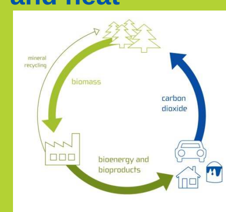
BIOSYNERGY

SIXTH FRAMEWORK PROGRAMME

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

Overview of the IP BIOSYNERGY (FP6)



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Bioref-Integ Workshop, 2 December 2009, Solihull, UK

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Contents

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

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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 of integral cellulose-ethanol based LC Biorefinery
- *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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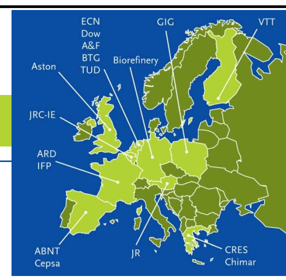
Consortium



17 partners from industry, R&D institutes and Universities from10 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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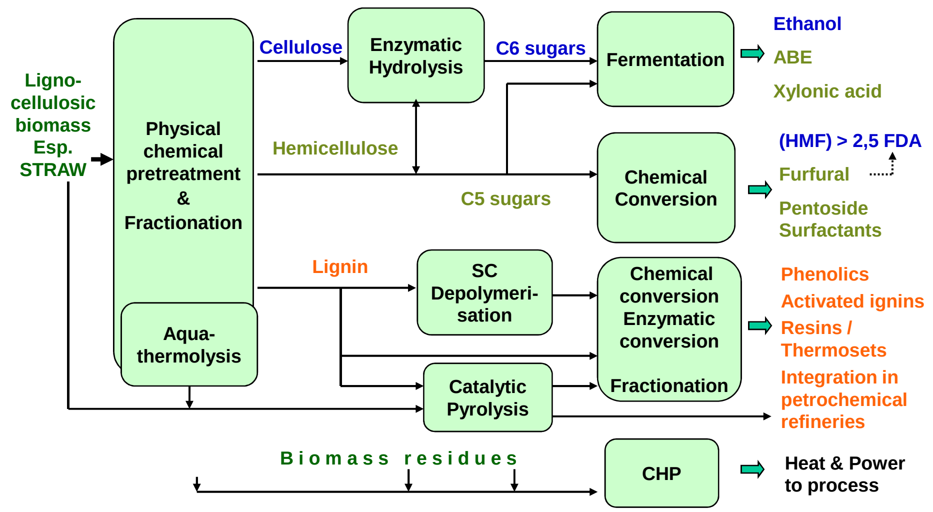
Product lines in the IP BIOSYNERGY

Multi-product biorefinery, Focus on residues cellulose ethanol i.e. C5 and lignin valorisation



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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: A&F, ABNT, ARD, Bioref, ECN, TUD

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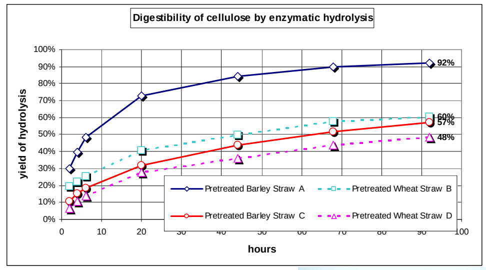
Preliminary conclusions pretreatment/fractionation

- 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
- Benchmarking/Economic evaluation in progress

Lignin products from Modified Organosolv Fractionation (ECN)

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Innovative thermo-chemical conversion (WP2)

<u>Topics</u>

- Staged (catalytic) thermochemical processing of biomass and lignin
- Catalytic fast pyrolysis
- Integrated development of separation/ upgrading technology

Partners: <u>ECN</u>, Aston, BTG

BFB reactor ECN

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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)

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

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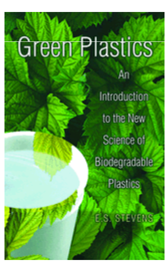
Potential applications of lignin-derived phenolics

'Green' plastics

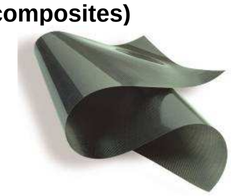


- **epoxies**
- **Poly-Urethanes**
- **polyolefins**

Wood-adhesives and resins

- **Fuel additives** (aromatic ethers)
- **BTX**
- **Binders**

- **Carbon Fiber (for CF composites)**



Specialty phenolics for high-value applications such as fragrances and pharmaceuticals

