Development of Lignocellulose biorefinery for co-production of chemicals, fuels, electricity and heat; Overview & results of the IP BIOSYNERGY (FP6)

Hans Reith, René van Ree, Reyes Capote Campos,

Robert Bakker, Paul de Wild, Fréderic Monot, Boris Estrine,

Tony Bridgwater, Alessandro Agostini

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Development of Lignocellulose biorefinery for co-production of chemicals, fuels, electricity and heat

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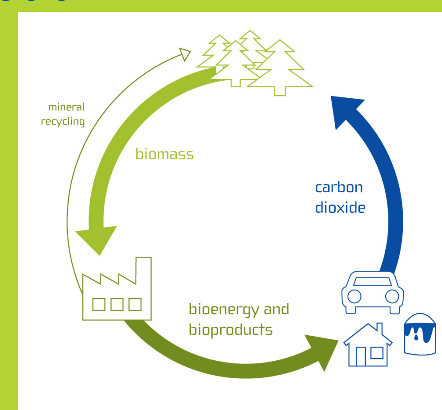

Biorefineries & bio-based products 15 March 2010, Amsterdam, NL.

Contents

- Background of the IP BIOSYNERGY
- Overview and results technology development and design activities
- Preliminary conclusions and perspectives

BIOSYNERGY

Features Integrated Project BIOSYNERGY

BIOmass for the market competitive and environmentally friendly **SYN**thesis of bio-products – chemicals and/or materials – together with the production of secondary en**ERGY** carriers – transportation fuels, power and/or CHP – through the biorefinery approach.

- Development multiproduct cellulose-ethanol based biorefinery technology
- **Focus on valorisation of residues from cellulose ethanol production** to make the production of this biofuel more cost competitive
- Bioprocessing and thermochemical pathways combined
- Process development from lab-scale to demonstration at pilot-scale.

EU FP6 Program: Contract No. 038994 – SES 6. EC Officer: Silvia Ferratini.
Duration: 1-1-2007 – 31-12-2010 (48 months). Budget: 13.4 M€, EC grant 7M€

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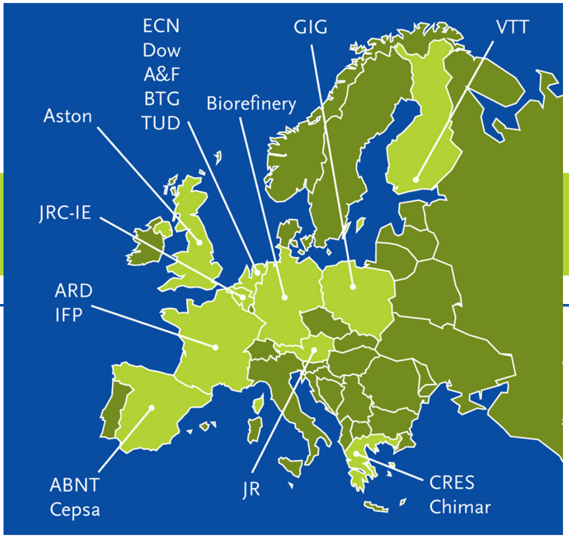
Consortium



17 partners from industry, R&D institutes and Universities from 10 EU countries

1	Energy research Centre of the Netherlands (ECN)	The Netherlands	NL
2	Abengoa Bioenergía Nuevas Tecnologías S.A. (ABNT)	Spain	ES
3	Compania Espanola de Petroles S.A. (Cepsa)	Spain	ES
4	DOW Benelux B.V. (Dow)	The Netherlands	NL
5	VTT Technical Research Centre of Finland (VTT)	Finland	FI
6	Aston University (Aston)	United Kingdom	UK
7	WUR Agrotechnology and Food Innovations B.V. (A&F)	The Netherlands	NL
8	Agro Industrie Recherches et Développements (ARD)	France	FR
9	Institut Francais du Pétrole (IFP)	France	FR
10	Centre for Renewable Energy Sources (CRES)	Greece	EL
11	Biomass Technology Group (BTG)	The Netherlands	NL
12	Joanneum Research Forschungsgesellschaft m.b.H. (JR)	Austria	AT
13	Biorefinery.de (Biorefinery)	Germany	DE
14	Glowny Instytut Gornictwa (GIG)	Poland	PL
15	Joint Research Centre – Institute for Energy (JRC-IE)	The Netherlands	NL
16	Chimar Hellas S.A. (Chimar)	Greece	EL
17	Delft University of Technology (TUD)	The Netherlands	NL

