Outline

- World-wide use of pulps for packaging, printing, hygiene and other materials/products
- Sustainability aspects of the forest industry - forest growth/cutting-rates, new bio-economy replacing old fossil based economy, carbon sink aspects
- Pulping processes – general aspects on Chemical, Mechanical, Recycled pulping systems
- Chemical pulping – system closure, internal generation of bioenergy and of process chemicals
- Chemical pulping – process outline - trends
- Effluent and environmental aspects – water and air
- Future possibilities – new materials from cellulose, hemicelluloses and lignins
- Summary

My background

- > 50 patents
- > 100 articles and conference contributions
- 18 PhD and Licentiate students (2008–2016)
- Research on improved and new process eco-friendly solutions for improved and new wood/cellulose, fibre and nanocellulose based materials

World-wide use of pulps for packaging, printing, hygiene and other materials/products

- FAO statistics – the world
- CEPI statistics - Europe
- Swedish Forest industry statistics
- Environmental statistics

Global production and trade of forest products in 2015 – available for everybody - must be structured -

<table>
<thead>
<tr>
<th>Product</th>
<th>2015</th>
<th>2005</th>
<th>Change [%] compared to 2005</th>
<th>2015</th>
<th>2005</th>
<th>Change [%] compared to 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycled cardboard</td>
<td>3,978</td>
<td>1,941</td>
<td>106%</td>
<td>3,285</td>
<td>1,941</td>
<td>69%</td>
</tr>
<tr>
<td>Wheat fibre</td>
<td>1,000</td>
<td>1,000</td>
<td>0%</td>
<td>870</td>
<td>870</td>
<td>0%</td>
</tr>
<tr>
<td>Wood pellets</td>
<td>28</td>
<td>28</td>
<td>0%</td>
<td>27</td>
<td>27</td>
<td>0%</td>
</tr>
<tr>
<td>Sawnwood</td>
<td>382</td>
<td>382</td>
<td>0%</td>
<td>382</td>
<td>382</td>
<td>0%</td>
</tr>
<tr>
<td>Wood-based panels</td>
<td>299</td>
<td>299</td>
<td>0%</td>
<td>300</td>
<td>300</td>
<td>0%</td>
</tr>
<tr>
<td>Vegetable and fruit</td>
<td>171</td>
<td>100</td>
<td>71%</td>
<td>171</td>
<td>100</td>
<td>71%</td>
</tr>
<tr>
<td>Wood chips</td>
<td>1,000</td>
<td>1,000</td>
<td>0%</td>
<td>870</td>
<td>870</td>
<td>0%</td>
</tr>
<tr>
<td>Wood chips</td>
<td>100</td>
<td>100</td>
<td>0%</td>
<td>100</td>
<td>100</td>
<td>0%</td>
</tr>
<tr>
<td>Forest products output</td>
<td>1,000</td>
<td>1,000</td>
<td>0%</td>
<td>870</td>
<td>870</td>
<td>0%</td>
</tr>
</tbody>
</table>

Source: FAO

Forests of the World

- Oceania 3% 19 1 Million Hectares
- North and Central America 17% 705 Million Hectares
- Asia 18% 393 Million Hectares
- Africa 17% 674 Million Hectares
- South America 21% 864 Million Hectares
- Europe 30% 1,058 Million Hectares [incl Russia]

Total area in the World: 5 Billion Hectares

Source: FAO
Global Use of Wood 2015

- Source: FAO

World Leading Exporters 2015
Pulp, Paper and Sawn Timber

- Source: Swedish Forest Industries Federation, CEPI, RISI, National Associations

Global Paper Production 2015
by Region

- Source: RISI

Global Paper Production 2015
by Grade

- Source: RISI

Global Pulp Production 2015
by Region

- Source: RISI

Global Pulp Production 2015
by Quality

- Source: RISI
Total World Production: 179 Million Tonnes (2014: 178 Million Tonnes)
Total World Exports: 51 Million Tonnes (2014: 50 Million Tonnes)

Production and Exports of Pulp 2015
Source: RISI, CEPI

Total World Production: 408 Million Tonnes (2014: 406 Million Tonnes)
Total World Exports: 111 Million Tonnes (2014: 112 Million Tonnes)

Production and Exports of Paper 2015
Source: RISI, CEPI

Paper Consumption in Europe* 2015
Deliveries from Various Countries and Regions

Total Consumption: 77 Million Tonnes (2014: 77 Million Tonnes)
* Europe= CEPI Countries
Source: CEPI

Paper Consumption in Europe 2015
by Grade

Total Consumption: 77 Million Tonnes (2014: 77 Million Tonnes)
Source: CEPI

Raw Materials in European Papermaking 2013

Total Paper Production: 91 Million Tonnes (2014: 91 Million Tonnes)
Source: CEPI

Recovery of Paper Products 2015
Per cent of Consumption

*Europe in FSC's Member and Switzerland
Source: RISI, CEPI
Sustainability aspects of the forest industry - forest growth/cutting rates, new bio-economy replacing old fossil based economy, carbon sink aspects

Some examples from Sweden
"The forest industry is a key to succeed in reducing the European net load of carbon dioxide"


