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1. Introduction

FSCN – Fibre Science and Communication Network is a multi-disciplinary research centre of Mid Sweden University. We work on improving the profitability of today’s papermaking and enabling new paper-based products. We are experts in chemical engineering, organic chemistry and engineering physics, and work closely together with colleagues in another research centre STC – Sensible Things that Communicate. STC specializes in industrial information technology and digital services. FSCN and STC together form the KK Research Environment of the university.

This report summarizes the results of our work during 2013. Our largest research program last year was Energy-Efficient Mechanical Pulping, e2mp, that continues intensive collaboration with paper industry. Another large program in 2013 was FORE, Forest as a Resource, that develops sustainable solutions for bio-economy. FORE will end 2014. We worked hard in 2013 to set up and secure funding for an Industrial graduate school, FORIC, that will focus on the practical applications. FORIC will start 2014.

The initiation of KM$^2$ was the second major achievement in 2013. Here we will be studying and developing paper-based solar cells, batteries etc. The name KM$^2$ refers to the ability to manufacture really large functional surfaces using papermaking and coating technologies. Both KM$^2$ and FORIC are run jointly by FSCN and STC.

Sundsvall 30 April 2014

Kaarlo Niskanen
FSCN Research Director
2. Doctoral and Licentiate Thesis

Year 2011

• Andersson, Stefan; "Low consistency refining of mechanical pulp: process conditions and energy efficiency", Mid Sweden University, Licentiate Thesis, 70 (2011)


Year 2012
• Hummelgård, Christine; "Nanoscaled structures of chlorate producing electrodes", Mid Sweden University, Doctoral Thesis, 134 (2012)


• Dahlström, Christina; "Quantitative microscopy of coating uniformity", Mid Sweden University, Doctoral Thesis, 129 (2012)


• Öhlund, Thomas; "Coated Surfaces for Inkjet-Printed Conductors", Mid Sweden University, Licentiate Thesis, 84 (2012)

• Zasadowski, Dariusz; "Removal of lipophilic extractives and manganese ions from spruce TMP water by flotation", Mid Sweden University, Licentiate Thesis, 74 (2012)

• Hägglund, Håkan; "Local optical variations in paper", Mid Sweden University, Licentiate Thesis, 90 (2012)
• He, Jie; “Gasification-based Biorefinery for Mechanical Pulp Mills”, Mid Sweden University, Licentiate Thesis, 93 (2012)


Year 2013


• Neuman, Magnus; “Applied problems and computational methods in radiative transfer” Mid Sweden University, Doctoral Thesis, 151 (2013)

• Lindenmark, Cecilia; “Time Induced Spreading and Adhesion of Latex Polymers”, Mid Sweden University, Licentiate Thesis, 102 (2013)


3. FSCN in Numbers

**Master by Research**
At the research centre Fibre Science and Communication Network (FSCN) we offer a programme called Master by Research in the subject Chemical Engineering with a bioenergy specialisation. The Master by Research programme targets those who are highly motivated to develop skills and knowledge for a future career in academic, industrial or public R&D. This is also an excellent preparation for doctoral studies.

**Master Degree**
Year 2011:
Alam Didarul
Ran Duan
Sinke Henshaw Osong
Jino John
Naeem Akhtar

Year 2012:
Britta Andres

| Table 2.1 Number of Doctoral degree, Licentiate degree and Master degree |
| --- | --- | --- |
| **Year** | **2011** | **2012** | **2013** |
| No Doctoral degrees | 1 | 4 | 3 |
| Proceeded to external position | 1 | 1 | 4 |
| No Licentiate degrees | 2 | 4 | 3 |
| No Masters degrees | 5 | 1 | 0 |

**Promotions and new employees**
Year 2011:
• Wennan Zhang - Docent
• Sverker Edwardsson - Professor
Year 2012:
- Jonas Örtegren - Docent
- Ismail Ibrahem - Docent

Year 2013:
- Lisbeth Hellström - Docent
- Bo Westerlind - Guest Professor

Table 2.2 Publications

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Article in Journals</td>
<td>45</td>
<td>59</td>
<td>27</td>
</tr>
<tr>
<td>Conference Paper</td>
<td>19</td>
<td>15</td>
<td>19</td>
</tr>
</tbody>
</table>

NPPRJ – Nordic Pulp and Paper Research Journal under new management

The ownership of NPPRJ was taken over by Mid Sweden University, FSCN, on January 1, 2013 from SPCI - Svenska Pappers- och Cellulosaingenjörsföreningen. The journal is now run as a project with five Swedish, four Finnish and one Norwegian University as participants in the project and they all have members of the editorial board. NPPRJ is an international scientific journal covering science and technology for the areas of wood or bio-mass constituents, pulp and paper including new fiber-based materials, recovery and by-products from pulping processes, bio-refining and energy issues. The journal is published quarterly in March, June, September and December. Since the journals start-up in 1986 NPPRJ has endeavoured to publish peer-reviewed articles in the field of pulp and paper science of direct relevance to the forest products industry and of the highest possible scientific quality. The editorial board are convinced that the change in ownership makes it possible for the journal to continue to do so, facing the dramatic changes in emphasis of research and development of commodities and advanced forest products that is presently taking place.

We hope that you will find NPPRJ a scientifically interesting, technologically stimulating and generally important journal. NPPRJ look forward to your manuscripts that are essential for the journal and that you will help us to maintain and improve the scientific and technological status of the journal. If you are interested to make a subscription or send in a manuscript please visit our web site www.npprj.se.
Open Seminars called Forskning möter Näringsliv
Last year FSCN’s seminar series continued in collaboration with Åkroken Bio-Business Arena under the name Forskning möter Näringsliv (“Research meets business”). These open seminars are intended to provide inspiration and knowledge about business development from industrial leaders and entrepreneurs. Understanding market trends and global economy are important for success in the applied research and new business creation that we pursue.

Year 2012
- Anna Holmberg, Arizona Chemical AB
- Ola Hildingsson, Domsjö Fabriker AB
- Birgitta Sundblad, Innventia AB
- Nippe Hylander, ÅF Engineering
- Per-Olof Wedin, Sveaskog Förvaltnings AB
- Per Nyström, Flextrus AB and Packbridge
- Hubertus Kroener, Innovation Scouting & IP Management, BASF, Germany

Year 2013
- Jan Provoost, Tetra Pak
- Lars Stigson, Sunpine och Chemrec
- Markku Karlsson, UPM Kymmene
- Sören Eriksson, Preem
- Roger Gudmundssäter, iTell
- Pernilla Walkenström, Swerea IVF
- Nils-Olof Nilvebrant, Borregaard Industries Ltd
Table 2.3 Funding FSCN (SEK)

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty funding (MIUN)</td>
<td>26 471 927</td>
<td>23 317 637</td>
<td>20 590 405</td>
</tr>
<tr>
<td>Research Councils (VR, FAS, Formas etc)</td>
<td>114 104</td>
<td>459 562</td>
<td>1 306 617</td>
</tr>
<tr>
<td>Swedish Foundations (e.g. Wallenberg, SSF, Vinnova, Rj, KK, etc)</td>
<td>13 103 717</td>
<td>19 184 203</td>
<td>20 207 050</td>
</tr>
<tr>
<td>EU</td>
<td>17 279 792</td>
<td>19 936 226</td>
<td>13 813 672</td>
</tr>
<tr>
<td>Direct funding from nonindustrial</td>
<td>5 386 008</td>
<td>5 485 059</td>
<td>4 365 605</td>
</tr>
<tr>
<td>organizations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct external funding from industry</td>
<td>2 218 622</td>
<td>1 858 764</td>
<td>1 436 948</td>
</tr>
<tr>
<td>Others (Bo Rydin, Kempestiftelsen)</td>
<td>7 382 196</td>
<td>6 163 683</td>
<td>5 248 816</td>
</tr>
<tr>
<td>Indirect external funding from industry</td>
<td>10 730 000</td>
<td>14 270 000</td>
<td>25 254 453</td>
</tr>
<tr>
<td>(in kind)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Funding</strong></td>
<td><strong>82 686 366</strong></td>
<td><strong>90 675 134</strong></td>
<td><strong>92 223 566</strong></td>
</tr>
</tbody>
</table>
4. Summary of research results

Forest as a Resource
Fibre Science and Communication Network (FSCN) is a multi-disciplinary research centre at Mid-Sweden University. We work on improving the profitability of today’s paper industry, and on finding new ways to use the Forest as a resource. We engineer materials that are extracted from the forest industry material flows, and then further refined to provide sustainable alternatives to e.g. plastics. We also develop ways to use wood fibres, paper and board in new ways, for example in three-dimensional packaging structures and functionalities. In the following pages you will find results and developments in our research areas during the past two years.

4.1. Bioenergy

The research area was earlier called Gasification.

Objectives
The bioenergy research group focuses on synthesis gas production from biomass for production of synthetic bio-transport fuels, including DME, FT fuels, ethanol, synthetic natural gas (SNG), and hydrogen. In the current work, the objectives are 1) to develop a pilot-scale dual fluidized bed gasifier (DFBG) for production of a high quality syngas; 2) to simulate the biorefinery concept when the gasifier is integrated in a mechanical pulp fibre line. The research emphasis is on developing and improving gasification technology by the use of catalytic bed material and internal reformer in the Miun DFBG and simulation of biomass-to-ethanol/Bio-SNG in the context of a mechanical pulp mill.

Motivation
The 1st generation of biofuels for transportation is no longer encouraged as it is usually difficult to meet criteria of greenhouse gas (GHG) saving when replacing fossil fuels. On the other hand, the 2nd generation of biofuels from lignocellulosic biomass has been more and more attractive for development and commercialization. Transport biofuels as well as chemicals can be produced from high-quality syngas (mainly hydrogen and carbon monoxide) via biomass gasification. The synthesis technologies are well established as applied to fossil fuels, but new for biomass and wastes. The problem is that producing high-quality syngas from biomass and wastes has not been done reliably, and the system efficiency is low. The biggest challenge for biomass
fluidised-bed gasification is the reforming of tars and CH4.

Main Results
A 150 kW indirect biomass gasifier has been improved for good quality syngas production, which was built up at the Härnösand campus of Mid Sweden University in 2007 (see Miun Gasifier below).

The gasifier is now able to produce syngas which is further synthesized to DME. The synthesis equipment has been installed beside the gasifier through cooperation with Institute of Guangzhou Energy Conversion of Chinese Academy of Sciences. The detail research can be divided into 3 activities and described below.

Gasifier optimal operation and catalytic bed materials
The first test was carried out to evaluate the optimal operation and performance of the MIUN gasifier. The test provides basic information for temperature control in the combustor and the gasifier by the bed material circulation rate. After proven operation and performance of the MIUN gasifier, an experimental study on in-bed material catalytic reforming of tar/CH4 is performed to evaluate the catalytic effects of the olivine and Fe-impregnated olivine (10%wtFe/olivine Catalyst) bed materials, with reference to non-catalytic silica sand operated in the mode of dual fluidised beds (DFB). A comparative experimental test is then carried out with the same operation condition and bed-materials but when the gasifier was operated in the mode of single bubbling fluidised bed (BFB). The
behaviour of catalytic and non-catalytic bed materials differs when they are used in the DFB and the BFB. Fe/olivine and olivine in the BFB mode give lower tar and CH$_4$ content together with higher H$_2$+CO concentration, and higher H$_2$/CO ratio, compared to DFB mode. It is hard to show a clear advantage of Fe/olivine over olivine regarding tar/CH$_4$ catalytic reforming.

Internal reformer
In order to significantly reduce the tar/CH$_4$ contents, an internal reformer, referred to as the FreeRef reformer, is developed for in-situ catalytic reforming of tar and CH$_4$ using Ni-catalyst in an environment of good gas-solids contact at high temperature. A study on the internal reformer filled with and without Ni-catalytic pellets was carried out by evaluation of the syngas composition and tar/CH$_4$ content. It can be concluded that the reformer with Ni-catalytic pellets clearly gives a higher H$_2$ content together with lower CH$_4$ and tar contents in the syngas than the reformer without Ni-catalytic pellets. The gravimetric tar content decreases from 25 g/m$^3$ down to 5 g/m$^3$ and the CH$_4$ content from 11% down below 6% in the syngas. The work leads to a patent application.