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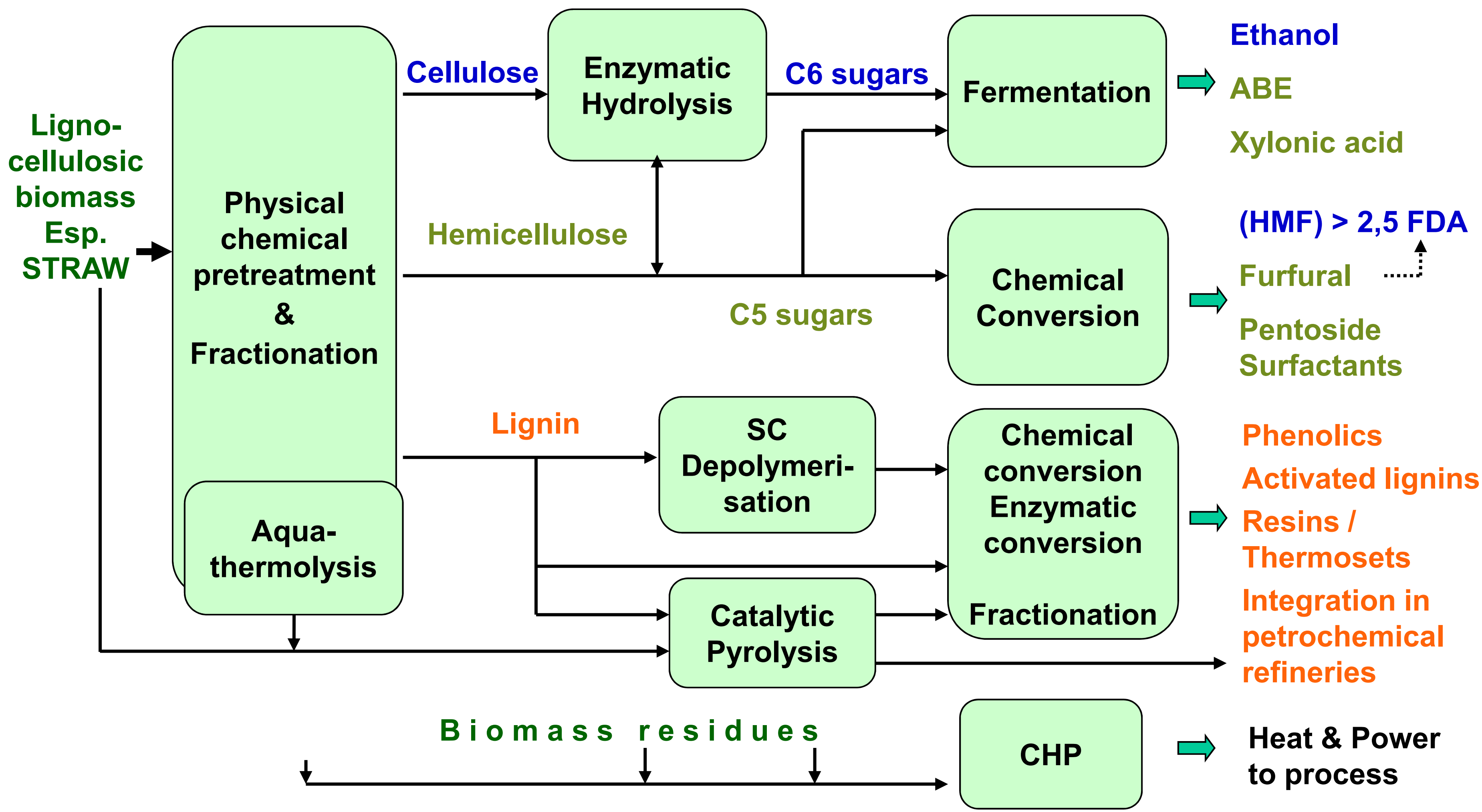
Product lines in the IP BIOSYNERGY

Multi-product biorefinery, Focus on residues cellulose ethanol: **C5 and lignin valorisation**

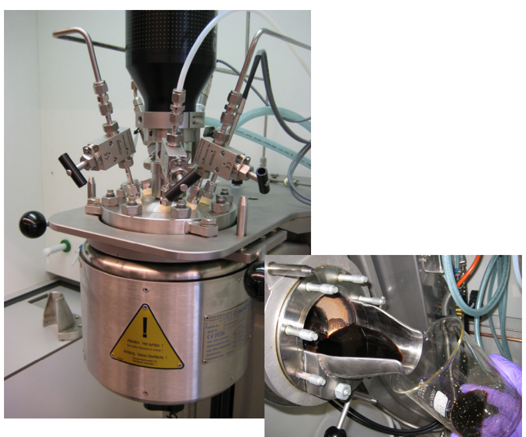


Advanced physical/chemical fractionation (WP1)

- Model feedstocks: **wheat straw**, woods

Processes studied

- Mechanical/Alkaline fractionation (A&F)
- Ethanol/water Organosolv (ECN)
- Organic acid organosolv (Avidell process; ARD)
- Acid hydrolysis (Biorefinery.de)
- Reference technology: steam explosion (ABNT)