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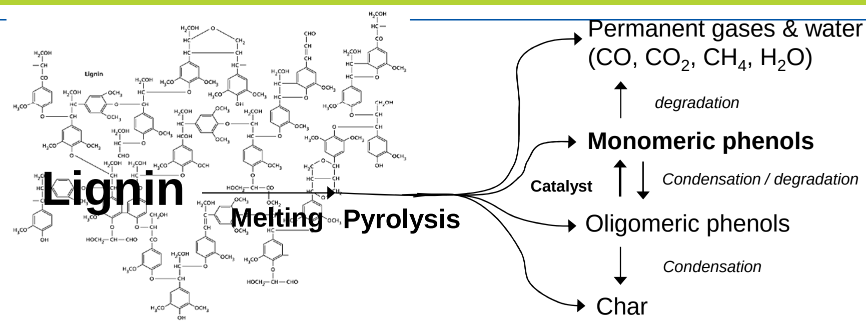
Lignin thermal conversion via pyrolysis: challenges



- First of all a <u>proper feeding procedure</u> is required to overcome lignin's thermoplastic behaviour that causes severe operational problems such as screw feeder clogging by molten lignin, agglomeration and subsequent defluidisation of the reactor bed.
- For a maximal conversion of lignin into (monomeric) phenols there is a <u>narrow window of pyrolysis conditions</u> such as temperature, heating rate, vapour and solid residence time.
- Use of catalyst to improve product selectivity and yield

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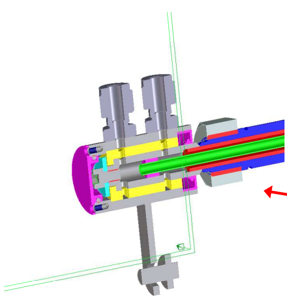
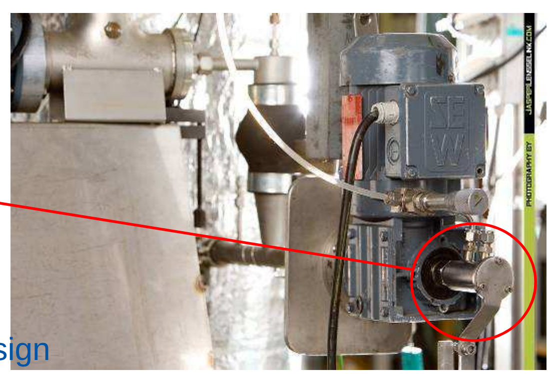
Improving feeding behaviour: construction of a water-cooled screw feeder





- Hollow screw design
- Alternative feeding approach: pellettizing

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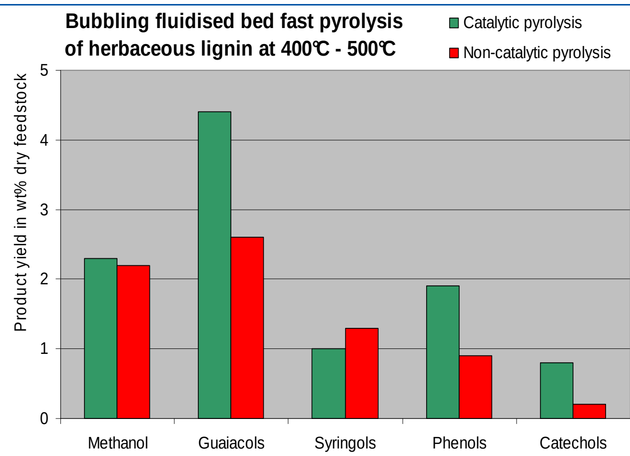
Improving thermal processing by application of a catalyst



Up to 10 wt% monomeric phenols (20 wt% incl. oligomers) from straw lignin produced

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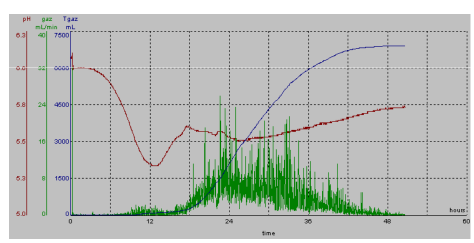
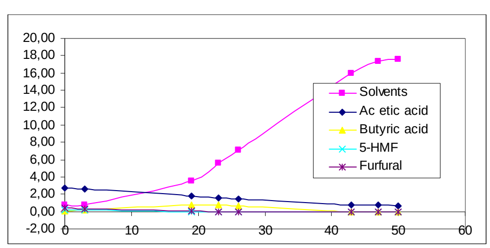
ABE – Production on wheat straw hemicellulose hydrolyzate