Simulation of gasifier and biomass-to-electricity/ethanol/bioSNG
A software package is developed based ASPEN Plus. The mathematical modelling starts from biomass DFBG gasifier. From the model, the yield and composition of the syngas and the contents of tar and char can be calculated. The model has been evaluated against the experimental results measured on a 150 KWth Mid Sweden University (MIUN) DFBG. As a reasonable result, the tar content in the syngas decreases with the gasification temperature and the steam to biomass (S/B) ratio. The biomass moisture content is a key parameter for a DFBG to be operated and maintained at a high gasification temperature. The model suggests that it is difficult to keep the gasification temperature above 850 degree when the biomass moisture content is higher than 15.0 wt.%. Thus, a certain amount of biomass or product gas needs to be added in the combustor to provide sufficient heat for biomass devolatilization and steam reforming.

For ethanol production, a stand-alone thermo-chemical process is designed and simulated. The techno-economic assessment is made in terms of ethanol yield, synthesis selectivity, carbon and CO conversion efficiencies, and ethanol production cost. The calculated results show that major contributions to the production cost are from biomass feedstock and syngas cleaning. A biomass-to-ethanol plant should be built over 200 MW.
In TMP mills, wood and biomass residues are commonly utilized for electricity and steam production through an associated CHP plant. This CHP plant is here designed to be replaced by a biomass integrated gasification combined cycle (BIGCC) plant or a biomass-to-SNG (BtSNG) plant including an associated Heat & power centre. Implementing BIGCC/BtSNG in a mechanical pulp production line might improve the profitability of a TMP mill and also help to commercialize the BIGCC/BtSNG technologies by taking into account of some key issues such as, biomass availability, heat utilization etc.. In this work, the mathematical models of TMP+BIGCC and TMP+BtSNG are developed and built up respectively, which are used to study three cases:

1. scaling of the TMP+BtSNG mill (or adding more forest biomass logging residues in the gasifier for TMP+BIGCC)
2. adding the reject fibres in the gasifier
3. decreasing the TMP SEC by up to 50%

The profitability of the TMP+BtSNG mill is analyzed in comparison with the TMP+BIGCC mill. As the major conclusions, the scale of the TMP+BIGCC/BtSNG mill, the prices of electricity and SNG are three strong factors for the implementation of BIGCC/BtSNG in a TMP mill. A BtSNG plant associated to a TMP mill should be built in a scale above 100 MW in biomass thermal input. Comparing to the case of TMP+BIGCC, the NR and IRR of TMP+BtSNG are much lower. Political instruments to support commercialization of bio-transport fuel are necessary.

Publications from Bioenergy group 2011-2014
Göransson, K., Söderlind, U. and Zhang, W.; “Experimental test on a novel dual fluidized bed biomass gasifier for synthetic fuel production”; Fuel, 90, 1340-1349; (2011)


He, J., Göransson, K., Söderlind, U. and Zhang, W.; “Simulation of biomass gasification in a dual fluidized bed gasifier”; Biomass Conversion & Biorefinery, 2, 1-10; (2012)
4.2 Complex Materials

Fibres, Networks, and Complex Materials. The research area was earlier called Papers Physics.

Exploring fibre future is an overarching goal for this group. Currently we are focusing our research in the following two application areas: (1) light-weight structural composites for packaging and transportation vehicles, and (2) soft, textile-like materials for hygiene and healthcare applications.

For light-weight structural composites, the most important question is whether one can use fibre-based materials for very demanding structural applications. The answer is often sought by determining strength properties, but real performance is a very complex property, far from represented by static strength. We recently introduced “reliability” as a new performance metric for materials and structural design. The approach is based on the recent progresses of statistical failure mechanics and reliability theories. We have found a very unique statistical property of long-term performance (Fig. 1), and this can be exploited to open new opportunities for developing high performance light-weight composites with less material and less energy. In the second area, our question is how to make a textile-like material from
wood fibres with a highly-efficient production machine, such as paper machine. Our basic idea for tackling this challenging question is to utilise both self-assembling and forced assembling properties. We have started exploration by applying “foam” suspensions of fibres, which have unique rheological properties and self-assembling properties. We have recently succeeded in creating a super-low density (4 kg/m$^3$) fibre network with 3D fibre orientation. Unlike typical papers or tissues which have layered-network structures, this new network contains a number of fibres oriented in the thickness direction, which render special softness and absorption property.

![Fig. 1 Typical probability density functions: Strength shows a normal bell-shape distribution (shape parameter ~ 10-20), whereas long-term performance (creep life time) shows a highly-skewed distribution (shape parameter ~ 0-1). The shape parameter is a new design parameter for both materials and structures.](image)
Fig. 2  Super low-density fibre network with 3D fibre orientation (Density=4 kg/m3). Fibres are from TMP reject line.

Recent publications selected from Complex Materials group


Research
• Quantitative microscopy of micro- and nano-particle systems
• 3D fibre networks
• Light-weight composites and materials reliability
• Microfluidics in fibre network

Researchers in the area
Tetsu Uesaka, Professor
Christina Dahlström, Researcher
Majid Alimadadi, Ph D student
Amanda Mattsson, Ph D student
4.3. Eco Chemistry

Research description
The research in Eco-Chemistry at Mid Sweden University can be divided into three closely connected research areas:

1. To use raw materials obtained from the forest and/or from by-products in the paper and pulp industry as turpentine, bark, process waters and waste waters etc. in protection of plants, trees and wood from moose, deer, vole, insects and wood decaying fungi.

2. To extract the above raw materials and use the pure compounds/polymers as (sometime chiral) synthetic building blocks to develop efficient methods for the preparation of natural based fine chemicals, polymers etc. that can be of high value and sometimes with useful biological activity.

3. To design and use tailor made separable complexing agents for separation of natural products and valuable or disturbing metals from industrial process- and waste waters, leachates etc.

Background
The majority of studies examining the effects of herbivores on plants communities as crop fields, grasslands and forests have been conducted on insect herbivores. (Vehviläinen and Koricheva 2006 and references therein) Insect species are the main cause of damage of living trees and high economic losses for the forest owners. Voles and moose are the main mammalian herbivores of Fennoscandian boreal forests and they damage trees mainly at early stages. (Mikkelä et al 2001 and references therein) Results have been published concerning the effect of moose browsing on Scots pine stands (See for example Heikkilä 1996 and references therein) but not many publications deals with the protection of forests from moose
browsing using natural compounds. But, some publications dealing with vole repellents including plant-based compounds have been published. (See for example Curtis et al 2002 and references therein)

Wood rot fungi degrade living trees, timber and wood products and are responsible for great economic losses in the society. As wood is the main raw material in many industries as paper industry, construction industry etc wood protection is an important research area. Conventional protection methods usually contain heavy metals and different copper complexes is commonly used as fungicides that in many cases cause environmental problems by leaching or at disposal. (See for example Schultz and Nicholas 2006 and references therein) Extending the service life of wood and wood products using natural compounds as bioactives is an attractive and an efficient approach even from an ecological point of view. (See for example Sing and Sing 2010 and references therein) As trees generally contain protective substances there is today ongoing research to find and evaluate fungicides from such natural sources. (See for example Shen-Jang Wang, 2005, Chedgy, 2009, Ubhayasekera et. al., 2009 and references therein)

References

• Ubhayasekera, W et.al. 2011, Plant Mol. Biol. 71, 277–289
• Vehviläinen, H. and Koricheva, J. 2006, Ecography, 29, 497–506
Wood consists mainly of cellulose, hemicelluloses and lignin in various proportions. It is known that these materials can be used as starting materials for synthesis of fine and specialty chemicals by for example heterogenic catalytic processes. (See for example Mäki-Arvela et al 2007 and references therein) One possible approach will be to use monomers isolated from terpine, that comes as a by-product from pulp and paper industry, to synthesis poly-terpenes. Poly-terpene resins are prepared commercially by cationic polymerization and the low molecular weight polymers obtained are widely used in adhesive applications. In this activity a-pinene and b-pinene can be used as main bio-based monomers and as a first step cationic polymerization will be optimized, by development of catalyst and polymerization system to allow a better control of polymer and co-polymer structures. The use of isolated and purified wood compounds obtained from all investigated natural materials from above will be further transformed for different applications.

References

Extraction of valuable chemicals can provide new sources of revenue to strengthen industrial competitiveness and growth. Unlike chemical processes to prepare paper the mechanical refining stands for a relatively mild treatment of the fiber raw material. This means that chemical substances and polymers naturally present in the tree is often left in processes, such as thermo mechanical pulp (TMP) and can thus be isolated in different ways. (see for example Sundberg 2002, Zasadowski 2012 and references therein) During production of TMP a wide variety of wood components are either dissolved or suspended as water-insoluble particles in the process water. (Ekman 1990 and references therein). Standard methods as distillation, liquid-liquid extraction, precipitation, etc can be used but also flotation using surface active compounds can be applied to isolate organic compounds from a water phase. (See for example Zasadowski et al 2012 and references therein) If necessary this can be followed up by further purification, structure elucidation and biological activity of the isolated compound and used as is or as building blocks for other products. For this purpose standard extraction methods will be optimised, tailor made surface active compounds will be explored and produced and synthetic paths explored.

References


**Publications from Eko-chemistry group 2012-2013**


Selected and evaluated by Gabriele Sorci, a Member of the Faculty of 1000 (F1000), which places the article in our library of the top 2% of published articles in biology and medicine.


journal.pone.0037230.
Zasadowski, D.; Norgren, M.; Hedenström, E.; Sundberg, A.; Willför, S.
Strand, A.; “Selective flotation of pitch components from spruce TMP process

Musa, N.; Andersson, K.; Burman, J.; Andersson, F.; Hedenström, E.; Jansson,
N.; Paltto, H.; Westerberg, L.; Winde, I.; Larsson, M.; Bergman, K.-O.;
Milberg, P.; “Using sex pheromone and a multi-scale approach to predict the
distribution of a rare saproxylic beetle.” PLoS ONE 2013, 8, e66149, 10.1371/
journal.pone.0066149.

Pokorny, T.; Hannibal, M.; Quezada-Euan, J. J. G.; Hedenström, E.; Sjöberg,
N.; Bång J.; Eltz, T.; “Acquisition of species-specific perfume blends: Influence
of habitat-dependent compound availability on odour choices of male orchid

**Patents**
Two granted national patents were granted during the period and a dozen
national applications submitted.

**Cooperation**
As the publications shows real research collaboration take part in MIUN and
from MIUN with national and international research groups. Additionally
direct collaboration with three regional companies.

**Researchers in the area**
Erik Hedenström, Professor
Hans-Erik Högborg, Professor
Fredrik Andersson,
Researcher
Kerstin Sunnerheim,
Researcher
Amelie Fagerlund Edfeldt,
Ph D Student
Joel Ljunggren,
Ph D Student
Rizan Rahmani,
Ph D Student
Natalia Sjöberg,
Ph D Student
Erika Wallin, Ph D Student
4.4. High-Yield Pulping Technology

Research focused on:

- Raw material
- Process technology
- New or improved products and qualities

High-yield pulp (HYP) is produced at a yield over 85% from different pulpwoods or annual plants by means of mechanical or combined chemical and mechanical unit processes. The research area is of high industrial importance. All Swedish and Norwegian forest industry companies producing high-yield pulps, the world’s primary machine suppliers as well as a number of chemical suppliers are all cooperating together with the HYP research group within FSCN in several projects.

We believe high-yield pulps to be a future key material in sustainable products and our mission is to potentiate an increased usage of high-yield pulps, even though the demand for newsprint paper grades is drastically decreasing. The research is focused on our primary goals, i.e., helping our industry partners to a new and improved level of knowledge with regard to process efficiency and product development. In order to succeed, we work in a multidisciplinary way engaging university researchers and industry experts in areas ranging from wood and fibre chemistry, paper technology, chemical and mechanical engineering to material physics and control engineering.