Ethanol/H2O Organosolv,ECN

Mech/alk pretreatment A&F

Acid organosolv Pilot plant ARD

Partners: <u>A&F</u>, ABNT, ARD, Bioref, ECN, TUD

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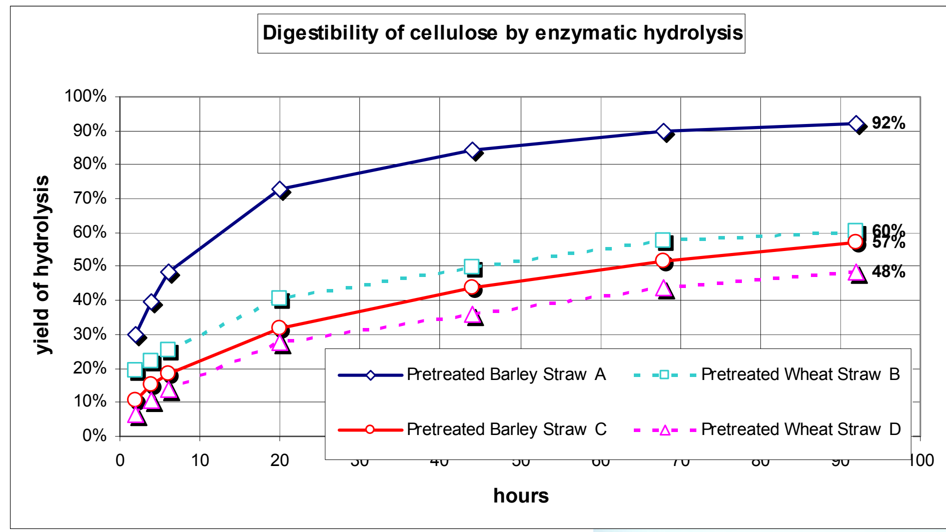
Conclusions pretreatment/fractionation

- No clear “winner”: All studied routes lead to significant fractionation of C5, C6 sugars and lignin from lignocellulose
- Differences in cellulose hydrolysis yields



- Processes need to be optimised toward a particular goal, for example:
  - Hemicellulose hydrolysis for further processing of C5
  - High enzymatic degradability of the cellulose fraction
  - Recovery of a high quality lignin stream

Lignin products from Modified Organosolv Fractionation (ECN)

Innovative thermo-chemical conversion (WP2)

Focus on thermochemical processing of **biomass and lignin.**

Development of:

- Hybrid, staged processing concept: aquathermolysis followed by fast pyrolysis
- Catalytic fast pyrolysis
- Separation and upgrading technology

BFB reactor ECN

Partners: ECN, Aston, BTG

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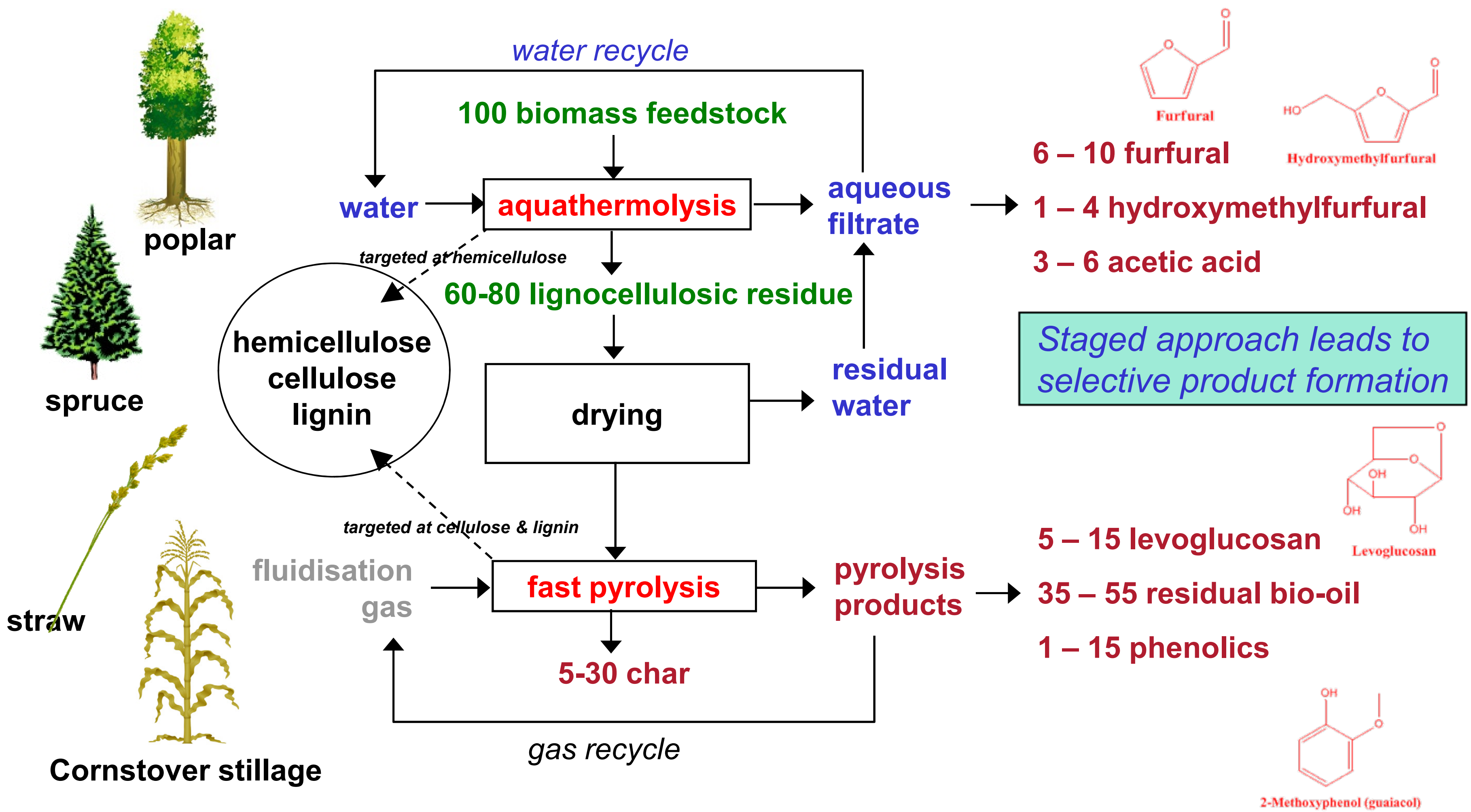
Hybrid staged process for biomass conversion

