Journal/conference** | 11$^{th}$ Int. Symp. Wood Pulping Chemistry, Nice, France, June 11-14, 2001, Vol. I: 17-20. |

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| **Author** | Hinterstoisser, B., M. Åkerholm & L. Salmén. 2001. |
| **Title of paper** | Effect of fiber orientation in dynamic FTIR study on native cellulose. |
| **Journal/conference** | Carbohydrate Research 334: 27-37. |

***<u>Project 8</u>, Phase 3: 2002 – 2004***

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| **Author** | Åkerholm, M. & L. Salmén. 2002. |
| **Title of paper** | Dynamic FT-IR spectroscopy for carbohydrate analysis of wood pulps. |
| **Journal/conference** | J. Pulp Paper Science 28: 245-249. |

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| **Author** | Åkerholm, M. & L. Salmén. 2002. |
| **Title of paper** | Orientation and dynamic behavior of lignin in the cell wall. |
| **Journal/conference** | Proc. 7th European Workshop on Lignocellulosics and Pulp. August 26-29, 2002. Turku/Åbo, Finland. |

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| **Author** | Åkerholm, M. & L. Salmén. 2003. |
| **Title of paper** | The oriented structure of lignin and its viscoelastic proerties studied by static and dynamic FT-IR spectroscopy. |
| **Journal/conference** | Holzforschung 57: 459-465. |

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| **Author** | Hinterstoisser, B., M. Åkerholm & L. Salmén. 2003. |
| **Title of paper** | Load distribution in native cellulose. |
| **Journal/conference** | Biomacromolecules 4:5 (2003) 1232-1237. |

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| **Author** | Åkerholm, M., B. Hinterstoisser & L. Salmén. 2004. |
| **Title of paper** | Characterization of the crystalline structure of cellulose using static and dynamic FT-IR spectroscopy. |
| **Journal/conference** | Carbohydrate Research 339 (2004) 569-478. |

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| **Author** | Åkerholm, M. & L. Salmén. 2004. |
| **Title of paper** | Softening of wood polymers induced by moisture studied by dynamic FT-IR spectroscopy. |
| **Journal/conference** | J. Applied Polymer Science 94, 2032-2040. |

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| **Author** | Salmén, L., M. Åkerholm & B. Hinterstoisser. 2004. |
| **Title of paper** | Two-Dimensional Fourier transform Infrared Spectroscopy Applied to Cellulose and Paper. |
| **Book** | In: Polysaccharides: Structural Diversity and Functional Versatility, 2$^{nd}$ ed., S. Dumitriu, ed. Marcel Dekker Inc., New York, pp. 159-187. |

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| **Author** | Salmén, L. & M. Åkerholm. 2006. |
| **Title of paper** | Moisture controlled dynamic FT-IR spectroscopy for characterizing the molecular rheology of wood fibres. |
| **Journal/conference** | Cellulose Chem. Technol. 40 (1-2), 5-11. |

***Project 12, Phase 1-2: 1997 – 2001***

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| **Author** | Fahlén, J. 2000. |
| **Title of paper** | AFM: a tool for revealing details on the wood ultrastructure. |
| **Journal/conference** | Proc. Workshop Fibre Wall & Microfibril Angle. COST Action E20 Wood Fibre Cell Wall Structure, 11-13 May, 2000, Athens, Greece. Printed by NTUA, Athens, Greece and MC/WG of COST Action E20, p. 57. |

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| **Author** | Fahlén , J. & L. Salmén. 2001. |
| **Title of paper** | Cross sectional structure of wood during pulping viewed with AFM. |
| **Journal/conference** | 11th Int. Symp. Wood Pulping Chemistry, Nice, France, June 11-14, 2001, Poster P155. |

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| **Author** | Fahlén, J. & L. Salmén. 2001. |
| **Title of paper** | Cross-sectional structure of the $S_2$ layer in native and processed wood. |
| **Journal/conference** | COST Action E11 Characterization methods for fibres and paper, 10-12 May, Louvain-la-Neuve-University, Brussels, Belgium. |

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| **Author:** | Fahlén, J. & L. Salmén. 2001. |
| **Title of paper** | The lamellar structure of the wood fiber wall - radial or concentric. |
| **Journal/conference** | COST Action E20 Wood Fibre Cell Wall Structure. Proc. Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden, p. 25. |

***Project 12, Phase 3: 2002-2004***

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| **Author** | Fahlén, J. & L. Salmén. 2002. |
| **Title of paper** | On the lamellar structure of the tracheid cell wall. |
| **Journal/conference** | Plant Biology 4(3), 339-345. |

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| **Author:** | Fahlén, J. & L. Salmén. 2003. |
| **Title of paper** | Pore size distribution in the transverse direction of the wood fibre wall |
| **Journal/conference** | COST Action E20 Workshop Building a Cell Wall, Helsinki, 4-6 September 2003 (Lecture). |

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| **Author** | Fahlén, J. & L. Salmén. 2003. |
| **Title of paper** | Cross-sectional structure of the secondary wall of wood fibers as affected by processing |
| **Journal/conference** | J. Material Science 38(1), 119-126. |

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| **Author** | Fahlén, J. & L. Salmén. 2004. |
| **Title of paper** | The AFM and the cell wall ultrastructure |
| **Journal/conference** | Proc. Ekmandagarna, SPCI, 3-4 February 2004, Stockholm, Sweden. |

***Project 12, Phase 4: 2005 – 2007***

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| **Author** | Salmén, L. 2004. |
| **Title of paper** | Micromechanical understanding of the cell wall structure |
| **Journal/Conference** | C. R. Biologies 327, 9-10, 873-880. |

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| **Author** | Fahlén, J. & L. Salmén. 2005. |
| **Title of paper** | Pore and matrix distribution in the fibre wall revealed by AFM and image analysis. |
| **Journal/conference** | Biomacromolecules 6, 433-438. |

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| **Author** | Fahlén, J. & L. Salmén. 2005. |
| **Title of paper** | Ultrastructural changes in the transverse direction of a holocellulose pulp revealed by enzymes, thermoporosimetry, and atomic force microscopy. |
| **Journal/conference** | Holzforschung 57(6), 589-597. |

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| **Author** | Salmén, L. & J. Fahlén. 2006. |
| **Title of paper** | Reflections on the ultrastructure of softwood fibres |
| **Journal/conference** | Cellulose Chem. Technol. 40 (1-2), 5-11. |

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| **Author** | Salmén, L. 2006. |
| **Title of paper** | Ultra-structural arrangement and rearrangement of the cellulose aggregates within the secondary wall. |
| **Journal/conference** | In "Proc. 5th Plant Biomechanics Conf.". Ed. L. Salmén, STFI-PF, p. 215-220. |

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| **Author** | Salmén, L. 2007. |
| **Title of paper** | The mechanical deformation of wood – Relation to ultrastructure. |
| **Journal/conference** | In "Understanding the physiological and biomechanical responses of very young trees (< 3 yrs) to environmental pressures". Workshop 2007. K.M. Entwistle & J.C.F. Walker Eds. Christchurch, University of Canterbury, New Zealand. |

***Project 16, Phase 4: 2005-2007***

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| **Author** | Stevanic Srndovic, J. & L. Salmén. 2006. |
| **Title of paper** | Interaction of the components within the outer fibre wall layers. |
| **Journal/ conference** | Proc. 5th Plant Biomechanics Conf., Stockholm, August 28-September 1, 2006, p. 151-156. |

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| **Author** | Stevanic, J.S. & L. Salmén. 2006. |
| **Title of paper** | The primary cell wall studied by dynamic 2D FT-IR: Interaction among components in Norway spruce (*Picea abies*). |
| **Journal/conference** | Cellulose Chem. Technol. 40 (9-10), 761-767 |

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| **Author** | Stevanic, J.S. & L. Salmén. 2008. |
| **Title of paper** | Characterizating wood polymers in the primary wall of Norway spruce (*Picea abies* (L.) Karst.) using dynamic FT-IR |
| **Journal/conference** | Cellulose 15: 285-295; DOI 10.1007/s10570-007-9169-1 |

***Project 9, Phase 1-2: 1997 – 2001***

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| **Author** | Hildén, L., G. Johansson, G. Daniel & T. Nilsson. 2001. |
| **Title of paper** | The ultrastructure of wood studied with specific enzymes. |
| **Journal/conference** | COST Action E20 Wood Fibre Cell Wall Structure, Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden. (Poster). |

***Project 9, Phase 3-4: 2002 – 2007***

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| **Author** | Hildén, L., G. Daniel & G. Johansson. 2003. |
| **Title of paper** | Use of fluorescence labelled, carbohydrate-binding module from *Phanerochaete chrysosporium* Cel7D for studying wood cell wall ultrastructure. |
| **Journal/conference** | Biotechnology Letters 25: 553-558, 2003. |

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| **Author** | Hildén. L. & G. Johansson. 2004. |
| **Title of paper** | Recent developments on cellulases and carbohydrate binding modules with cellulose affinity. |
| **Journal/conference** | Biotechnology Letters 26, 1683-1693. |

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| **Author** | Hildén. L., P. Väljamäe & G. Johansson. 2005. |
| **Title of paper** | Surface character of pulp fibres studied using endoglucanases. |
| **Journal/conference** | Journal of Biotechnology 118, 386-397. |

***<u>Project 10</u>, Phase 1-2: 1997 – 2001***

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| **Author** | Terashima, N., J. Hafrén, U. Westermark, Y. Xie, K. Fukushima, C. Lapierre & D. L. van der Hart. 1999. |
| **Title of paper** | Proposed 3D structural model for softwood lignin. |
| **Journal/conference** | 10th Int. Symp. Wood Pulping Chemistry, Yokohama, Japan, June 7-10, 1999, Vol. I, p. 106-109. |

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| **Author** | Hafrén, J., G. Daniel & U. Westermark. 2000. |
| **Title of paper** | The distribution of acidic and esterified pectin in the cambium of developing xylem amd mature xylem of *Pinus sylvestris*. |
| **Journal/conference** | IAWA Journal 21, 157-169. |

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| **Author** | Mellerowicz, E. J., K. Blomqvist, V. Bourgin, H. Brumer, M. Christiernin, S. Denman, S. Djerb, M. Eklund, Å. Kallas, J. Lehtiö, S. Raza, S. Regan, U. Rudsander, B. Sundberg & T. Teeri. 2000. |
| **Title of paper** | Cell wall enzyme discovery using high throughput sequencing and in-depth expression analysis in poplar wood forming tissues. |
| **Journal/conference** | Proc. Symp. "Friendly and Emerging Technologies for a Sustainable Pulp and Paper Industry". Taiwan Research Institute, Taipei, Taiwan. 25-27 April, 2000. |

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| **Author** | Bourquin, V., E. Mellerowicz, S. Denman, M. Eklund, T. Terri & B. Sundberg. 2000. |
| **Title of paper** | Immunolocalization of xyloglucan endotransglycosylase (XET16A) from Poplar wood-forming tissues. |
| **Journal/conference** | Graduate student meeting in Gothenburg 10-14 August 2000. |

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| **Author** | Gray-Mitsumune, M., E. J. Mellerowicz, K. Blomqvist, S. Regan, V. Bourquin, J. Lehtiö, T.T. Teeri & B. Sundberg. 2000. |
| **Title of paper** | Expansins involved in the wood fiber formation in poplar. |
| **Journal/conference** | Plant Cell Walls - Gordon Conference, Meriden, New Hampshire, Aug 20-25, 2000 |

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| **Author** | Gray-Mitsumune, M., E. J. Mellerowicz, K. Blomqvist, A. Gouget, J. Schrader, S. Regan, J. Lehtiö, T.T. Teeri & B. Sundberg. 2001. |
| **Title of paper** | Characterization of expansin genes specifically expressed during secondary xylem development in hybrid aspen. |
| **Journal/conference** | COST Action E20 Wood Fibre Cell Wall Structure. Proc. Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden, p. 4. |

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| **Author** | Mellerowicz, E., H. Aspeborg, K. Blomqvist, H. Brumer, V. Bourquin, S. Denman, M. Gray-Mitsumune, A. Gouget, S. Regan, B. Sundberg & T.T. Teeri. 2001. |
| **Title of paper** | Xylem cell formation in hybrid aspen: Enzymes involved in the cell wall formation and restructuring. |
| **Journal/conference** | COST Action E20 Wood Fibre Cell Wall Structure. Proc. Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden, p. 3 |

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| **Author** | Bourquin, V., E. Mellerowicz, H. Brumer, S. Denman, M. Eklund, T.T. Terri & B. Sundberg. 2001. |
| **Title of paper** | Localization by indirect immunofluorescence of the xyloglucan endotransglycosylase (XET16A) in the cambial region tissues of hybrid aspen. |
| **Journal/conference** | COST Action E20 Wood Fibre Cell Wall Structure. Proc. Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden, p. 54. (Poster). |

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| **Author** | Mellerowicz, E., H. Aspeborg, K. Blomqvist, V. Bourquin, S. Denman, M. Gray-Mitsumune, S. Regan, B. Sundberg & T.T. Teeri. 2001. |
| **Title of paper** | Enzymes involved in the cell wall formation and restructuring in the wood forming tissues of hybrid aspen. |
| **Journal/conference** | 4th Carboh. Bioeng. Meeting, June 10. - 13. 2001, Royal Institute of Technology, Stockholm, Sweden, http://www.print.kth.se/cbn/ |

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| **Author** | Aspeborg, H., S. Djerbi, M. Hertzberg, J. Schrader, B. Sundberg, E. Mellerowicz, P. Nilsson, T. Teeri & K. Blomqvist. 2001. |
| **Title of paper** | Transcript profiling of genes involved in carbohydrate metabolism in the wood forming tissue from *Populus tremula* L.X *tremuloides* Michx. |
| **Journal/conference** | 4th Carboh. Bioeng. Meeting, June 10. -13. 2001, Royal Institute of Technology, Stockholm, Sweden, http://www.print.kth.se/cbn/ |

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| **Author** | Schukarev, A.V., B. Sundberg, E. Mellerowicz & P. Persson. 2001. |
| **Title of paper** | XPS Study of living tree. |
| **Journal/conference** | 9th Eur. Conf on Conference on applications of surface and interface analysis, 30 September-5 October 2001, Avignon, France. http://www.enscp.jussieu.fr/ECASIA/ |

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| **Author** | Andersson, S., M. Hertzberg, Y. Ohmiya, J. Hellgren, E. Mellerowicz, P. Nilsson & B. Sundberg. 2001. |
| **Title of paper** | Gene Expression During Tension Wood Formation. |
| **Journal/conference** | 9th International Cell Wall Meeting, 2-7 Sept 2001 Toulouse, France (Poster). |

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| **Author** | Mellerowicz, E., H. Abe, H. Aspeborg, K. Blomqvist, H. Brumer, V. Bourquin, S. Denman, A. Gouget, M. Gray-Mitsumune, M-A. Péronne, T.T. Teeri & B. Sundberg. 2001. |
| **Title of paper** | Xylem Cell Formation In Hybrid Aspen: Enzymes Involved In The Cellulose-Hemicellulose Network Formation and Restructuring. |
| **Journal/conference** | 9th International Cell Wall Meeting, 2-7 Sept 2001 Toulouse, France (Lecture). |

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| **Author** | Bourquin, V., E. Mellerowicz, H. Abe, H. Brumer S. Denman, M. Eklund, T.T. Teeri & B. Sundberg. 2001. |
| **Title pf paper** | Localization of the xyloglucan endotransglycosylase (XET16A) in the cambial region of hybrid aspen. |
| **Journal/conference** | COST E20 MC-meeting and Workshop on "Methods to Localise and Characterise Cell Wall Components" held in Grenoble, France 25 - 27 October 2001. (Lecture). |

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| **Author** | Mellerowicz, E. J., M. Baucher, B. Sundberg, & W. Boerjan. 2001. |
| **Title of paper** | Unraveling cell wall formation in the woody dicot stem. |
| **Journal/conference** | Plant Mol. Biol. - Special issue on plant cell walls, August 2001. Plant Mol. Biol. 47: 239-274. |

***Project 10, Phase 3: 2002 - 2004***

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| **Author** | Denman, S., K. Blomqvist, H. Aspeborg, M. Hertzberg, Å. Kallas, U. Rudsander, E. Mellerowicz, A. Ohlsson, T. Berglund, P. Nilsson, B. Sundberg, J. Lundeberg & T.T. Teeri. |
| **Title of paper** | Enzymes for innovative fibre modification. 2002. |
| **Journal/conference** | Twenty seventh annual Lorne conference on protein structure and function.10-14 February 2002, Lorne, Australia. (Poster). |

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| **Author** | Shchukarev, A.V., B.Sundberg, E. Mellerowicz & P. Persson. 2002. |
| **Title of paper** | XPS Study of Living Tree. |
| **Journal/conference** | Surface and Interface Analysis 34: 284-288. |

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| **Author** | Bourquin, V., N. Nishikubo, H. Abe, H. Brumer, S. Denman, M. Eklund, M. Christiernin, T.T. Teeri, B. Sundberg & E.J. Mellerowicz. 2002. |
| **Title of paper** | Xyloglucan endotransglycosylases have a function during the formation of secondary cell walls of vascular tissues. |
| **Journal/conference** | Plant Cell 14: 3073-3088. |

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| **Author** | Gray-Mitsumune, M., E.J. Mellerowicz, H. Abe, K. Blomqvist, J. Schrader, S.J. McQueen-Mason, T.T. Teeri & B. Sundberg. 2002. |
| **Title of paper** | Overexpression of an aspen expansin gene results in alteration of growth response in transgenic aspen. |
| **Journal/conference** | Canadian Society of Plant Physiologists June 8 to 12, 2002 Calgary, Alberta (Lecture). |

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| **Author** | Sundberg, B. et al. 2002. |
| **Title of paper** | Functional genomics in poplar: wood cell wall biosynthesis. |
| **Journal/conference** | Plant Cell Wall Biosynthesis Meeting, 12-15 May, 2002, UCLA Lake Arrowhead Conference Center, California (Oral). |

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| **Author** | Siedlecka, A., M-A. Péronne, J. Lesniewska, L. Richard, F. Michelli, A. Shchukarev, M. McCann, M. Bush, B. Sundberg & E. Mellerowicz. 2002. |
| **Title of paper** | Altered expression of Pectin Methyl Esterase PME1 cases multiple changes in the aspen wood-forming tissues. |
| **Journal/conference** | COST E20 meeting "Cell Wall and Stress" held 30/5-1/06 2002 at INRA, Reims. (Poster). |

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| **Author** | Nishikubo, N., B. Sundberg & E. Mellerowicz. 2002. |
| **Title of paper** | The expression analysis of xyloglucan endotransglycosylase/hydrolases in the cambial region of hybrid aspen and mature hypocotyl of *Arabidopsis*. |
| **Journal/conference** | 13th FESPP CONGRESS, September 1-6, 2002, Heraklion, Crete, Greece (Oral). |

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| **Author** | Mellerowicz, E.J., N. Nishikubo, A. Siedlecka, M. Gray-Mitsumune, M-A. Péronne, V. Bourquin, F. Micheli, L. Richard, S. McQueen-Mason, H. Brumer, T.T. Teeri & B. Sundberg. 2003. |
| **Title of paper** | Custom-tailored wood fibers. |
| **Journal/conference** | Talk at the IUFRO Tree Biotechnology Meeting, Umeå, June 7-12, 2003. |

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| **Author** | Siedlecka, A., M-A. Péronne, F. Micheli, L. Richard, B. Sundberg & E.J. Mellerowicz. 2003. |
| **Title of paper** | Pectin methyl esterase regulates fibre length in poplar by acting on intrusive tip growth. |
| **Journal/conference** | Poster at the IUFRO Tree Biotechnology Meeting, Umeå, June 7-12, 2003. |

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| **Author** | Takahashi, J., E.R. Master, T.T. Teeri, B. Sundberg & E.J. Mellerowic. 2003. |
| **Title of paper** | Role of cellulases in the wood formation. |
| **Journal/conference** | Poster at the IUFRO Tree Biotechnology Meeting, Umeå, June 7-12, 2003. |

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| **Author** | Nishikubo, N., B. Sundberg & E. Mellerowicz. 2003. |
| **Title of paper** | The role of XET for wood formation. |
| **Journal/conference** | Poster at the IUFRO Tree Biotechnology Meeting, Umeå, June 7-12, 2003 |

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| **Author** | Mellerowicz, E. 2003. |
| **Title of paper** | Pectin methyl esterase regulates cell expansion and intrusive growth during wood development in poplar. |
| **Journal/conference** | Talk at the Gordon Research conference: Plant Cell Walls, Meridem NH, August 2003. |

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| **Author** | Teeri, T.T. 2003. |
| **Title of paper** | Chemo-enxymatic modification of cellulosic materials. |
| **Journal/conference** | Proc. Workshop Building a Cell Wall, COST Action E20 Wood Fibre Cell Wall Structure, September 4-6, 2003, Helsinki, Finland (Keynote lecture). |

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| **Author** | Mellerowicz, E., N. Nishikubo, M. Gray-Mitsumune, A. Siedlecka, & B. Sundberg. 2004. |
| **Title of paper** | Cell expansion in developing wood. |
| **Journal/conference** | Plant Cell Wall meeting in Sorrento, Aug 28-Sept 3, 2004. |

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| **Author** | Takahashi, J., E.R. Master, U. Jonsson Rudsander, E. del Campillo, T.T. Teeri, B. Sundberg & E.J. Mellerowicz. 2004. |
| **Title of paper** | Role of cellulases in the wood formation. |
| **Journal/conference** | Plant Cell Wall meeting in Sorrento, Aug 28-Sept 3, 2004 |