The research covers different topics such as wood chipping, mechanical and chemical pre-treatments, high and low consistency refining, bleaching, and further development of nano-scale fibrils. Most of the projects and activities can be categorized into three fields:

**Raw material**

Understanding the properties of the wood matrix and wood polymers is important already in the chipping process where energy efficiency in the following refining stages can be improved if the chipping process is optimized. Similarly, knowledge of how wood polymers can be softened and swelled by thermal, mechanical and chemical pre-treatments under relevant process conditions is needed to be able to drastically improve process efficiency in refining.

**Process technology**

Chip refining is responsible for more than 60% of the electric energy
consumption in most HYP processes. Increasing refining efficiency is therefore crucial. Examples of projects in this area are focusing on refiner stability and control, replacing part of the high consistency refining by low consistency refining, pre-treatment in combination with intensified refining and developing radically new segment designs for small refiner gaps.

New or improved products and qualities
To make it possible to replace low yield bleached chemical pulps in various products it is essential to reach higher brightness maxima and reduce chemical costs in HYP bleaching. In order to enable a broader use of pulps produced with known low energy refining techniques we also study new combinations of multilayer techniques that can improve the strength properties of the final product. Moreover we are studying the possibilities of rejecting fibre and fines materials detrimental to final product properties from the main line enhancing product quality. The possibilities of utilizing these rejects for more unconventional new purposes are studied in parallel.

Researchers in the area
Per Engstrand, Professor
Myat Htun, Professor
Hans Höglund, Professor
Per Gradin, Professor
Torbjörn Carlberg, Professor
Thomas Granfeldt, Adjunct Professor
Magnus Paulsson, Adjunct Professor
Lennart Salmén, Adjunct Professor

Researchers
Olof Björkqvist
Birgitta Engberg
Olof Ferritsius
Rita Ferritsius
Helena Fjellström
Louise Logenius
Sven Norgren
Gunilla Pettersson
Christer Sandberg
Lisbeth Hellström

PhD students
Kerstin Andersson, SCA
Sofia Enberg, Norske Skog
Kristian Goldszer, Stora Enso
Sinke Henshaw Osong, MIUN
Anette Karlsson, SCA
Erik Nelsson, Holmen
Jesper Nåvik, Metso Paper
Sofia Reyier, Stora Enso
Karin Walter, Eka Chemicals
Engineer Staffan Nyström
**4.4.1 Industrial Research College for mechanical pulping**

FSCN together with the KK-foundation and representatives of forest industry have had an Industrial Research College for “Mechanical Pulp Technology”. The programme is now completed.

One of the goals of the Industrial Research College was to educate key R&D staff in the companies – to the long-term benefit of the whole industry. Another goal was to carry out research projects that will form the basis for producing new, high quality, high value-added products from the limited Swedish forest raw materials, using energy-efficient methods. This will further increase the export value of this important industrial sector.

**Projects within the Industrial Research College**

Financed by the KK-foundation and the companies

- **Lignin’s Role as COD-Generator in Mechanical Pulping**, Kerstin Andersson, SCA R&D Centre
- **Improved brightness of wood-containing printing papers (Bright Paper 1)**, Sofia Enberg, Norske skog
- **Shives from hardwood CTMP**, Jesper Nåvik, Metso Paper
- **Bonding Distribution of Fibres in Mechanical Pulp Furnishes**, Sofia Reyier, StoraEnso
- **The Influence of Fibre Characteristics on Bulk and Strength Properties of TMP and CTMP from Spruce**, Niklas Klinga, Holmen Paper
- **Energy Efficient Grinding to Uniform Quality**, Mikael Rautio, Stora Enso
- **Complex automation functionality and usability in advanced refiner control systems**, David Sikter, Holmen Paper
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Financed by other financier

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- *Refining mechanisms in high capacity secondary stage low consistency refining*, Stefan Andersson, Holmen Paper
- *Mechanical and Chemical Chip Pre-Treatment of Norway Spruce*, Erik Nelsson, Holmen Paper

### 4.4.2 Filling the Gap

**Summary**

As energy prices continue to rise long-term it is very important to come up with suggestions to efficiency-improving solutions based on modifications of the existing refining technology without large investments. There are several suggestions to relatively large modifications of process solutions, in design of refiner plate patterns, chip pre-treatment and chip feed strategies to existing refiners, but these suggestions are often expensive and difficult to implement as the knowledge of the mechanisms prevalent in the refiner gap is still insufficient.

To help solving this problem FSCN and Chalmers Industriteknik initiated the research project “Filling the Gap” together with the companies Dametric, Holmen, Metso Paper, Norske Skog, Pöyry, SCA and Stora Enso co-financed by the Swedish authorities Vinnova and the Swedish Energy Agency. The research project was designed with the intention to show how to improve the electric energy efficiency of chip refining by means of utilizing fundamental knowledge of wood material properties relevant for chip refining in relation to refining hypotheses and in combination with output variables from new and improved refining zone measurement methods as; exact gap distance, temperature-, force- and fibre material radial distributions combined with the traditional out/in-put variables normally used. The potential of the above mentioned ideas as well as the specific goal of this project was to show how to reach 25% efficiency improvement in existing refiners and at the same time
reduce refiner caused stops by >50% and plate wear also by >50%.
The data produced within the project was utilized in two ways:
1. To optimize refining conditions in a static way, i.e. optimization of conditions to maximize energy efficiency to reach the functional fibre properties aimed for.
2. To maximize process stability and minimize quality variations at the functional fibre properties aimed for.

The general conclusion from the project is that we can show that there are great opportunities to improve electric energy efficiency in refining according to the goal by means of using the above mentioned measurement techniques. More specifically the full-scale trials performed during the period 2010 – beginning of 2013 showed the possibility to improve the electric energy efficiency by 25% at similar functional properties of the pulp, i.e. a reduction in electricity consumption by 20%. In order to implement similar strategies in other TMP or CTMP lines it will just as in this case be necessary to use the same measurement system and evaluation techniques together with very thorough and statistically well controlled pulp/fibre evaluation techniques. It would of course be interesting to implement the same techniques on as many other production lines as possible within the participating companies, but it must be emphasized that the procedure is very demanding. Each production line needs to perform a corresponding detailed process analysis as the one performed in the mill case study of this research project. Furthermore it would also be necessary to utilize the refiner gap measurement techniques, especially the combination of temperature profile and gap distance measurements, in a modern but still simple process control system making it easier for the operator to continuously run the process in a more energy efficient mode. Implementation of the techniques evaluated in pilot scale within this research project, i.e. fibre distribution and force distribution measurements, would of course have potential to
further improve the process efficiency as well as improve the fibre property level.

**Introduction**

It has been seen that there within productions systems for TMP and CTMP can be very large differences in energy efficiency to very similar fibre (pulp) properties. In most cases these differences can be attributed to variations in incoming wood material or due to wear of refiner plates and other equipment e.g. related to the feeding system. Most production engineers and operators have however noted that it is possible to optimize the refining systems in different ways also with a given raw material, process equipment set and equipment wear situation. Also in this “known” situation it is possible to run the production system in a more or less energy efficient way still reaching the “same” fibre properties. Furthermore, it was shown in mill trials by Engstrand et al. (1995) that also very fast load variations in refining systems seem to be reflected in relatively large variations in fibre properties. Many researchers have described fast variations by means of measuring variations in load, gap distance, pressure, acceleration, temperature inside the gap of refiners, but normally without connecting this to variations in fibre properties (Gradin et al. 1999, Backlund et al. 2003, Eriksen 2003, Berg and Karlström 2005, Johansson and Richardson 2005, Senger et al. 2005, Karlström et al. 2007, Sikter et al. 2007, Fredrikson and Salminen 2011, Olender et al. 2011). Moreover, it is also so that most of the strategies to achieve improved energy efficiency means utilizing a reduced gap distance, examples of this are; high temperature refining as in the cases of Thermopulp and HTCTMP (Höglund et al. 1997, Norgren et al. 2004, Vesterlind 2006), combinations of high rotational speed and high temperature as in the case of RTS as well as in the case of the ATMP process (Sabourin et al. 2001, Hill et al. 2009). In addition to this the
refiner plate suppliers has for a long time period provided refiner plates that makes it possible to increase the feeding rate and at the same time increase intensity which improves energy efficiency with regard to tensile strength. However, the process does also in these cases become more demanding for the operators to control. These energy efficiency improving process solutions thus further increases the needs to improve the knowledge on how to in detail understand how to control the refiners. In order to minimize also variations that would seem to be relatively small we need to develop better control systems to be able to control the chip refiners, and the other refiners in the TMP and CTMP systems more carefully. In order to develop improved control models we need to understand the refining action in the gap of the refiner on an improved level compared to the present situation.

We have since many years had access to successively improved suggestions to models describing what happens in the gap, e.g., Miles and May (1990), (1993), Härkönen et al. (1997), Huhtanen (2004), Karlström et al. (2008). The problems with these are that they are difficult (or impossible) to utilize as basis for process control as long as we are not able to validate them. The fundamental objective of this project was to improve the understanding of the action in a typical chip refiner gap by means of testing existing refining models. When testing these models we are utilizing the best available measurement technology in terms of gap distance, temperature profiles etc. In parallel we developed new techniques to measure force distribution and fibre distribution. These data are in addition to the earlier commonly measured data necessary for validating the refining models mentioned above. The industrial goal of this project was to show how to improve electric energy efficiency with 25% at similar functional properties of the fibres/pulp.

The project comprised three parts:
1. An in-depth review work of the refining theories combined with validation of these theories utilizing already existing advanced refiner gap measurements presented in the literature. This work was combined with a thorough series of interviews of key TMP and CTMP experts within the participating companies in order to catch how thoughts and hypothesis are utilized at the mills in practice.
2. Development of measurement technologies describing pulp/fibre- and force distribution along the gap of chip refiners. This information is necessary for validation of the refining theories mentioned above. The techniques were developed and tested in pilot scale in two sub-projects at CIT of Chalmers University and at FSCN of Mid Sweden University respectively.
3. Full-scale testing in a chip refiner which was successively improved based on refining theories, expert experiences and the improved measurement technologies. It should be emphasised that in order to measure the improvements in energy efficiency reached, an initial evaluation of the TMP line utilized in this study was performed during project year one. After this, the TMP-line was equipped with state of the art measurements as the gap distance technique AGS® (Dametic) and temperature profile measurement equipment (Sikter et al. 2007).

**Current status in theory and practice**

The main objective with this part of the project was to find, comprehend and compile the current knowledge about what happens in the refiner gap during mechanical pulp production. Three different approaches have been utilized to succeed in this:

- Reviewing the literature comprising experimental studies done to measure what happens in the refiner gap
- Studying and comparing the predictions and descriptions that existing HC refining models can provide regarding what happens in the refiner gap
- Interviewing mill personnel regarding operative details in controlling refiner operation

Photographic and optical studies carried out to learn more about the refining actions in the plate gap have given us general insights and also support to assumptions regarding e.g. the velocities of fibre and steam in the plate gap including back-flows. Measurements of fibre residence times, and the distributions of fibre residence time, have given us valuable information about the how fibres travel through the refiner. Taking out samples from the refining zone is also very interesting and enlightens how the fibres are developed along the refiner radius. However, all the above mentioned techniques may disturb the flow of fibres in the gap to some extent, which in turn should affect the results. The different measurement techniques plate gap, temperature, pressure and force measurements can all help us to build better knowledge for the process without disturbing it significantly. Today, plate gap and temperature measurements can be considered mature techniques. More research and development are needed to make pressure measurements in the plate gap more established and considered a mature technique. Force measurements in refiners should be considered a very useful measurement technique e.g. when it comes to segment design. However, the technique is to consider immature since the robustness of the sensors is still a problem.