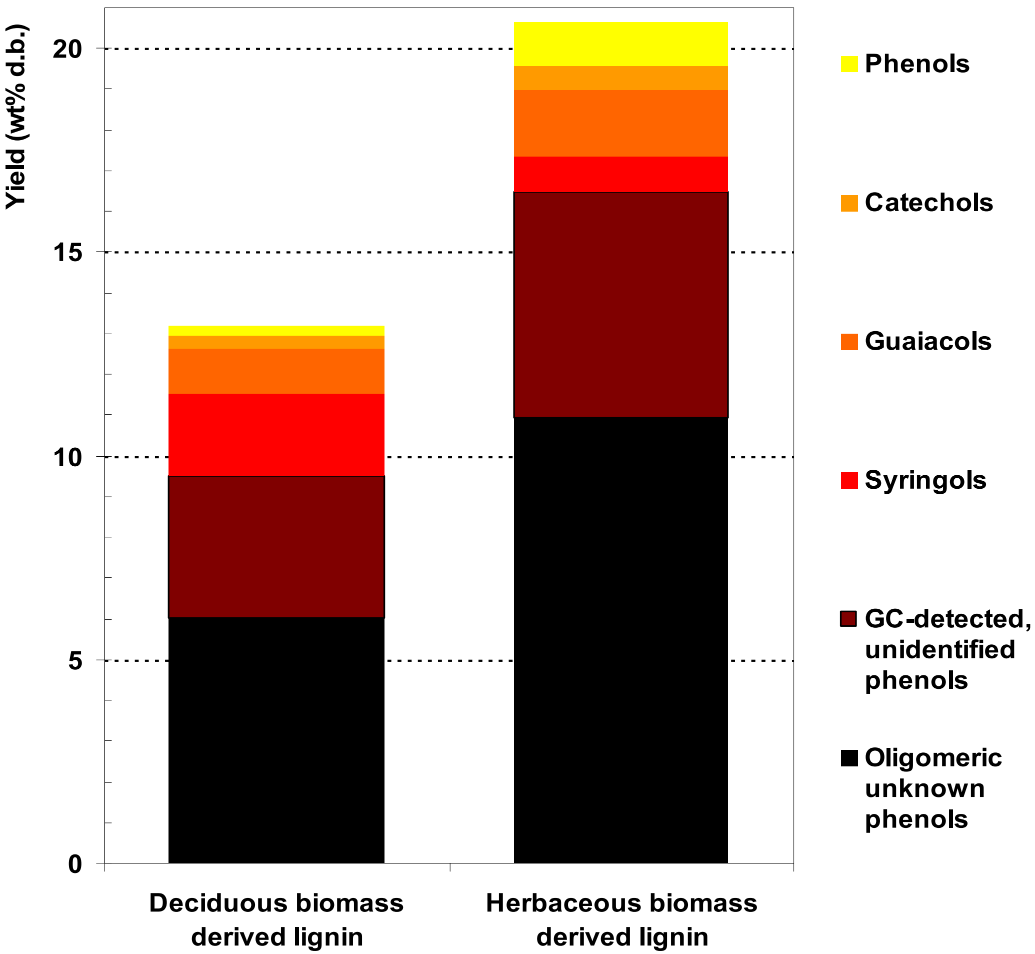
- **aquathermolysis:** pressurised hot water (pre)treatment (200 °C, 30 min.)
- followed by **BFB fast pyrolysis** (350-400°C, vapour residence time 1-2 sec.)



Continuous catalytic pyrolysis of lignin: results

- 100 lignin pyrolyse to:
  15 - 20 gas (CO, CO_2, CH_4)
  20 - 25 water
  15 - 25 organic condensables
  30 - 35 solid (char)

- The liquid product has been collected in two fractions, a thick, homogeneous oily liquid with an aromatic smell and an aqueous fraction with a pungent smell