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| **Author** | Gray-Mitsumune, M., H. Abe, B. Sundberg & E.J. Mellerowicz. 2004. |
| **Title of paper** | Liquid-phase fluorescence in situ RT-PCR for high resolution and high throughput gene expression analysis in woody stems tissues. |
| **Journal/conference** | Plant Biology 6: 47-54. |

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| **Author** | Djerbi, S., H. Aspeborg, P. Nilsson, B. Sundberg, E. Mellerowicz, K. Blomqvist & T.T. Teeri. 2004. |
| **Title of paper** | Identification and expression analysis of genes encoding putative cellulose synthases (CesA) in the hybrid aspen, *Populus tremula* (L.) x *P. tremuloides* (Michx.). |
| **Journal/conference** | Cellulose 11 (3-4), 301-312. |

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| **Author** | Gray-Mitsumune, M., E.J. Mellerowicz, H. Abe, S. McQueen-Mason, A. Winzéll, F. Sterky, K. Blomqvist, J. Schrader, T.T. Teeri & B. Sundberg. 2004. |
| **Title of paper** | Secondary growth-specific expansin genes belong to the Subgroup A α-expansin gene family and exhibit conservation among different wood-forming species |
| **Journal/conference** | Plant Physiology 135, 1552-1564. |

***Project 10, Phase 4: 2005 - 2007***

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| **Author** | Aspeborg, H, J. Schrader, P.M. Coutinho, M. Stam, Å. Kallas, S. Djerbi, P. Nilsson, S. Denman, B. Amini, F. Sterky, E. Master, G. Sandberg, E. Mellerowicz, B. Sundberg, B. Henrissat & T.Teeri. 2005. |
| **Title of paper** | Carbohydrate-active enzymes involved in the secondary cell wall biogenesis in hybrid aspen. |
| **Journal/conference** | Plant Physiology 137: 983-997. |

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| **Author** | Andersson-Gunnerås S., E. J. Mellerowicz, Y. Ohmiya, P. Nilsson, B. Henrissat, J. Love, T. Moritz & B. Sundberg. 2006. |
| **Title of paper** | Biosynthesis of cellulose-enriched tension wood in Populus: global analysis of transcripts and metabolites identifies biochemical and developmental regulators in secondary wall biosynthesis. |
| **Journal/conference** | Plant J 45: 144-165. |

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| **Author** | J. Geisler-Lee, M. Geisler, P.M. Coutinho, B. Segerman, N. Nishikubo, J. Takahashi, H. Aspeborg, S. Djerbi, E. Master, S. Andersson-Gunnerås, B. Sundberg, S. Karpinski, T.T. Teeri, L.A. Kleczkowski, B. Henrissat & Ewa J. Mellerowicz. 2006. |
| **Title of paper** | Poplar carbohydrate-active enzymes (CAZymes). Gene identification and expression analyses. |
| **Journal/conference** | Plant Physiol. 140: 946-962. |

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| **Author** | Meng, M., M. Geisler, H. Johansson, E.J. Mellerowicz, S. Karpinski & L.A. Kleczkowski. 2007. |
| **Title of paper** | Differential tissue/organ-dependent expression of two sucrose- and cold-responsive genes for UDP-glucose pyrophosphorylase in *Populus*. |
| **Journal/conference** | Gene 389: 186-195. |

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| **Author** | Nishikubo N, T. Awano, A. Banasiak, V. Bourquin, F. Ibatullin, R. Funada, H. Brumer, T. Teeri, T. Hayashi, B. Sundberg & E.J. Mellerowicz. (2007). |
| **Title of paper** | Xyloglucan *endo*-transglycosylase (XET) functions in gelatinous layers of tension wood fibers in poplar - a glimpse into the mechanism of the balancing act of trees. |
| **Journal/conference** | Plant and Cell Physiology 48 (6), 843-855. |

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| **Author** | Pelloux, J., C. Rustérucci & E.J. Mellerowicz. 2007. |
| **Title of paper** | New insights into pectin methylesterase (PME) structure and function. |
| **Journal/conference** | Trends in Plant Sciences 12: 267-277. |

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| **Author** | Philippe, S. & E. J. Mellerowicz, 2007 |
| **Title of paper** | Development of FTIR spectroscopy for secondary wall analysis in *Arabidopsis* |
| **Journal/conference** | XIth Cell Wall Meeting, Copenhagen, Denmark, 12-17 August 2007(Poster). |

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|---|---|
| **Author** | Takahashi, J.,T. Awano, Å. Kallas, C. Ratke, F. Berthold, T.T. Teeri, B. Sundberg & E. J. Mellerowicz, 2007. |
| **Title of paper** | Xylanase has a role in wood development in aspen |
| **Journal/conference** | XIth Cell Wall Meeting, Copenhagen, Denmark, 12-17 August 2007 (Poster). |

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| **Author** | Nobuyushi, N., S. Endo, J. Takahashi, A. Banasiak, T. Awano, A. Andersson, H. Stålbrand, R. Funada, K. Piens, H. Brumer, T T. Teeri, T. Hayashi, B. Sundberg, E.J. Mellerowicz 2007. |
| **Title of paper** | Novel functions of XETs in poplar wood development |
| **Journal/conference** | XIth Cell Wall Meeting, Copenhagen, Denmark, 12-17 August 2007 (Poster). |

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| **Author** | Nobuyushi, N., S. Endo, J. Takahashi, A. Banasiak, T. Awano, A. Andersson, H. Stålbrand, R. Funada, K. Piens, H. Brumer, T T. Teeri, T. Hayashi, B. Sundberg, E.J. Mellerowicz 2007. |
| **Title of paper** | Novel functions of XETs in poplar wood development |
| **Journal/conference** | IUFRO Tree Biotechnology 2007 meeting, Ponta Delgada, Azores, Portugal, June 3rd-8th, 2007. (Lecture). |

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| **Author** | Takahashi, J., T. Awano, Å. Kallas, A. Gorzsàs, J. Lesniewska, F. Berthold, T.T. Teeri, B. Sundberg & E.J. Mellerowicz, 2007. |
| **Title of paper** | Xylan biosynthesis and modification in poplar |
| **Journal/conference** | COST Action D29 Working Group Meeting Production and Functionalization of Hemicelluloses for Sustainable Advanced Products, March 19-20, 2007, Hamburg, Germany (Lecture). |

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| **Author** | Takahashi, J., T. Awano, Å. Kallas, F. Berthold, T.T. Teeri, B. Sundberg & E. J. Mellerowicz. 2007. |
| **Title of paper** | Xylanase has a role in wood development in aspen |
| **Journal/conference** | COST Action E50 Int. Conf. "Cell Wall Macromolecules and Reaction Wood". Warsaw Agricultural University, Warsaw, October 19-22, 2006 (Lecture). |

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| **Author** | Siedlecka, A., S. Wiklund, M-A. Péronne, F. Micheli, J. Leoniewska, L. Richard, B. Sundberg & Ewa J. Mellerowicz. 2006. |
| **Title of paper** | PME inhibits symplastic and intrusive growth in poplar |
| **Journal/conference** | Gordon Research Conf. Plant Cell Walls, University of New England, Biddeford, ME, Jul 30-Aug 4, 2006. (Poster). |

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| **Author** | Geisler-Lee, J., M. Geisler, P. M. Coutinho, B. Segerman, N. Nishikubo, J. Takahashi, H. Aspeborg, S. Djerbi, E. Master, S. Andersson-Gunnerås, B. Sundberg, S. Karpinski, T. T. Teeri, L. A. Kleczkowski, B. Henrissat & E. J. Mellerowicz. 2006 |
| **Title of paper** | Poplar carbohydrate active enzymes. gene identification and expression analyses. |
| **Journal/conference** | 17th Arabidopsis Research Conf., Univ. of Wisconsin, Madison, June 28-July 2, 2006, P Gordon Research Conf. Plant Cell Walls, University of New England, Biddeford, ME, Jul 30-Aug 4, 2006 (Poster). |

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| **Author** | Geisler-Lee1, J., M. Geisler, P. M. Coutinho, L. A. Kleczkowski, B. Henrissat & E.J. Mellerowicz. 2006 |
| **Title of paper** | Poplar carbohydrate active enzymes. gene identification and epression analyses. |
| **Journal/conference** | The 49th Annual Conf. of the Genetics Society of Canada, University of Western Ontario, London, Ontario, June 18-21 2000 (Poster). |

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| **Author** | Sundberg, B. & E.J Mellerowicz. 2005 |
| **Title of paper** | Engineering Wood Structures. |
| **Journal/conference** | 6th Pacific Regional Wood Anatomy Conf., Kyoto, Japan, December 1-5, 2005 (lecture). |

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| **Author** | Takahashi, J., T. Awano, Å. Kallas, F. Berthold, T. T. Teeri, B. Sundberg & E. Mellerowicz. 2005 |
| **Title of paper** | Exploring the role of xylanase in wood formation. |
| **Journal/conference** | 6th Pacific Regional Wood Anatomy Conf., Kyoto, Japan, December 1-5, 2005, (Lecture). |

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| **Author** | Takahashi, J., U. Jonsson Rudsander, E. Master, T.T. Teeri, B. Sundberg & E.J. Mellerowicz. 2005 |
| **Title of paper** | Role of cellulases in the wood formation. |
| **Journal/conference** | Int. Symp. on Wood Science and Technologies, Yokohama, Japan, November 27-30, 2005 (Poster). |

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| **Author** | Mellerowicz, E J. .2005 |
| **Title of paper** | Pectin methylesterification affects many aspect of wood cell development |
| **Journal/conference** | IUFRO Tree Biotechnology Meeting, Pretoria, RSA, November 2005 (Lecture). |

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| **Author** | Mellerowicz, E J. .2005 |
| **Title of paper** | Remodeling pectin in developing wood cells. |
| **Journal/conference** | 2nd Conf. of Polish Society of Experimental Plant Biology, Poznan Poland, Sept. 26-30, 2005, Pub. in Biological Lett. 42(2): 98. (Lecture). |

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| **Title of paper** | Exploring the role of xylanase in wood formation |
| **Journal/conference** | SPPS Congress, Umeå, Sweden June 2004 (Poster). |

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| **Title of paper** | Role of cellulases in the wood formation |
| **Journal/conference** | Int. Botanical Congress. Vienna, Austria, July 2005. (Poster). |

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| **Author** | Mellerowicz, E.J. 2005. |
| **Title of paper** | Pectins – the secret agents acting on wood cells and their secondary walls |
| **Journal/conference** | Umeå Plant Science Centre, Umeå, Sweden, February 4-5, 2005 (Lecture). |

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| **Author** | Mellerowicz, E.J. |
| **Title of paper** | Using *Arabidopsis* to study wood formation |
| **Journal/conference** | Swedish Tree Biotechnology Conf. Stockholm, October 11-12, 2004 (Lecture) |

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| **Author** | Björklund, S., J. Love, S. Andersson, J., Vahala, H. Tuominen, J. Kangasjärvi, E.J. Mellerowicz, E. & B. Sundberg. 2004. |
| **Title of paper** | Formation of specialized cell wall in tension wood |
| **Journal/conference** | Int. meeting on Plant cell walls, Sorrento, August 2004 (Poster). |

***<u>Project 11</u>, Phase 1- 2: 1997 – 2001***

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| **Author** | Larsson, T. 1999. |
| **Title of paper** | Structural Elements in Cellulose I. |
| **Journal/conference** | Biopolymer Technology (ICBT), 29 September - 1 October 1999, Universidad de Coimbra, Coimbra, Portugal. |

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| **Author** | Larsson, P.T., H-L. Hult, K. Wickholm, E. Pettersson & T. Iversen. 1999. |
| **Title of paper** | CP/MAS 13C NMR spectroscopy applied to structure and interaction studies on cellulose I. |
| **Journal/conference** | Solid State NMR, 15: 31-40. |

***<u>Project 14</u>, Phase 2: 2001 & Phase 3-4: 2002 – 2007***

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| **Author** | Eriksson, L. 2001. |
| **Title of paper** | Lignin biosynthesis and degradation; A theoretical perspective. |
| **Journal/conference** | Presented at the International Workshop on Physical Chemistry, University of the Basque Country, San Sebastian, Spain, 2001-07-05. |
| **Author** | Durbeej, B. & L.A. Eriksson. 2003. |
| **Title of paper** | Spin distribution in dehydrogenated coniferyl alcohol and associated dilignol radicals. (Short note) |
| **Journal/conference** | Holzforschung 57(1): 150-164 |
| **Author** | Durbeej, B. & L.A. Eriksson. 2003. |
| **Title of paper** | A density functional theory study of coniferyl alcohol intermonomeric cross linkages in lignin - Three-dimensional structures, stabilities and the thermodynamic control hypothesis. |
| **Journal/conference** | Holzforschung 57(2): 59-61 |
| **Author** | Durbeej, B. & L.A. Eriksson. 2003. |
| **Title of paper** | Formation of β-O-4 lignin models – A theoretical study. |
| **Journal/conference** | Holzforschung 57(5): 466-478 |
| **Author** | Eriksson, L., Y-N. Wang & L.A. Eriksson. 2002 & 2003. |
| **Title of paper** | Lignin biosynthesis and degradation – a major challenge for computational chemistry. |
| **Journal/conference** | VECPAR 2002 Conf. Proc., Lecture notes in Computational Sciences 2565; Palma, Dongarra, Hernandéz, Sousa (Eds), Springer Verlag (2003). |
| **Author** | Li, X. & L.A. Eriksson. 2004. |
| **Title of paper** | Molecular modeling of lignin constituents in aqueous solution. |
| **Journal/conference** | Int. Soc. for Quantum Biology and Pharmacology meeting, Como, Italy, June 5-8, 2004 (Poster). |
| **Author** | Li, X. & L.A. Eriksson. 2005. |
| **Title of paper** | Molecular dynamics simulations of lignin constituents in aqeous solution. |
| **Journal/Conference** | Holzforschung 59, 253. |
| **Author** | Durbeej, B. & L.A. Eriksson. 2005. |
| **Title of paper** | Photodegradation of substituted stilbene compounds. What colors aging paper yellow? |
| **Journal/Conference** | J. Phys. Chem. A. 109, 5677. |
| **Author** | Matxain, J.M., B. Durbeej & L.A. Eriksson. 2006. |
| **Title of paper** | Theoretical modelling of lignin photodegradation. |
| **Journal/conference** | Proc. 5$^{th}$ Plant Biomechanics Conf., Stockholm, August 28-September 1, 2006, p. 163-168. |
| **Author** | Matxain, J.M. & L.A. Eriksson. 2007. |
| **Title of paper** | Photodegradation of hydroxycinnamyl alcohols and stilbenes |
| **Journal/conference** | Submitted to J. Phys. Chem B, July 2007 |

***<u>Project 15</u>, Phase 3: 2002 – 2004***

| | |
|---|---|
| **Author** | Brändström, J. 2003. |
| **Title of paper** | Ultrastructure of compression wood fibres in fractions of a thermomechanical pulp. |
| **Journal/conference** | Proc. Workshop Building a Cell Wall, COST Action E20 Wood Fibre Cell Wall Structure, September 4-6, 2003, Helsinki, Finland (Poster). |
| **Author** | Fernando, D. & G. Daniel. 2003. |
| **Title of paper** | Micro-morphological observations of spruce thermo-mechanical pulp fibre fractions with emphasis on fibre cell wall fibrillation and splitting |
| **Journal/conference** | Proc. Workshop Building a Cell Wall, COST Action E20 Wood Fibre Cell Wall Structure, 4-6 September 2003, Helsinki, Finland (Poster). |

| | |
|---|---|
| **Author** | Hafrén, J. 2003. |
| **Title of paper** | Pectin on mechanical pulp fibre surfaces. |
| **Journal/conference** | Proc. Workshop Building a Cell Wall, COST Action E20 Wood Fibre Cell Wall Structure, September 4-6, 2003, Helsinki, Finland (Poster). |

| | |
|---|---|
| **Author** | Hafrén, J. & G. Daniel. 2003. |
| **Title of paper** | Distribution of methyl-esterified galacturonan in chemical and mechanical pulp fibers. |
| **Journal/conference** | Journal of Wood Science 49, 361-365. |

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|---|---|
| **Author** | Hafrén, J. & G. Daniel. 2003. |
| **Title of paper** | A bioassay for methylated galacturonan on pulp-fiber surfaces. |
| **Journal/conference** | Biotechnology Letters 25, 859-862 |


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|---|---|
| **Author** | Hafrén, J. & G. Daniel. 2003. |
| **Title of paper** | Distribution of methyl-esterified galacturonan in chemical and mechanical pulp fibers. |
| **Journal/conference** | Journal of Wood Science 49, 361-365. |

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|---|---|
| **Author** | Hafrén, J. & G. Daniel. 2003. |
| **Title of paper** | A bioassay for methylated galacturonan on pulp-fiber surfaces. |
| **Journal/conference** | Biotechnology Letters 25, 859-862 |


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|---|---|
| **Author** | Brändström, J. & G. Daniel. 2004. |
| **Title of paper** | Höj värdet med fiberkunskap. |
| **Journal/conference** | Vi Skogsägare 1, 27. |

| | |
|---|---|
| **Author** | Fernando, D. & G. Daniel. 2004. |
| **Title of paper** | Micro-morphological observations on spruce TMP fibre fractions with emphasis on fibre cell wall fibrillation and splitting |
| **Journal/conference** | Nordic Pulp Paper Res. J. 19(3), 278-285. |

| | |
|---|---|
| **Author** | Fernando, D., J. Hafrén, J. Brändström & G. Daniel. 2004. |
| **Title of paper** | Influence of native fibre structure on refiner mechanical pulp and final products |
| **Journal/conference** | 4th Fundamental Mechanical Pulp Seminar, 7-8 June, Stockholm, Sweden. p. 2-9. |

| | |
|---|---|
| **Author** | Brändström, J. 2004. |
| **Title of paper** | Ultrastructure of compression wood fibres in fractions of a thermomechanical pulp. |
| **Journal/conference** | Nordic Pulp Paper Res. J. 19:1, 13-17. |

| | |
|---|---|
| **Author:** | Brändström, J. 2004. |
| **Title of paper** | Microfibril angle of the S1 cell wall layer of Norway spruce compression wood tracheids. |
| **Journal/conference** | IAWA J. 25(4), 415-423. |

| | |
|---|---|
| **Author** | Brändström, J., D. Fernando, J. Hafrén & G. Daniel. 2004. |
| **Title of paper** | Tracheid ultrastructure of Norway spruce (*Picea abies* L. Karst) wood and its influence on mechanical pulp and final products. |
| **Journal/Conference** | Int. Symp. on Wood Sciences (IAWA-IAWS), 24-29 October, Montpellier, France. |

***<u>Project 15</u>, Phase 4: 2005 – 2007***

| | |
|---|---|
| **Author** | Brändström, J., J.P. Joseleau, A. Cochaux, N. Giraud-Telme & K. Ruel. 2005. |
| **Title of paper** | Ultrastructure of commercial recycled pulp fibers for the production of packaging paper. |
| **Journal/Conference** | Holzforschung 59, 675-680. |

| | |
|---|---|
| **Author** | Fernando, D., G. Daniel & J. Lidén. 2005. |
| **Title of paper** | The state and spatial distribution of extractives during birch kraft pulping, as evaluated by staining techniques. |
| **Journal/conference** | Nordic Pulp Paper Res. J. 20(4), 383-391. |

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|---|---|
| **Author** | Hafrén, J. & A. Córdova. 2005. |
| **Title of paper** | Direct organic-acid catalyzed polyester derivatization of lignocellulosic material. |
| **Journal/conference** | Nordic Pulp Paper Res. J. 20(4), 477-480. |

| | |
|---|---|
| **Author** | Hafrén, J. & G. Daniel. 2005. |
| **Title of paper** | Chemoenzymatic modifications of charge in chemithermomechanical wood pulp |
| **Journal/conference** | Nordic Pulp Paper Res. J. 20, 200-204. |

| | |
|---|---|
| **Author** | Hafrén, J. 2005. |
| **Title of paper** | Antibody-based assay for galacturonan de-esterification on wood pulp fibers during bleaching |
| **Journal/conference** | J. Wood Science 51(6), 655-658. |

| | |
|---|---|
| **Author** | Fernando, D., J. Lidén & G. Daniel, G. 2005. |
| **Title of paper** | Staining techniques for determining the state and spatial redistribution of extractives during birch kraft pulping. |
| **Journal/conference** | Int. Symp. Wood Science & Technology (IAWPS), Yokohama, Japan, November 27-30, p. 286-287. |

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|---|---|
| **Author** | Fernando, D., J. Lidén & G. Daniel. 2005. |
| **Title of paper** | The nature and behavior/redistribution of extractives during birch kraft pulping: microscopical histochemical approach. |
| **Journal/conference** | 6th Pacific Regional Wood Anatomy Conference (PRWAC), Kyoto, Japan, December 1-5, p. 37-38. |

| | |
|---|---|
| **Author** | Hafrén, J. 2007. |
| **Title of paper** | Protein in Norway spruce thermomechanical pulp. |
| **Journal/conference** | J. Wood Science 53, 143-146 |