By using the same input data in three different refining models the model...
predictions could be compared both in relation to each other and related to experimental data. Predictions delivered by the Miles and May model deviated most from the estimates based on measured values. The fluid dynamical model and the entropy model showed good agreement both when it came to describing the specific energy distribution and the local refining intensity distribution over the refiner radius. However, the entropy model had problems with predicting the mean fibre velocity close to the refiner inlet while the fluid dynamical model had a tendency to overestimate the fibre velocity when approaching the periphery, see figure 1.

![Figure 1: The diagram to the left shows specific energy distribution (dE/dr) and the diagram to the right shows mean fibre velocity (m/s) along the refiner radius.](image)

In conclusion, the models studied here were developed with different objectives; for increased understanding and for segment- and control design purposes. Despite that, they seem capable of predicting what happens in the refiner gap quite realistically. Still, the models need to be developed to be able to depict refining actions even better. To validate new or improved models, more research including measurements from refiner gaps is needed.

The main objective when travelling around doing interviews was to document experiences and knowledge told by the mill’s personnel. Another objective was to extend the involvement among the participating companies and to reach other employees than the persons in the reference groups. When visiting a mill we also took the opportunity to briefly discuss all four sub-projects within Filling the gap. This activity was very good and educating for us in the academy to learn more about the mills of our participating companies. During the interviews we were fortunate to have many good and
giving discussions. The discussions have actually already led to new research projects. In many of the mills we were told about experiences and practical situations that had come up which gave rise to fundamental questions about refining mechanisms and what actually happened in the refiner gap during that situation. And last but not least, in the mills the persons we interviewed (operators, process engineers and development engineers) were happy about having the time to sit down and discuss the process in such detail. “We never have this kind of discussion about the process – we wish we would have more time for it.”

**New measurement techniques**

In order to minimize the number of assumptions in the models described above as well as for model validation purposes it is necessary to develop robust measurement technologies describing material/fibre and force distribution along the gap of chip refiners. We are successively striving for techniques measuring forces acting in both tangential and nominal directions, on a specified amount of fibres trapped as fibre network (fibre flocs) in between the bar-bar-interactions. Depending on approach, researchers has somewhat different opinions regarding the level of important of active edge length compared to the active bar surface. Furthermore, researchers in the mechanical pulping area are aware of that wood fibre material temperature from the inlet along the radius of the gap control final pulp properties and also that the steam pressure distribution that is directly connected to temperature is of major importance. Moreover, variations in fibre-, force-, temperature- / pressure distribution leads to variations in pulp/fibre properties. This is the background to the two sub-projects 1 and 2 run at CIT of Chalmers University and at FSCN of Mid Sweden University.

**On the development of new techniques for measuring fiber distribution in refining zones**

The objective of this sub-project was to develop measurement techniques to strengthen the knowledge about fiber distribution inside refining zones. A method where light extinction, dynamic pressure and temperature are simultaneously measured at high sampling rates was developed, see figure 2. The method was tested and evaluated on a ROP28 pilot refiner. Trials were conducted at three different occasions and, already when performing the trials, significant variations in the measured signals were observed as a result of applied changes in the operating conditions.

The characteristics of the sampled signals were clearly affected by changes in production rate, changes in dilution water feed rate and changes in plate...
Strong correlations between the light extinction measurements and the pressure measurements were obtained, especially when running the refiner at relevant refining conditions. At a sampling rate of 1 MHz the pressure signal gives a good resolution of the segment pattern at a representative rotational speed. In pressure frequency spectra distinct peaks corresponding to the characteristics of the pattern can be identified. In addition, pressure pulses related to single bar-passages could be studied in the time domain. For the light extinction signal, however, a much poorer resolution of the segment pattern was obtained due to limitations imposed by the laser light pulsation frequency. Moreover the light extinction signal was found to have intensity variations unrelated to the refining process conditions. Still, it is verified that measurement techniques like this can be used for qualitative studies on fiber distribution inside the refining zones.

Figure 2: Upper left: photo of pilot refiner segment with three sets of holes. The larger hole is for the pressure sensor, the smaller is for the laser probe. Upper right: the refiner segment mounted in the housing, photo taken from underneath the refiner, i.e. where the pulp is discharged. Lower left: laser equipment here installed near the refiner for the trials. Lower right: photo of how the pressure sensor (light silver) and the laser probe (red) are mounted in the refiner housing.
Taken together, the results strengthen several earlier hypotheses related to pulp distribution in refining zones. Trials with changes in plate gap suggest that at narrow gaps a more sparse fiber network and a higher refining intensity are obtained. Considering dilution water flow rate, the results suggest high refining intensities at both low and high refining zone consistency. When a moderate dilution water flow rate is used, the low pressure variations obtained indicate that the refining is, in comparison, fairly uniform and gentle. Lastly, the trials focusing on the impact from plate gap and from dilution water flow rate both gave results showing that the process response to an applied change are much dependent on the direction in which the process conditions was changed. Such phenomena, referred to as directional-dependent dynamics, have been observed in earlier projects on full-scale refiners and it is still an area of research interest.

Although further research using this technique could be of motivated, the method verification and strengthening of hypotheses obtained within this project implies that a future project should focus on in-depth studies using high-speed dynamic pressure measurements, preferably in combination with temperature and force distribution in full-scale refiners. The results obtained and presented here have delivered a potential for development of theoretical models for refining processes and future targeted experimental work should focus on expanding this opportunity further.

**Development of a Technique Measuring Tangential Forces in Pulp Refiners**

The objective of this sub-project was to develop measurement techniques to strengthen the knowledge about force distribution inside refining zones. In order to succeed with this a force sensor capable of measuring the tangential force distributions in the plate gap in a refiner was developed. Together with this, guidelines determining these distributions from measured strain values should be given. The idea behind the sensor was to attach strain gauges in different positions on the inside of a hollow radial bar. In this way the active components i.e. the strain gauges are protected against the harsh (steam, wear etc.) environment in the plate gap, see figure 3. The measured strains were then intended for use in an integral equation formulation relating strains to the tangential force distribution. This has been accomplished and a prototype of a force sensor has during pilot trials, proven to have sufficient sensitivity and to be able to sustain the loads appearing and the otherwise harsh environment during refining, without any malfunction.

In order to show the full potential of the force distribution sensor we would need data acquisition equipment for all 16 channels. Since the equipment
available during the pilot trials only had four channels it was not possible to get fully synchronous strain signals from all strain gauges and hence, it was not possible to determine the tangential force distribution in such a detail as otherwise would be possible. Hopefully this will be made possible in future projects.

Figure 3: To the left The force sensor before assembly and to the right force sensor mounted in the refiner disc ready for use.

Mill case study
The overall project goal has been to show how the specific energy consumption could be reduced by 25%. This sub-project has provided possibilities to discuss and test ideas, technologies and strategies that could contribute to improved energy efficiency in the operation of full-scale refiners.

Experimental work has been carried out on a TMP plant with a single stage primary wood chip refiner of type CD82 at Stora Enso Kvarnsveden. In 2010 a large amount of pulp samples were taken from two sampling points, at ten different occasions with the purpose of establishing a base-line for normal operation. These pulp samples were prepared, distributed and thoroughly analyzed by laboratories at Stora Enso Research, SCA, Holmen and Norske Skog.

A year later, in 2011, new measurement technology in form of adjustable gap sensors, AGS, had been installed together with new equipment for logging of process data. The experimental procedure from the year before was repeated at five occasions in 2011. In the autumn of 2012 refining zone temperature sensor arrays were installed in both flat-zone and CD-zone of the refiner. Shortly thereafter, a series of specific trials were carried out and these generated pulp
samples and process data that, during the analyses that followed, proved to be extremely comprehensive. Stora Enso and MIUN performed evaluations of the laboratory measurements. Process data that were logged during all sampling occasions were used in process analysis performed by CIT and QualTech.

The process analysis showed that there was a considerable improvement in the refiner feed stability from 2011 until 2012 due to process alterations and basic control improvements. In 2012 the best opportunities for further stability improvements were found in the process after the refiner. In fact the temperature sensors in the refining zones revealed counter current disturbance propagation impacting both fiber development in the refiner and its steam evacuation. In particular the conditions in the CD-zone were impaired by variations in consistency and in steam flow.

It was found that the pulps sampled during normal operation displayed large variations in pulp properties as well as in specific energy consumption. Neither in 2010 nor in 2011 was any increase or decrease in any pulp properties identified with respect to increasing specific energy. More specifically, the reference samples from the first experimental period in 2010 indicated that a pulp with similar properties could be produced consuming 1350 kWh/admt as well as when consuming 1600 kWh/admt. The trials conducted in 2012-2013 showed that, by deliberate changes in the process conditions, a difference in specific energy consumption of the same magnitude could be obtained within a couple of hours, still at maintained levels of pulp property variables.

Motivated by ideas that during the project were generated by the mill personnel and by results from sampled process data, a series of process modifications were implemented. As a result, the process stability was improved. This was reflected as a reduction in the motor load variability which in turn allows optimization of the process operating condition and thereby a reduction of the energy consumption can be achieved. Moreover, the importance of keeping a stable consistency throughout the refiner was illuminated and furthermore, it was shown that the availability of temperature sensor arrays allows estimation of this variable as a function of radius, see figure 4.

Based on this mill case study a process control strategy is proposed, where refining zone temperature measurements are utilized together with measurements from plate gap sensors to stabilize the refining zone conditions and the consistency of the produced pulp. A control system like this can constitute the necessary tool that ensures energy efficient operation when desired operating conditions have been defined in detail.
Figure 4: Left figure: estimated consistency through the refiner for one sample. Right figure: consistency estimates as function of time at two positions. Black shows estimated consistency at the outlet of the flat zone, while red shows estimated consistency at the refiner outlet, i.e. in the refiner casing. Estimations derived from the entropy model using data from trial 2, 2012.

Discussion
Pulps sampled during normal operation displayed large variations in pulp properties as well as in specific energy. As discussed above it was shown from mill trials already 1995 that also very fast load variations in refining systems seem to be reflected in relatively large variations in fibre properties. Many researchers have described fast variations by means of measuring variations in load, gap distance, pressure, acceleration, temperature inside the gap of refiners, but normally without connecting this to variation in fibre properties. In the mill case study performed here, the reference samples from the first experimental period in 2010 indicated that a product with equally good properties could be produced consuming 1350 kWh/admt as well as when consuming 1600 kWh/admt. Process modifications based on results from evaluations of pulp properties together with sampled process data were implemented. Trials performed to evaluate the possibilities created when precise measurements of plate gap and temperature became available gave new important knowledge. This information was used to show how to improve energy efficiency. In this mill case study compared at same tensile index a 23% reduction in specific electrical energy consumption was achievable.

Considering analysis of sampled process variables, the results of the process modifications implemented can be illustrated by a reduced refiner motor load as given in figure 5. Here, the black curve represents the distribution
in motor load in 2011. In 2012, the curve had changed shape and position as a result of increased process stability. The red curve is added to illustrate the potential benefit by further process stabilization which is achievable by improved process control. Based on the results from this project it is suggested to implement a process control strategy where refining zone temperature measurements are utilized together with measurements from plate gap sensors to stabilize the refining zone conditions and the consistency of the produced pulp.

**Figure 5: Illustration of improvements in refining process stability with respect to refiner motor load.** The black curve represents the project reference while the green curve illustrates the improved stability in 2012. The red curve gives a future outlook by improved process control. Purple vertical line indicates a lower limit that relates to acceptable values of pulp properties.

Successful implementation of control systems as well as continuous follow-up does also resolve the need for more engineers at MSc level skilled in the areas of measurement and control as well as in basic process knowledge at the mills. Due to the very high cost savings potential this would for sure be beneficial. Unfortunately many pulp & paper mills do however lately seem to reduce the amount of engineers. A way to increase the level of competition for Scandinavian mechanical pulp mills would be to find ways to co-operate in the area of refiner control both due to the high degree of complexity and due to the high cost savings potential.