Growth is Larger than Felling 2014

Forest Land, Environmental Protection Areas and Certified Forest Land
Ownership of Forest Land 2012

Emissions of Greenhouse Gases 2000-2014 from Land Use in Sweden

Wood Flow for the Forest Industries 2014

Pulping processes – general aspects
Chemical, Mechanical and Recycled pulping systems

Pulping – fibre separation for production of packaging, printing, hygiene and other products

Wood structure

Pulping / fibre separation for production of packaging, printing, hygiene and other products
Mechanical pulping systems
Chemical pulping systems
Pulping systems for recycled paper
Mechanical pulping systems
- Grinding introduced already around 1850
- PGW – Pressure Groundwood
- Yield >95%
- Debarked wood logs are ground under pressure at elevated temperatures to fibres and fine particles – and further processed
- TMP – Thermomechanical Pulp – yield >95%
- Wood chips are defibrated and refined in pressurized refiners at elevated temperatures to fibres and fine particles – and further processed
- CTMP – Chemithermomechanical pulp – yield 85-96%
- As TMP but wood chips are further chemically softened before defibration resulting in a much wider end product range

Chemical pulping - system closure, internal/external use of bioenergy, internal generation of process chemicals

Principles of chemical pulping technology:
- "positive processes"
  - Liberate fibers from wood
  - Make the fiber more flexible
  - Remove lignin
  - Eliminate colored groups
  - Recovering cooking (and bleaching) chemicals
  - Convert dissolved organic materials into energy – products

Principles of pulp technology:
- "negative processes"
  - Mechanical fiber damage, shortening and shape change
  - Degradation of carbohydrates affects the yield and may reduce the strength
  - Chemical cutting of cellulose chains
  - Effluent to water and air

Recycled pulping ex: DIP (deinked pulp) for newsprint
Ref: Stieker T, Moe, Norwegian University of Science and Technology (NTNU), Annan Raiti, Nordic Slag Research, PESC TP Recycled Paper Conference 2002, Munich

Chemical pulping – process outlines

Figure 1.4 A continuous cooking system (Kiefer)
Liberation of fibers

- 1/3 lignin
- 1/3 cellulose
- 1/3 hemicellulose

Composition of wood spics

<table>
<thead>
<tr>
<th>Wood Type</th>
<th>Wt-% on dry wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce</td>
<td>35</td>
</tr>
<tr>
<td>Pine</td>
<td>40</td>
</tr>
<tr>
<td>Birch</td>
<td>45</td>
</tr>
</tbody>
</table>

Conditions for Kraft cooking

- Cooking temperature 140°C to 170°C
- Active chemicals
  - Hydrogen sulfide ions (HS⁻)
  - Hydroxide ions (OH⁻)
- Both are consumed but at different rates during the reactions in the cooking system.

Continuous Digester System

Capacity development

2600 ADMT/24h/15300 days = 770 000 ton/year
Stora Enso = 30 000 000/770 000 = 22 digesters
Year 1990 (30 ADMT/24h) corresponding to 1900 digesters
Bleaching of chemical pulps

- Chemical pulps—especially kraft pulps—are dark brown due to modified lignin structures.
- Bright paper for printing needs high whiteness for good contrast etc.
- Homogenous pulps need complete defibration.
- Brightness stability.
- Hygienic reasons.
- Pure cellulose.

**Figure 10.** A bleaching sequence with four stages according to Defalikos. (After Paper)

**Development of oxygen delignification** maximizes recovery and minimizes effluents

- Removable lignin by depolymerization and hydrophilization.
- Removal of hexenuronic acid, “non-lignin” and extractives.
- Minimal damage on cellulose and hemicellulose.
- Low cost.
- Environmental friendly.

**The oxygen based bleaching chemicals**

- O - Oxygen, P - Peroxide, Z - Ozone and T - PAA, Peracetic acid.
- Often cheap (O).
- Environmental friendly.
- Relatively Poor selectivity (OPZ).
- All can not degrade hexenuronic acid.
- Sometimes expensive (Z, T).

**Commonly used bleaching chemicals / methods**

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Code</th>
<th>pH</th>
<th>Form of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen delignification</td>
<td>O2</td>
<td>O</td>
<td>High</td>
<td>Gas</td>
</tr>
<tr>
<td>Alkali hydrogen peroxide</td>
<td>H2O2</td>
<td>P</td>
<td>High</td>
<td>Solution</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl2</td>
<td>C</td>
<td>Low</td>
<td>Gas</td>
</tr>
<tr>
<td>Hypochlorite</td>
<td>NaClO</td>
<td>H</td>
<td>High</td>
<td>Solution</td>
</tr>
<tr>
<td>Alkaline extraction</td>
<td>NaOH</td>
<td>E</td>
<td>High</td>
<td>Solution</td>
</tr>
<tr>
<td>Xylanase</td>
<td>Protein</td>
<td>X</td>
<td>Very</td>
<td>Solution</td>
</tr>
<tr>
<td>Chlorate</td>
<td>EDTA or DTPA</td>
<td>Q</td>
<td>~5</td>
<td>Solution</td>
</tr>
<tr>
<td>Acid wash</td>
<td>H2SO4</td>
<td>A</td>
<td>Low</td>
<td>Solution</td>
</tr>
<tr>
<td>Water wash</td>
<td>H2O</td>
<td>W</td>
<td>-7</td>
<td>Liquid</td>
</tr>
<tr>
<td>Increase temperature</td>
<td>*</td>
<td>*</td>
<td>High</td>
<td>Higher temp/time</td>
</tr>
</tbody>
</table>