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|---|---|
| **Author** | Hafrén, J. 2007. |
| **Title of paper** | Excitation wavelength specific changes in lignocellulosic autofluorescence. |
| **Journal/conference** | J. Wood Science 53, 358-360. |

| | |
|---|---|
| **Author** | Fernando, D., J. Hafrén, J. Gustafsson & G. Daniel. 2007. |
| **Title of paper** | Micromorphology and topochemistry of extractives in pine and spruce TMP; a cytochemical approach. |
| **Journal/conference** | J. Wood Science 54: 134-142. |

| | |
|---|---|
| **Author** | Fernando, D., P. Rosenberg, E. Persson & G. Daniel. 2007 |
| **Title of paper** | Fibre development during stone grinding; ultrastructural characterization for understanding derived properties. |
| **Journal/Conference** | TAPPI Int. Mechanical Pulping Conf., May 7-9, 2007, Minneapolis, Minnesota, USA. (on CD). |

| | |
|---|---|
| **Author** | Fernando, D., P. Rosenberg, E. Persson & G. Daniel. 2007 |
| **Title of paper** | Ultrastructural aspects of fibre development during the stone groundwood process: New insights into derived pulp properties. |
| **Journal/Conference** | Holzforschung 61, 532-538 |

| | |
|---|---|
| **Author** | Fernando, D. & G. Daniel. 2008 |
| **Title of paper** | Exploring pine fibre development mechanisms during TMP processing; Impact of cell wall ultrastructure (morphological and topochemical) on negative behaviour. |
| **Journal/Conference** | Holzforschung. (In Press). |

***<u>Project 19</u>, Phase 3-4: 2002 – 2007***

| | |
|---|---|
| **Author** | Persson, P.V., T. Iversen, A. Fogden, G. Daniel & J. Hafrén. 2002. |
| **Title of paper** | Bringing the nanostructure to light – silica-casts of the fiber cell wall. |
| **Journal/conference** | STFI Industrikontakt, October 2002. |

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|---|---|
| **Author:** | Persson, P.V., A. Fogden, J. Hafrén, G. Daniel & T. Iversen. 2003. |
| **Title of paper** | Bringing the wood nanostructure to light – silica casts of the fiber cell wall. |
| **Journal/conference** | Proc. 12th ISWPC, June 2003, Madison, USA, 159-162. |

| | |
|---|---|
| **Author:** | Wahlberg, J., P.V. Persson, T. Olsson, E. Hedenström & T. Iversen. 2003. |
| **Title of paper** | Structural characterizationof a lipase-catalyzed copolymerization of ε-caprolactone and D,L-lactide. |
| **Journal/conference** | Biomacromolecules 4 (2003) 1068-1071. |

| | |
|---|---|
| **Author:** | Persson, P.V., A. Fogden, J. Hafrén, G. Daniel & T. Iversen. 2004. |
| **Title of paper** | Silica-cast replicas for morphology studies on spruce and birch xylem. |
| **Journal/conference** | IAWA J. 25, 155-164. |

| | |
|---|---|
| **Author:** | Gustavsson, M.T., P.V. Persson, T. Iversen, K. Hult & M. Martinelle. 2004. |
| **Title of paper** | Polyester coating of cellulose fiber surfaces by a cellulose-binding module – *Candida antarctica* lipase. |
| **Journal/conference** | Biomacromolecules 5 (2004) 106-112. |

| | |
|---|---|
| **Author:** | Persson, P.V., J. Hafrén, A. Fogden, G. Daniel & T. Iversen. 2004. |
| **Title of paper** | Silica nanocasts of wood fibers: a study of cell wall accessibility and structure. |
| **Journal/conference** | Biomacromolecules 5:3 (2004) 1097-1101. |

| | |
|---|---|
| **Author:** | Persson, P.V., J. Schröder, K. Wickholm, E. Hedenström & T. Iversen. 2004. |
| **Title of paper** | Selective organolytic organolytic ring-opening polymerization: a versatile route to carbohydrate-functionalized poly(ε-caprolactones). |
| **Journal/conference** | Macromolecules 37, 5889-5893. |

| | |
|---|---|
| **Author:** | Gustavsson, M.T., P.V. Persson, T. Iversen, M. Martinelle, K. Hult, T. Teeri & H. Brumer. 2005. |
| **Title of paper** | Modification of cellulose fiber surfaces using a lipase and a xyloglucan endotransglycosylase. |
| **Journal/conference** | Biomacromolecules 6, 196-203. |

| | |
|---|---|
| **Author:** | Persson, P.V., T. Iversen & A. Córdova. 2006. |
| **Title of paper** | Direct organolytic synthesis of dendrimer-like star polymers. |
| **Journal/conference** | Macromolecules 39, 2819-2822. |

***<u>Project 20</u>, Phase 3: 2002 – 2004***

| | |
|---|---|
| **Author** | Olsson, A-M. & L. Salmén. 2002. |
| **Title of paper** | Mechanical properties of hemicelluloses related to water |
| **Journal/conference** | Proc. 7th European Workshop on Lignocellulosics and Pulp. August 26-29, 2002 Turku/Åbo, Finland. (Oral presentation). |

| | |
|---|---|
| **Author** | Olsson, A-M. & L. Salmén. 2004. |
| **Title of paper** | The softening behavior of hemicelluloses related to water. |
| **Journal/conference** | ACS Symp. Ser. 864, 184-197. |

***<u>Project 30</u>, Phase 3-4: 2002 – 2007***

| | |
|---|---|
| **Author** | Kallas, Å., L. Filonova, J. Lehtiö, L. Greffe, G. Daniel & T. Teeri. 2004. |
| **Title of paper** | Carbohydrate binding modules as analytical tools for mapping surfaces. |
| **Journal/conference** | Proc. 9th Int. Conf. Biotechnol. Pulp Paper Ind., 10-14 October 2004, Durban, South Africa |

| | |
|---|---|
| **Author** | Daniel, G., L. Filonova, Å.M. Kallas & T.T. Teeri. 2006. |
| **Title of paper** | Morphological and chemical characterization of the G-layer in tension wood fibres of *Populus tremula* and *Betula verrucosa*: Labelling with cellulose-binding module $CBM1_{HjCel7A}$ and Fluorescence and FE-SEM microscopy. |
| **Journal/Conference** | Holzforschung 60, 618-624. |

| | |
|---|---|
| **Author** | Teeri, T., H. Brumer III & G. Daniel. 2007. |
| **Title of paper** | Biomimetic engineering of cellulose-based materials. |
| **Journal/Conference** | Trends in Biotechnology 25(7), doi:10.1016/j.tibtech.2007.05.002. |

| | |
|---|---|
| **Author** | Filonova, L., Å.M. Kallas, L. Greffe, G. Johansson, T.T. Teeri & G. Daniel. 2007. |
| **Title of paper** | Analysis of the surfaces of wood tissues and pulp fibres using carbohydrate-binding modules specific for crystalline cellulose and mannan. |
| **Journal/Conference** | Biomacromolecules 8(1), 91-97. |

| | |
|---|---|
| **Author** | Filonova, L., L. Cicortas Gunnarsson, G. Daniel & M. Ohlin. 2007. |
| **Title of paper** | Synthetic xylan-binding modules for mapping of pulp fibres and wood sections. |
| **Journal/Conference** | BMC Biotechnology, 7:54 54. |

| | |
|---|---|
| **Author** | Daniel, G., L. Filonova, T.Teeri, 2007. |
| **Title of paper** | Topochemical and morphological characterization of tension wood and pulp fibres using carbohydrate binding modules and correlated fluorescence and FE-SEM. |
| **Journal/Conference** | The Pan-American Regional Group, International Association of Wood Anatomists (IAWA ), San Luis Potosi, Mexico, August 2007. |

***<u>Project 32</u>, Phase 3-4: 2004-2007***

| | |
|---|---|
| **Author** | Christiernin, M., A.B. Ohlsson, T. Berglund & G. Henriksson. 2005. |
| **Title of paper** | Analysis of lignin isolated from primary walls of hybrid aspen cell suspension cultures indicates large differences from secondary cell wall. |
| **Journal/Conference** | Plant Physiology and Biochemistry 43, 777-785. |

| | |
|---|---|
| **Author** | Henriksson, G., M. Lawoko, M. Christiernin & M. Henriksson. 2005. |
| **Title of paper** | Monocomponent endoglucanases – An excellent tool in wood chemistry and pulp processing. |
| **Journal/conference** | 13th ISWFPC, Auckland, New Zeeland 16-19 May, 2005. 4D22. V2, p. 503-508. |

| | |
|---|---|
| **Author** | Christiernin, M., L. Zhang , T. Nilsson & G. Henriksson. 2005. |
| **Title of paper** | Analysis of lignin isolated from spruce with secondary cell wall removed. |
| **Journal/conference** | 13th ISWFPC, Auckland, New Zeeland 16-19 May, 2005. Poster 12. V3, p. 73-80. |

| | |
|---|---|
| **Author** | Christiernin, M., A.B. Ohlsson, T. Berglund & G. Henriksson. 2005. |
| **Title of paper** | Analysis of lignin isolated from poplar cell suspension cultures |
| **Journal/conference** | 13th ISWFPC, Auckland, New Zeeland 16-19 May, 2005. Poster 13. V3, p. 81-86. |

| | |
|---|---|
| **Author** | Christiernin, M., A.B. Ohlsson, T. Berglund & G. Henriksson. 2006. |
| **Title of paper** | Analysis of lignin isolated from primary walls of hybrid aspen cell suspension cultures indicates large differencies from secondary wall |
| **Journal/conference** | Plant Physiology and Biochemistry 43, 777-785. |

| | |
|---|---|
| **Author** | Christiernin, M. 2006. |
| **Title of paper** | Structure of lignins in developing xylem of Norway spruce. |
| **Journal/conference** | Plant Physiology and Biochemistry 43(11-12), 693-699. |

| | |
|---|---|
| **Author** | Christiernin, M. 2006. |
| **Title of paper** | Ligin composition in cambial tissues of poplar. |
| **Journal/conference** | Plant Physiology and Biochemistry 43(11-12), 700-706. |

| | |
|---|---|
| **Author** | Henriksson, G., L. Zhang, T. Nilsson, A.B. Ohlsson & T. Berglund. 2006 |
| **Title of paper** | Inhomogeneity in lignin structure between different cell wall layers in conifers and hardwood. |
| **Journal/conference** | Proc. 5th Plant Biomechanics Conf., Stockholm, August 28-September 1, 2006, p. 145-150. |

***Project 33, Phase 3-4: 2002 – 2007***

| | |
|---|---|
| **Author** | Hildén, L., J. Zhang, E. Persson, G. Johansson & J. Brändström. 2006. |
| **Title of paper** | Distribution and characterization of discolouring substances appearing in Norway spruce (*Picea abies* L. Karst.) pulp wood stored under water sprinkling. |
| **Journal/conference** | Holzforschung 60, 93-98. |

***Project 34, Phase 4: 2005-2007***

| | |
|---|---|
| **Author** | Lindström, M.L., F. Berthold, T. Iversen, K. Gamstedt, P.V. Persson & C. Neagu. 2005 |
| **Title of paper** | Nano or not nano: Strategies in the development of new biofiber composite materials. |
| **Journal/conference** | Abstracts of Papers at the American Chemical Society, 229 (2005), U310-U311. |

| | |
|---|---|
| **Author** | Neagu, R.C., E.K. Gamstedt & F. Berthold. 2006. |
| **Title of paper** | Characterization methods for elastic properties of wood fibres from mats for composite materials. |
| **Journal/conference** | Wood and Fiber Science 36, 95-111. Second price in: "The George G. Marra Award of excellence in research and writing", 10 June 2007, http://www.swst.org/marrarecip.html |

| | |
|---|---|
| **Author** | Neagu, R.C., E.K. Gamstedt, S.L. Bardage & M. Lindström. 2007. |
| **Title of paper** | Ultrastructural features affecting mechanical properties of wood fibres. |
| **Journal/conference** | Wood Material Science & Engineering 1, 146-170. |

| | |
|---|---|
| **Author** | Neagu, C. & E.K. Gamstedt. 2007. |
| **Title of paper** | Modelling of effects of ultrastructural morphology on the hygroelastic properties of wood fibres. |
| **Journal/conference** | Journal of Materials Science 42: 24, 10254-10274. |

| | |
|---|---|
| **Author** | Berthold, F., C. Neagu, K. Gamstedt & M. Lindström |
| **Title of paper** | The influence of pulp fibre quality on the mechanical properties of a vinyl ester composite. |
| **Journal/conference** | Proc. of the Pre-Symposium on Chemistry and Performance of Composites Containing Wood and Natural Plant Fibres, 59th Appita Annual Conference and Exhibition, 2005, p. 33-40. |

| | |
|---|---|
| **Author** | Neagu, R.C., E.K. Gamstedt & M. Lindström. 2006. |
| **Title of paper** | Modelling the effects of ultrastructural morphology on the elastic properties of wood fibres |
| **Journal/Conference** | Proc. 5th Plant Biomechanics Conf., Stockholm, August 28-September 1, 2006, p. 193-198. |

| | |
|---|---|
| **Author** | Wilhelmsson, D., R.C. Neagu, S. Bardage & E.K. Gamstedt. 2006. |
| **Title of paper** | Finite element modelling of mechanical properties of geometrically characterized wood fibers. |
| **Journal/conference** | Proc. 5th Plant Biomechanics Conf., Stockholm, August 28-September 1, 2006, p. 181-186. |

***Project 35, Phase 4: 2005-2007***

| | |
|---|---|
| **Author** | Wäne, G., Basta J., Järnström L. & U. Germgård. 2007. |
| **Title of paper** | Influence of bleaching methods on fibre surface properties and effects of ageing softwood pulps. |
| **Journal/conference** | Appita Journal 60, (5) 396-399. |

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# *Appendix 2.*

## *Scientific Output:*

## *WURC-Industry Interactive Seminars;*

## *WURC International Seminars*

## ***WURC-Industry Interactive Seminars***

Duchesne, I. The ultrastructure of wood fibre surfaces. Presentation of WURC Project 2 at SCA Research, Sundsvall, Jan. 1999.

Hult E-L. 1999. Fiberkemi-cellulosa och hemicellulosastruktur. Poster. Information Day STFI Basic Research.

Molin, U. 1999. The fibre strength of pulp fibres. Presentation of WURC Project 5, SCA Research, Sundsvall, Jan. 1999.

Nyholm, K., & P. Ander. 1999. Dislokationer eller noder i vedfibrer. June 16, MoDo, Örnsköldsvik, Oral presentation.

Brändström, J. 2000. Fibermodeller. AssiDomän Corporate R & D Piteå. Oral presentation.

Bardage, S. L. 2000. 3D visualisering av trä- och massafibrer. WURC board meeting, 30 May, Arlanda.

Duchesne, I. 2000. Surface composition of kraft pulp fibres using XPS and FE-SEM. April 26-27, Eka Chemicals, Bohus, Sweden.

Duchesne, I. 2000. Preliminary XPS and FE-SEM results obtained on kraft pulp fibres. March 27, Akzo Nobel Chemicals General Science, Dept. of Microstructure Analysis, Arnhem, The Netherlands.

Duchesne, I. 2000. Results from Project 2. The ultrastructure of wood fibre surfaces. May 2, Korsnäs, Gävle.

Bardage, S. & Brändström, J. 2001. 3-dimensionell simulering av tracheid cellväggar. WURC seminarium 12 februari, SCA, Sundsvall.

Daniel, G. 2001. Ultrastrukturen hos vedfiberns ytor. WURC seminarium 12 februari, SCA, Sundsvall.

Molin, U. & Teder, A. 2001. Fiberstyrka hos massafibrer. WURC seminarium 12 februari, SCA, Sundsvall.

Brelid, H. 2001. Ultrastrukturell modifiering av ved med avseende på metalljoner + sulfatkokets inverkan på metalljoner. WURC seminarium 12 februari, SCA, Sundsvall.

Nyholm, K. & Ander, P. 2001. Dislokationer och noder i vedfibrer. WURC seminarium 12 februari, SCA, Sundsvall.

Fahlén, J. 2001. Ultrastrukturella ändringar vid mekanisk bearbetning och torkning av massa. WURC seminarium 12 februari, SCA, Sundsvall.

Presentation 2002 of WURC to four researchers from M-real at SLU, 7 March, Uppsala.

1. S. Bardage, SLU: Presentation of WURC
2. P. Ander, SLU: Dislocations in fibres
3. J. Fahlén, STFI: Ultrastructural modification after mechanical processing and drying of pulp
4. T. Larson, STFI: Fibre chemistry. Structural design of cell wall-NMR
5. T. Iversen, STFI: Fibre chemistry. Structural design of cell wall-Mineralisation
6. S. Bardage, SLU: Fibre models

Ander, P. 2003. Education HCl-method. Two researchers from Södra Cell. July, SLU, Uppsala.

Ander, P. 2004. WURC/Fiberdislokationer i granvedsfibrer, bildning, egenskaper, ultrastruktur samt inverkan på arkegenskper. Lecture February 2004 at SCA, Sundsvall.

Ander, P. 2006. Education HCl-method; Anette Heijnesson-Hultén, EKA Chemicals. May, SLU, Uppsala.

## ***WURC Internal Seminars***

## *1) Date: 10 February 1998; Place: Borgvik, Säffle*

Mohlin, U-B.: Massans egenskaper.

Brolin, A.: Fiberns roll i fibernätverket.

Salmén, L.: Fiber och vatten – porstruktur.

Peng, F.: Ved och fiberdimensioner. *Sulfatmassans egenskaper – inverkan av vedråvara och process.*

Rehnberg, O.: Ved och fliskondition. *Sulfatmassans egenskaper – inverkan av vedråvara och process.*

Högman, S.: Kontinuerlig kokning + $O_2$-delignifiering. *Sulfatmassans egenskaper – inverkan av vedråvara och process.*

Jansson, U.: Batchkokning. *Sulfatmassans egenskaper – inverkan av vedråvara och process.*

Holm, A-S.: Blekning. *Sulfatmassans egenskaper – inverkan av vedråvara och process.*

Nilsson, T.: Vedfibers uppbyggnad. *Ultrastrukturell nivå.*

Duchesne, I.: Fiberytor, literatursammanställning. *Ultrastrukturell nivå.*

Iversen, T.: Cellulosastrukturer i ved och massa. *Ultrastrukturell nivå.*

Westermark, U.: Kondensationsreaktioner under kokning. *Ultrastrukturell nivå.*

Olm, L.: Selektiv ligninutlösning i koket. *Ultrastrukturell nivå.*

Brelid, H.: Metaller i ved och massa, förekomst och roll. *Ultrastrukturell nivå.*

Peng, F.: Fiberdimensioner. *Fiberns morfologiska struktur.*

Nilsson, T.: Fiberns ultrastruktur – vägg, yta m m. *Fiberns morfologiska struktur.*

Laine, J.: Fiberns ytkemi – laddning. *Fiberns morfologiska struktur.*

Salmén, L.: Vattenupptagande förmåga. *Fiberns morfologiska struktur.*

Mohlin. U-B: Fiberskador. *Fiberns morfologiska struktur.*

Hult, E-L: Cellulosa och hemicellulosa. *Topokemi och kemisk struktur.*

Westermark, U.: Lignin. *Topokemi och kemisk struktur.*

Salmén, L.: Samverkan mellan polymerer. *Topokemi och kemisk struktur.*

Eriksson, I.: Skogen, råvaran. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?*

Rehnberg, O.: Vedgård och renseri. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?*

Högman, S., Jansson, U. & L. Olm: Kokeri- och $O_2$-delignifiering. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?*

Eriksson, I.: Sileri. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?*

Holm, A-S: Blekning. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?*

Salmén, L.: Torkning. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?*

Brolin, A.: Fiberstyrka och/eller flexibilitet. *Vad är väsentligt hos fibermaterialet för att erhålla styrka hos arket.*

Mohlin, U-B: Malning och formning. *Vad är väsentligt hos fibermaterialet för att erhålla styrka hos arket*.

Gellerstedt, G.: Vilka kompletteringar behövs? *Vad tar programmet hand om?*

## *2) Date: 25 May 1999; Place: Lastberget, Bålsta*

Molin, U.: Cellulosa/hemicellulosa och styrka. *Forskningsresultat*.

Hult, E-L: Cellulosa och hemicellulosa – mängd och struktur i olika massor. *Forskningsresultat*.

Duchesne, I.: Fiberytors ultrastruktur – FE-SEM iakttagelser. *Forskningsresultat*.

Nyholm, K.: Dislokationer. *Forskningsresultat*.

Berglund, A.: Metallfördelning. *Forskningsresultat*.

Brändström, J.: Fiberstruktur – modeller. *Forskningsresultat*.

Vickes, M.: Mekanisk interaktion mellan vedpolymerer. *Forskningsresultat*.

Önnerud, H.: Lignin och hemicellulosastruktur. *Forskningsresultat*.

Basta, J. (Eka): Fiberforksning inom Akzo. *Karakterisering av massor*.

Sandström, P. (SCA): Brottseghet – körbarhet. *Karakterisering av massor*.

Jansson, U. (Södra): Prediktion av massastyrka med hjälp av fibermätningar. *Karakterisering av massor*.

Marklund, A. (MoDo): Massastyrka – fiberdimensioner. *Karakterisering av massor*.

Högman, S. (Korsnäs): Fibermaster – fiberdeformationer. *Karakterisering av massor*.

Thuvander, F. (Karlstad Univ.): Ny metod för bestämning av fiberns mekaniska egenskaper. *Karakterisering av massor*

Rehnberg, O. (AssiDomän): Homogenisering eller särbehandling av råvaror – inverkan på massaegenskaper. *Egenskaper*.

