New Course May 2010: The Forest based Biorefinery:

Chemical and Engineering Challenges and Opportunities

(Course code: 416509.0, 5 s.p.)

Producing new and more valuable products from trees, the forest biorefinery, is seen by industry and the government as the future of the forest industry in Finland and an integral part of a more sustainable society. Five laboratories in Chemical Engineering (Analytical Chemistry; Fibre and Cellulose Technology; Industrial Chemistry and Reaction Engineering; Inorganic Chemistry; and Wood and Paper Chemistry) have come together to provide an overview of the technical challenges to chemical engineers in realizing the forest biorefinery.

For: Students 4th year and above, including graduate students

Dates: 3 – 7 May 2010

Location: Monday – Wed, Friday ASA C122
Thursday ASA A120
(Fänriksgatan 3; FI-20500 Åbo, Finland)

Credits: 5 study points

Project/Exam: Graduate students will have both a project and an exam.
Undergraduate students will only have an exam.

Website: http://web.abo.fi/instut/pcc/latestnews.html

Contact: Nikolai DeMartini (nmartini@abo.fi); +358 (0)2 215 4762

Monday 3 May 2010 ASA C122	**Tuesday 4 May 2010 ASA C122**	**Wednesday 5 May 2010 ASA C122**	**Thursday 6 May 2010 ASA A120**	**Friday 7 May 2010 ASA C122**
10:00-12:00 *Introduction*	**8:30-10:45** *Chemical analysis in the biorefinery – Inorganics* (JB) **11:00-12:00** *Fractionation Technologies, Extraction and Utilization of Wood Components* (PF)	**8:30-10:30** *Extractives* (BH) **10:45 – 12:15** *Lignin* (SW & JG)	**8:30-10:45** *Catalytic conversion of sugars and extractives to fuels and chemicals* (DM) **11:00 – 12:00** *Challenges and opportunities of reactor technology in forest-based biorefineries* (TS)	**8:30-9:30** *Catalytic Upgrading of Pyrolysis Oil* (DM) **9:45 – 12:00** *Cataclytic conversion of syngas to fuels and chemicals* (DM)
12:00-13:15 Lunch	12:00-13:15 Lunch	12:15-13:15 Lunch	12:00-13:15 Lunch	12:00-13:15 Lunch
13:15-15:15 *Chemistry of Biomass* (AS) **15:30 – 17:00** *Chemical analysis in the biorefinery – Organics* (SW)	**13:15-14:15** *Cellulose* (PF) **14:30- 17:00** *Hemicellulose* (SW)	**13:15-14:15** *Metals in Biorefineries* (AI) **14:30 – 17:00** *Ionic liquid technologies and platform molecules* (J-PM)	**13:15 - 15:30** *Thermal conversion of biomass & syngas clean-up* (MH) **15:45 – 17:00** *Energy in thermal conversion* (ND)	**13:15 – 15:00** *Board discussion* (TBD)

AI: Ari Ivaska
AS: Anna Sundberg
J-PM: Jyri-Pekka Mikkola
MH: Mikko Hupa
BH: Bjarne Holmbom
DM: Dmitry Murzin
ND: Nikolai DeMartini
PF: Pedro Fardim
JB: Johan Bobacka
JG: Jan Gustafsson
SW: Stefan Willför
TS: Tapio Salmi

Åbo Akademi University

PROCESS CHEMISTRY CENTRE

Introduction (TBD)

Bio-based products are not a new idea and currently exist in many forms, however, replacing a significant percentage of our current use of fossil fuels with biomass feedstocks represent a significant challenge. Efficient use of biomass must be achieved to maximize the benefits of replacing some fossil feedstocks with biomass. Biomass can be broken down into its base components such as cellulose, hemicelluloses, lignin and extractives for direct use or these can be further converted to smaller molecules which can be used as a feedstock for fuels or chemicals. Forest biomass is the focus of this course because of its significance to Finland and many countries around the world. The introduction will provide an overview of the big picture in going from forest biomass to chemicals and fuels with a focus on the questions and challenges that must be met to realize economically competitive future biorefinery options.

Chemistry of Biomass (Anna Sundberg)

Structure of the most common components in biomass, especially wood

- cellulose
- hemicelluloses and pectins
- lignin
- extractives

Chemical analysis in the biorefinery

*Methods of Organics (*Stefan Willför)

An overview of the main methods used for analysis of extractives (including analytic extraction), polysaccharides, and lignin. Both aspects of identification, quantification, structural determination, and molar mass determination will be briefly discussed.

*Inorganic Components (*Johan Bobacka*)*

Instrumental methods that are widely used for analysis of inorganic compounds will be presented and discussed. The main focus will be on basic principles and unique features of the following methods:

- atomic absorption spectroscopy (AAS)
- atomic emission spectroscopy (AES, ICP-OES)
- inductively coupled plasma-mass spectrometry (ICP-MS)
- ion chromatography
- ion-selective electrodes

Fractionation Technologies, Extraction and Utilization of Wood Components (Pedro Fardim)

A general overview about state-of-the art concepts in science and technology for disassembly of biomass, including extraction, fractionation and purification of biopolymers, oligomers and biomolecules. Current and prospective technologies are critically presented and discussed as potential base for industrial biorefineries.