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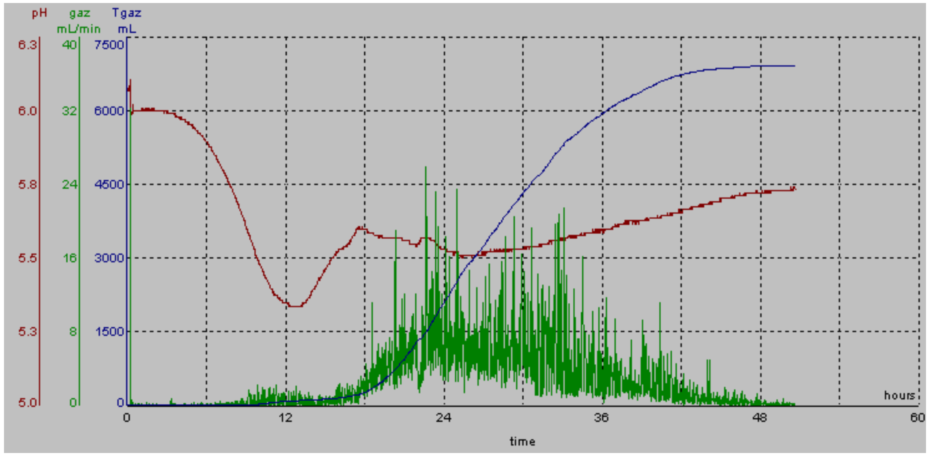
Upgrading thermochemical product mixtures & bio-oils

- Staged condensation for separation of (groups of) chemicals from pyrolysis vapours
- Procedures to improve quality of fast pyrolysis oil (filtration, dewatering)
- Fractionation of bio-oil in fractions for resins and wood preservatives

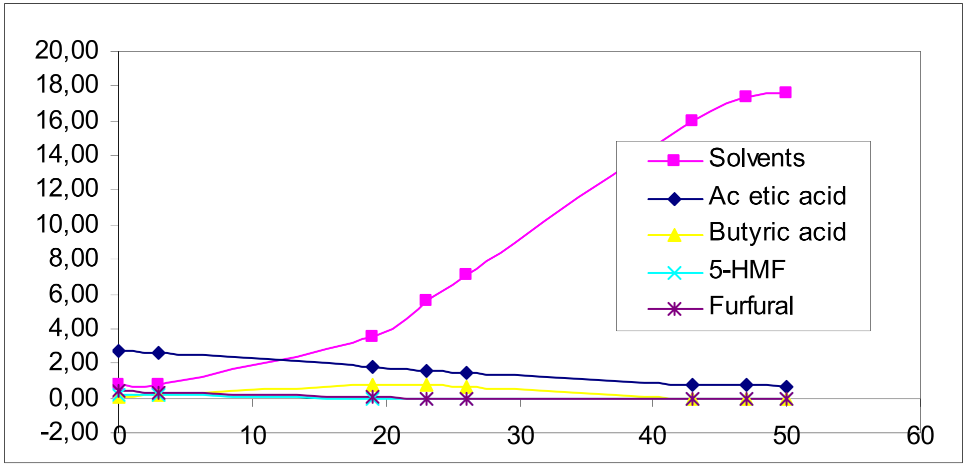
80-250 kg/hr rotating cone fast pyrolysis pilot plant at BTG

ABE – Production on wheat straw hemicellulose hydrolyzate (IFP/A&F)

- Successful screening and selection of strains on pure substrates
- ABE Production on wheat straw hemicellulose hydrolyzates prepared by steam explosion in mild acidic conditions
- 50% Hydrolysate in synthetic medium (60 g/L total sugars (Glu 9; Xyl 51 g/L)
- Strain *Clostridium beijerinckii* NCIB 8052 / pH controlled at 5.3



- Results :
  - •Gas release : 8.9 L / L
  - •**Final solvents (ABE) : 17,6 g/L**
- **Continuous fermentation still a challenge**



Functional lignin derivatives: lignin ‘activation’ (VTT)

- Enzymatic lignin modification by *Trametes hirsuta* laccases
- **Aim**: improvement of reactivity (cross linking behaviour) to enhance product options

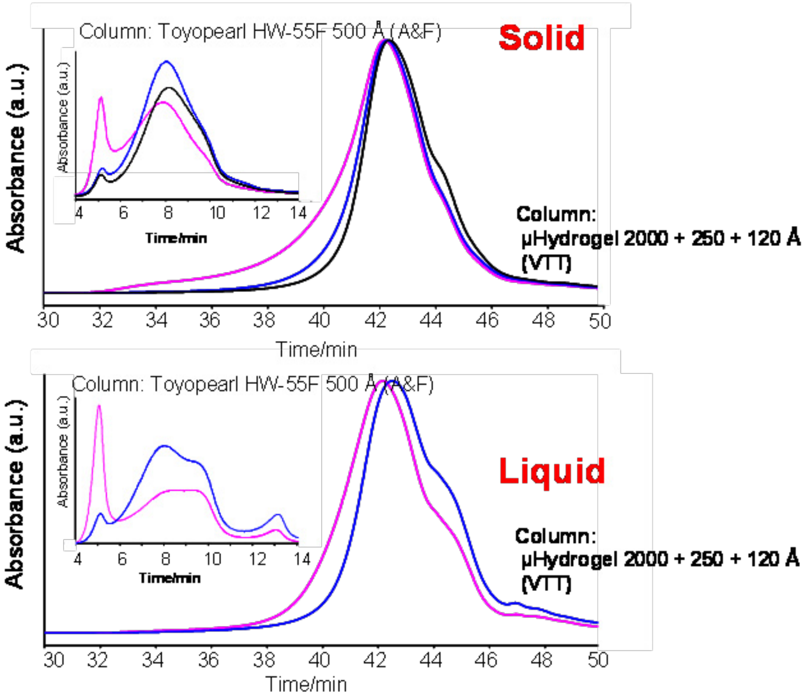
Characterization of modified lignin polymers by chemical and spectroscopic methods.