**Concluding remarks and acknowledgements**

This project was initiated in discussions between experienced people in the industry and researchers at Chalmers and FSCN (MIUN). The project organization would like to thank the Swedish Energy Agency and VINNOVA for economic support. All companies have been very active and the project organization would like to express grateful thanks to everybody!
References


4.4.3 Energy Efficient Mechanical Pulping (e2mp)

The total annual pulp production in Sweden 2012 was 12,0 Mt of which 3,6 Mt was mechanical pulps. It should be emphasized that virgin pulp production in Sweden is increasing while recycled pulp production is decreasing due to high pricing on recycled paper. Mechanical pulps are used in various printing and packaging products with an annual export value of 20-30 billion SEK. Since electricity prices have doubled during the latest ten years and the key elements of the mechanical pulping processes, fibre separation and fibrillation consume about 6 TWh/y, it is important to understand how to improve the energy efficiency of the production processes.

Energy Efficiency in Mechanical Pulping is a research program initiated by the leading producers of mechanical pulp in Scandinavia.

• **e2mp-i** – This part of the program will be executed along two main roadmaps, one with incremental improvements in existing processes and the other looking for radically new process solutions.

• **e2mp-rp** – The objective of this part is to demonstrate how it would be possible to reduce the energy consumed in producing products based on mechanical and chemimechanical pulps, without degrading the
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functional properties of the final products. The research will largely be performed in pilot and demonstration scale in a series of projects demonstrating how to improve the electrical energy efficiency.

- **e2mp-ox** – The basic idea of this project is to develop and support mill scale implementation of technology for achieving minimum 25% reduction in energy consumption for production of mechanical pulp while maintaining pulp quality and avoiding negative environmental impacts. This part of the program is handled by PFI-Paper and Fibre Research Institute in Norway.

The Norwegian Research Foundation and the Swedish Energy Agency finance e2mp-ox and e2mp-i respectively. The KK foundation and the participating companies invest 36 MSEK each and MIUN invests 12 MSEK in the research profile – e2mp-rp. Thus, the research profile is a part of a larger industrial energy initiative started by forest industry companies in Sweden and Norway; Holmen, Norske Skog, SCA and Stora Enso as the main partners. In total the industry and the governmental authorities are investing 200 MSEK about 50% each, detailed information is found on the web page http://e2mpi.se/.

**e2mp-rp**
The technical goal of the research profile is to use an academy-industry research co-production strategy to find new and/or further develop earlier suggested technologies to reduce the specific electric energy consumption of the processes by as much as 50%.

During the first half of the research profile (2011–2013) a series of projects have been started according to the intentions of the original outline. The project portfolio is mainly designed to achieve the general goals for the research profile, but at the same time also balancing the efforts with capabilities of the participating companies and of FSCN-MIUN respectively. Results from the individual profile projects are summarized for each project below.

**BAT analysis of sixteen production lines**
The aim of this project was to establish a base line, from where to reduce the specific electrical energy level, by defining today’s best available technology (BAT). Almost 200 pulps where sampled at normal operating conditions in 16 TMP- and CTMP-lines for publication and board grades, this was done in order to cover as many as possible of the current technologies. The pulp lines and pulps were analyzed thoroughly both with regard to power consumption, production/flow measurements and by means of laboratory analyses. The project was financed by Norske Skog, Holmen, SCA, Stora
Enso, the KK foundation, the Swedish Energy Agency, Åforsk, and ÅF AB. The production lines evaluated are the most energy efficient according to the participating forest industry companies. The quality profile of the pulps produced in the lines differed a lot, even for similar product grades. The lowest amount of specific refining energy was for the publication grades 1800 kWh/bdmt, while it was 2760 kWh/bdmt for SC grade. Corresponding value for the board grades was 840 kWh/bdmt. However, depending on mill specific requirements due to furnish, grade, paper and board machine etc. it may be that the BAT will end up with higher levels of specific energy in order to maintain the functional properties of the product. There was no pulp line, which could be concluded to have the most energy efficient unit process in every stage. The most energy efficient lines were operating at the highest production rates and with high relative speed of the refiner discs. The screen room configuration in the investigated lines differed a lot. With respect to the final pulp quality there was no obvious influence of how the screen room was equipped. It was possible to develop the fibres in a proper way just by refining of the whole pulp stream at low or high consistency. Based on this study the following hypothesis can be postulated: “Correct conditions in the primary refiner stage followed by a very simple post treatment which develops the fibres just enough to the required level is a feasible way to reduce the specific energy consumption in mechanical pulping”.

Pre-treatment strategies for high yield pulps
In this project, the objective is to develop new pre-treatment strategies that can reduce the energy needed to produce high yield pulps (TMP and CTMP qualities) by 30% while maintaining similar pulp properties. Chemical pre-treatment have potential to reduce energy consumption since, for example, sulphite, peroxide and alkali introduces charged groups in the lignin which facilitates the fibre separation. To reach maximum effect of traditional as well as new pre-treatments
we need increased fundamental knowledge of how wood properties can be changed and how this can be related to refining conditions and the character of the final pulp. In the first part of this project the objective has therefore been to study how wood mechanical properties are changed after chemical pre-treatment. Sulphite pre-treatment (sulphonation) was chosen as a reference since that is the most common and well documented pre-treatment of today. In the literature there are examples where wood chips sulphonated at a low pH resulted in pulp with lower freeness and higher light scattering than chips sulphonated at alkaline pH despite lower energy input in the refining stage. According to the mechanical testing carried out in this project, this can probably be explained by the fact that wood material sulphonated at low pH (pH 4) is considerably stiffer than the well softened material that is achieved at alkaline pH. At a given refining intensity (deformation rate and amplitude) it is likely that a stiff material undergoes more plastic deformation than a softened material. This means that more of the applied energy leads to structural changes in the material. Also friction measurements (wood-steel surfaces) were used to study sulphonated wood material at different pH. Sulphonation at alkaline pH led to increased friction which can probably be explained by that a larger part of the wood surface and bulk were deformed in the contact. More energy can therefore be transferred to a softened wood material in sliding contact; however, most likely a large part of this energy goes to hysteresis losses in both the wood surface and bulk. Thus, to be able to refine a well softened material it seems important to achieve large deformation “amplitudes”, large deformations and high deformation rates, both to increase the plastic deformations and reduce the hysteresis losses. It is both costly and time-consuming to perform pilot- and full scale trials, especially using new untested chemicals and without knowing in what direction to go for adjusting the process (refining gap, temperature, production, …) to get most out of the pre-treatment. Based on mechanical testing, literature studies and the combined knowledge in the project group a series of pilot-scale trials will be carried out starting in February 2014 – to investigate new pre-treatments and process conditions.

**Chip pre-treatment combined with high intensity DD-refining**

The goal of the project is to examine if the electric energy consumption in a modern TMP process can be reduced by 15% by means of combining wood chips pre-treatment with increased refining intensity. The fundamental hypothesis behind this project is that softening of wood makes it possible to treat wood fibres in a more efficient way using increased refining intensity without negative influence on fibre properties. In this project this hypothesis was tested by combining mechanical chip-pretreatment with softening of
wood chips (wood fibres) by means of lignin sulphonation optimized by well-balanced sulphite treatment with increased refining intensity achieved by means of changed refiner segment design. To demonstrate this, five full-scale experiments were conducted at the Braviken Paper Mill (Holmen Paper AB). The results show that when the chips were pre-treated with only 3 kg sulphite per ton and refined with a high intensity segment design at increased production rate, the electric energy consumption was reduced by 15%. The reference pulp was produced by means of refining with the standard segments without chip pre-treatment and sulphite impregnation to the same tensile strength and light scattering. It should be emphasized that the combination of wood softening and new segment design also makes it possible to increase the production rate by ~25%.

**Refining of softened TMP fibres**

Most of the proposed ways to reduce energy consumption in high-yield pulping involves refining at a smaller plate gaps. However, small gaps can be difficult to control in daily operation. Small gaps are normally achieved when refining at increased rotational speed, at increased refining temperature and when using feeding segments or processing a softened raw material. How small or how large the gap can be during stable refining can also be affected by the segment design. In this project, new segment designs are utilized to introduce forces to the fibre material in a new and different way. The project objective is to develop new refining technology for a reduction in energy consumption of at least 400 kWh/ton compared with today’s BAT in commercial TMP-producing installations for printing paper grades. The approach is to develop a plate design that will be able to efficiently treat softened wood fibres i.e. the fibre loading should cause structural changes in the fibre material without cutting the fibres - cyclic loading of the fibres in the visco-elastic region should be minimized. A few pre-trials have been carried out in a ROP 20 single-disc refiner under atmospheric conditions using a high-freeness CTMP as the starting material. The new segments were placed in the stator while one traditional (standard) and one feeding segment were used in the rotor. From the trials it was found that refining at high consistency and at high rotational speed was beneficial. No fibre shortening was achieved even at extremely small refiner gaps. A feeding rotor plate together with the new segments in the stator resulted in extremely stable operation. By using different new segment designs, the refiner could be operated with high load at both small, medium and at large gaps while keeping the production level constant. Normally, refining a softened material using high loads requires small gaps. Most likely, this new technique will be most beneficial combined with high temperature refining or when refining a chemically softened raw
material. The operational difficulties, that earlier were related to energy efficient refining of softened fibres, should thus have potential of being substantially reduced. It is known from earlier mill trials that the combination of softening and harsh or intensive refining is successful when it comes to energy reductions. Continued trials with the new segments in both stator and rotor are planned to start in February 2014.

**Improved low consistency refining efficiency**

Low consistency (LC) refining is in some mills used as a tool to improve refining energy efficiency and improve the production capacity in TMP, GWD and CTMP lines. Full scale installations have though revealed some current limitations, mainly, the maximum specific refining energy that can be applied, which limits the energy saving potential. The purpose of this project is to increase the specific energy in LC refining of TMP and increase the efficiency of the refining i.e. attain higher degree of fibre development at a certain SEC. The goal is to reduce refining energy with 300 kWh/adt compared to a BAT TMP line today. Most of the work in this project will be made with LC refiners installed in mills. The work is focused on two areas; 1) Increasing the loadability, i.e. the maximum specific energy that can be applied to a certain fibre length decrease. 2) Improving the energy efficiency of LC refining itself, i.e. at a certain specific energy, tensile index increase should be larger.

Two pre-trials for chemical treatments before LC refining have been made in mill-scale at Stora Enso Kvarnsveden. During refiner bleaching trials samples were taken out before and after the LC refiner operating as 2nd stage after the primary HC refiner. The results indicate that a combination of peroxide and NaOH have an effect on LC refiner efficiency (SEC for certain tensile index increase). No effect could be seen with peroxide and Mg(OH)$_2$. Unfortunately this TMP line was permanently shut down during 2013, and thus no further trials could be made. It has not been possible to make trials with chemicals in any other mill so far, but discussions are ongoing for the next period. A pilot trial was performed in Andritz’ pilot plant in Springfield to find explanations to the stronger response in tensile index increase in LC refining of DIP compared to TMP and thus find ways to improve the energy efficiency of LC refining. It was found that the main explanation of the higher efficiency of LC refining of DIP is the content of kraft pulp. A conclusion from this trial is that co-refining of TMP and kraft could be utilized to improve the LC refining performance. A possible application could be in a process where TMP is post-refined and where kraft pulp is added (i.e. magazine paper production). A trial was performed at the Braviken Paper Mill, Norrköping, in order to investigate the effect of flow recirculation on fibre development and refining efficiency.
The conclusion of this trial is that re-circulation: 1) Helps to keep the refiner in a more stable operating condition. 2) Does not have a large effect on the pulp property development. 3) Does not significantly affect the refining efficiency. 4) The pulp with recirculation is not more inhomogeneous.

Piping work, to be able to do trials with two-stage LC refining, has recently been finished in the Hallstavik mill. Also new pipes have been installed in Braviken to be able to do trials with LC refining combined with fractionation. No trials have been done yet in either of the mills, but are planned for the spring 2014. Much work has been made in Braviken to get the large TwinFlo 72 refiner up and running continuously. During the spring 2014 it will be possible to do trials comparing LC refining of DD pulp and SD pulp. Two short trials have shown good potential on SD pulp. To the same tensile index, the refining energy was around 300 kWh/adt lower than a two stage SD line and 150 kWh/adt lower than DD refined pulp. The TF72 can be used in the next part of the research profile. It is quite clear from these trials, that it is important to have a process with an efficient primary HC refining in order to improve the total energy efficiency. This issue will be addressed in the next period.