Cellulose (Pedro Fardim)

Cellulose is the most abundant biopolymer on earth. In this lecture we present its fascinating properties as a source for functional materials, main routes for cellulose modification (chemical and enzymatic) and utilization in commercial products.

*Hemicelluloses (*Stefan Willför*)*

Aspects of utilization of native and modified/functionalized hemicelluloses will be discussed, mainly through examples of different potential applications. Both chemical and enzymatic modification will be briefly discussed.

*Lignin (*Stefan Willför & Jan Gustafsson*)*

Lignin valorization through chemical or enzymatic treatments and possible areas of application for the valorized lignin materials.

Extractives (Bjarne Holmbom)

Trees are rich in unique bioactive compounds with different biological functions. They include various terpenoids, fatty acids, sterols as well as polyhenols. Traditional products from extractives are wood tar, turpentine and different tall oil fractions. More recently, products based on polyhenols such as tannins, lignans, flavonoids and stilbenes have been developed. Opportunities and challenges in development of new products from extractives are discussed.

Metals in Biorefineries (Ari Ivaska)

Management of the metal flows and balances is important in order to minimize the negative and maximize the positive effects the different metal ions have on the quality of the final product.

The following subjects will be covered:

- Metals in trees and fibres
- Metal ions and functional groups in trees and pulp
- Fuel analysis and presence of trace elements in biofuels

*Ionic liquid technologies and Platform Molecules (*Jyri-Pekka Mikkola*)*

'Ionic liquid technologies and Platform Molecules' important in recent developments towards NextGen biorefinery will be presented and discussed. The main focus will be on basic properties, applications and unique features of the following topics:

- Ionic liquids or molten salts
- Ionic liquids in biorefining
- Platform molecules the industry needs - what are they and how to get them?

Catalytic conversion of sugars and extractives to fuels and chemicals (Dmitry Murzin)

Wood biomass contains many valuable raw materials for producing fine and specialty chemicals. The catalytic derivatization methods of these different chemical compounds, like carbohydrates, fatty acids, terpenes and lignans as well as the economic importance of the products along with existing industrial methods will be reviewed in the lecture.

Challenges and opportunities of reactor technology in forest-based (Tapio Salmi)

The role of chemical reactors, particularly continuous reactor technology in the production of fuels and chemicals from renewable sources is reviewed. The coupling of kinetics, thermodynamics and mass transfer is described and illustrated with several examples related to hydrogenation, oxygenation, hydrodexygenation and decarboxylation processes. The new challenges of reaction engineering are discussed.

Thermal conversion of biomass & syngas clean-up (Mikko Hupa)

Energy can be extracted from biomass by burning and this energy can be used to produce steam and electricity through the steam cycle. Alternatively, biomass can be pyrolyzed or gasified to produce fuels and chemicals. Pyrolysis will result in the production of a gas, a bio-oil and char with the distribution and characteristics changing with the processing conditions. Gasification allows for the production of a syn-gas which can be converted to fuels and chemicals by catalytic processing.

Energy in thermal conversion (Nikolai DeMartini)

Production of fuels from Thermochemical conversion processes involves using heat to break down the original biomass structure into something that can be used as a precursor to making fuels. Temperature, pressure, residence time and gas atmosphere are all variables that can be changed depending on the product/route desired. Energy is consumed in these endothermic reactions. The fuel precursor must be further processed to produce fuel and in this step energy is lost in the form of heat. Thus, the energy content of the final fuel is considerably smaller than the energy content of the original biomass. Heat recovery and integration can improve the overall energy efficiency. This lecture takes a brief look at the energy flows from biomass to fuels.

Catalytic up-grading of pyrolysis oil (Dmitry Murzin)

Thermal (or catalytic) treatment of biomass, e.g. thermal or catalytic pyrolysis, is a route to bio-based synthesis gas and biofuels. The liquid product from biomass pyrolysis, known as bio-oil is are multi-component mixtures of different size molecules derived from depolymerization and fragmentation of cellulose, hemicellulose and lignin. Since such deleterious properties as high viscosity, thermal instability and corrosiveness present many obstacles to the substitution of fossil derived fuels by bio-oils upgrading processes by reducing the oxygen content are required.

The lecture will focus on hydrodeoxygenation and catalytic cracking of pyrolysis vapors.

Catalytic conversion of syngas to fuels and chemicals (Dmitry Murzin)

Synthesis gas, a mixture of carbon monoxide and hydrogen, can be converted into liquid hydrocarbons of various forms, as well as methanol. Details of the Fischer–Tropsch process with a purpose to produce a synthetic petroleum substitute, and synthesis of methanol will be discussed in the lecture, reviewing process chemistry, catalysts, kinetics and reactor design.