SEC of a model lignin

ThL treated lignin

Solubilized / Control lignin

Raw lignin / unsolubilised / untreated lignin



Mattinen et al. (2008). "Polymerization of different lignins by laccase," *BioResources* 3(2), 549-565.
Mattinen et al, (2009) "Modifications of lignans by Trametes hirsuta laccase" *BioResources* 4(2), 482-496.

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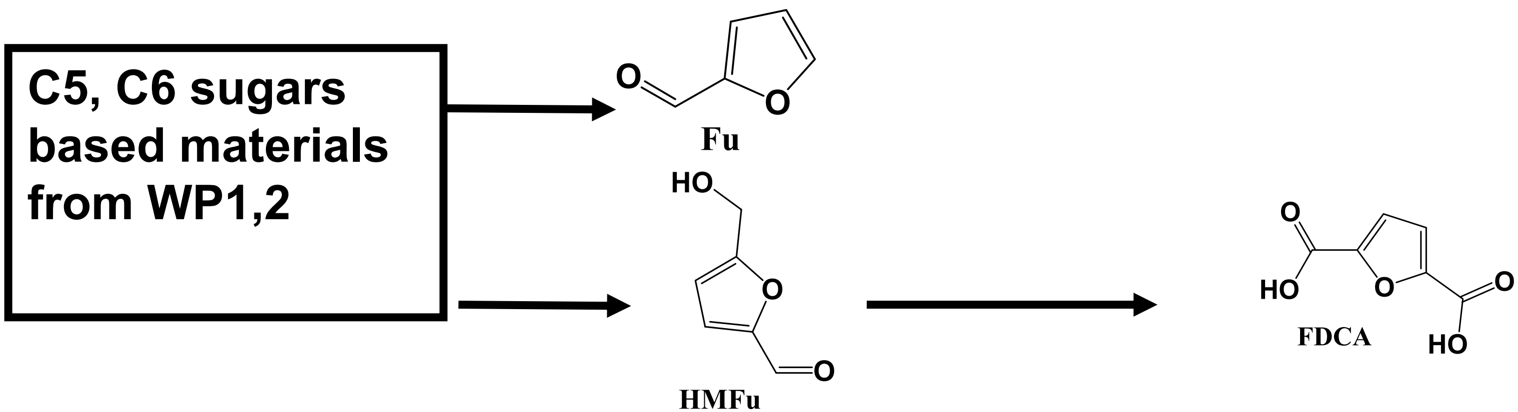
Production & characterisation platform chemicals (WP4)

Partners: DOW, A&F, ARD, Bioref, GIG, Chimar, TUD

- Lignin depolymerisation in supercritical CO2 (A&F) **Improved yields**
- Analysis kinetics furfural (Fu) synthesis from xylose and modelling to improve furfural production process: TUDelft. **Yield improvement to 85%**



- Hydroxymethylfurfural production from glucose dehydration>> **substantial yield improvement by use of ionic liquids (Bioref)**
- **Synthesis 2,5-Furandicarboxylic acid (2,5-FDCA)** from HMF with yield > 90% (Bioref/ A&F)

Application testing and market validation

- Application testing 2,5 FDCA-derived polymers is in progress **with promising initial results**
- Succesfull tests performed by Chimar: **phenol substitution up to 25 wt%** by (organosolv) lignin in thermosetting phenol-formaldehyde resin for particle board application
- Use of **pentose based surfactants for paper impregnation**

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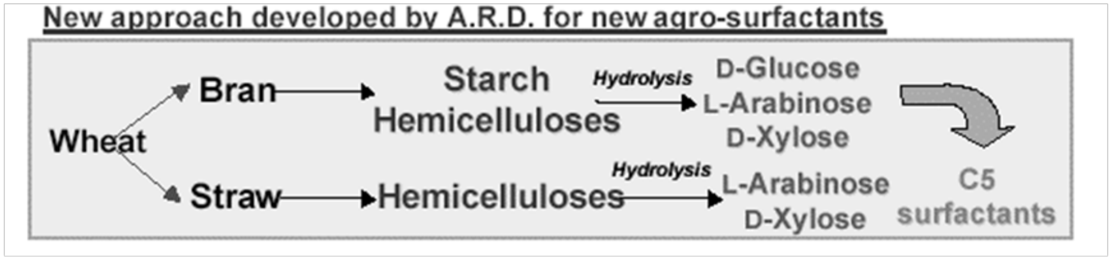
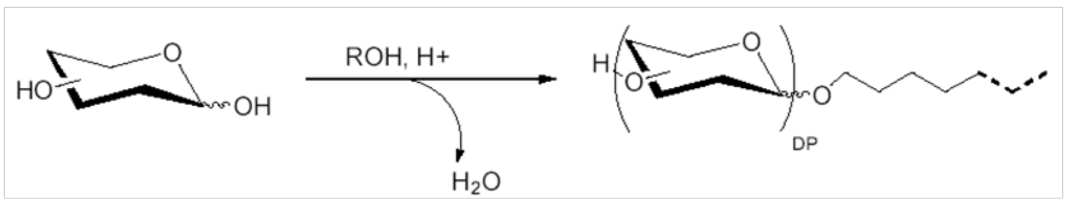
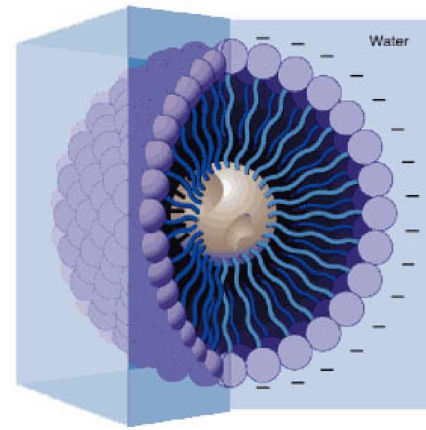
Pentose valorisation as raw material for surfactants; ARD