Energy efficient chip refining
The major part of the electric energy consumption for production of refiner process based mechanical pulps, as TMP and CTMP, is applied in the chip refining. It is therefore necessary to optimize the unit operation of chip refining in the best possible way. One of the subprojects in the Vinnova and Swedish Energy Agency financed project “Filling the gap” (2009-2013) used the same full-scale refiner as has been used until now in this project. This refiner, a Metso RGP82CD situated at Stora Enso Kvarnsveden mill, is equipped with the new and more accurate plate gap measurement AGS from Dametric and temperature measurement arrays from Chalmers IndustriTeknik along the radius, 8 in the flat zone and 8 in the conical zone. As the same refiner was to be studied in this project, the opportunity to coordinate the experimental work was regarded beneficial for both projects. Five full-scale trials were performed and Stora Enso Kvarnsveden performed laboratory analyses of the pulps. Process variables and pulp properties were investigated both when the set points for the process variables were in conventional process mode and when successive step changes were made. Very large variations in both process variables and in pulp quality can be seen also when the refiner is running in conventional operation. It was shown that it is very important to carefully design the sampling procedure to get statistically valid data during full-scale refiner trials. Having reliable process and pulp quality data it could be shown
that similar tensile index level could be reached with a difference of 200 kWh/admt in two trials during the same day and using the same production level. When all tests are considered, the same tensile index level could be reached with a difference of 300 kWh/admt. If energy efficiency is defined by specific electrical energy consumption to a certain tensile index level it seems to be a maximum at pulp consistencies around 50-55% for this specific refiner and this specific wood fibre material. It was further shown that pulp samples with approximately the same freeness level could have large variations in tensile index and shive content. This indicates that there is a potential to reduce the specific energy consumption necessary to reach a certain tensile index. It is of course also important to have more information of the pulp quality than only freeness and fibre length (commonly available in online measurement) to use for the control of the refiner.

**Fibre Development**

The project was started in January 2014. The general project idea, when considering pulp quality and energy efficiency, is to:

1. make it possible to combine results, conclusions and insights from all the other projects within e2mp to be able to reach the e2mp objective of reducing energy efficiency with 50%
2. propose ways to evaluate different pulp line concepts (up to disc filter or equivalent position) for various end products
3. develop mathematical models to describe unit processes and quality in CTMP/TMP lines and by this develop a better understanding for the interactions between fibres, pulp and products.

**Energy efficiency by means of control-based process design**

This project is planned for start-up after the first three-year period.

**Maximized fibre wall swelling in TMP and CTMP refining**

When producing high-yield pulps the fibre separation will take place in the weakest part of the wood matrix. The position of where the weakest part of the wood matrix is situated can to a large extent be controlled by adjustment of the swelling and softening properties of each of the wood polymers. The combination of position of fibre-fibre separation together with the efficiency of the external and internal fibrillation will to a large extent determine the energy demand to produce high-yield pulps. In order to improve the level of knowledge on how to influence the degree of wood matrix and fibre wall swelling of high-yield pulps we have undertaken to study the swelling properties of these fibres. The influence of sulphonylic and carboxylic acid groups in combination with the effect of counter ion form and temperature, on
the fibre wall swelling of high-yield pulp fibres was studied by means of water retention value (WRV). In the first trial, unbleached TMP, peroxide bleached TMP and peroxide bleached HTCTMP were ion exchanged into H⁺, Na⁺, Ca²⁺, Mg²⁺ and Al³⁺ form, and then their WRV were measured in the temperature range from 25 to 95°C. It was found that pulps not containing sulphonic acid groups need to be heated above the softening temperature of lignin in order to be able to swell to their full capacity. Introduction of sulphonic acid groups also opens up the rigid structure of lignin which lowers the softening temperature and increases the swelling potential even at lower temperatures. The effect of valence of the counter ion was also shown to be more pronounced after adding more carboxylic acid groups to a pulp. In the second trial, unbleached spruce TMP taken from the blow line was treated with hydrogen peroxide and sodium sulphite during conditions resembling those used in chemimechanical and bleaching processes commonly used in the industry. When subjecting sodium sulphite treated pulps to a subsequent hydrogen peroxide step, all pulps show a decrease in sulphonic acid groups, which could be owed to dissolution of highly charged lignin. Pulps treated with a high hydrogen peroxide charge (4%), showed a loss in carboxylic acid groups during subsequent treatment with sodium sulphite. This loss is probably due to dissolution of highly charged fibre material such as demethylated pectins. Both increased degree of sulphonation and carboxylation of the lignin reduces the softening temperature by means of reducing the degree of cross-linking in the lignin matrix. This softening probably improves the compressibility of the fibre pads in the sample holders of the WRV centrifuge, which would counteract an otherwise expected increasing WRV-value due to increased swelling potential. This makes it difficult to see clear trends in WRV as a function of increase in degree of sulphonation and carboxylation. When changing counter ion form from proton or calcium form to sodium form there is however always a clear increase in WRV in the range from 20 to 30%.

Chipping technology for improved energy efficiency
The activities in this project deviate to some extent from what was put forward in the original application. This is partly because many of the planned activities are parts of an existing (KK-financed) project. However, the topic of this project is also directed towards wood chipping, however the chipping that is performed in the sawmill industry. Since wood chips from sawmills is a large part of the chips used in the pulp and paper industry the so called chipper cantor process is also of interest – where the circular cross section of a log is reduced to a quadratic form. More specifically, theoretical models were here developed by which it were possible to estimate the power needed in the two sub-processes which constitutes the canting process. One sub-project
with a clear experimental focus was also included. The result of this project, so far, is a mathematical model that can be used to estimate the power needed for canting of arbitrary log dimensions, feeding rates, canting strategies etc. The work has this far resulted in three journal publications; two in NPPRJ and one in Holzforschung.

**Plans for the next 3-year period**

Some of the projects have already reached their technical objectives. For example, “BAT analysis of sixteen production lines” will be finalized, reported and ended by 2014-03-31. The project has been very appreciated among the forest industry companies and the conclusion is that not only has a reference line of today’s best available technologies been established but the careful trials and measurements performed have given a lot of valuable input to the companies running the 16 benchmarked TMP- and CTMP-lines. The project “Chip pre-treatment combined with high intensity DD-refining” has reached the goal of 15% improved energy efficiency but still the project will continue with more fundamental analysis, writing articles and Erik Nelsson will defend his doctoral thesis in 2015. Other projects started with a more fundamental approach and lab-scale studies. For example, “Pre-treatment strategies for high yield pulps” has started out with most of the experimental activities performed in lab-scale. To reach the technical goal of showing how to increase energy efficiency with 30% more of the activities are now carried out in pilot-scale. This is also an approach that will be used in the next three-year period. More activities are planned for pilot or full scale while parallel lab-scale studies will support these. Also the faculty financed projects have predominantly focused on lab-scale studies and theoretical approaches during the first three-year period of the research profile. The focus on lab-scale will probably continue during the next period as well, however, more pilot and full scale activities will most likely be carried out in cooperation with the other projects. “Fibre development” is a project that has started only recently, 1 January 2014, and also the “Chip refining efficiency” project has only been running for a little more than one year. We also plan to include a CTMP project focusing on hardwood in the research profile and start a project using control-based process design to create a more efficient process during the last three-year period. When these projects are started the project portfolio will be very similar to the plan in the original application. In conclusion, we feel confident that the projects will reach their goals and contribute to the overall goal of the profile – to show how to reduce electric energy consumption by 50% while maintaining important fibre properties for the products.
4.4.4 Mechanical pulp based nano-ligno-cellulose

Almost all research on biorefinery concepts are based on chemical pulping processes and ways of utilising lignin, hemicelluloses and extractives as well as a part of the remaining cellulose for production of nano materials in order to create more valuable products than today. Within the Forest as a Resource (FORE) research program at FSCN we are utilizing the whole chain of unit processes from forestry to final products as paper and board, where the pulping process research focus on high yield processes as TMP and CTMP. As these process solutions are preserving or only slightly changing the properties of the original wood polymers and extractives, the idea is to find high value adding products designed by nature.

From an economic perspective, the production of nanocellulose from chemical pulp is quite expensive as the pulp has to be either enzymatically (e.g. mono-component endoglucanase) pre-treated or chemically oxidized using the TEMPO (2, 2, 6, 6 -tetramethyl-piperidine-1-oxil)-mediated oxidation method in order to make it possible to disrupt the fibres by means of homogenisation.

In high yield pulping processes such as in TMP and CTMP, the idea with this study was to investigate the possibility to use fractions of low quality materials from fines fractions for the production of nano-ligno-cellulose (NLC). The integration of a NLC unit process in a high yield pulping production line has a potential to become a future way to improve the quality level of traditional products such as paper and board grades. The intention of this research work was that, by using this concept, a knowledge base can be created so that it becomes possible to develop a low-cost production method for its implementation.
In order to study the potential of this concept, treatment of thermo-mechanical pulp (TMP) fines fractions were studied by means of homogenization. It seems possible to homogenize fine particles of thermo-mechanical pulp (1% w/v) to NLC. A corresponding fines fraction from bleached kraft pulp (BKP) was tested as a reference at 0.5% w/v concentration.

The objective presented in this work was to develop a methodology for producing mechanical pulp based NLC from fines fractions and to utilize this material as strength additives in paper and board grades. Laboratory sheets of CTMP and BKP, with the addition of their respective NLC, were made in a Rapid Köthen sheet former. It was found that handsheets of pulp fibres blended with NLC improved the z-strength and other important mechanical properties for similar sheet densities.

The characterization of the particle-size distribution of NLC is both important and challenging and the crill methodology developed at Innventia (former STFI) already during the 1980s was tested to see if it would be both fast and reliable enough. The crill measurement technique is based on the optical responses of a micro/nano particle suspension at two wavelengths of light; UV and IR. The crill values of TMP and CTMP based nano-ligno-celluloses were measured as a function of the homogenization time. Results showed that the crill value of both TMP-NLC and CTMP-NLC correlated with the homogenization time.

### 4.4.5 Low energy CTMP in paperboard

**Summary**

The project started in January 2011 and has hence been going on for almost 3 years. The goal with the project is to develop and demonstrate a technique, which will make it favourable to use a low energy HTCTMP in manufacturing of multiply paperboard. The total energy consumption in refining of such CTMP should be lower than 600 kWh/ton. The CTMP should principally be added to a middle ply in the paperboard composite and create options for reduction of the grammage at production of a final product quality with certain bending stiffness.

The companies involved in the project are SCA R&D, SCA Östrand Mill and Stora Enso R&D. Great deals of efforts during past period have been spent on performing pilot plant trials on paper machines and further development of the low energy HTCTMP pulp (High Temperature CTMP) technology at the
SCA Östrand mill. With maintained or somewhat improved pulp properties, the electric energy consumption in manufacturing of the HTCTMP was reduced to approximately 600 kW/h in a second mill trial. In the pilot plant trial on the paper machine, Euro FEX at Innventia in Stockholm, the HTCTMP fibres were treated with multilayers of starch and CMC to get high strength in both in and out of plane properties. This is crucial for the low density middle ply of paperboard that is created from HTCTMP. This resulted in more than doubled z-strength and Scott Bond values at a certain sheet density.

**Project plan activities**

**Optimization of the Multilayer Process**

Two different strategies to modify the fibre surfaces with polymers were investigated in a laboratory study. Both could improve the out of plane sheet properties (i.e. Z-strength and Scott- Bond) with about 100% at a given sheet density. In-plan sheet properties like tensile index, SCT and stretch-at-break values were all improved as well. Figure 1 below shows results from the laboratory study in the project. It shows how starch/CMC treated CTMP fibers, in comparison with untreated CTMP fibers and CTMP fibres in furnishes with added chemical pulp fibres, gives improved out of plane strength (measured as Z-strength) on paper sheets. When treated HTCTMP fibres are added to a middle layer in a paperboard composite the stiffness is improved, which create options for reduction of grammage in the final product.