Lif, J. (StoraEnso): Papperets fukt- och tidsberoende mekaniska egenskaper. *Egenskaper*.

Östlund, S. (KTH-STFI): Massa och papper sedda med materialtekniska ögon. *Egenskaper*.

## *3) Date: 15-16 November 2000; Place: Ansgarsliden, Sigtuna*

***Recents WURC results:***

| | | |
|---|---|---|
| ***II*** | ***Projects 2, 9, 10*** | ***Cell wall ultrastructure & morphology*** |
| ***III*** | ***Projects 4, 7, 11*** | ***Fibre chemistry of wood polymers at molecular level*** |
| ***IV*** | ***Projects 6, 6A (13)*** | ***Metals in wood*** |
| ***V*** | ***Projects 5, 8, 12*** | ***Physical properties of fibres*** |
| ***VI*** | ***Project 3*** | ***Dislocations and structural damages*** |

*Industry* - Current problems which need answers; new practical experiences which need to be considered.

*AssiDomän* : Sågverksflis - en massaråvara med varierande kvalitet

*EKA Chemicals*: Bleaching and Fibre

*Korsnäs*: Behandling av blekt barrvedsmassa med cellulaser

*MoDo Paper*: Inverkan av huggningsbetingelser på fiber- och massaegenskaper

*SCA*: Styrkeförluster vid kokning och syrgasblekning

*Stora Enso*: Strength Delivery

*WURC Scientists* - What have we learnt us so far? Our understanding of fibres before WURC and now. (*Input from all WURC project leaders and Ph.D students*)

How can we best utilize the results so far? (*Industry)*

Where do we go from here? Phase 3? What do we do now to best utilize the results? (*All round discussion – all WURC participants*)

THEME DISCUSSION: *Modelling of fibres*: A tool for understanding fibre ultrastructure and chemical and physical properties

Fibre, ultrastructure & nanostructure modelling:
a) Whole fibre and cell wall modelling (*Project 1*)
b) Molecular cell wall modelling (*Project 14 - L. Eriksson, Bo Durbeej*)

## *4) Date: 30-31 October 2001; Place: Aronsborg, Bålsta*

Theme: Vår fiber i Norden. Ny kunskap för framtida nyttjande. Together with Research School on Wood and Wood Fibre supported by SJFR (Forskarskolan Trä och Träfiber).

Program Day 1

Eriksson, L., STFI: *Skogsindustrins behov av tvär- och mångvetenskaplig forskning och utbildning*

Sandberg, G., SLU: *Skogsbioteknik*

Karlsson, M., SLU: *Molekylär reglering av lignifiering i asp*

Gregersen, O., Norske Skog: *Skogsindustriell forskning och utbildning i Norge*

Johansson, J., LuTU: *Oförstörande prövning av trä med mikrovågor*

Lagerström, J., Svenskt Trä: *Den trämekaniska industrins framtida FoU*

Olesen, P.O., KVL, Denmark: *Biofibres for new material and products*

Önnerud, H., KTH: *Ligninets inhomogena struktur*

Viikari, L.,VTT, Finland: *Use of enzymes in the pulp and paper industry*

Sjöberg, J., STFI: *Fiberytans hemicellulosor*

Paulapuro, H., HUT, Finland: *International academic programs on pulp and paper technology in Finland*

Hällgren, J.-E., SLU: *Avslutningsanförande*

Program Day 2 for WURC researchers

Group meetings and general discussion about the future.

Lectures on Mechanical Pulping – "*Ultrastructure of mechanical pulping*":
Höglund, H., Mid-Sweden University, Sundsvall
Zhang, Y., Holmen, Hallstavik

## *5) Date: 26-27 February 2002; Place: Stora Bränbo, Sigtuna*

***Kick-off meeting and seminar WURC Phase 3***

Program Day 1.

Industrial Advisory Group meeting
Pulp 2000
Strength delivery
Refiner Project

Program Day 2. (Projects for WURC Phase 3)

***I. Mechanical and physical properties of fibre materials***

-IFP-1. Changes in fibre properties & morphological organisation during processing (Industry/STFI/SLU)

-IFP-2. Effects of refining on wood fibre structure (Industry/STFI/SLU)

-IFP-0. Pulp 2000 (Massa 2000) (Industry/STFI/SLU)

-Dislocations in wood fibres (SLU)

-Mechanical cooperation & orientation of wood polymers in the wood structure (STFI)

-Ultrastructural modifications after mechanical processing & drying of pulp (STFI)

-Mechanical properties of hemicelluloses within the fibre cell wall matrix (STFI)

***2. Cell wall ultrastructure***

-Ultrastructural studies of wood fibres using specific enzymes (SLU/UU)

-Fibre cell wall biosynthesis (SLU/KTH)

-Mechanical pulp fibres (Industry/SLU/STFI)

-Carbohydrate binding modules as analytical tools for fibre structure (KTH/SLU)

-Fibre surface ultrastructure Part II (SLU)

-Occurrence & morphological distribution of metals in wood with sulphate cooking (CTH/SLU)

***3. Fibre chemistry of wood polymers at the molecular level***

-Lignin & hemicellulose structures in wood (KTH)

-Fibre chemistry of supramolecular nano-aggregates (STFI)

-Characterisation of lignin from surface cell wall layers (KTH)

***4. Wood and pulp fibre models***

-Pulp fibre models Part II – 3D modelling & visualisation (SLU)

-Molecular modelling (UU)

## *6) Date: 4-5 November 2002; Place: Kappa Kraftliner, Piteå*

Program Day 1.

Group meetings:
Industrial reference group
Industrial scientists
Ph.D-students

Presentation of Kappa Kraftliner: Ove Rehnberg
Visit to Kappa Kraftliner – “Sulfat och Pappersbruk”: Ove Rehnberg et al.

Program Day 2.

### *I. Mechanical & physical properties of fibre materials*

IFP-Changes in fibre properties/organization with processing: K. Sjöström *et al.* (Södra/Industry/STFI/SLU)

IFP-Effects of refining on wood fibre structure: A. Moberg/R. Bredemo *et al.* (StoraEnso/Kappa/SLU/STFI)

IFP-Massa 2000: StoraEnso *et al.* + WURC Scientists (STFI/SLU)

Project 3. Dislocations in wood fibres: P. Ander *et al.* (SLU)

Project 8. Mechanical cooperation & orientation of wood polymers: L. Salmén *et al.* (STFI

Project 12. Ultrastructural modifications after mechanical processing: L. Salmén *et al.* (STFI/SLU/KTH)

Project 15. Mechanical pulp fibres: J. Hafrén/J. Brändström/G. Daniel (SLU/SCA/Mitthögskolan)

Project 20. Mechanical properties of hemicellulose within the fibre wall matrix: L. Salmén *et al.* (STFI)

Project 33. Microbial degradation of pulp wood: J. Brändström/E.Persson et al. (SLU/Holmen)

### *II. Cell wall ultrastructure and morphology*

Project 2. Fibre surface ultrastructure. Part 2: G. Daniel et al. (SLU)

Project 9. Utrastructural studies of wood using specific enzymes: G. Johansson *et al.* (UU/SLU)

Project 10. Fibre cell wall biosynthesis: E. Mellerowicz/B. Sundberg/G. Daniel *et al.* (SLU/KTH/STFI)

Project 13. Occurrence & morphological distribution of metals: H. Brelid *et al.* (CTH)

### *III. Fibre chemistry of wood polymers at the molecular level*

Project 19. Fibre chemistry of supramolecular nanoaggregates: T. Iversen *et al* (STFI/SLU)

Project 32. Characterization of lignin from surface cell wall layers: G. Gellerstedt *et al.* (KTH)

### *IV. Wood & pulp fibre models.*

Project 1. Fibre models part II: S. Bardage *et al.* (SLU)

Project 14. Molecular modelling of fibre cell walls: Leif Eriksson *et al.* (UU)

## *7) Date: 3-4 November 2003; Place: Nova Park Hotel, Arlanda/Knivsta*

Program Day 1.

Morning: WURC Board meeting SkyCity, Arlanda
Afternoon: Industrial Reference Group meeting (IRG) at Nova Park Hotel
Evening*: Forskningsutmaningar inom fiber- och cellulosaområdet*, T. Lindström (BiMAC/FPIRC/KTH)

Program Day 2.

### *1. Mechanical & physical properties of fibre materials*

IFP1. Strength Delivery (*K. Sjöström et al., Södra*)

IFP2. Effects of refining on wood structure (*A. Moberg et al., StoraEnso*)

IFP0. Massa 2000/Fibre models (*S. Bardage et al., SLU*)

Project 15. Mechanical pulp fibres (*J. Brändström et al., SLU*)

Project 8. Mechanical cooperation & orientation of wood polymers (*M. Åkerholm et al., STFI*)

### *2. Cell wall ultrastructure*

Project 9. Ultrastructural studies on wood fibres with enzymes (*L. Hildén et al.,* SLU/UU)

### *3. Fibre chemistry of wood polymers*

Project 19. Fibre chemistry of supramolecular aggregates (*T. Iversen et al., STFI*)

Project 32. Characterization of lignin from cell wall layers (*G. Henriksson et al., KTH*)

### *4. Wood and pulp fibre models*

Project 14. Molecular modelling (*L. Eriksson et al., UU*)

## *8) Date: 20 April 2004; Place: Room L, SLU, Uppsala*

### *1. Mechanical and physical properties of fibre materials*

IFP-1. Changes in fibre properties & morphological organization during processing “Strength Delivery”. (*K. Sjöström et al., Södra*)

Project 3. Dislocations in wood fibres (*N. Terziev et al., SLU*)

Project 12. Ultrastructural modifications after mechanical processing and drying of pulp (*J. Fahlén et al., STFI*)

Project 20. Mechanical properties of hemicelluloses within the fibre wall matrix (*L. Salmén, STFI*)

Project 15. Ultrastructural studies on mechanical pulp fibre surfaces (*D. Fernando & J. Hafrén, SLU*)

Project 33. Ultrastructural studies of post harvest changes in wood (*L. Hildén & E. Persson, SLU & Holmen*)

### *2. Cell wall ultrastructure*

Project 9. Studies on wood fibres with specific enzymes (*G. Johansson, Lars Hildén, UU/SLU*)

Project 10. Biosynthesis of the fibre cell wall (*B. Sundberg et al., SLU*)

Project 30. Carbohydrate binding modules (CBMs) as analytical tools for fibre structure (*Å. Kallas/L. Filonova et al. KTH/SLU*)

### *3. Fibre chemistry of wood polymers at the molecular level*

Project 19. Fibre chemistry of supramolecular nano-aggregates. (*T. Iversen et al., STFI*)

Project 32. Characterization of lignin from surface cell wall layers. (*G. Henriksson et al., KTH*)

***4. Wood and pulp fibre models***

Project 1. Part II Fibre models (*S. Bardage et al., SLU*)

Project 14. Molecular modeling (*L. Eriksson et al., Örebro Univ.*)

***New project outline:*** Wood cell ultrastructure, composites and engineering (*C. Neagu et al., STFI/KTH*)

## *9) Date: 7-8 February 2005; Place: Stora Bränbo, Sigtuna*

***Day 1: Meetings of Strength Delivery group, Refiner TMP project group and by IRG.***

***<u>Day 2: Project reports</u>***

***1. Mechanical and physical properties of fibre materials***

***Chemical pulps***

IFP-1. Changes in fibre properties & morphological organization during processing "Strength Delivery"
*(K. Sjöström et al., Södra/all companies + SLU/STFI)*

Project 3. Dislocations in wood fibres (*P. Ander & N. Terziev, SLU/M-real*)

IFP-2. Fundamental of fibre properties (*A. Moberg et al., StoraEnso/KTH*)

Project 12. Ultrastructural modifications after mechanical processing and drying of pulp (*J. Fahlén et al., STFI-Packforsk/Eka Chemicals*)

***Mechanical pulps***

IFP-4. Morphological differencies between pine & spruce for mechanical pulps (*E. Persson, et al., Holmen, SCA, StoraEnso, Eka Chemicals*)

Project 15. Ultrastructural studies on mechanical pulp fibre surfaces (*SLU/STFI/SCA/Mid Sweden Univ.*)

i) Surface ultrastructure; D. Fernando et al. (SLU/SCA)

ii) Fibre collapsibility; J. Brändström et al. (SLU/SCA)

Project 16. Physical properties of wood fibre outer wall layers (*J. Stevanic/L. Salmén, STFI-Packforsk/Holmen*)

Project 33. Post harvest changes in wood (*E.Persson/L. Hildén et al., SLU/Holmen*)

***2. Fibre wall ultrastructure & mechanical properties***

Project 10. Fibre wall biosynthesis. (*B. Sundberg et al., SLU/KTH/Sveaskog*)

Project 30. CBMs binding modules for fibre structure analysis (*Å. Kallas/L. Filonova et al., KTH/SLU*)

Project 2. Fibre surface ultrastructure (*G. Daniel/J. Hafrén et al., SLU/Eka Chemicals*)

Project 1. Part II Fibre models (*S. Bardage, SLU/Svea Skog*)

Project 34. Wood cell ultrastructure, composites and engineering (*C. Neagu/M. Lindström, STFI-Packforsk/KTH*)

***3. Fibre chemistry of wood polymers at the molecular level***

Project 14. Molecular modeling. (L. Eriksson et al., Örebro Univ.)

Project 19. Fibre chemistry of supramolecular nano-aggregates (*T. Iversen et al., STFI-Packforsk/SLU*)

Project 32. Characterization of lignin from surface cell wall layers (*G. Henriksson/M. Christiernin et al. KTH*)

## *10) Date: 20 September 2005; Place: Room L, SLU, Uppsala*

### *1. Mechanical and physical properties of fibre materials*

### *Chemical pulp fibres*

IFP-1. Changes in fibre properties & morphological organization during processing "Strength Delivery" *(K. Sjöström et al., Södra/all companies + SLU/STFI)*

IFP-2. Effects of refining on wood fibre structure (*A. Moberg et al., Lic./KTH, Stora Enso*)

Project 3. Dislocations in wood fibres (*P. Ander, SLU/M-real*)

### *Mechanical pulps*

IFP-4. Morphological differencies between *Pinus sylvestris, P. contorta* & *Picea abies* for mechanical pulps (*E. Persson, et al., Holmen, SCA, SLU, Mid Sweden Univ.*)

Project 15. Ultrastructural studies on mechanical pulp fibre surfaces (*G. Daniel/D. Fernando et al., SLU/Mid Sweden Univ., Holmen, StoraEnso PhD*)

Project 16. Physical properties of wood fibre outer wall layers (*J. Stevanic/L. Salmén, STFI-Packforsk/Holmen*)

Project 33. Ultrastructural studies of post harvest changes in wood (*L. Hildén/J. Brändström et al., SLU/Holmen*)

### *2. Fibre wall ultrastructure & mechanical properties*

Project 2. Fibre surface ultrastructure Part II (*J. Hafrén/G. Daniel et al., SLU, SCA, Eka Chemicals*)

Project 10. Fibre wall biosynthesis (*B. Sundberg et al., SLU/KTH*)

Project 30. CBMs binding modules for fibre structure analysis (*Å. Kallas/L. Filonova et al., KTH/SLU,Ph.D*)

Project 1. 3D modeling & visualization; Pulp fibre models II (*S. Bardage et al. SLU*)

Project 34. Transfer of hygromechanical properties: From the wood cell wall ultrastructure to composite material for engineering applications (*C. Neagu et al. STFI-Packforsk/KTH*)

### *3. Fibre chemistry of wood polymers at the molecular level*

Project 19. Fibre chemistry of supramolecular nano-aggregates. (*T. Iversen et al., STFI-Packforsk/SLU*)

Project 32. Characterization of lignin from surface cell wall layers. (*G. Henriksson/M. Christiernin, KTH*)*(Ph.D)*

### *Additional WURC Projects not presented*

Project 14: Molecular modelling. (*L. Eriksson et al., Örebro Univ.*).

Project 35: Surface properties of bleached hardwood kraft pulp fibres: Influence of wood raw material, bleaching sequence & storage. (*U. Germgård et al., Karlstad Univ./StoraEnso/Eka Chemicals) (Lic.*).

## *11) Date: 18-19 May 2006; Place: Sigtunahöjden, Sigtuna*

***Day 1: Strength Delivery project meeting.***

***<u>Day 2: Project reports</u>***

### *1. Mechanical and physical properties of fibre materials*

### *Chemical pulps*

IFP-1. Changes in fibre properties & morphological organization during processing "Strength Delivery"

*(K. Sjöström et al., Södra/all companies + SLU/STFI-Packforsk)*

Project 3. Dislocations in wood fibres (*P. Ander et al. SLU/M-real*)

IFP-2. Fundamental of fibre properties (*A. Moberg et al., StoraEnso/KTH*)

### *Mechanical pulps*

IFP-4. Morphological differencies between *Pinus sylvestris, P. contorta* & *Picea abies* for mechanical pulps (*E. Persson, et al., Holmen/SCA, StoraEnso, Eka Chemicals*.)

Project 15. Ultrastructural studies on mechanical pulp fibre surfaces (*G. Daniel/D. Fernando et al., SLU/MidSweden Univ., Holmen, StoraEnso PhD*)

Project 16. Physical properties of wood fibre outer wall layers (*J. Stevanic/L. Salmén, STFI-Packforsk/Holmen*)

Pulp & paper research at Karlstad Universiy (*Ulf Germgård*)

Studies on bleached pulps (*Gerd Wäne, Karlstad Univ.*)

Project 33. Ultrastructural studies of post harvest changes in wood (*L. Hildén et al., SLU/Holmen*)

### *2. Fibre wall ultrastructure & mechanical properties*

Project 10. Fibre wall biosynthesis (*E. Mellerowicz, B. Sundberg et al., SLU/KTH*)

Project 30. CBM binding modules for fibre structure analysis (*Å. Kallas/L. Filonova et al., KTH/SLU,Ph.D*)

Project 2. Fibre surface ultrastructure Part II (*J. Hafrén/G. Daniel et al., SLU, SCA, Eka Chemicals*)

Project 1. 3D modeling & visualization; Pulp fibre models II (*S. Bardage et al., SLU*)

Project 34. Transfer of hygromechanical properties: From the wood cell wall ultrastructure to composite material for engineering applications (*C. Neagu et al. STFI-Packforsk/KTH*)

### *3. Fibre chemistry of wood polymers at the molecular level*

Project 14. Molecular modeling (*L. Eriksson et al., Örebro Univ.*)

Project 19. Fibre chemistry of supramolecular nano-aggregates (*T. Iversen et al., STFI-Packforsk/SLU*)

Project 32. Characterization of lignin from surface cell wall layers (*G. Henriksson/M. Christiernin, KTH*)*(Ph.D)*

## *12) Date: 20-21 September 2006; Place: Johannesbergs slott*

### *Meeting theme: "Gaps in knowledge" and the future of WURC*

***Participants:***

**WURC Scientists**
Lennart Salmén (STFI-Packforsk)
Tommy Iversen (STFI-Packforsk)
Leif Eriksson (Örebro Univ.)
Björn Sundberg (SLU)
Paul Ander (SLU)
Stig Bardage (SLU)
Gunnar Henriksson/Göran Gellerstedt (KTH)
Mikael Lindström (KTH)
Lars Wågberg (KTH)

**WURC's International Advisory Board**
Malcolm Brown (Univ. Texas, USA)

**Industry Representetives**
Peter Sandström (SCA)
Ann Marklund (M-real)

**WURC´s Board**
Lennart Eriksson
Geoffrey Daniel
Lars Ödberg

***Research papers intended as a forum for discussion of a future WURC application.***

Bernard Monties: From saving WURC´s ultrastructural knowledge at micro-and nanoscales to revealing of the macromolecular bases of wood organization: a proposal for two WURC´s challenges.

Lennart Salmén: Gaps in knowledge regarding fibre structure and fibre processing.

Tommy Iversen: Gaps in knowledge regarding fibre structure and fibre processing.

Leif A. Eriksson: Gaps in knowledge regarding fibre structure and fibre processing. Molecular modelling perspective.

Geoffrey Daniel: Gaps in our knowledge regarding fibre ultrastructure/microstructure and possible benefits of the information for fibre properties.

Björn Sundberg: Gaps in knowledge regarding fibre structure and fibre processing.

Paul Ander: WURC Project 3. Dislocations in wood fibres – "Gaps in knowledge".

Stig Bardage: Gaps in our knowledge. Project: Fibre models.

Gunnar Henriksson/Göran Gellerstedt: Structural inhomogeneities in lignins.

Mikael Lindström: Gaps in knowledge regarding hemicellulose ultrastructure and it's impact on paper strength.

Mikael Lindström/Martin Ragnar. Gaps in our knowledge regarding tochemical hindrance of efficient bleaching.

Lars Wågberg: Gaps in our knowledge. Interactions between fibres, moist air and water and the influence of water on fibre properties.

Mikael Lindström/Kristofer Gamstedt (STFI-Packforsk): Gaps in knowledge regarding fibre ultrastructure and mechanical properties of the fibre.