- 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





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Functional lignin derivatives: lignin 'activation'

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

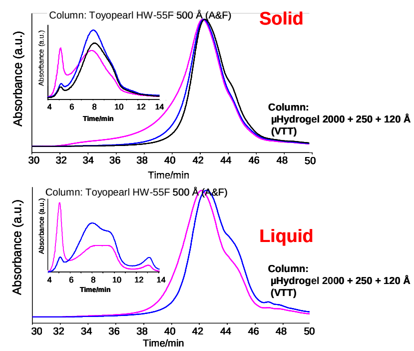
Characterization of modified lignin polymers by chemical and spectroscopic methods.

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," *BioRes.* 3(2), 549-565.

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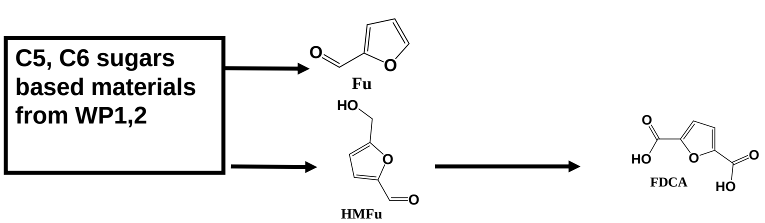
Production & characterisation platform chemicals (WP4)

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

- Lignin depolymerisation in supercritical CO_2: A&F
- Analysis kinetics furfural (Fu) synthesis from xylose and modelling to improve furfural production process: TUDelft
- Hydroxymethylfurfural production from glucose dehydration>> high conversion rates and selectivity reached: Biorefinery.de



- Synthesis 2,5-Furandicarboxylic acid (FDCA) from HMF: Biorefinery/ A&F
- Polymerisation trials and application testing in progress

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Application testing and market validation

- Succesfull tests performed by Chimar: **phenol substitution up to 25 wt%** by (organosolv) lignin in thermosetting phenol-formaldehyde resin for particle board application (lab scale)

- Use of **pentose based surfactants for paper impregnation** in the wood-based industry

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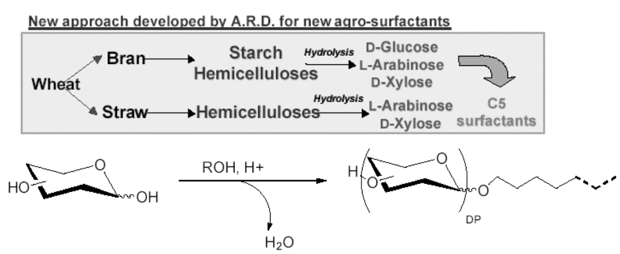
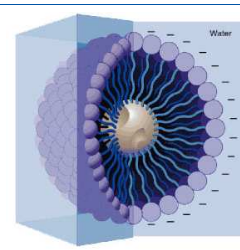
Pentose valorisation as raw material for surfactants; ARD





- Reaction of: Pentoses + Fatty alcohols (ROH) C:4 - C:18
- Production of pentoside surfactants by a green technology in order to access the price level of fossil based competitors (1.5 €/kg)
- Development of technology to directly convert pentose containing hydrolyzates to surfactants in high yields: **good progress obtained**

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Planned scale up pentoses valorisation in surfactants ARD

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

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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

BCyL cellulose ethanol demo plant AB, Salamanca, 5 Million L EtOH / year

Partners: ABNT, Aston, ECN

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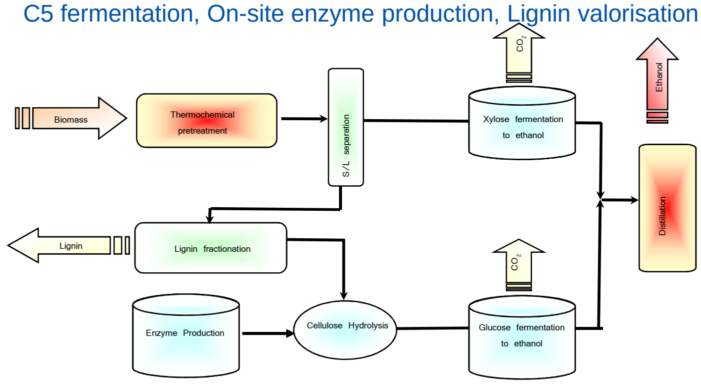
Conceptual design biorefinery plant (WP5)