![Figure 1. Z-strength vs. density on sheets for different type of CTMP pulps with different ratio of kraft pulp (KP) and with and without dry strength agents (PEM) on Formette Dynamic sheets.](image-url)
Pressdrying
The highest strength values value are achieved on sheets, which are dried under pressure up to a final high dryness, figure 2. Using higher temperature during pressing than what is specified in the ISO sheet method gives even better strength, which is a consequence of that the pulps containing native wood lignin (TMP, CTMP). In this project we have shown that using high temperature during the pressing stage gives a good impact on the strength properties for the pulps treated with starch/CMC in a multilayer. Z-strength can be improved a lot with these techniques in combination.

![Figure 2. Strength in sheet Z-direction measured as Scott-Bond value. Drying effects studied at different dryness levels after pressing at high temperature (Rapid Köthen). The figures in the legends specify temperature level during pressing. “U” means that fibres have not been treated with chemicals. “M” means that fibres surfaces have been treated with starch/CMC according to the multilayer technique.](image)

Recent Pilot and Mill Trials
In a second full scale trial at SCA Östrand Mill we succeeded to produce a HTCTMP at quality specification that consumed less than 600 kWh/t in refining energy. The HTCTMP pulp was produced with special types of low energy segments and at higher temperature in the refiner. That pulp showed very good paper board properties in a pilot trial at Innventia pilot paper machine, which has recently been carried out. Fibre treatment with the multilayer technique that was developed in the laboratory studies was tested in this pilot study. The results from the pilot trial are shown in Figure 3.
Project achievements
The project has basically shown even better potential compared to what was expected. Partly as it has been able to manufacture a CTMP pulp (HTCTMP) with high quality at energy consumption less than 600 kWh/t at SCA Östrand mill and partly as extensive laboratory studies of these pulps have paved the way for new applications in the future. During the project period, the cooperation has been very good between the companies and the researchers at MIUN. The companies are considering a patent of parts of the project.

In this project, two papers have been accepted at IMPC 2014 in Helsinki, one oral presentation regarding low energy HTCTMP treated with multilayer and one oral presentation regarding pressdrying.

![Figure 3. The figure shows results from a pilot trial at EuroFEX at Innventia in Stockholm. Z-strength vs. density on sheets from HTCTMP fibres treated with starch/CMC according to the multilayer technique compared with untreated CTMP that has been post refined in a low consistency stage.](image)

4.4.6 Modifying the wood chipping process

Increasing the Energy Efficiency in Mechanical Pulping by Modifying the Wood Chipping Process. The pulp and paper industry is a key Swedish industry, since much of Sweden’s net export income originates from it. One part of the pulp produced is mechanical pulp, the production of which was 3.3 million tons 2009.

When producing both chemical and mechanical pulp, the raw material (i.e. the logs) must be decomposed into small chips in a wood chipper before the pulp can be produced.
When it comes to mechanical pulp, ignoring a small loss of material during refining, it is clear that the above amount of chips have to be produced on a yearly basis (in Sweden only) for the purpose of mechanical refining.

The mechanical pulping industry in Sweden consumes something like 5 TWh/year of electric energy. Of this, 80 – 90 % is consumed in the refining process. Hence, reducing the electric energy consumption is of utmost importance to producers of mechanical pulp, because of both increasing price of electric energy and the importance of environmental issues.

The main goal of this project is to further develop and exploit, in order to make suitable for industrial implementation, some preliminary findings concerning the possibility to reduce the electric energy consumption during refining by modifying the wood chipping process.

4.4.7 Wood and fibre mechanics

Examining the wood chipping process
The Wood and Fibre Mechanics research group is examining the wood chipping process and the possibility of tailoring this process to reduce energy consumption during subsequent refining.

Correctly modelling the wood cutting process using finite element (FE) analysis and characterizing the damage induced in wood chips during chipping are other research interests. In addition, the group is exploring the use of numerical tools (i.e., finite element analysis) in determining wood chipping process parameters, in order to optimize energy efficiency during refining. Several group members are involved in developing a measuring device for measuring (in real time) the forces acting in the gap of a mechanical refiner.

An ongoing effort of this group is part of the Extreme Papermaking project, one activity of which is modelling wet web strength and constitutive behaviour. This will help build our understanding of the fibre properties and sheet structures that control the mechanical and strength properties of wet sheets that determine stochastic strength characteristics. In the future, the group will study the thickness properties of cardboard with a special emphasis on damage evolution.

The process of casting aluminium alloys using the direct chill (DC) casting technique is being studied to improve ingot quality, in terms of improved
internal structure for subsequent extrusion steps, and to minimize surface defects and inclusions. This work is being performed in close cooperation with all Swedish companies using DC casting, and is done by modelling diffusion processes, experimentally simulating solidification, and full-scale industrial trials.
4.5 Digital Printing Centre

The research at DPC has its origin in the possibilities arising with digital print production (i.e. inkjet). The research mainly concerns materials and methods for the forest and printing industries and is involving the manufacture and characterization of materials for graphic and functional applications. Within the area of printing technology functionalization of surfaces, we conduct research in graphic and functional printing concerning printing technology, substrates, ink-substrate interaction, surface treatment and post-processing. Characterization and appearance of materials is a more general research area that applies to many materials and surfaces where we use angle resolved, spectral and imaging measurement instruments for optical characterization of appearance or functionality of materials and surfaces. Our research is supported by a broad industrial cooperation and good laboratory facilities for optical characterization, printing and surface functionalization.

Printing technology as a manufacturing tool
In this project, printing technology is used as a tool for functionalization of surfaces. Materials are patterned by depositing specified amounts of liquids only were desired. Technology is developed within three areas; flexible electronics, barriers and anti-bacterial surfaces. The work includes the synthesis of inks and coatings, surface treatment and post-processing (sintering).

Ink-Substrate interaction and sintering for functional materials
Research at DPC is ongoing in the field of surface-ink interactions for functional inks and printed functionalities on paper substrates. The main focus is to develop knowledge about physical and chemical interaction between surfaces and functional nanoparticle layers, and the mechanisms of sintering such layers. DPC has during 2013 gained deeper insight in nanoparticle synthesis, inkjet ink development and sintering/pulsed light post-processing. This has given us new important possibilities and tools for the future research in this exiting and promising field of research.

Spectral Printing
Colorimetric color reproduction is limited in the way that it is only valid for a specific viewing situation, if the illumination changes – the color of the reproduction will most probably not match the original. For high-end
printing, such as reproduction of art, spectral printing technology provides a foundation for an alternative approach. By using multi-channel printing (typically more than 8 channels), the spectral reflectance of an original is reproduced so that it matches the original under all viewing conditions. The work involves printer modeling, gamut prediction and mapping, development of halftone algorithms and image quality evaluation.

Spectral goniophotometry
A 3-year research project was completed with the main results being:
- Guidelines for angle resolved measurements on paper products were developed from a thorough investigation of limitations of compact benchtop-sized instruments for measuring bidirectional reflectance of paper and the accuracy required in order to study problems relevant for the paper industry.
- A novel method for separating the total reflectance into its bulk and surface components, which is of particular interest in product development of paper, but also for analysis of coated surfaces in general.
- Increased knowledge of how the addition of filler pigments and fluorescent whitening agents in paper and board affects the angular distribution of the total radiance factor.
The project was carried out in close cooperation with several industrial partners, universities and international research institutes.

**New models for light scattering simulations**
Ongoing work is focused on continued development of models for light scattering. Current radiative transfer based model will be further developed, but the main activity will be to develop a discrete-dipole based particle model, which gives a more general and flexible tool for simulating and predicting the optical response of a large range of materials.

**Development of laboratory facilities**
To further strengthen the optical characterization laboratory, a modular spectral imaging system has been designed and acquired. This will enable studies of lateral properties such as inhomogeneities and artifacts at a larger scale, and provides us with new methods for optical characterization of materials and surfaces.

Equipment for intense pulsed light (IPL) sintering has been developed and built at DPC. The equipment has power in the Megawatt range, and allows effective sintering and material conversions of nanoparticle layers in less than a millisecond. Successful experiments have been made to transform coated and printed CuO layers into to pure copper by IPL-induced chemical reduction. We have hopes for successful application of this technology to process and alter properties, also for semi-conductive materials within the KM2 projects.

**The ROND conference**
This year, the bi-annual conference ROND was arranged on the topic Spectral Printing. Over 50 happy participants from industry and academy listened to well-reputed speakers such
as Joseph Padfield from National Gallery, UK, Jan Morovic from Hewlett-Packard, Spain and Prof. Jon-Yngve Hardeberg GUC, Norway. During the week of the conference, DPC also hosted a training event for all students, supervisors and industrial representatives in the EU Marie-Curie training and Networks programme Colour Printing 7.0.

Awards and scholarships
Thomas Öhlund was granted a scholarship from Gunnar Sundblads forskningsfond financing 3 months research at Center for Functional Materials, Åbo Akademi University during the autumn of 2013. The research during this period was focused on synthesis of functional nanoparticles and development of inkjet inks based on functional nanoparticles. Additionally, further knowledge was gained in the development of printed sensors and pulsed light processing of functional layers in printed sensors. A lesser part of the scholarship was used for participation in the International Conference on Flexible and Printed Electronics 2013 in South Korea.

Exams
Niklas Johansson; “Spectral Goniophotometry – Applications to Light Scattering in Paper”, Mid Sweden University

Selected publications


Researchers in the area
Mattias Andersson, Researcher
Ole Norberg, Researcher
Jonas Örtegren, Researcher
Petru Niga, Researcher
Niklas Johansson, Ph D Student
Thomas Öhlund, Ph D Student
Viviane de Almeida Alecrim, Ph D Student
Atiqur Rahaman, Ph D Student

4.6 Ink-media Interaction

The introduction of compounds such as polyelectrolytes or polyvalent metal ions to a porous surface may, in the subsequent printing step, cause adhesion of ink dyes to the surface, or may destabilize a colloidal nano particle dispersion to yield an assembly of agglomerated nano particles at the surface. The added compounds immobilize the ink dyes or nano particles during ink vehicle evaporation and absorption. The compounds used commercially exhibit strong local displacement of charges. Therefore, the stability of such nano particle inks appears to be governed mainly by electrostatic interaction. In our recent work it was aimed at an improved understanding of the electrostatic interactions governing nano particle stability. Printing technology as a tool for functionalizing surfaces was demonstrated by flexographic printing on paper. It was shown that the flexographic film can be used to control the surface energy of the paper, and at the same time leave several other important paper characteristics, such as porosity and surface roughness, largely unaltered. [1] It was further shown that the presence of divalent and trivalent salts on a
paper surface improves the inkjet print density as well as the optical density after ink draw down treatment [2]. This is believed to be due to the ability of the salt to screen the double layer repulsion between nano particles [3]. In the same work, the threshold for the print density with respect to the amount of salt present at the paper surface was determined.

Studies of the electrostatic interaction between nano particles was performed using atomic force spectroscopy. Measurements were made on nano particles with and without dispersants. Selected raw pigments without dispersants did not interact with charged silica and mica surfaces leading us to the conclusion that the raw pigments tested are uncharged at their surfaces. By attaching polyelectrolytes to the pigment surfaces, it was shown that addition of salt had a strong effect on the force field between the nano particles. This was very well correlated to print density data with and without salt at the paper surface. One of the salts had a very strong effect on the nano particle force field, and we believe that this salt triggers a mechanism different from the ColorLok® technology [4,5].

References
4.7 Materials Physics

Our research efforts aim at providing materials and processing solutions for large-area energy and electronics applications such as batteries (rolled-up surfaces), solar cells, or wallpaper displays. We mainly use nanomaterials, such as graphene or nanoparticles, which are coated or printed on paper.