***Possible research areas:***

1) Products made from chemical pulps
2) Products made from mechanical pulps
3) Fundamental fibre structure; micro- and nanostructure

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# ***WURC International Seminars***

## ***1. WURC Inauguration***

***Date: 10 April 1997***
***Place: Swedish University of Agricultural Sciences, Uppsala, Main lecture hall***

*WOOD ULTRASTRUCTURE SEMINAR*
Chairman: *Inger Eriksson*, SCA AB

THE TRUE STRUCTURE OF WOOD FIBRES
Thomas Nilsson and Geoffrey Daniel, SLU, Uppsala

CONTROL OF WOOD FORMATION
Björn Sundberg, SLU, Umeå

ON THE FORMATION OF LIGNIN IN THE WOOD CELL WALL
Gösta Brunow, University of Helsinki, Finland

THREE-DIMENSIONAL STRUCTURE OF CRYSTALLINE CELLULOSE MICROFIBRILS
Olle Teleman, VTT, Finland

CHIRAL PROPERTIES OF CELLULOSE AND WOOD FIBRES
Derek Gray, PAPRICAN, McGill University, Montreal, Canada

## ***2. International Seminar 1998***

***Date: 22 April 1998***
***Place: Swedish University of Agricultural Sciences, Uppsala, Main lecture hall***

INTRODUCTION
*Lennart Eriksson, STFI, Chairman, WURC*

***SESSION 1 Chairman: Brita Swan WURC***

METAL IONS – WOOD ULTRASTRUCTURE
*Annica Berglund, Harald Brelid and Rune Simonson*
*Chalmers University of Technology (CTH)*

FUTURE CHEMICAL PULPING PROCESSES
*Ants Teder, Royal Institute of Technology (KTH)*

ENZYMES – TOOLS FOR ULTRASTRUCTURAL RESEARCH ON WOOD FIBRES
*Paul Ander, Swedish University of Agricultural Sciences (SLU)*

***SESSION 2 (Invited speakers) Chairman: Inger Eriksson, SCA***

TOWARDS A MORE COMPREHENSIVE MODEL FOR THE BIOGENESIS OF WOOD CELL WALLS: ORGANIZATION AT THE NANOSCALE LEVEL.
*Rajai Atalla, USDA, Forest Products Laboratory, Madison, USA*

THE VARIABILITY OF LIGNIN STRUCTURE AND LIGNIFICATION PATTERNS IN WOOD SPECIES AND ANNUAL PLANTS.
*Bernard Monties, INRA, Grignon, France*

MOLECULAR MODELLING OF LIGNOCELLULOSIC CELL WALLS.
*Lubo Jurasek, McGill University, Montreal, Canada*

***SESSION 3***
Report from an EU-project

THE STRENGTH OF WOOD FIBRES ASSOCIATIONS BETWEEN HEMICELLULOSE AND CELLULOSE AT THE MOLECULAR LEVEL.
*Olle Teleman and Andreas P. Heiner, Finland; Tommy Iversen and Tomas Larsson, Sweden; Bas Leeflang, The Netherlands; Gaston Gilli, Italy; PeterBiely, Slovakia*

## *3. International Seminar 1999*

***Date: 21 April 1999***
***Place: Swedish University of Agricultural Sciences, Uppsala, Main lecture hall***

INTRODUCTION TO WURC
*Björn Henningsson*, Swedish University of Agricultural Sciences, SLU

***SESSION 1 Chairman: Björn Henningsson, SLU/WURC***

DEVELOPMENT OF WURC AT THE EDGE OF THE NEW MILLENIUM
*Brita Swan*, WURC

SUPRAMOLECULAR STRUCTURE OF CELLULOSE IN SPRUCE WOOD AND KRAFT PULP
*Eva-Lena Hult*, *Tomas Larsson* and *Tommy Iversen*, STFI

A MULTIDISCIPLINARY APPROACH TO FIBRE WALL FORMATION – PRESENTATION OF A NEW PROJECT
*Björn Sundberg*, Swedish University of Agricultural Sciences (SLU), and *Tuula Teeri*, Royal Institute of Technology (KTH)

***SESSION 2 (Invited speakers) Chairman: Inger Eriksson, SCA***

CELLULOSE SYNTHASE GENES AND RELATED GENE PRODUCTS: ON THE ROAD TO THE FUTURE DESIGN OF CELLULOSE BIOSYNTHESIS IN THE WOOD CELL WALL
*Malcolm Brown Jr*., University of Texas at Austin, Austin, USA

NUMBER AND DISTRIBUTION OF CELLULOSE SYNTHASES, FIBRIL TO MATRIX RATIO, AND CELL GEOMETRY: PARAMETERS DETERMINING PLANT CELL WALL TEXTURE
*Anne Mie C. Emons*, Wageningen Agricultural University, The Netherlands

IMMUNOCYTOCHEMICAL STUDIES ON CELL WALL FORMATION IN WOODY PLANTS
*Keiji Takabe*, Kyoto University, Kyoto, Japan

***SESSION 3 Chairman: Geoffrey Daniel (SLU/WURC)***

COST ACTION E20 WOOD FIBRE CELL WALL STRUCTURE - SHORT INFORMATION
*Paul Ander*, Swedish University of Agricultural Sciences (SLU)

HIGHLIGHTS FROM WURC PROJECTS GENERATED DURING THE FIRST TWO YEARS

## *4. International Seminar 2000*

***Date: 12 April 2000***
***Place: Swedish University of Agricultural Sciences, Uppsala, Main lecture hall***

***SESSION 1 Chairman: Geoffrey Daniel (SLU/WURC)***

FIBRE STRUCTURE AND PAPER PROPERTIES
*Ulla-Britt Mohlin*, STFI

THE INFLUENCE OF MOLECULAR WEIGHT ON MECHANICAL PROPERTIES OF PULP FIBRES
*Ulrika Molin, Helena Lennholm and Ants Teder*, KTH

ULTRASTRUCTURE OF SPRUCE WOOD CELL WALLS
*Adya Singh*, Forest Research Institute, Rotorua, New Zealand

***SESSION 2 (Invited speakers) Chairman: Lars Ödberg, AssiDomän AB***

MOLECULAR DIRECTIONALITY IN CELLULOSE AND CHITIN MICROFIBRILS – A MICROSCOPIC APPROACH
*Junji Sugiyama*, Wood Research Institute, Kyoto University, Japan

SUPERMOLECULAR ARCHITECTURE OF CELLULOSE IN SOME NATIVE AND ARTIFICIAL SYSTEMS

*Tetsuo Kondo*, Forestry and Forest Products Research Institute, Tsukuba Norin Kenkyu, Ibaraki, Japan

NMR SPIN-RELAXATION OF SUBMICROSCOPIC STRUCTURES IN WOOD FIBRES
*Roger Newman*, Industrial Research Limited, Lower Hutt, New Zealand

***SESSION 3 Chairman: Thomas Nilsson (SLU/WURC)***

COST ACTION E20 "WOOD FIBRE CELL WALL STRUCTURE" – SHORT INFORMATION
*Paul Ander*, SLU

HIGHLIGHTS FROM WURC PROJECTS

## *5. International Seminar 2001*

***Date: 25 April 2001***
***Place: Swedish University of Agricultural Sciences, Uppsala, Loftet lecture hall***

***SESSION 1 Chairman: Geoffrey Daniel (SLU/WURC)***

DO FIBRE SURFACE PROPERTIES HAVE AN INFLUENCE ON PAPER STRENGTH?
*Janne Laine* (STFI)

CELL WALL STRUCTURE OF KRAFT PULP FIBRES AS DETERMINED BY DIFFERENT MICROSCOPY TECHNIQUES
*Isabelle Duchesne* (SLU/WURC)

ULTRASTRUCTURE OF WOOD AND PULP FIBRES
*EVA-LENA HULT* (STFI/WURC)

LIGNIN BIOSYNTHESIS AND DEGRADATION FROM A THEORETICAL PERSPECTIVE
*Leif Eriksson* (UU/WURC)

***SESSION 2 (Invited speakers) Chairman: Göran Gellerstedt (KTH/WURC)***

MONOLIGNOL COUPLING NETWORKS AND DOWNSTREAM METABOLISM: IMPLICATIONS FOR SAPWOOD AND HEARTWOOD FORMATION
*Norman Lewis* (USA)

PROPOSED 3D STRUCTURAL MODEL FOR SOFTWOOD LIGNIN IN THE CELL WALL
*Noritsugu Terashima* (Japan)

THE METABOLIC PLASTICITY OF LIGNIFICATION
*John Ralph* (USA)

***SESSION 3 Chairman: Thomas Nilsson (SLU/WURC)***

VARIABILITY OF MICROFIBRIL ANGLE IN SPRUCE
*Jonas Brändström* (SLU/WURC)

INHOMOGENEITIES IN THE CHEMICAL STRUCTURE OF SPRUCE LIGNIN
*Hans Önnerud* (KTH/WURC)

SUPRAMOLECULAR CHEMISTRY AT THE CELLULOSE FIBRIL SURFACES
*Thomas Larsson* (STFI/WURC)

CHANGES IN CELL WALL STRUCTURE DURING REFINING OF PULPS WITH DIFFERENT MOLECULAR WEIGHTS
*Ulrika Molin* (KTH/WURC)

REMOVAL AND REDISTRIBUTION OF METAL IONS DURING KRAFT PULPING
*Harald Brelid* (CTH/WURC)

## *6. International Seminar 2002*

***Date: 17 April 2002***
***Place: Swedish University of Agricultural Sciences, Uppsala Loftet lecture hall***

***SESSION 1: Mechanical Pulps***

***Chairman: Hans Höglund (Mid Sweden University)***

MECHANICAL PULP - A MIXTURE OF STIFF AND FLEXIBLE COMPONENTS
*HANS HÖGLUND* (MID SWEDEN UNIVERSITY)

THE CHARACTER OF MECHANICAL PULPS - DO WE KNOW ENOUGH?
*LARS JOHANSSON* (PFI, NORWAY)

SOME NEW METHODS TO CHARACTERIZE FINES FROM MECHANICAL PULPS
*LARS ÖDBERG* (ASSIDOMÄN, WURC)

SCANNING PROBE MICROSCOPY FOR THE SURFACE CHARACTERISATION OF NATURAL FIBRES
*JOUKO PELTONEN* (ÅBO ACADEMY UNIVERSITY, FINLAND)

***SESSION 2: Microscopy techniques and cellulose***

***Chairman: Geoffrey Daniel (SLU/WURC)***

AFM - POSSIBILITIES AND LIMITATIONS
*SHANNON NOTLEY* (FIBER SCIENCE AND COMMUNICATION NETWORK (FSCN), MID SWEDEN UNIVERSITY)

MODERN ELECTRON MICROSCOPY OF BIOLOGICAL SPECIMENS
*PAUL WALTHER* (UNIVERSITY OF ULM, GERMANY)

THE FAST MOVING FIELD OF CELLULOSE RESEARCH - A LOOK INTO THE FUTURE FOR THE FOREST PRODUCTS INDUSTRY
*MALCOLM BROWN* (UNIVERSITY OF TEXAS, USA)

***SESSION 3: WURC projects***

***Chairman: Lars Ödberg (AssiDomän/WURC)***

RECOGNITION OF MOLECULAR DIRECTIONALITY IN CRYSTALLINE BETA-CHITIN: HYDROLYSIS BY CHITINASES A AND B FROM *SERRATIA MARCESCENS* 2170
*EVA-LENA HULT* (STFI/WOOD RESEARCH INSTITUTE, KYOTO UNIVERSITY, JAPAN)

PROJECT 1: FIBRE MODELS
*STIG BARDAGE* (SLU/WURC)

PROJECT 10: EXPANSINS AND XYLOGLUCAN ENDOTRANSGLYCOSYLASES OF THE CAMBIAL REGION TISSUES
*EWA MELLEROWICZ* (SLU/WURC)

PROJECT 12: FIBRE ULTRASTRUCTURAL AND SURFACE CHANGES DURING MECHANICAL AND CHEMICAL TREATMENTS
*JESPER FAHLÉN* (STFI/WURC)

## *7. International Seminar 2003*

***Date: 23 April 2003***
***Place: Swedish University of Agricultural Sciences, Uppsala Loftet lecture hall***

***SESSION 1: Optimising the use of forest fibres in current production***
***Chairman: Geoffrey Daniel (WURC)***

MEASUREMENTS AND MODELS FOR IMPROVED FIBER UTILIZATION
*SVEN-OLOF LUNDQVIST* (STFI, SWEDEN)

STRENGTH DELIVERY - THE PULPING PERFORMANCE GAUGE
*PANU TIKKA* (HUT, FINLAND)

FIBRE CHARACTERISATION USING CONFOCAL MICROSCOPY
*HO FAN JANG* (PAPRICAN, CANADA)

TEXTURE ANALYSIS - A NEW METHOD FOR QUANTIFYING CELL WALL NANOSTRUCTURE
*LLOYD DONALDSON* (FOREST RESEARCH, NEW ZEALAND)

***SESSION 2: The potential of forest fibres in new products***
***Chairman: Malcolm Brown (Univ. Texas, USA)***

TOWARDS BIOMIMICKING OF WOOD: SELF-ASSEMBLY PHENOMENA AT CELLULOSE SURFACES
*PAUL GATENHOLM* (CTH, SWEDEN)

CAN COMPOSITE PRINCIPALS INSPIRE CREATION OF NEW FOREST FIBRE MATERIALS?
*LARS BERGLUND* (KTH, SWEDEN)

*CHEMO-ENZYMATIC MODIFICATION OF CELLULOSIC MATERIALS*
TUULA TEERI (KTH, SWEDEN)

***SESSION 3: WURC projects***
***Chairman: Lars Ödberg (WURC/SveaSkog)***

PROJECT 9: PULP CHARACTERISATION WITH CELLULOSE DEGRADATION ENZYMES
*LARS HILDÉN* (SLU/WURC)

PROJECT 19: SILICA-CAST REPLICA FOR MORPHOLOGY STUDIES ON WOOD AND PULP
*PER PERSSON* (STFI/WURC)

PROJECT 14: MOLECULAR MODELLING - AN ALTERNATIVE APPROACH IN WOOD ULTRASTRUCTURE RESEARCH
*BO DURBEEJ* (UU/WURC)

## *8. International Seminar 2004*

***Date:*** ***21 April 2004***
***Place:*** ***Swedish University of Agricultural Sciences, Uppsala Loftet lecture hall***

***SESSION 1: From the forest to fibres & microfibrils***
***Chairman: Geoffrey Daniel (WURC)***

FORESTRY RESEARCH AT SLU - SOME IDEAS ABOUT THE FUTURE FROM A STRATEGIC VIEWPOINT
*THORBJÖRN FAGERSTRÖM*, PRORECTOR SLU

THE MAIN SOURCES OF VARIATION IN WOOD PROPERTIES AND FIBRE DIMENSIONS - THE FORESTRY PERSPECTIVE
*LARS WILHEMSSON* (SKOGFORSK, SWEDEN)

CHEMICAL AND BIOLOGICAL VARIABILITY OF LIGNIFICATION STATES
*BERNARD MONTIES* (INRA, FRANCE)

THE EFFECT OF RAW MATERIALS AND REFINING ON FIBRE AND FIBRE-BASED COMPOSITE PROPERTIES
*LES GROOM* (USDA, USA)

RELATION OF THE STRUCTURE OF WOOD TO ITS MECHANICAL PROPERTIES: INVESTIGATION USING X-RAY SYNCHROTRON
*MARTIN MÜLLER* (KIEL, GERMANY)

***SESSION 2: Properties and future use of fibres***
***Chairman: Malcolm Brown (Univ. Texas, USA)***

FIBRE DAMAGES AND THEIR APPEARANCE IN THE MILL

*KARIN SJÖSTRÖM* (SÖDRA CELL, SWEDEN)

PROPERTIES AND FUTURE USE OF BIOFIBRES
*ROGER ROWELL* (USDA, USA)

CELLULOSE NANOCHEMISTRY, POSSIBILITIES FOR THE FOREST PRODUCTS INDUSTRY
*TOMMY IVERSEN* (STFI-PACKFORSK, SWEDEN)

***SESSION 3: WURC projects***
***Chairman: Lars Ödberg (WURC/SveaSkog)***

A NEW METHOD TO COMPARE INDUSTRIAL AND LABORATORY PULP FIBRES IN STRENGTH DELIVERY (SD) INVESTIGATIONS
*PAUL ANDER* (WURC/SLU, SWEDEN)

TOWARDS UNDERSTANDING MECHANISMS THAT REGULATE FIBRE MORPHOLOGY IN TREES
*EWA MELLEROWICZ* (WURC/SLU, SWEDEN)

MORPHOLOGICAL DISTRIBUTION OF METAL IONS IN SOFTWOOD KRAFT PULP
*HARALD BRELID* (WURC/CTH, SWEDEN)

## *9. International Seminar 2005*

***Date:*** ***21 September 2005***
***Place:*** ***Swedish University of Agricultural Sciences, Uppsala Loftet lecture hall***

WELCOME
***OVERVIEW OF WURC TODAY: Geoffrey Daniel (WURC/SLU)***

***SESSION 1: Fibres for the future***
***Chairman: Geoffrey Daniel (WURC/SLU)***

"SÖDRA INSIDE"-FUTURE FIBRE FUNCTIONALITY
*LEIF BRODÉN (SÖDRA CELL, SWEDEN)*

NEW FIBRE PRODUCTS AT WEYERHAEUSER: THREE CASE STUDIES
*MIKE MCCAW (WEYERHAEUSER, USA)*

THE GROWING FIBRE POTENTIAL OF MOLECULAR FIBRE BREEDING
*BJÖRN SUNDBERG (UPSC, SLU, SWEDEN)*

***SESSION 2: What happens to fibres in current processes***
***Chairman: Lennart Salmén (STFI-Packforsk)***

WURC STRENGTH DELIVERY PROJECT
*KARIN SJÖSTRÖM ET AL. (SÖDRA CELL, SWEDEN)*

SOME ASPECTS ON THE DIFFERENCIES IN PULP STRENGTH BETWEEN INDUSTRIAL AND LABORATORY KRAFT PULPS
*ELISABET BRÄNNVALL & MICHAEL LINDSTRÖM (KTH, SWEDEN)*

CHARACTERIZATION OF INDUSTRIAL SOFTWOOD FIBRE DAMAGE AND A NEW TESTING METHOD OF PULP FLUIDIZATION
*IRINA RAUVANTO & KAJ HENRICSON (TECH. UNIV. VILLMANSTRAND, FINLAND*

PULP STRENGTH AND FIBRE DEFECTS
*LEIF ROBERTSÉN (KCL, FINLAND)*

***SESSION 3: Modification of fibres – current & future***
***Chairman: Bernard Monties (INRA, France)***

PHYSICAL AND CHEMICAL MODIFICATION OF FIBRES. TAILORING OF SURFACES FOR OPTIMAL ADHESION
*LARS WÅGBERG (KTH, SWEDEN)*

ENZYMATIC MODIFICATION FOR PULP AND PAPER FIBRES
*HANNE HØST PEDERSEN (NOVOZYMES, DENMARK)*

BACTERIAL CELLULOSE AND ELECTRONIC PAPER
*R. MALCOLM BROWN, JR. (UNIV. TEXAS, USA)*

***SESSION 4: Fibres in future products***
***Chairman: Lars Ödberg (WURC/KTH)***

THE POTENTIAL OF WOOD FIBRES AS REINFORCEMENT IN BIOCOMPOSITES
*CHRISTIAN NEAGU (KTH/STFI-PACKFORSK/WURC, SWEDEN)*

FIBRE DISLOCATIONS – FROM FOREST TO PAPER PRODUCTS
*NASKO TERZIEV (WURC/SLU, SWEDEN)*

***The future of WURC***
***Lennart Eriksson (STFI-Packforsk), Chairman WURC***

## *10. International Seminar 2006*

***Date:*** ***28 August 2006***
***Place:*** ***5th Plant Biomechanics Conference, KTH, Stockholm (L. Salmén, STFI-Packforsk & WURC)***

WURC'S IMPACT ON OUR UNDERSTANDING OF WOOD FIBRE NANOSTRUCTURE
*GEOFFREY DANIEL (WURC/SLU, SWEDEN)*

INHOMOGENEITY IN LIGNIN STRUCTURE BETWEEN DIFFERENT CELL WALL LAYERS IN CONIFERS AND HARDWOOD
*GUNNAR HENRIKSSON (KTH, SWEDEN)*

INTERACTION OF THE COMPONENTS WITHIN THE OUTER FIBRE WALL LAYERS
*JASNA STEVANIC (STFI-PACKFORSK, SWEDEN)*

THEORETICAL MODELLING OF PHOTODEGRADATION OF LIGNIN AND SUBSTITUTED STILBENES
*LEIF A ERIKSSON (ÖREBRO UNIVERSITY, SWEDEN)*

DISLOCATION COUNTING AND COMPARISON OF PULP FIBRE PROPERTIES AFTER HCL-TREATMENT AND FIBRE LENGTH DETERMINATION
*PAUL ANDER (WURC/SLU, SWEDEN)*

REGENERATION FEATURES OF NORWAY SPRUCE FORESTS AND MECHANICAL PROPERTIES OF PAPER
*NASKO TERZIEV (WURC/SLU, SWEDEN)*

FINITE ELEMENT MODELLING OF MECHANICAL PROPERTIES OF GEOMETRICALLY CHARACTERIZED WOOD FIBRES
*DENNIS WILHELMSSON (KTH, SWEDEN)*

MODELLING THE EFFECTS OF ULTRASTRUCTURAL MORPHOLOGY ON THE ELASTIC PROPERTIES OF WOOD FIBRES
*CHRISTIAN NEAGU (KTH, SWEDEN)*

ULTRA-STRUCTURAL ARRANGEMENT AND REARRANGEMENT OF THE CELLULOSE AGGREGATES WITHIN THE SECONDARY CELL WALL
*LENNART SALMÉN (STFI-PACKFORSK, SWEDEN)*

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# *Appendix 3.*

## *WURC´s International evaluations:*

## *1998, 2001, 2004*

# The NUTEK Competence Centre Programme

## *First International Evaluation Competence Centre in Wood Ultrastructure Research, WURC*

## *June 1998*

NUTEK
Swedish National Board for Industrial and Technical Development

R 1998:28

# Foreword

The Swedish National Board for Industrial and Technical Development (NUTEK) regularly evaluates its R&D-programmes with the assistance of international experts.