**Historical role of oxygen delignification**

**Bleaching – a challenging mission**

The solution—a multi-step procedure

- Removal of lignin by depolymerization and hydrophilization.
- Removal of hexenuronic acid, “non-lignin” and extractives.
- Minimal damage on cellulose and hemicellulose.
- Low cost.
- Environmental friendly.

- Oxidative or reductive.
- Mostly oxidative for chemical pulps.
- Ionic attack or radical attack.
- Electrophilic or nucleophilic.
- Kraft pulping is nucleophilic, so first step generally electrophilic.
- High, neutral, and low pH.
- High pH gives better extractability and reactivity of lignin.
- In some cases Hydrolysis and Substitutions.
- Chemistry of bleaching much more complex than of pulping. Reactivity low and understood.

**The solution—**

- Schematic illustration of the development of pulping and bleaching technologies for softwood kraft pulp (Kitts 2001).

**Commonly used bleaching chemicals / methods**

- **Table:** Formulas, Code, pH, Form of application.
Chlorine based bleaching chemicals

- D – chlorine dioxide, C - Chlorine gas, H - Hypochlorite
- High selectivity towards lignin
- Able to attack non-phenolic lignin and hexenuronic acid
- Relatively high price
- Environmental problems, Chlorine
- In Sweden only D is used
- The chemistry of the different bleaching methods "hooks" into each other even more than for oxygen based bleaching.

Two-stage oxygen delignification

Modern bleaching sequence for hardwood kraft - (DQ)*PO

Modern bleaching sequence for softwood kraft - (DQ)PO*D

Effluent aspects – water and air

Overview of Kraft Recovery
White liquor preparation

Regeneration of cooking chemicals

Regeneration of cooking chemicals, cont.

Main suppliers of equipment for the pulp and paper industry

Valmet (Papemaking, recovery, digesters, bleach plants, chemical recovery, wood handling, mechanical pulp) Finland - Switez
Andritz (digesters, bleach plants, wood handling, chemical recovery, mechanical pulp, recycled fiber)
Austria-Finland
GL&V (digester, bleach plants) North America
Voith (Papemaking, recycled fiber) Germany
Symbioses between New value streams and main products

FORE: A Concept of a multi-product Bio-RefinEry

Requisites for industrial RE-innovation

- New product ideas
- Production process development
- New actors / new perspectives
- New business networks
- FORIC address all conditions above

Partners in FORIC phase one

Industry:
- SCA (2 students)
- Stora Enso
- Valmet
- Ragn Sells
- Frontway
- Sylvestris
- Skogforsk
- SenseAir
- Pulp Eye
- McRe
- Innventia
- Sundsvall Energi

Academy:
- KTH
- SLU
FORIC 2014: Research Projects Areas

Energy Systems Integration
Sugar based Chemicals
Improved Materials
Measurement Technology
Refining Technology
Natural Chemicals
Waste Material Utilization

FORIC Projects 2015

www.miun.se/foric

Mittuniversitetet

FORIC Projects 2015

Sven Arne: Methane measurement system and analyser
Innventia: Fibrillar chemical pulp fines to enhance paper board strength
Skogforsk: Wood Supply Logistics
Frontway: Techno-economic analysis of bio-refinaries
Pulp Eye: Improved fines material control

Mittuniversitetet

All the on going research projects

• Jonas Johansson, SCA Timber AB
• Robert Norgren, Ragn-Sells AB
• Bakram Gaynullin, SenseAir AB
• Alexander Hedlund, Frontway AB
• Mathias Lundberg, PulpEye AB
• Hafizur Rahman, SCA Forest Products AB, SCA R&D Centre
• Anna-Karin Stengard, Sundsvall Energi AB

Mittuniversitetet

Global Production of Sawn Softwood 1960-2015
Production of Sawn Softwood 2014
World Leading Producers

Exports of Sawn Softwood 2014
World Leading Exporters

Consumption of Sawn Softwood 2015
per Capita

Net Trade of Paper 2015
by Region

Net Trade of Pulp 2015
by Region

Paper Consumption per Capita 2015

Source: FAO

Source: RISI
Nature builds materials in hierarchical structures:

- Tree
- Transverse section
- Growth ring
- Cell structure
- Cell wall structure
- Fibril matrix structure
- Fibril structure (micro fibril)
- Cellulose
- Hemicellulose
- Lignin
- Extractives

Non-phenolic groups are more difficult to oxidize, but also phenols vary in reactivity:

- Phenolic groups
- Non-phenolic groups

PI: Utilize fundamental knowledge to create simple functional manufacturing processes.