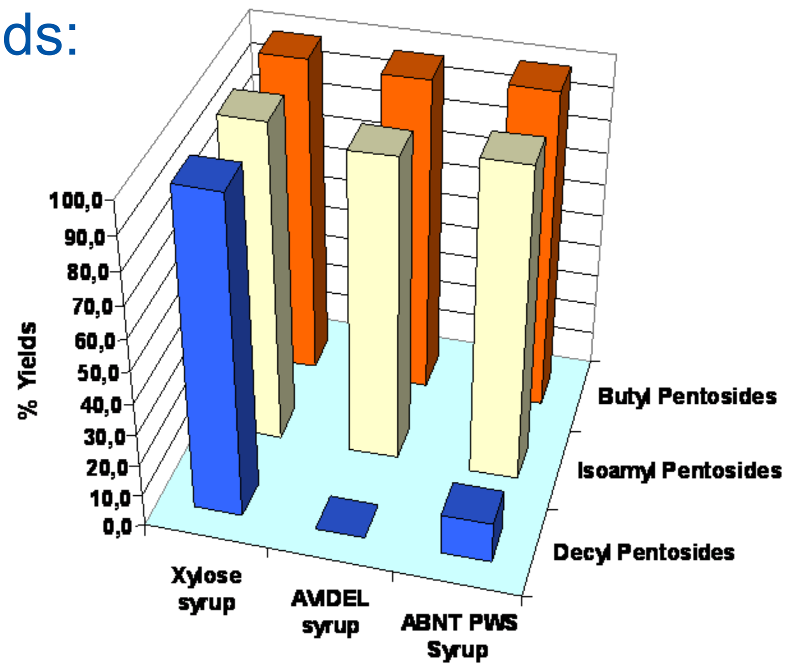




- Reaction of: Pentoses + Fatty alcohols (ROH) C:4 - C:18
- **Aim**: Production of pentoside surfactants by a green technology in order to access the price level of fossil based competitors (~1500 €/ton)

Pentose valorisation as raw material for surfactants; ARD

Direct conversion of pentose containing hydrolyzates to surfactants in high yields: **good progress obtained**



Yields of Alkyl pentosides obtained for three pentose syrups and for 3 types of alcohols.

Short tail Pentoside surfactants prepared **in quantitative yields from straw derived pentose syrups**

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Planned scale up pentose valorisation in surfactants ARD

- Production pentoside surfactants from C5 hydrolyzates at 100-1000 kg scale (ARD)

Integration of results in Conceptual design biorefinery plant (WP5)

Basic design for integral lignocellulose biorefinery plant at an existing cellulose ethanol site: AB BCyL demonstration plant, Salamanca.

- Targeted outputs:
  - bio-ethanol,
  - chemicals, materials, CHP
- 5 EtOH based biorefinery types
- maximum revenue and minimum environmental impact

Partners: ABNT, Aston, ECN

BCyL cellulose ethanol demo plant AB, Salamanca, 5 Million L EtOH/yr from 25,000 ton straw. ***Operational since Oct. 2009.***

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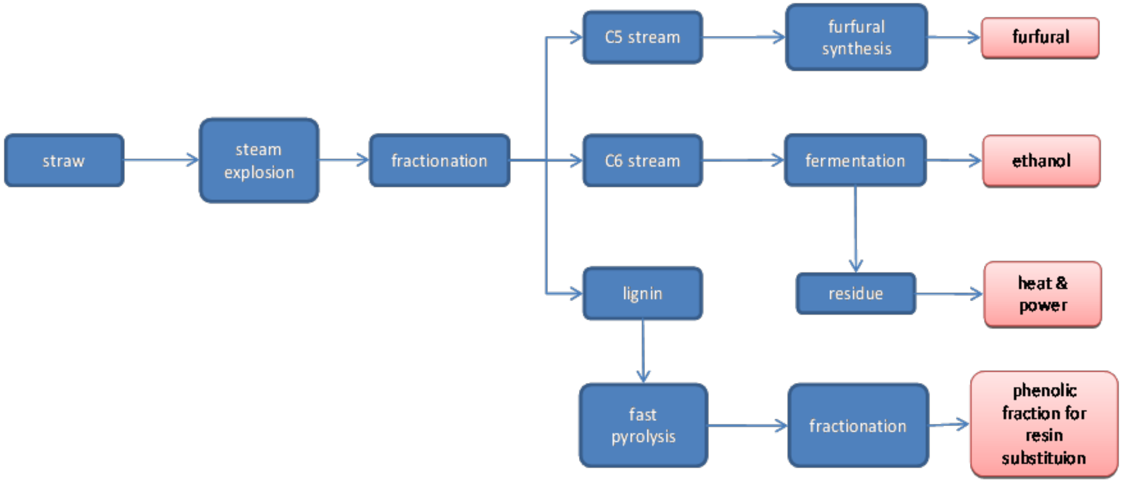
Biomass-to-products chain design (WP6, Aston)