The NUTEK Competence Centre Programme is an effort to build bridges between science and industry in Sweden by creating vigorous academic research environments in which industrial companies participate actively and persistently in order to derive long-term benefits. Over the period March 1995 - July 1996, 28 NUTEK Competence Centres at 8 universities or institutes of technology started their activities.

The Programme is intended to run for at least 5 and up to 10 years. The building-up and development of the centres is based on stepwise funding and follow-up. The main purpose of this first evaluation is to give an input to the decisions about the development of the Programme and of the individual Competence Centres.

During 1997 26 Competence Centres were evaluated in 3 groups:

Group 1. 12 centres for which Stage 1 expired in June 1997 were evaluated in March 1997 (NUTEK Report R 1997:18).

Group 2. 7 centres for which Stage 1 expired in August - October 1997 were evaluated in June 1997 (NUTEK Report R 1997:47).

Group 3. 7 centres for which Stage 1 expired in December 1997 were evaluated September 29 - October 2 1997 (NUTEK Report R 1997:76).

Two centres, which started during 1996, were evaluated during 1998:

* Speech Technology, CTT, at KTH was evaluated in January 1998 (NUTEK Report R 1998:2).

* Wood Ultrastructure Research Centre, WURC, at the Swedish University of Agricultural Sciences, SLU (this report).

As this first evaluation was carried out already after less than 20 months of activities, its primary purpose was not to review scientific and industrial results. The main focus of the evaluation has been to look into and review from an international point of view the introductory efforts to develop Competence Centres at Swedish universities.

The evaluation was carried out by international experts with experience from similar programs for university - industry research collaboration. The Team for the evaluation of this Centre consisted of two members of the group which has carried out the previous evaluations:

Professor Tom M. Husband
Chairman, UKERNA, UK Education and Research Networking Assoc.
Atlas Centre, Oxfordshire, United Kingdom

Dr Marshall M. Lih
Director, Division of Engineering Education and Centers
National Science Foundation, NSF
Arlington, USA

On behalf of NUTEK I want to express my great appreciation to the evaluators, who carried out this final part of the evaluation programme with the same professionalism and engagement as the previous ones. The reports will be of great value for the future development of the Competence Centres and the Programme.

Stockholm June, 1998

Christer Heinegård
Director
NUTEK Technology
Swedish National Board for
Technical and Industrial Development

# EVALUATORS´ REPORT

## CONTENTS

## 1. Preface, Methodology, and Acknowledgements

In this evaluation, we employed the same methodology as in previous ones without formally developing any new questions prior to the visit. We felt that by having evaluated 27 Centres before, we had accumulated a fairly consistent picture of how to pinpoint the strengths and weaknesses of a developing Competence Centre. Obviously new questions were asked as they occurred to us and/or as the situation suggested during the site visit.

We wish to express our appreciation to NUTEK and colleagues at the Wood Ultrastructure Research Centre for their time and effort in preparing for this visit. The fact that NUTEK brought us here from afar for just this one single Centre spoke loudly for its commitment to a high quality programme.

Uppsala, June 24, 1998

Prof. Tom M. Husband

Dr. Marshall M. Lih

## 2. Assessment of the Competence Centre in Wood Ultrastructure Research, WURC, Swedish University of Agricultural Sciences, SLU, Uppsala

*Summary*
WURC is seeking to establish a critical mass of faculty and student research teams. Continued University commitment is needed to maintain the momentum and to replace upcoming retirees. The research environment is healthy and stimulating to the doctoral students. Financial support from industry is solid; intellectual participation should be greatly strenghtened. Centre Leadership needs to be enhanced in terms of both time commitment and proactiveness.

*1. Competence Profile*
WURC is involved in basic research of relevance to industry. The research is based mainly at SLU but a key feature is the inputs from KTH, CTH and STFI. The research is highly multi-disciplinary in nature requiring expertise in fields such as plant anatomy, polymer chemistry, biochemistry and microbiology.

There seems to be a broad range of scientific expertise available within WURC but it is too early for a real critical mass to emerge. A matter for concern is the retirement of one of the central professors in the near future. His particular competence and expertise are crucial to WURC. It is important that WURC and SLU give serious consideration to dealing with this loss.

WURC has ambitions to become a leading international research centre. There are plans to involve visiting scientists from various countries in future years. This is an important dimension. Indeed the competence profile of WURC could benefit from organised inputs by international technical experts. It may be useful to establish a small international technical advisory group which might visit WURC on a, say, yearly or two yearly basis.

*2. Concentrated Research Environment*
Presently the research programme consists of eight projects in fibre and lignin structure, chemistry, strength, and models. Current emphasis is on spruce which is an important raw material for the Swedish pulp and paper industry. With the exception of the two newest ones, each project seems to have a team of appropriate research personnel in place. However, other than the collaboration between STFI and KTH, there does not appear to be much inter-institutional collaboration within each project. This is meant to be an observation, not necessarily a criticism.

The doctoral students at the site visit expressed strong enthusiasm for the positive environment provided by WURC. In addition to such "standard"

advantages for a centre as contacts and visits with industry, networking and exchanging results and information with other researchers, they indicated that they had also learned such nontechnical but important skills as communication, project planning, and company organization.

While NUTEK and WURC deserve to be congratulated for the success in building up the competence areas, we urge continued vigilance and flexibility in recruiting competent and committed new researchers and faculty to replace possible retirees in the not-too-distant future. New personnel needs to be able to interact with industry. Strategic thinking is needed here.

*3. Industrial Involvement and Interaction*
There are seven WURC industrial members drawn from leading companies in the sector. Due to the nature of the technology, they are mainly non-SME firms.

Currently the industrial partners provide very strong financial support. We suggest that WURC moves gradually towards a significant increase of in kind support from industrial members. This would ensure industrial relevance and value for its investment.

We were told at the site visit that it is an industry which has not put great emphasis on basic research. As a result there seems little by way of intellectual input from the industrial members. Nevertheless we learned from the PhDstudents that industrial members offer valuable practical assistance and support for their research projects.

Assuming intellectual capabilities exist, we suggest that WURC redouble its "evangelistic" effort and/or offer added incentives to elicit such participation by member companies. On the other hand, companies should offer opportunities for internship, seminar attendance, and other channels for university personnel to interact with them.

*4. Leadership and Management*
WURC is fortunate in having a Board Chairman who understands both industry and university dimensions. He clearly takes his role seriously and gives close consideration to the current position and future trends. The Centre is also fortunate in having a Director, who knows the relevant companies very well indeed. However we wonder if the nominal 20 % of her working week dedicated to WURC is sufficient. As WURC develops, the Director's role is likely to require at least a 50 % weekly input.

WURC has a Board, an Industrial Advisory Group, a Managing Group and a Researchers Group. We wondered if this is top-heavy. We also wondered if it is wise, in a collaborative centre, to separate the researchers from the industrial advisers. However this is a matter for WURC itself. If the present set up delivers good management then so be it.

The University Leadership is very supportive of the Centre, and places high priority on its programme and success. There is administrative support and two new research posts have been funded recently. This is a good sign since WURC is an important element of SLU activities.

It is important that the leadership of WURC continues to seek new industrial members and to greatly increase industrial participation in the Centre´s research and education programmes.

WURC needs a strategic development based on quantified targets e.g. numbers of PhDstudents, publications in particular international journals, numbers of patents, etc. It is not sufficient to argue that basic research cannot be dealt with in this way. For WURC to achieve its own ambitious aims it will be vital to create strategic measures.

*5. Recommendations*

- SLU should continue to give strong support for WURC and in particular give serious considerations to replacing the professor who retires soon, with a person of similar expertise and distinction.

- WURC should pursue its plans to invite distinguished overseas scientists to Uppsala and also to consider establishing an international advisory group.

- The role of the Centre Director is likely to require a major increase from the current nominal 20 % input if Phase 2 is to be dynamic and good support for PhDstudents is to be provided.

- WURC should seek to increase its industrial members and to greatly increase industrial in kind support and participation in the Centre´s programmes.

- WURC should develop a strategic plan for Phase 2 which sets out the objectives in as quantitative terms as possible.

*First Evaluation of the NUTEK Competence Centre Programme*

# Facts about the Wood Ultrastructure Research Centre, WURC

*The summary in this appendix is based on the Centre Report to the Evaluation Team and was edited by NUTEK. The Parties' contributions and the Industrial partners listed are according to the Competence Centre Agreement for stage 1.*

## Wood Ultrastructure Research Centre, WURC

Swedish University of Agricultural Sciences, SLU, Uppsala
Centre Director: Brita Swan
Chairman of the Board: Lennart Eriksson, Swedish Pulp and Paper Research Institute, STFI

Contributions (MSEK) Stage 1: July 1996 - June 1998
NUTEK: 5.24
SLU (incl. Chalmers, KTH and STFI): 6.6
7 Industrial Partners: 5.88
AssiDomän 1.0; Eka Chemicals 0.15; Korsnäs 0.775; Mo och Domsjö 0.94; SCA 0.73; STORA 1.71; Södra Cell 0.575

*Summary*
WURC's objective is to enhance industrial utilization of wood fibre by improving the understanding of its morphological and chemical ultrastructure, including the interaction between the constituent polymers and the changes that can be introduced in fibres during the processing.

Research will concentrate on wood and fibres from spruce and the research area comprises:
* ultrastructural morphology of wood and fibres
* surface ultrastructural morphology and chemistry of wood and pulp fibres
* chemistry of wood polymers on a molecular level
* metals and extratives in wood and fibres - their location and nature
* ultrastructure and related physical properties of pulp fibres.

In terms of competence profile, WURC is centered around the following disciplines: plant anatomy, electron microscopy, polymer chemistry, materials physics, polymer physics, biochemistry, microbiology.

WURC's main activities are at the Department fo Forest Products, SLU, where ultrastructural research has expanded significantly due to WURC. Chalmers University of Technology, the Royal Institute och Technology, KTH, and the Swedish Pulp and Paper Research Institute, STFI, provide important complementary competence and equipment. The participation from industry is gradually increasing.

WURC's international network develops steadily. Two international seminars have been arranged during stage 1 and a guest researcher from Japan is contracted.

September 27, 2001

# Evaluation of the Competence Centre Wood Ultrastructure Research Centre, WURC at the Swedish University of Agricultural Sciences, SLU, Uppsala

## 1. Preface, Methodology, and Acknowledgement

On Wednesday 26th September, 2001, the scientific experts of the evaluation team, Professors Derek Gray (Paprican/McGill University, Montreal, Canada) and Torbjörn Helle (Norwegian University of Science and Technology, Trondheim, Norway) visited the Competence Centre in Wood Ultrastructure Research(WURC) at the Swedish University of Agricultural Sciences (SLU) in Uppsala. They were given a summary of the research in progress by the Director of the Centre, Professor Geoffrey Daniel and gradute students and research staff of WURC. The next morning they were joined by the Competence Centre experts, Dr Marshall Lih (National Science Foundation, USA) and Professor Tom Husband (formerly Vice-Chancellor, Salford University, UK) for a General Review Meeting at SLU together with selected staff and graduate students from WURC, the vice rector of SLU, Christer Heinegård, WURC Board members and Industrial Reference Group members.

We would like to thank the Centre Director Professor Geoffrey Daniel and the Board Chair Lennart Eriksson for their efforts in planning a full and interesting programme to brief us on the progress of the Centre. A warm thank to the graduate students and staff who presented their research with enthusiasm and care, and acted as generous hosts. We thank Susanne Andersson and Staffan Hjorth of VINNOVA for their invitation to participate in the evaluation, and for looking after us patiently, and assisting in every way with the review process.

## 2. Development as a Competence Centre. Added Values

Long Term Strategies and Progress of the Centre

WURC has made impressive progress since the first evaluation in June 1998. The Centre responded positively to the recommendations suggested at that time and has built imaginatively on a sound base. The Centre is managed by an excellent Director and is moving towards a strategic future with the guidance of a highly competent Board and Chairman. The PhD-students we met were of a high quality and the all-round morale of the Centre seemed high.

WURC carries out fundamental research in the field of morphological and chemical ultrastructure of wood fibres. The broad aim is to enhance the efficient industrial utilisation of wood fibres and, consequently, is of central importance to Sweden´s pulp and paper industry.

The objective is to pursue pre-competitive research which WURC's industrial partners find attractive but infeasible to be done in-house. In addition, WURC seeks to produce relevant findings which serve as a basis for further R&D by its industrial partners.

We concluded that the Centre has begun to achieve these difficult objectives. WURC has established excellent technical resources, especially in microscopy and spectroscopy. It is building important synergies between the various disciplines and has an unrivalled access to all of the key facilities available in Sweden.

We also concluded that WURC has managed to avoid any serious overlap with research being pursued in sister organisations either in Sweden or internationally.

There are, naturally, some strategic areas which could be improved. For example it has proved extremely difficult to recruit industrial PhD/Licentiate students. This is a difficult problem to resolve. Nevertheless it is an aspect which WURC should persist in pursuing.

International Collaboration and Ranking

The 1998 evaluation of WURC recommended that the Centre should move quickly towards establishing an international profile. We are very pleased with the practical outcomes from the WURC response to this recommendation.

The Centre has hosted a series of international seminars. WURC has also led an EU COST initiative in wood fibre cell wall structure, involving 17 countries, which promises to act as a foundation for a future, major EU-funded project. We would urge WURC to continue to give this activity priority treatment. A major infusion of EU funds would be a valuable means of enhancing the international profile of the Centre.

It is pleasing to note that WURC has set up a panel of three acknowledged international experts from France, Japan and the USA. This action will help significantly to further establish the research profile of the Centre.

Another pleasing development in this context is the growing number of publications which have flowed from the Centre. Many of these have appeared in high quality national and international journals and conference proceedings.

Collaboration and Linkages within the Centre

WURC has developed a number of university/company interaction activities. For example industry partners have provided characterized pulp fibre material for several projects. There has been some joint supervision of diploma theses. Some PhD-students have had valuable industrial experience at partner facilities. Another good example is the joint participation at WURC internal seminars.

The WURC activities appear to have generated improved linkages between the main players. There appears to be enhanced interactions and cooperation between STFI, KTH, Chalmers, UU and SLU. Nevertheless the Centre staff stated that there is still room for

improvement in the interactions between senior scientists and that "old loyaties" must still be overcome so as to produce a truly intergrated Competence Centre. It was also agreed that, to keep momentum going, there is still a need for further improvement in liason across the Centre. We urge all concerned to keep tackling this inherently difficult organisational problem.

Identity and Management of the Centre

We are favourably impressed by the quality of the management of WURC. The Centre Director is highly motivated, hard working and able to transmit his enthusiasm to all concerned. It is good that he is now committed to 50% of his effort for the management of WURC. It is also good that the Centre is able to give the Director the additional support of 20% input from a senior industry partner.

The Board and its Chairman should also be congratulated on their efforts to think strategically and guide the Centre into the next, important phase of activity. It was pointed out to us that the Board is particularly pleased with the inputs from its Industrial Advisory Group. This structure is clearly working well. The June 1998 evaluation questioned the overall structure and wondered if it was top heavy. It still "looks" top heavy but since it is effective it should clearly stay in place.

We were told that there is general satisfaction with the level of support and encouragement given to WURC by SLU. This is important in our view and we urge SLU to continue to give the Centre all the assistance it can afford.

Overall, WURC seems to be developing a distinctive identity and is well managed. The prospects for the next phase are very encouraging.

## 3. Scientific and Technical Achievements

Research Programme

The objective of WURC is to contribute to a significantly increased basic knowledge of the chemical and morphological structure and characteristics of wood and wood fibres. It is our opinion that the work that has been undertaken during the evaluation period has been well focused in the planned directions. The work has been concentrated on Norway spruce, in accordance with the opinion of the industrial partners. The industry's interests in this respect have been secured by the industry having supplied the scientists with the raw material of their choice. As the details of spruce fibre structure become known it might be interesting to compare with other woods such as pine.

The ultrastructure has been studied by a variety of methods, by research groups around Sweden, having a varied background in methodology and competence. The work has been gradually expanding over time, from the initial 5 projects at the start, to a current total of 14. A few have now been closed, mainly because they have consisted of Ph.D. studies that have graduated. It is obvious that the coordination and co-operation between different groups of scientists and engineers, using different approaches and methods, has contributed to valuable synergies, thus being valuable in itself.

By its wide but coordinated approach, the programme represents a quite unique effort of significant relevance to the wood based industry. The recent consolidation of the Swedish wood based industry into large companies, means that the collective and university localized research should be limited to pre-competitive basic problems. The approaches should be of long term importance to the companies, and at the same time contribute to the training of scientists becoming familiar with modern techniques of relevance to the future challenges of the industry for further process and product development. We feel that the work of the various research groups have met this challenge in a balanced way.

The different studies have been undertaken by a variety of modern and high quality approaches, utilizing modern and partly novel techniques. Among these, we may mention computer modeling of fibers and molecules, including mechanisms for the forming of lignin. The cell wall ultrastructure has been looked at by anti-body techniques in co-operation with the industry. Cellulose has been marked using specific enzymes, fluorescence labeling and gold marking.

The micro-fibril aggregates in wood and chemical pulps have been analyzed by improved techniques, and interesting differences have been identified between wood and chemical pulp fibres.

The distribution of metal ions in the cell wall has been studied by novel x-ray techniques, using the European synchrotron, located in Grenoble. The relative contributions by cellulose and hemi-cellulose components, to mechanical fiber properties have been analyzed by new methods. The bio-synthesis of the cell wall was looked into by modern gene analyses.

We recommend WURC to extend the techniques available to look at the ultrastructure of mechanical pulp fibres and fibre fractions. This would require interaction with appropriate present and new industrial partners.

Technical Results

Overall, excellent progress has been evident in the past 1 - 2 years, as projects have reached their most productive stage, with students writing up their theses and papers being prepared and published. The results of the fourteen projects were grouped for convenience into six areas. In the opinion of the evaluators, the following are some of the highlights of each area:

*I. Wood and pup fibre models:* A novel aspect of the results from this project is that they are illustrated by 3-D models of complete spruce fibres, indicating the effects of pulping, drying and fibre collapse along the fibre. The approach provides a framework for visualizing the behaviour of real pulp fibres; some eye-catching interactive videos of the work have been placed on the WURC Web-site. At the molecular level, high level quantum chemical calculations are being undertaken, with the aim of understanding and predicting the basic chemical reactions involved with lignin biosynthesis and

structure. In this case, the novelty rests on the skills and computational facilities being brought to bear on the problem.

*II. Cell wall ultrastructure*: This is one of the most important areas of activity. The fibre-surface ultrastructure is a key to the end use of wood fibres in papermaking, and an impressive array of state of the art microscopy techniques has been brought to bear on this problem. The results are excellent; dramatic high-resolution images of fibre surfaces showing details of fibrillar structure have been generated by techniques such as FE-SEM and cryo- FE-SEM. The images alone would be an impressive addition to our knowledge. But the images have been combined with techniques that indicate the chemical composition of the same fibre surfaces. XPS was used to give an indication of the relative amounts of carbohydrate and lignin and extractives on the surface, and ingenious immunochemical binding techniques were used to indicate the presence of the hemicellulose glucomannan on the surface.

An ambitious project on cell wall biosynthesis in co-operation with the strong Umeå Plant Science Centre and KTH uses the new and powerful biotechnological tools to develop an understanding of the complex enzymatic processes involved in cell wall biosynthesis. In the long run the future of the pulp and paper industry may depend on appropriate tailoring and selection of raw materials. This project addresses some of the complex and challenging problems of isolating and identifying the genes that control the process of plant cell biosynthesis. Another project that makes ingenious use of tagged cellulose binding domain (CBD) enzymes to indicate free cellulose surfaces on pulp fibres is making good progress.

*III. Fibre chemistry of wood polymers at the molecular level:* A number of projects address the physiochemical structure of wood polymers. The crystalline state of cellulose in spruce kraft pulp fibres has been determined from 13C CP-MAS NMR spectroscopy, and even the dimensions of the constituent fibrillar species have been determined from a model; the results were in accordance with the microscopic observations reported under area I above. Particularly important, and of practical interest were the observations relating to the role of hemicelllulose in the changes during pulping, where an aggregation of microfibrils during pulping was noted. This aggregation was also observed and quantified by Atomic Force Microscopy (AFM). The results are relevant to the preservation of fibre strength and the recyclability of fibres.

*IV. Metal ions in wood:* For many practical purposes, the amount of distribution of metal ions in pulp fibres should be known. The amount in fibres is routinely measured, but detecting the distribution of the small amount of metals in fibres is challenging. In one of the projects in this area, the relative amounts of some metals (Ca, K, Mn, Fe, Zn, Cu) in spruce wood before and after acid treatment were measured by x-ray florescence at the European Synchrotron Facility at Grenoble.