Projects
The research is performed in a number of projects where the work on supercapacitors, a kind of very fast batteries, is performed in the KEPS and Modulit projects. In the Energywise project (2011-2013) several subjects were studied including initial work on supercapacitors and electrochemical electrodes with an active surface of metal oxides. In COAT several subjects are studied including coating of thin films, the industrial design of wallpaper displays, and solar cells.

Supercapacitors - KEPS
Our focus here is on paper-based supercapacitors for energy applications and for printed electronics. The research team behind Kinetic Energy Storage of Paper-Based Supercapacitors (KEPS) has demonstrated that graphene coated on paper could provide inexpensive as well as efficient supercapacitors with high power content. Forest industry processes are well suited for production of such capacitors and the motor industry is interested in new ways to store energy.

New products for storage of energy
The combination of the forest industry’s coating know-how and the progress in nanotechnology, means that we are optimistic about the prospects of finding new products for the storage of energy, says Sven Forsberg, project manager at Mid Sweden University.

Cooperation with STT Emtech
Using KEPS in a car would make it possible to efficiently store the energy released when applying the brakes in a car. This energy can later be used when accelerating. In this way, it is possible to recycle up to twenty per cent of the energy used in a driving cycle (stop and start). A requirement is of course for the supercapacitors to be made lightweight, inexpensive and efficient. This is theoretically possible using the methods we are developing together with industrial partners in the project, which runs until april 2016.
Modulit

In December 2013 the research on supercapacitors was strengthened by a new project; Modulit. Inexpensive and efficient energy storage is a prerequisite for the development of power-driven vehicles and for an efficient use of renewable electrical energy like wind power and solar energy. This project is a larger cooperation in research for our Material Physics group. The project time is four years, until 2017. The project is lead by the research institute Acreo Swedish ICT. Other participants are KTH Royal Institute of Technology, Linköping University, Innventia and SICS East Swedish ICT. Stored energy is expensive today and we will develop ways to build devices for energy storage that are a lot more cost-efficient. Hopefully, our study will lead to new, energy-efficient and good value storage devices with a good environmental performance. The development can be compared to computers that have gone from being a big, complicated intertwining database with a large number of components to a small, integrated circuit that can do more. It also is smaller and easier to adapt to customers. Our aim with this project Modulit is to make the development of batteries go in the same direction. The idea of Modulit is that the storage of energy and the control electronics, that is always needed, are built at the same time and therefore can be integrated in the same device.
**COAT - Printed electronics**

Electrical sintering of nanoparticles, graphene as an environmentally friendly conductor, and materials for memristors are examples of studies for printed electronics applications. The aim of the COAT project is to strengthen the establishment of the region and Mid Sweden University as a national centre for forest industry research. This goal can be reached, in part, by developing knowledge in functional coating of paper. The research programme has two specific goals: to study a new process technique and its possible application. At Mid Sweden University there are several research projects on fibre and energy. Despite the dismal outlook expressed by some in the printing paper industry, we see great potential for the future in the production and process know-how of the forest industry. Coating could be a way to develop new paper products, such as solar cells and interactive wallpapers.

**Process technique**

We carry out initial studies on coating on paper by a new way of coating a number of very thin layers in a single step in the process (multi-layer coating using foaming surfactants). The goal is to gain knowledge that can provide a foundation for development of large-scale industrial application.

**Applications**

The process technique will be used to develop functional papers, large surfaces that demonstrate the new technique. The goal is to show possible paper-based products with a higher added-value than traditional bulk products. The three demonstrations selected by the project are:

- Paper solar cells
- Paper changing pattern and colour
- New functional and sensory surfaces on paper
The next step
The COAT and KEPS projects should be considered the beginning of a larger unified research effort in the field of large-area functional surfaces. The most promising tests will be developed further within the frames of a long-term follow-up research project under the working title “KM²”. KM² is short for square kilometres and the name has been inspired by the large need of advanced surfaces. The global need exceeds a million km² with a market potential of more than one T$. Included in KM² is also the green demand for renewable materials and eco-friendly processes.

Researchers in the area
Håkan Olin, professor
Tetsu Uesaka, professor
Sverker Edvardsson, professor
Per Edström, professor
Lena Lorentzen, professor
Sven Forsberg, researcher
Joakim Bäckström, researcher
Renyun Zhang, researcher
Magnus Hummelgård, researcher
Henrik Andersson, researcher
Mikael Gulliksson, researcher
Magnus Neuman, researcher
Abdipour Morteza, researcher
Martin Olsen, Ph D Student
Britta Andres, Ph D Student
Nicklas Blomqvist, Ph D Student
4.8 Organic Chemistry

The aim of our research is to develop new eco-friendly technology and products using renewable resources as the starting material.

Some selected highlights during 2012-2013
We have developed new “green” technology for making cellulose-based products stronger and water resistant. We have also invented a fire and mold resistant technology for wood preservation. These technologies have been performed on multi-ton scale and are now used throughout the Swedish and International industry. The technology has been used in replacing the use of toxic fluorocarbons for use in cloths and textiles well as brominated flame-retardants. We have also found several new anti-cancer agents, which we have developed through the use of compounds from the bark of the yew three. A strong research area is the use of multi-catalytic methods. Here we have pursued our seminal reports with respect to the combination of metal- and organic catalysts and expanded it with enzyme catalysis. In collaboration, with KTH we have converted lignin feed stock to valuable compounds used in the food and pharmaceutical industry. This eco-friendly technology was also applied for the synthesis of a compound that is very useful for inhibiting the growth of algae on boats in the Baltic sea. We have also developed recyclable heterogeneous metal catalysts, which we are using for the conversion of lignin to fuel as well as fine chemicals.

Selected publications


Córdova, A.; "Examples of Metal-Free Direct Catalytic Asymmetric Mannich-Type Reactions using Aminocatalysis", Rios Torres, R. Ed. John Wiley & Sons


Researchers in the area
Armando Córdova, Professor
Samson Afewerki, Ph D Student
4.9 Surface and Colloid Engineering

The research area was earlier called Water Chemistry.

Short summary
In recent years the group has been focusing on process- and waste water cleaning technology, where the goals have been to remove unwanted (process disturbing) and harmful (environmentally disturbing) substances and at the same time finding use of side streams and wasted materials from wood-based processes (new product generation). The group’s core competence is within surface and colloidal chemistry, and includes great knowledge of the physicochemical properties of wood constituents. The group works multidisciplinary and the research is mainly needs-driven, where the visionary innovation strategy is to develop new technology that can be competitive on an existing market or to transfer existing technology to new market applications. The research is performed by co-production with industry as well as in university driven projects where cooperation with other groups at Mid Sweden University (High-Yield Pulping Technology, Paper Physics, Eco-chemistry, Analytical Chemistry and Engineering Physics), and external academic collaborations are practised. The published articles from the group can be found in scientific journals dedicated to pulp and paper industry research, as well as in the highest-quality scientific journals of physical and chemical sciences.

Research group development during 2013
During 2013 four main research projects were run in full speed; Återvinn and Biopolyvision included in the platform project FORE and funded by EU Objective 2, the County board of Västernorrland and Mid Sweden University, Uniclean 2.0 funded by the County board of Västernorrland and Mid Sweden University, and Clean funded by the Bo Rydin Foundation for Scientific Research. In December it was decided that the name of the research group will be changed from Water Chemistry to Surface and Colloid Engineering (Teknisk yt- och kolloidkemi) to better reflect the academic identity. The progress is briefly summarised below.

Milestones
Återvinn and Clean
• Based on anti-solvent additions and phase studies, a new and promising route for fractionation and separation of hemicelluloses from process water was found.
• A new method for indirect determination of conditional stability
constants of metal ion-chelates based on electrospray ionization mass spectrometry was established.

- The anomalies in solution behavior of an in-house developed and patented chelating surfactant could be explained.

**Biopolyvision**
- Flexible foamed materials based on polysaccharides (hemicelluloses, starch) was synthesized and found highly water absorbent due to its structure (highly porous) and surface chemistry (highly charged).
- Promising results from studies on a new plasticization method for pulp fibres/paperboard have been achieved and continuous work on this will be performed.

**Uniclean 2.0**
- A method for electrochemical deposition of cupper at alkaline pH by utilizing chelating agents was established, and possibilities for further studies on chelating surfactants were achieved.

**External cooperation**
- The fruitful cooperation with researchers at Åbo Akademi resulted in an additional publication in the area of mechanical pulp mill process water treatment during the year.
- An ongoing collaboration with KTH and Swinburne University of Technology, Australia, did also result in a joint publication.
- A pre-study project on hemicellulose extraction from mechanical pulp mill process waters together with SCA R&D Centre and MoRe Research, was approved for funding by SP Processum and initiated during the fall.
- Another new project, Compac, was also granted by the European Union WoodWisdom ERA-NET+ (and Vinnova) during the fall. The project is a collaboration on “Plasticized lignocellulose composites for packaging materials” between a conglomerate of different European companies, and the Cooperative State University Baden Wurttemberg – Karlsruhe, University of Oulu and Mid Sweden University.

**Lab equipment**
A new micro-electrolysis system delivered by ElectroCell A/S has been set up in our labs.

**PhD Students**
In the beginning of the year, the group comprised seven campus PhD-students and one industrial PhD-student, currently on leave of absence to work full-
time in the industry. During the year one PhD-student left after defending her licentiate thesis in June, and at the end of the year three of the PhD-students are writing on their theses (1 licentiate and 2 PhD-theses) to be defended during quarter 1 and quarter 2, 2014.

**Licentiate Thesis**

**Patents**
Patents were approved in China and in the USA for the pending application “Chemical and method for chelating metal ions”.

**Spin-Off**
ChemseQ International AB, established in 2009.

**Event**
The group was represented at five conferences during the year;
- Ekmandagarna (Resource efficiency and value creation) in Stockholm, January 22-23
- Pre-Symposium on Cellulose Nanocrystals in Victoria, Canada, June 9-10
- ISWFPC 2013 in Vancouver, Canada, June 12-14,
- The Wallenberg Symposium in Stockholm, Sept. 23-24
- Trends in green and sustainable surface and materials chemistry in Stockholm, October 23.

**External group member appointments**
- Prof. Magnus Norgren was appointed to the Swedish Research Council’s (VR) evaluation groups NT-17.
- Prof. Håkan Edlund was elected to the section board of surface chemistry and materials chemistry of the Swedish Chemical Society for a period of two years.
- Prof. Norgren was chairman of the examination board of Dr. Kristoffer Lund (Pulp fibres in absorption applications: Modifications and properties), Chalmers.
- Prof. Norgren was opponent at the PhD defense of Dr. Tuan-Anh Nguyen (Polyhedral oligomeric silsesquioxanes: Effects on adhesion, water and water vapour barrier properties of paperboard), NTNU, Norway.
- Prof. Edlund was appointed to the examination board of Dr. Andreas B. Fall (Colloidal interaction and orientation of nanocellulose particles), KTH.
• Prof. Norgren was acting managing director at ChemseQ International AB (part time).

New employees
Dr Ismail Ibrahem started working in the group as senior researcher.

Publications


Duan, R.; Ismael, I.; Hedenström, E; Edlund, H.; Norgren, M. Novel Methods to Produce Foamed Materials from Renewable Sources, ISWFPC 2013, Vancouver, Canada (oral).

Yang, J.; Edlund, H.; Norgren, M. Selective separation of wood substance from a TMP mill process water by flotation – Analysis of the foam fraction, ISWFPC 2013, Vancouver, Canada (poster).
Zasadowski, D.; Edlund, H.; Norgren, M. *Selective flotation – Key for chemical recovery and better production processes*, ISWFPC 2013, Vancouver, Canada (poster).


**Researchers in the area**
Magnus Norgren, Professor
Håkan Edlund, Professor
Ismail Ibrahem, Docent
Kerstin Andersson, Ph D Student
Susanne Boija, Ph D Student
Ran Duan, Ph D Student
Alireza Eivazihollagh, Ph D Student
Ida Svanedal, Ph D Student
Jiayi Yang, Ph D Student
Dariusz Zasadowski, Ph D Student

**Close collaborators**
Erik Hedenström, Professor
Fredrik Andersson, Researcher