- **Base case:** Integral model for the BCyL lignocellulose to bio-ethanol process scaled-up to 400 ton/day of wheat straw incl. biomass fractionation, C5 fermentation, On-site enzyme production, Lignin valorisation



- Economic model to evaluate design concepts and scenarios

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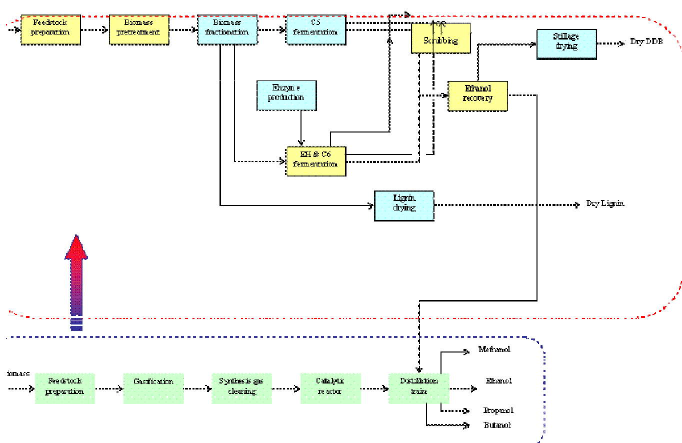
100 % ethanol biorefinery concept: integrating biochemical + thermochemical ethanol production



- thermochemical process uses residues from the bioprocess
- surplus heat from the thermochemical process covers energy requirements of the bio-process

Biomass-to-products chain design (WP6)

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

Objectives

Identification of the most promising biorefinery chains for the European Union, in terms of:

- Performance as yield and efficiency,
- Energy efficiency,
- Environmental performance as LCA,
- Cost as capital, operating and product costs
- Socio-economic aspects

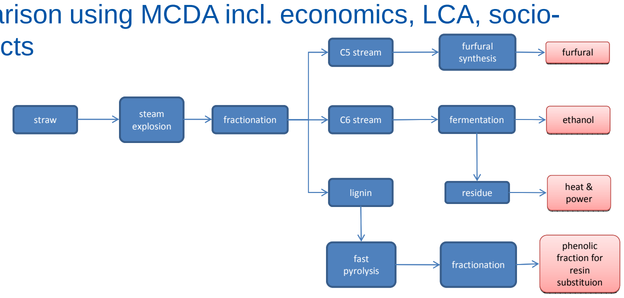
•Focus on ethanol based biorefineries

•Plant energy from biomass fired CHP (residues + straw)

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

Development modelling tool with modular structure

- Process synthesis and simulation
- Process comparison using MCDA incl. economics, LCA, socio-economic aspects



Biorefinery co-producing ethanol, furfural, phenolic resins and CHP

Preliminary results economic evaluation indicate that integral biorefinery processes (ethanol + chemicals) have better economic perspectives than ethanol only (+CHP) production

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Preliminary conclusions & perspectives

- Development LC Biorefinery –combining bioprocesses, chemical processes + CHP – offers good perspectives to fully exploit the potential of lignocellulose.

- Biosynergy RTD shows good progress and provides a basis for large-scale valorization of C5 sugars and lignin. Scale-up is planned for several conversion routes.

- Pretreatment and enzymatic hydrolysis are critical for fractionation and therefore for the quality of the end products and techno-economic feasibility:
  - Pretreatment technologies need to be optimised toward a particular goal.
  - Enzymes are a major processing tool in the LC Biorefinery. Further development and cost reduction are needed.
  - Integrated development of the trajectory Feedstock-pretreatment-hydrolysis-fermentation is required.

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Preliminary conclusions & perspectives

- Lignin valorization (at least in part) to chemicals is an important tool for economic profitability and for reduction of the carbon footprint.

- Direct application of (organosolv) lignin, catalytic thermochemical processing (pyrolysis) and enzymatic lignin conversion show promising results for lignin valorization

- Biorefinery processes (ethanol + chemicals) show better economic perspectives than production of only ethanol (+ CHP).

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

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BIOSYNERGY SIXTH FRAMEWORK PROGRAMME

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LignoValue

SenterNovem EOS-LT