*V. Physical properties of fibre materials:* One of the problems in the field that sometimes appears deceptively easy to outsiders is the generation of fibre samples that are both representative of industry practice, but where the key parameters are varied in a systematic and meaningful way over a wide range of values. In particular, independent variation of the hemicellulose content of pulps is seldom achieved. A series of pulps

where this was achieved was used for strength measurements, with particular attention to the cellulose/hemicellulose ratio. These results complemented work in areas II and III on the effects of hemicellulose on fibre ultrastructure.

Two other novel techniques were applied to follow the mechanical processing and drying of wood fibres. An elegant study of changes in IR-spectra of wood polymers under mechanical cyclic stress clearly showed the relative roles of cellulose, hemicellulose and lignin in contributing to the mechanical properties of pulp fibres. This is important in efficient preservation of fibre strength during pulping and bleaching.

*VI. Fibre defects and structural changes*: An approach to the technologically important effect of dislocations or weak points in wood fibre walls was based on the effect of fibre ballooning. When wood fibres are immersed in a strongly swelling agent, that swelling may start at the weak points in the fibre wall. While an interesting and visually striking phenomena, we feel that it can only partially answer questions relating to the distribution of dislocations in the fibre wall, and should be supplemented by a search for other indicators for cell wall damage.

Scientific Production and its Quality

The scientific work is of international standard, as measured by the quantity and quality of publications and theses. The level of scientific production has increased during the last years. This is to be expected as several theses have been completed recently. We are pleased to see that many papers have been submitted for publication in high quality journals widely read by the pulp and paper industry.

Furthermore there has been a very satisfactory participation by WURC researchers in conferences such as the recent International Symposium on Wood and Pulping Chemistry held in Nice, June 2001. Participation in this and other important international conferences certainly raises WURC's profile. In addition, the WURC researchers have presented their results at internal seminars, WURC-Industry interactive seminars, and the well-attended annual WURC international seminars. The overall level of information dissemination at all levels is very high.

Education and training

We have noted with satisfaction that WURC has been quite active in dispersing information of its activity and projects, through five international symposia. The fact that they have on average attracted 110 participants gives the best proof of the interest for the WURC projects. The reported high attendance in the in-house seminars for the participating companies gives a good indication that the WURC activity is met by extensive interest in the industry.

We understand that WURC has not established any special course in its fields, and accept the explanation that this is because of many other post graduate courses having been developed in related fields in Sweden in recent years. We support the suggestion of arranging undergraduate courses in various techniques, both as a general service and as a means to recruit potential Ph.D. students. We also assume that there will be an interest

in the industry and possible other academic institutions for courses in the advanced techniques that have been developed and applied in WURC projects. The participation of WURC in the EU based COST activities also means that the results of the WURC activity are spread to the relevant international community.

## 4. Industrial Relevance and Benefits

Industrial Involvement and Commitment

Despite the dynamic changes in the pulp and paper industry in Sweden in the form of restructuring, mergers, and acquisitions, industrial partners continued to be deeply involved and committed in supporting the Centre. By serving on the Board and various groups, industrial personnel has been instrumental in formulating and developing WURC's vision and strategy. Centre leadership should be commended for having orchestrated this achievement.

The leadership has also followed the recommendation of the previous evaluation to increase the in-kind support of industry at the actual working level. This benefits not only the university participants, particularly the students, in gaining valuable industrial perspective and experience but also the industry itself in developing much needed culture for research that seemed to be lacking as previously observed. For example, WURC has already sparked strong industrial interest in wood ultrastructures. With the current Centre Director's enthusiasm and articulateness, we expect a continuation and enhancement of this positive trend.

Along with the aspired goal of leading or participating in a future European network of centres in this area, plans should also be drawn to start interacting or attracting industry from overseas. There should be no major hindrance, either conceptual or physical, since many of WURC's current industrial partners already have international operations, as observed by WURC leadership. It has also reported expansion of the industrial base, which should be continued in the type of firms, such as those engaged in mechanical pulping. The Centre seems to be quite active in "marketing" to potentially new partners.

Strength in Technology Transfer and Implementation of New Technology

In view of the basic nature of the work to date, technology transfer and implementation have not occurred to a great degree. They will occur when more industrial personnel, such as via an industrial PhD initiative, start working at the Centre, especially in learning to use and appreciating the powerfulness of modern instrumentation as possibly related to their daily process work. Thus far the major benefits have been mainly intangibles and possibilities, such as access to knowledge and Centre personnel, interactions and new ideas developed. Extensive experience here and abroad has shown that published reports and even software are rather poor vehicles for technology transfer. Thus we recommend WURC to further expand active involvement of personnel from industrial partners.

## 5. General Conclusions and Recommendations

WURC has made impressive progress since the first evaluation in 1998. It is managed by an excellent Director and is moving towards a strategic future. The Centre carries out fundamental research in the field of morphological and chemical ultrastructure of wood fibres. The scientific work is of international standard, as measured by the quantity and quality of publications and theses. Overall, excellent productivity has been evident in the past 1 - 2 years. Centre leadership has successfully maintained strong industrial support during turbulent times.

For the further enhancement of progress we want to make the following recommendations. WURC should

- extend the techniques available at WURC to look at the ultrastructure of mechanical pulp fibres and fibre fractions. This would require interaction with appropriate present and new industrial partners.

- emphasize Norway spruce in line with industrial partners' suggestion where appropriate. As the details of spruce fibre structure become known it might be interesting to compare with other woods such as pine.

- seek to expand its industrial base and explore internationalization of industrial participation

- further expand active involvement of personnel from industrial partners and explore the possibilities for industrial PhD/Licentiate students, in order to enhance technology transfer and implementation, as well as to develop research culture in the industry

- continue to find ways of improving liaison and interaction amongst all of the Centre members

- continue to seek major EU funding for at least one major programme or project.

It is crucially important for SLU to continue its full support to WURC in terms of both resources and recognition.

Uppsala, September 27, 2001

Prof. Derek G. Gray

Prof. Torbjörn Helle

Prof. Tom M. Husband

Dr Marshall M. Lih

September 21, 2004

# Evaluation of the Competence Centre Wood Ultrastructure Research Centre, WURC at the Swedish University of Agricultural Sciences, SLU, Uppsala

## 1. Preface, Methodology, and Acknowledgements

On Monday, 20th September 2004 two of us, the scientific experts Torbjørn Helle, Norwegian University of Science and Technology, Trondheim and Arnis Treimanis, Institute of Wood Chemistry, Riga, visited the Wood Ultrastructure Research Centre (WURC) at the Swedish University of Agricultural Sciences (SLU) in Uppsala, to be given presentations of the scientific progress and range of projects within the Centre.

The following morning the scientific experts were joined by the competence centre experts, Professors John S. Baras, University of Maryland and Per Stenius, Helsinki University of Technology, for the main review meeting on the research and general issues concerning WURC. The Centre Director, Professor Geoffrey Daniel, the Chairman of the Board, Lennart Eriksson, STFI-Packforsk, the vice-rector of SLU, Christer Heinegård, Centre Board members, representatives of member companies, senior scientists and students participated in the meeting.

This evaluation is based on these meetings as well as on reports and scientific publications received beforehand, the most important document being the "WURC Evaluation Report 2004", Geoffrey Daniel, August 2004.

We would like to thank the whole WURC team for their efforts in planning a full and interesting programme, for giving their presentations with enthusiasm, openness and care, and for acting as generous hosts. We thank Susanne Andersson and Staffan Hjorth of VINNOVA for their invitation to participate in the evaluation and for helping us in all ways during our review work.

## 2. Technical and Scientific Outcomes

The research theme of WURC, wood ultrastructure, has an influence on the properties of all wood-based products. Wood fibres are very complex, the dimensions of the fibres in a population of trees of the same species vary from tree to tree, and the way the fibre material is modified in pulping and papermaking processes also varies between trees and between individual fibres.

For this reason, knowledge and understanding of the relationship between wood ultrastructure and the effects of processing on fibre and product properties are limited and, to a large extent, only statistical. The pulping and papermaking industry is a very old one, and production facilities represent enormous investments. Hence, inventions that lead to dramatic changes of processes are unusual, improvements tend to be gradual improvements and patents are rarely issued. On the other hand, due to the enormous scale

of the processes, machinery and product volumes involved, even small changes may imply substantial gains in terms of economy, runnability and sustainability of the processes as well as product quality and ability to compete. A deeper insight into the properties of the fibre raw material is of great importance in the continuing efforts to achieve such gains, and also in meeting the new demands set by evolving printing technologies and development of new paper products.

It is important to be aware of this industrial background in an evaluation of the WURC activity. From the start, it was agreed that research at WURC should be pre-competitive, a basis for in-house industrial R&D projects oriented towards development of products and processes. In this way the member companies, on the basis provided by WURC, would gain their main achievements in terms of new products and process improvements. Such improvements are largely kept inside the mills, as a part of their know-how.

From being dominated by fundamental studies of fibre ultrastructure, WURC activity in Phase 3 has focused more on issues originating from the industry partners, as recommended in the midterm evaluation in 2001. Concomitantly, several fundamental studies have continued.

WURC activity has been divided into four project areas:

1. *Mechanical & physical properties of fibre materials*
2. *Cell wall ultrastructure*
3. *Fibre chemistry of wood polymers at the molecular level*
4. *Wood and pulp fibre models*

During phase 3, projects within *area 1* of the above have been given the strongest attention, reflecting recommendations from industry. Here may be mentioned:

- *Pulp 2000*
- *Strength delivery*
- *Effects of refining on wood fibre structure*
- *Dislocations in wood fibres*
- *Ultrastructural modifications after mechanical processing & drying of pulp*
- *Mechanical pulp fibres*
- *Ultrastructural studies of post harvest changes in wood*

Major Technical Achievements. Implementation

A major project, *"Pulp 2000"*, was completed in 2003. The aim of this project was characterization of Kraft pulps using conventional and ultrastructural methods with emphasis on pulp fibre strength properties. WURC's industrial partners collaborated by producing pulp samples with large variations in chemical composition. The studies demonstrated useful correlation between ultrastructural characteristics and conventionally determined pulp strength properties. For example, it was found that zero-span tensile index increases linearly with cellulose aggregate width and crystallinity.

An important project has been *"Changes in fibre properties & morphological organization during processing, Strength delivery"*. Laboratory and mill produced pulps from the same chips produced by similar methods were compared. The tear strength of

mill pulps was, in the mean, 15-20% lower. It was found that the mill fibres had more damaged areas (dislocations introduced by mill processes) at which rupture occurred.

An interesting follow up project, *"Dislocations in wood fibres"* studied the relationship between dislocations and strength loss. Analytical methods were developed for quantifying dislocations in fibres in a standardized way, using image analysis. No such method has been available before. This method will be a very useful tool for the pulp mills, where the pulp may be damaged in poorly designed process stages. Considering the significant paper strength drop due to dislocations, changing process conditions so that dislocations are reduced or removed may result in substantial economical gains.

The project *"Ultrastructural modifications after mechanical processing and drying of pulp"* dealt with changes in pulp fibres dried in paper. The quality of paper produced from recycled raw material is reduced by irreversible "hornification" of old fibres produced by chemical pulping. A possible utilization of project results is to develop improved methods to "revitalize" dried fibres, a very important aspect as more than 50% of paper is now recycled.

The 2001 evaluation recommended projects on mechanical pulping. We note with satisfaction that WURC has responded by starting such projects. Thermo-mechanical pulp fibre (TMP) surfaces formed by splitting and fibrillation of wood chips were analyzed in the project *"Mechanical pulp fibres"*. The mechanisms involved are closely related to fibre ultrastructure. The industry partners will have to evaluate the practical implications. It would be interesting to include groundwood pulp, as the TMP and GWP processes result in different kinds of fibre destruction and fine material.

A new project on mechanical pulping, started in 2004, attempts to find morphological explanations for the differences in processing behaviour and properties of mechanical pulps made from pine (*Pinus silvestris*) and Norway spruce (*Picea abies*). This is a problem of highest importance to the industry. Fundamental knowledge on fibre ultrastructure should offer a unique option to come closer to a solution here.

The project *"Ultrastructural studies of post harvest changes in wood"* is related to serious problems in industry. Stored wood deteriorates over time, due to redistribution of bark substances (tannin). The causes for this were studied. Improved wood storage routines will be a challenge to the industry.

Interactions leading to lignin formation in the cellulose/hemicellulose matrix were studied by molecular modelling in project 14. One aspect of this problem would be to relate it to the causes of photo yellowing of paper, which ranks among the biggest problems for paper quality.

The chemistry of supramolecular nanoaggregates in fibres was studied in project 19. The effects of pulping and papermaking on such aggregates have an influence on all paper properties. Some interesting new techniques were developed, based on *in situ* silica sol-gel mineralization in the pores of the fibres. Removal of the organic material results in a silica cast of the pore structure of impressive accuracy, allowing the study of nano-

aggregates inside the fibre. It will be very interesting to explore the method's potential to elucidate processes in which the ultrastructure is changed.

Several projects (9, 10, 30) involved studies of the biosynthesis of the fibre wall and the ultrastructure of wood fibres using specific enzymes and carbohydrate binding modules (CBM) as analytical tools. For instance, CBM have been separated from the enzyme, purified, and used as marker molecules for the labelling of cellulose in cellulose/lignin hemicellulose matrices. These projects are scientifically in the frontline of developments of tree biology and fibre engineering. Very interesting results have been achieved in studies of the effects of enzymes on fibre chemical components. This is long-term fundamental work, but there are many interesting potential applications.

Major Scientific Achievements and Productivity

WURC activity has been successful, drawing together contributions from many studies at different laboratories, and with a very satisfactory rate of scientific productivity. About 200 articles have been published, about 100 of them during Phase 3, mainly in refereed journals. All projects have resulted in publications, which indicates good quality control and high productivity. Besides the written reports, a large number of oral presentations have been given at international symposia in addition to those given at the six internal seminars and three international seminars arranged by WURC during 2002 – 2004.

No patents have been issued. As discussed above, a main reason for this is the nature of the pulp and paper industry, which implies that WURC has dealt with pre-competitive research, providing the industry with basic knowledge.

Education and Training

WURC has no formal obligation to develop an educational programme. However, training of students at different levels is a natural activity for a programme like WURC. The main emphasis has been on the graduate level, so far resulting in 12 Ph.D. theses; three in 2001, four in 2002, two in 2003 and three in 2004, and six licentiate theses. Six more Ph.D. students are currently working at WURC. In addition, six degree projects by undergraduate students have been completed. Supervision of all these students represents a significant educational effort. WURC scientists at all levels have been involved in teaching at their universities and have given lectures at diverse Ph.D. courses.

WURC staff contributed chapters on fibre and fibre structure to the "Ljungberg text book" used in undergraduate pulp and paper courses at KTH, Karlstad University and Chalmers. Expansion of undergraduate and Ph.D. courses on "Wood biology" at SLU Umeå, involving fibre ultrastructure and processing, is planned. An international Ph.D. course will be organized in November 2004 at the WURC Centre in Uppsala.

Several student trips to the industry have been organized for the Ph.D. students who have been working on WURC projects. Very commendably, practice for Ph.D. students at participating industries has been provided.

As before, during Phase 3, WURC has arranged two internal seminars per year, the first one in conjunction with an annual international seminar in April and the second one late in the autumn.

Conclusions and Recommendations

WURC has resulted in a sharply increased Swedish activity in the study of wood fibre structure, concentrating on pre-competitive research. In addition to producing scientific and technical results, the impact of WURC through consolidation and expansion the research on fibre fundamentals in Sweden and production of a number of experts in the field has been very useful. While the projects initially were mainly aimed at providing a fundamental description of the ultrastructure of the fibres, several new, more applied projects suggested and lead by industry scientists were started during Phase 3.

In the project *"Strength delivery"* a new method of quantifying fibre dislocations was developed, of great interest to industry by offering ways of identifying process details which cause fibre damages and reduced fibre strength. The studies on fibre wall biosynthesis and ultrastructural details using specific enzymes and CBM techniques resulted in very promising potential ways of improving the tree basis for the industry. The methods will yield results only on a long-term basis, but will be very important for the survival of a wood-based industry in Sweden. The silica-cast technique to study the void structure of individual fibres is a very interesting method that may be utilized for several kinds of studies on fibres.

We generally support the suggestions for future work in WURC's report. In addition, we point out that the fundamental studies have produced information that appears promising for working on issues such as

- *The problem of "hornification" of recycled chemical pulp fibres*
- *The discolouring of pulp manufactured from water stored raw material*
- *The yellowing of pulp over time*
- *The problem of making mechanical pulp from pine (Pinus silvestris)*
- *The utilization of ultrastructural information in the production of fibres and fines by mechanical pulping.*

We wish to submit the following recommendations:

- We support the proposals of continuing the work on the industry directed projects during Phase 4.
- The number of projects might be reduced. We recommend looking into the points listed above, of potentially important avenues for application of the techniques already worked out.
- We support the idea that WURC scientists write a State of the Art report on wood fibre ultrastructure.

## 3. Industrial Benefits and Impact on Industrial Partners

Industrial Interaction and Involvement in Centre Activities

During Stage 3 WURC made excellent progress towards fulfilling the key requirements for a successful Competence Centre. Indeed, while WURC has become an internationally recognized centre of excellence within its research area it has also created a unique environment for close collaboration and knowledge transfer with all of the pulp and paper industries in Sweden.

WURC has currently nine industry partners; eight from the forest industry and one chemical company. They all enthusiastically supported the Centre and the benefits resulting from their participation. None of the partners that participated at the outset of WURC has left the Centre. Indeed, membership has been preserved in spite of substantial mergers and reorganization of the industries. This is strong evidence that they consider the activity to be useful. Most of the participating companies have worldwide activity and the policy of supporting research *"where it is best"*, proving their recognition of the quality of WURC.

The management of WURC, involving the Director, the Board, the Industry Advisory Board, the Managing Group and the Project Leaders, is functioning well and is well coordinated. An important factor in fostering this excellent organisation has been the enthusiastic and inspiring leadership of the Centre Director Geoffrey Daniel. The Board, with members from academia and all of the industries, meets twice a year. Board responsibilities include decisions on strategies, approval of work plans, Centre organization, budget and financial reports, intellectual property and membership issues, follow-up and evaluation. Thus, WURC has created a productive environment for cross-disciplinary collaboration among academic researchers guided by the expertise needed to address long-term research for the benefit of industry. This cooperation between industry partners and universities goes beyond the traditional industry-university collaboration in this research area through STFI-Packforsk.

Industry involvement in WURC is very effective. Industry and academic scientists collaborate in all of the current projects. Industry supports WURC with both substantial cash and in-kind contributions. The latter are critical for the transfer of knowledge to industry. All industry partners were very appreciative of the working model of WURC and enthusiastic about their derived benefits. They support very strongly the pre-competitive nature of research at WURC, and help in ensuring its practical relevance. This is a highly commendable characteristic of the overall WURC research portfolio.

As recommended by the 2001 evaluation, efforts were increased during Phase 3 to develop and sustain projects with closer relationship to technical processes in areas suggested by industry partners. Several projects were initiated and led by industry personnel. Industry involvement focused on projects of this type. As also recommended, several projects on mechanical pulp fibres and refining were established. We note this implementation of recommendations with satisfaction. We also note clear statements of appreciation on this point from the industry partners.

Overall, during Phase 3 the WURC research project portfolio shifted towards more emphasis on applied research. In addition, closer industry/university interactions developed through Ph.D. students working at part of their theses or in industrial practice projects (recently introduced) at industry partner sites in order to contribute to solution of industrial problems. However, such practice has not been made compulsory by WURC management, mainly for practical reasons.

Industry participates in the Board, the Industry Advisory Board, and in project work. Especially, during Phase 3 direct work by industry personnel in projects increased. For example three industry partners and two universities are engaged in the new project *"Mechanical pulp fibres"*. The same industry partners also participate in the very end-use relevant project, *"Morphological differences between Pinus Silvestris and Picea abies for mechanical pulp"*.

Through its partners WURC has access to a unique set of research laboratories and facilities. There has been reasonably good personnel mobility between industry and academia in WURC.

Internal meetings and seminars, on-site seminars at industrial sites as well as more formal workshops, seminars, and international symposia technical reports, biannual progress reports to industry and industrial vetting of publications are used for information dissemination and knowledge transfer to industry and have built a strong interaction network within WURC.

During the evaluation strong evidence was provided of the industrial benefits of participation in WURC: increased knowledge of wood and pulp fibre fundamentals and its use for improving competitiveness and process and product design, access to facilities and experts, access to short courses, seminars and other training programmes. WURC students were equally enthusiastic about the benefits derived from their collaboration with industry and from internships at industry sites, even when their work there was not directly related to their Ph.D. thesis topic.

Implementation of Results: Technology Transfer, Commercialization, Success Stories

Although improved knowledge of raw material details will be useful to the industry, WURC research has not yet resulted in any directly commercial product. As discussed above, this is largely due to the nature of the pulp and paper industry and WURC research should be viewed in this perspective. As detailed above, important measures to promote technology transfer have been implemented: initiation of projects inspired by industrial interests, participation of industry personnel in projects (including industry leadership in four major projects), enhancement of student/industry contacts.

The requirement from industry that WURC should mainly deal with "pre-competitive" research projects means that the main contribution from WURC to the industry and the scientific community will be basic knowledge, albeit of industrial relevance. Another effect of WURC will be the training of highly skilled candidates for industry, with top training and knowledge of relevant research. It is noteworthy, however, that so far none

of the students that graduated as Ph.D's from WURC have been employed by the Swedish forest products industry.