Aim: Identification of the most promising biorefinery chains for the EU

- Modelling tool with modular structure developed
- Process synthesis and simulation: ongoing
- Process comparison using **MCDA** (techno-economics, LCA, socio-economics)



Focus on ethanol based biorefineries: **Biorefinery co-producing ethanol, furfural, phenolic resins and CHP**

*Preliminary results economic evaluation indicate that **biorefinery processes** (ethanol + chemicals) have **better economic perspective** than cellulose ethanol only (+CHP) production*

Partners: **Aston,** ECN, IFP, CRES, JR, JRC, Cepsa, ABNT.

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Preliminary conclusions and perspectives

- Biosynergy RTD provides a good basis for valorization of C5 sugars and lignin. Demonstration of several processes on pilot scale will be performed in 2010.

- Pretreatment and enzymatic hydrolysis are a major cost factor and are critical for the quality of intermediates and end products and for techno-economic feasibility
  - Pretreatment technologies need to be optimized toward a particular goal / end products
  - For further improvement an integrated approach of the trajectory feedstock<>pretreatment<>hydrolysis<>fermentation is required

- Lignin valorization (at least in part) to chemicals is an important tool for economic profitability and for (further) reduction of the carbon footprint. Promising results for lignin valorization attained for:
  - direct application of (organosolv) lignin in resins
  - catalytic thermochemical processing (pyrolysis) of lignin to phenolics
  - enzymatic lignin conversion to improve reactivity

- Biorefinery of lignocellulose to ethanol + chemicals + CHP shows better economic perspectives than production of only cellulose ethanol + CHP.

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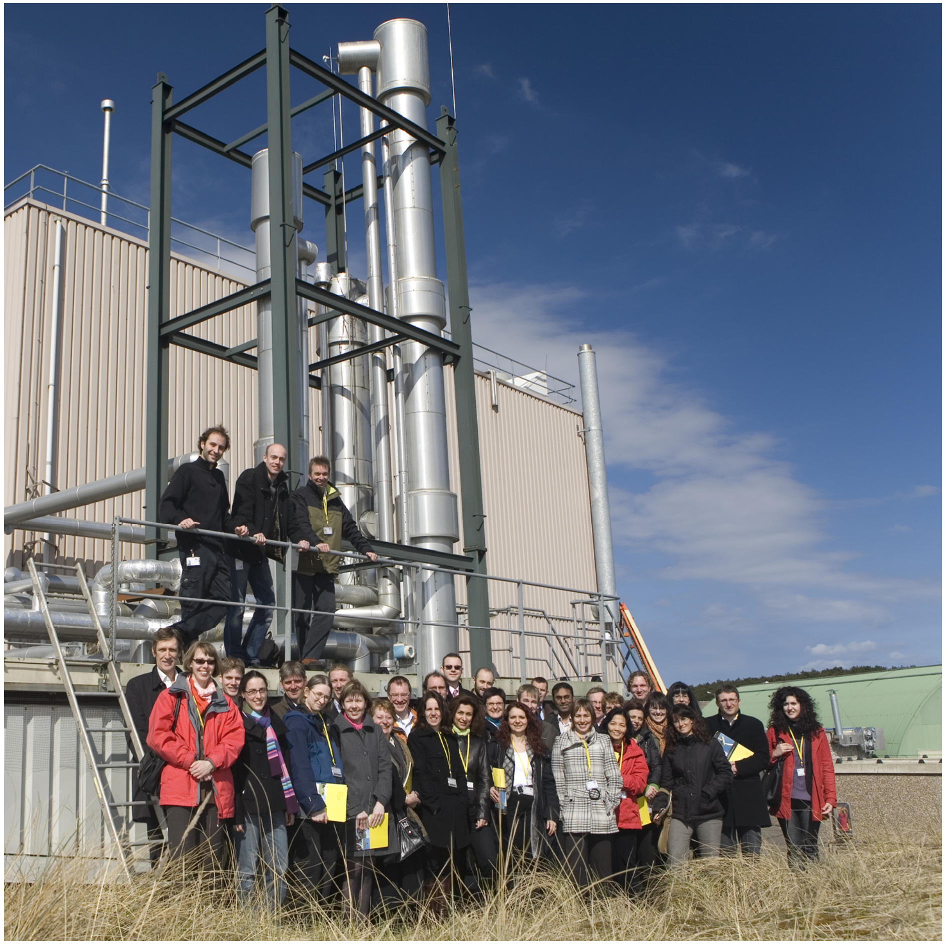

BIOSYNERGY Team during Technical Excursion at ECN in April 2008. Photo: Jasper Lensselink.