In their comments on the WURC activity, the companies uniformly emphasized the significance and value of new analytical methods and of improved insight into fibre surface and strength details. Their presentations demonstrated the value of better understanding and basic knowledge of wood and pulp fundamentals. For example, in the project on strength delivery it was shown how a better understanding of the reasons for strength differences between lab and mill pulp can lead to improved processes and products. Another project illustrated how a deeper knowledge of the effects of dislocations on paper quality may lead to better processes and products and even may have an influence on tree-growing practices.

Conclusions and Recommendations

WURC has created a unique and successful collaborative industry-university environment in a technical area critical to an important and large sector of Swedish industry. WURC has successfully gathered under its umbrella various diverse and distributed competencies in this technical area. We would like to offer the following recommendation:

- For Phase 4 a concerted effort should be undertaken to document applications or potential to industry from WURC research and basic knowledge. At the same time, this repository of knowledge can be the "legacy" of WURC and an invaluable asset for industry.

## 4. Present Standing of the Centre

International Ranking and Attractiveness

We are impressed by the international position achieved by WURC. The Centre is now an internationally recognized Centre of Excellence in morphological ultrastructure, chemical structure and physical properties of wood and pulp fibres. We are happy to see that expansion of the activity has continued during Phase 3.

A main area for international contacts has been the European COST organisation, where WURC has been an important contributor in several actions. In particular, WURC initiated and chaired the successful COST Action E-20 *"Wood Fibre Cell Wall Structure"*. Other COST actions in which WURC has been active are E-23 *"Biotechnology in the Pulp and Paper Industry"*, E-35 *"Fracture mechanics and micromechanics of wood and wood composites with regard to wood machining"*, and the recently proposed action *"Cell wall macromolecules and reaction wood"*.

WURC has not applied for EU projects, reportedly due to lack of suitable themes within the EU framework programmes. However, scientists at WURC participate in several international projects.

WURC has attracted a number of international guest scientists for studies during varying periods, coming from five countries and laboratories of high scientific standard.

The attractiveness of WURC is also reflected in the attendance to the international symposia arranged by the Centre at SLU. A total of eight such symposia have been held, three during Phase 3, each attracting around 100 participants.

Very commendably, the International Advisory Group has evaluated the activity at WURC annually in connection with the international symposia. This has provided valuable feedback that is used effectively.

Thus, although participation in international projects is still somewhat limited, WURC has implemented the recommendation from the evaluation of Stage 3 to explore internationalization.

The Centre as a National Asset

Before WURC was established, there were some activities in Swedish universities within its research field. However, these were relatively small and spread among a number of universities and companies, without any overall organization. The advent of WURC has allowed this scattered activity to be organized, coordinated and greatly expanded in volume. To unite all parties has been challenging, but cooperation now seems to run smoothly and effectively.

WURC has consolidated its position as the major centre in Sweden for studies of basic aspects of plant fibres, both chemical, structural and growth characteristics. Thus, the recommendation to improve liaisons and interactions between Centre members given in the previous evaluation has been commendably implemented. The main partners continue to be in the Uppsala/ Stockholm region, and located at SLU/ Uppsala University and STFI-Packforsk/ KTH. The total activity of WURC (i.e. university/industry) has increased significantly, and now involves 50-60 scientists. This can be considered as satisfactory from a "critical mass" point of view.

Importantly, it was stated by industrial representatives that WURC is seen as a resource of fundamental knowledge of a link in the production chain from trees to final products that is not available anywhere else in Sweden, be it universities, institutes or industrial research laboratories.

Thus, WURC is undoubtedly a national asset of great importance to university education in forestry and forest products technology and to the Swedish forest products industry, with a comprehensive competence that is also internationally unique.

Role and Impact of the Centre as a Part of the University

WURC's main activity is localized at the Department of Wood Science, SLU. WURC is a main component of the department, now employing for some 60 % of its staff.

The Vice Rector of SLU noted that WURC is a part of the core competence at SLU that urgently needs to be preserved for the future, essentially for three reasons: the research area is of importance for education in wood science; the working model represented by WURC is an excellent example for the university as a whole; and WURC has created

important links between SLU and pulp and paper experts in the forest industry. However, WURC's research area is not included as a separate entity in the general educational scheme at SLU and the Centre is not formally involved in the education of undergraduate or post-graduate students. It is clear that it would be beneficial for education at SLU to enhance transfer of new research results into education by involving WURC more directly in basic education (*e.g.* organization of undergraduate courses).

Conclusions and Recommendations

WURC is now an internationally recognized research centre and part of an extensive international network within its research field. It represents a unique collection of competences and is a national asset of immediate importance both to university education and to the Swedish forest products Industry. WURC is an essential part of the Wood Science department and represents one of the core competences at SLU. Our recommendations are:

- WURC should continue its participation in European COST Actions.
- WURC should endeavour to enhance transfer of its competence and research results into university education by becoming more directly involved in basic education at SLU.

## 5. Future Prospects and Strategies

Technological-Scientific Prospects of Research Area. Focus of Future Research.

WURC is a resource of knowledge in the production chain from trees to final products that is not available anywhere else in Sweden. A deeper understanding of wood ultrastructure may imply a better understanding of how fibre handling and pulping chemistry should be designed, of the connection between fibre properties and physical properties of paper products, of how wood should be preserved, of recycling procedures etc. So far, these connections are very incompletely understood. Hence the research area of WURC has the potential of yielding new technological applications within a well established, mature and for the Swedish economy very important industry.

Another potential application of a better knowledge of wood ultrastructure is the use of wood fibres in completely new products (e.g. reinforced composites, "intelligent" papers and packages) presently not manufactured on a large scale by the pulp and paper industry.

Interests and Priorities of Centre Partners

From an industrial point of view, research on wood ultrastructure is fundamental and thus the industries that support WURC agree that WURC research is on an area that is not and generally cannot advantageously be studied at industrial research laboratories. It should therefore be located in a university and/or institute environment. We agree with this assessment. On the other hand, we were given examples of research results that already have been implemented or have clear potential of implementation in industry. The time seems to be ripe for the realization of projects that focus more directly on potential applications than has hitherto been the case.

The participating industries emphasize that the area is of great interest to them and that as a consequence the competence and the high scientific standard of the work at WURC should be preserved. In several of the presentations and comments at the evaluation, as well in the industrial assessments given in the written report, the view was also brought forward that WURC activity should be more focused on the end products, closer to the industry problems and processes. The companies emphasize that WURC serves as a good supplement to their own product and process development.

As stated by the Vice Rector, SLU also has a strong interest in maintaining the research area of WURC as one of the core competences at the university. Transfer of the knowledge created into basic educations would be very important; the university also sees the contact with industry through competence centres as a very effective and productive way of communication.

Strategies for Stage 4 and Beyond

There seems to be general agreement within WURC that during Stage 4 the Centre should concentrate on continuing and finalizing present projects, and consolidating reporting of results. No new Ph.D projects, pre-studies or industrially oriented post-doc projects will be started. The industry partners suggest some additional activities for the final years, mainly implying studies of closer relevance to production processes and end products. In view of the uncertainties associated with financing of WURC activities after year 10, this strategy appears sensible and commendably careful.

The WURC Board has initiated investigations and planning for the future of WURC beyond the ten years. Several options have been considered, mainly based on the possibilities to find financing. Government funding is essential for the programme to continue in the successful mode currently achieved.

The actual future research programme seems to have been less deeply discussed. In our view, it would be important to formulate a clearer vision of what should be included in a future research programme and the organization within which it should be carried through. This would create a solid and essential background to efforts in solving the financial problems.

Conclusions and Recommendations

The prospects for new scientific findings with productive technological applications within the WURC research area are excellent. All partners involved agree that WURC activities and competences are so valuable that they must not break up or dissolve after year 10. The priorities of both industry and academia are well defined and the Board and Centre leadership have already initiated strategic planning for the future of WURC. While financing is of course essential, we wish to make the following recommendation:

- A clearer and enthusiastically expressed vision should be formulated of the future research programme and its organization, to function as a solid background to efforts in solving the financial problems.

## 6. General Conclusions and Recommendations

WURC has become an internationally recognized research Centre within its research field. It represents a unique collection of capabilities, not available elsewhere, and is one of the core competences of SLU. By consolidating and expanding research on fibre fundamentals in Sweden and producing a number of experts in the field WURC has become a national asset of immediate importance both to university education and to the Swedish forest products industry.

The Board and the Director are to be commended for responding and implementing most of the recommendations from the 2001 evaluation. Thus, projects that are more closely related to direct industrial interests were initiated, internationalization was explored, increased participation of industry personnel in projects was implemented and mechanical pulp projects and studies of other wood species than spruce were initiated.

The activities and competences at WURC are very valuable and need to be preserved beyond the present financing period. We wish to make the following general recommendations:

- WURC should endeavour to enhance transfer of its competence and research results into university education by becoming more directly involved in basic education at SLU.
- A concerted effort should be undertaken to document applications or potential to industry from WURC research and basic knowledge. Based on this, a clear vision should be formulated of the future research programme and its organization as an essential background to finding the solution of future financial problems.
- We agree with all partners involved in WURC that a way should be found to maintain WURC activities and competences after year 10.

Uppsala, September 21, 2004

Prof. John S. Baras

Prof. Torbjörn Helle

Prof. Per Stenius

Prof. Arnis Treimanis

# *Appendix 4.*

## *Human resources within WURC*

| Representative | Affiliation | 96-98 Phase 1 | 99-01 Phase 2 | 02-04 Phase 3 | 05-07 Phase 4 |
|---|---|---|---|---|---|
| Lennart Eriksson | STFI-PF ***Chairman*** | **X** | **X** | **X** | **X** |
| Inger Eriksson | SCA Graphic | **X** | **X** | **X** | **X** |
| Björn Henningsson | SLU | **X** | | | |
| Steve Moldenius | Södra Cell | **X** | | | |
| Anders Nordstrand | MoDo | **X** | | | |
| Sune Wännström | MoDo Paper | **X** | **X** | **X** | |
| Ola Sallnäs | SLU | **X** | | | |
| Yngve Stade | Stora Enso | **X** | **X** | **X** | **X** |
| Lars Ödberg | AssiDomän/Sveaskog | **X** | **X** | **X** | **X** |
| Håkan Jöves | Korsnäs | **X** | | | |
| Anders Brolin | Stora Enso | | **X** | **X** | **X** |
| Thomas Nilsson | SLU | **X** | **X** | | |
| Torsten Nilsson | Korsnäs | **X** | **X** | | |
| Sune Linder | SLU | | **X** | | |
| Karin Emilsson | Södra Cell | | **X** | **X** | **X** |
| Lennart Salmén | STFI-PF | | | **X** | **X** |
| Ulf Carlsson | SCA | | | **X** | |
| Per Engstrand | Holmen | | | **X** | **X** |
| Jan Stenlid | SLU | | | **X** | **X** |
| Magnus Wikström | Korsnäs | | | **X** | |
| Jiri Basta | Akzo Nobel/Eka Chemicals | | **X** | **X** | **X** |
| Ove Rehnberg | AssiDomän/Kappa kraftliner SmurfitKappa | | | **X** | **X** |
| Ann Marklund | M-Real | | | | **X** |
| Helena Tuvfesson | Korsnäs | | | **X** | **X** |
| Folke Österberg | SCA | | | | **X** |

**Table 1. Representatives on WURC´s board through phases 1-4. Company representatives occasionally changed within phases but for simplicity persons are shown for the entire phase. During the pre-WURC era Bengt Hylander (AssiDomän), Tom Lindström (MoDo) were also involved and Håkan Jöves (Korsnäs) was the interim chairman.**

| Representative | Affiliation | 96-98 Phase 1 | 99-01 Phase 2 | 02-04 Phase 3 | 05-07 Phase 4 |
|---|---|---|---|---|---|
| Bo Ahlqvist | MoDo | **X** | | | |
| Sture Backlund | SCA | **X** | | | |
| Anders Brolin | StoraEnso | **X** | | | |
| Ivan Dalin | EKA Chemicals | **X** | | | |
| Monica Edsborg | AssiDomän | **X** | | | |
| Ulrika Ekholm | Korsnäs | **X** | | | |
| Stefan Högman | Korsnäs ***Chairman (phases 1-2)*** | **X** | **X** | | |
| Ulla Jansson | Södra Cell | **X** | | | |
| Carina Johansson | EKA Chemicals | **X** | | | |
| Ann Marklund | MoDo/M-real | **X** | **X** | **X** | **X** |
| Frank Peng | StoraEnso | **X** | | | |
| Ove Rehnberg | AssiDomän/Kappa Kraftliner Smurfit Kappa | **X** | | | |
| Brita Swan | StoraEnso | **X** | | | |
| Jiri Basta | EKA Chemicals | | **X** | **X** | **X** |
| Monica Edsborg | AssiDomän | | **X** | | |
| Karin Emilsson | Södra Cell | | **X** | | |
| Ulla Jansson | Södra Cell | | **X** | | |
| Per Larsson | Södra Cell | | **X** | **X** | |
| Mikael Lindström | STFI-PF | | **X** | | |
| Lennart Salmén | STFI-PF | | **X** | **X** | **X** |
| Torsten Nilsson | Korsnäs | **X** | **X** | | |
| Peter Sandström | SCA ***Chairman (phases 3-4)*** | | **X** | **X** | **X** |
| Gunilla Söderstam | StoraEnso | | **X** | **X** | |
| Björn Dillner | Södra Cell | | **X** | **X** | |
| Mattias Johansson | Korsnäs | | **X** | **X** | |
| Anders Moberg | StoraEnso | | | **X** | **X** |
| Dag Molteberg | Södra Cell | | | **X** | |
| Erik Persson | Holmen | | | | **X** |
| Karin Sjöström | Södra Cell | | | **X** | **X** |
| Lars Ödberg | Sveaskog | **X** | **X** | **X** | **X** |
| Geoffrey Daniel | SLU | | **X** | **X** | **X** |
| Stig Bardage | SLU | | **X** | **X** | **X** |

**Table 2. Representatives in WURC´s industrial reference (advisory) group through phases 1-4. Company representatives occasionally changed within phases but for simplicity persons are shown for the entire phase. Note, the list does not include all the industrial persons involved in the projects through the phases.**

| Representative | Affiliation | 96-98 Phase 1 | 99-01 Phase 2 | 02-04 Phase 3 | 05-07 Phase 4 |
|---|---|---|---|---|---|
| Björn Henningsson | SLU | **X** | | | |
| Per Jennische | SLU | **X** | **X** | | |
| Thomas Nilsson | SLU | **X** | **X** | | |
| Brita Swan | WURC | **X** | **X** | | |
| Lars Ödberg | AssiDomän/Sveaskog | | | **X** | **X** |
| Geoffrey Daniel | SLU | | **X** | **X** | **X** |
| Gabriella Danielsson | SLU | **X** | **X** | **X** | **X** |
| Fredrik Gunnarsson | SLU | | **X** | **X** | **X** |

**Table 3. Representatives in WURC´s managerial group through phases 1-4.**

| Representative | Affiliation | 96-98 | 99-01 | 02-04 | 05-07 |
|---|---|---|---|---|---|
| | | Phase 1 | Phase 2 | Phase 3 | Phase 4 |
| Paul Ander | SLU | X | X | X | X |
| Stig Bardage | SLU | X | X | X | X |
| Harald Brelid | CTH | X | X | X | |
| Geoffrey Daniel | SLU | X | X | X | X |
| Göran Gellerstedt | KTH | X | X | X | X |
| Thomas Nilsson | SLU | X | X | | |
| Tommy Iversen | STFI | X | X | X | X |
| Tomas Larsson | STFI | X | X | X | X |
| Lennart Salmén | STFI | X | X | X | X |
| Rune Simonsson | CTH | X | X | | |
| Björn Sundberg | SLU | X | X | X | X |
| Brita Swan | WURC | X | X | | |
| Ants Teder | KTH | X | X | X | |
| Tuula Teeri | KTH | X | X | X | X |
| Ulla Westermark | LUTH/STFI-PF | X | X | | |
| Björn Henningsson | SLU | X | | | |
| Leif Eriksson | UU | | X | X | X |
| Jonas Hafrén | SLU | | X | X | X |
| Gunnar Henriksson | KTH | | X | X | X |
| Gunnar Johansson | UU | | X | X | X |
| Helena Lennholm | KTH | | X | | |
| Ewa Mellerowicz | SLU | | X | X | X |
| Yan Ni Wang | UU | | X | X | |
| Nasko Terziev | SLU | | | X | X |
| Jonas Brändström | SLU | | | X | X |
| Chisuzu Tokoh | | | | X | |
| Li Xiaoyi | Örebro U | | | X | |
| Lada Filonova | SLU | | | X | X |
| ***Technical staff*** | | | | | |
| Anne-Mari Olsson | STFI-PF | | X | X | |
| Ann-Sofie Hansén | SLU | X | X | X | X |
| Eva Nilsson | SLU | X | | | |

**Table 4. WURC´s senior scientists and technical staff through phases 1-4.**

***Additional scientists from Universities/research Institutions active in a supervisory capacity of WURC Ph.D students and/or involved in WURC projects during include:***

*F. Thuvander, C-H. Ljungqvist, U. Germgård (Karlstad Univ); B. Pettersson, L. Wågberg, T. Berglund, A. Ohlsson (KTH); T Awano (SLU); U-B. Mohlin, S. Östlund, J. Hornatowska, M. Lindström (STFI-PF); A. Rindby (CTH); J. Zhang (UU); P. Väljamäe (Univ. Tartu, Estonia); A. Fogdon (YKI); L. Thygesen, A. Thygesen (DTU, Denmark); H. Höglund (MHS); L. Donaldson, A. Singh (Forest Research, NZ).*

| Representative | Affiliation | 96-98 | 99-01 | 02-04 | 05-07 |
|---|---|---|---|---|---|
| | | Phase 1 | Phase 2 | Phase 3 | Phase 4 |
| Jonas Brändström | SLU | X | X | X | |
| Isabelle Duchesne | SLU | X | X | | |
| Eva-Lena Hult | STFI/KTH | X | X | | |
| Ulrika Molin | KTH | X | X | X | |
| Karolina Nyholm | SLU | X | X | | |
| Hans Önnerud | KTH | X | X | X | |
| Bo Durbeej | UU | | X | X | X |
| Jesper Fahlén | STFI/KTH | | X | X | X |
| Lars Hildén | SLU/UU | | X | X | X |
| Annica (Berglund) Sundén | CTH | X | X | | |
| Kristina Wickholm | STFI | X | X | | |
| Margaretha (Vickes) Åkerholm | STFI/KTH | X | X | X | |
| Rickard Berggren | STFI-PF/KTH | | X | X | |
| Maria Christiernin | KTH | | | X | X |
| Dinesh Fernando | SLU | | | X | X |
| Åsa Kallas | KTH | | | X | X |
| Cristian Neagu | STFI-PF/KTH | | | X | X |
| Pritt Väljamäe | UU | | X | X | |
| Per Persson | STFI-PF/KTH | | X | X | |
| Jasna Stevanic | STFI-PF/KTH | | | X | X |
| Miyuki Takeuchi | SLU | | | X | |
| Gerd Wäne | KaU | | | X | X |
| Anders Moberg | KTH | | | X | X |

**Table 5. WURC PhD and Licentiate students through the phases**

| Representative | Affiliation | 96-98 | 99-01 | 02-04 | 05-07 |
|---|---|---|---|---|---|
| | | Phase 1 | Phase 2 | Phase 3 | Phase 4 |
| Jiri Basta | EKA Chemicals | | X | | |
| Anders Brolin | Stora Enso | | X | | |
| Inger Eriksson | SCA | | X | | |
| Stefan Högman | Korsnäs | | X | | |
| Ulla Jansson | Södra Cell | | X | | |
| Per Larsson | Södra Cell | | X | | |
| Ann Marklund | M-Real | | X | X | X |
| Torsten Nilsson | Korsnäs | | X | | |
| Peter Sandström | SCA | | X | | |
| G. Söderstam | Stora Enso | | X | | |
| M.W.-de Puiseau | Södra Cell | | X | | |
| Lars Wågberg | SCA/Mid University of Sweden | | X | | |

T**able 6. Contact (mentors) persons from industry active within the projects**

# WURC

**The Wood Ultrastructure Research Centre (WURC) is a competence centre which was initiated in 1996 by NUTEK (Swedish National Board for Technical and Industrial Development) and established in cooperation with VINNOVA, SLU, eight companies from the Swedish pulp and paper industry (Stora Enso, SCA, M-real, SmurfitKappa, Sveaskog, Södra Cell, Holmen) and one chemical company (Eka Chemicals). NUTEK was replaced by VINNOVA (The Swedish Agency for Innovation Systems) January 2001.**

**The Centre is based at SLU, but within WURC´s organization, close cooperation has occurred over the years with STFI-Packforsk, KTH (Royal Institute of Technology), UU (Uppsala University), CTH, Chalmers University of Technology), Karlstad and Örebro Universities. WURC is financed jointly by VINNOVA, the industrial companies and by the various research organizations.**

**WURC provides a creative and stimulating environment for both research and education on wood fibre ultrastructure where industries within the forestry sector are active and involved in the long-term planning of its aims. The Centre´s research should increase the basic understanding of the morphological architecture and chemical structure of wood fibres and thereby contribute in the development of new wood-based processes and products. The Centre should work with a comprehensive view of wood, wood fibre ultrastructure, wood properties and its utilization.**


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