Development of integrated lignocellulose biorefinery for co-production of chemicals, transportation fuels, electricity and heat

Overview and preliminary results of the EU FP6 Integrated Project BIOSYNERGY


Biorefinica 2009, 27 & 28 January 2009, Osnabrück, Germany
Objectives

1. To develop the best thermochemical/(bio-)chemical fractionation and conversion technologies for major side-streams of an ethanol fermentation plant, but also applicable for other wet and dry feedstocks.
2. To define the potential of identified platform chemicals for chemical and petrochemical industries.
3. To come from lab-scale to pilot-scale processes using techno-economic assessments and clear exploitation guidelines.
4. Making the production of biofuels more cost competitive by utilisation of all biomass components at maximum added value

- (Bio)chemical and thermochemical pathways combined
- Focus on valorisation of residues from bio-ethanol production
## Consortium

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

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**Work Packages**

**Man**
- WP 0 – Management activities

**RTD**
- WP 1 – Advanced physical/chemical fractionation
- WP 2 – Innovative thermo-chemical conversion
- WP 3 – Advanced biochemical conversion
- WP 4 – Innovative chemical conversion and synthesis
- WP 5 – Conceptual design Biorefinery pilot-plant BCyL of ABNT in Salamanca
- WP 6 – Integral biomass-to-products chain design, analysis and optimisation

**Demo**
- WP 7 – Demonstration at pilot-scale

**T/Diss**
- WP 8 – Training and knowledge dissemination
WP1: Advanced physical/chemical fractionation

Objective: Coordinated development of physical/chemical fractionation technologies for raw biomass

Processes studied:
- Mechanical/Alkaline fractionation (A&F)
- Modified Organosolv (ECN)
- Fractionation with organic acids (Avidell process; ARD)
- Acid hydrolysis (Biorefinery.de)
- Hemicellulose acid hydrolysis (TuD)
- Reference case: steam explosion (ABNT)

Partners: A&F, ABNT, ARD, Bioref, ECN, TUD
WP1: Advanced physical/chemical fractionation

Model feedstocks:
straw, woods, DDGS

Organosolv R&D at ECN
Mech./alk pretreatment A&F
Pilot plant ARD
Main applications for fractions produced

- C6 sugars to ethanol
- C5 sugars to Acetone Buthanol Ethanol (ABE) fermentation
- C5 and C6 sugars to furans, surfactants, diols, di-acids,…….
- Lignin for higher value applications
  - Component in resins
  - Functional lignin derivatives: Nanoparticles, enzymatically modified lignin polymers
  - Depolymerisation of lignin for chemicals production

Lignin products from Modified Organosolv Fractionation (ECN)
Fractionation: Results to date

- Experimental R&D 5 fractionation routes
- Enzymatic hydrolysis tested and compared
- Modelling of fractionation routes + benchmark
  - investigate costs of fractionation routes on similar basis
  - Compare results to the reference case

Example of modeling Fractionation (ARD)
Preliminary Conclusions

- All studied routes lead to significant fractionation of C5, C6 sugars and lignin from lignocellulose
- Processes need to be optimised toward a particular goal, for example:
  - Hemicellulose hydrolysis for further processing of C5
  - Recovery of a high quality lignin stream
  - High enzymatic degradability of the cellulose fraction
- Economic evaluation of the studied fractionation routes is on-going
WP2: Innovative thermo-chemical conversion

Topics

• Staged (catalytic) thermochemical processing of biomass and lignin (ECN, Aston)

• Catalytic fast pyrolysis (BTG, Aston)

• Integrated development separation/upgrading technology

Partners: ECN, Aston, BTG

BFB reactor ECN
Staged thermochemical processing

**Opportunities**

- Sequential thermal decomposition: hemicellulose > cellulose > lignin
- Condensable products: C2-C4, acids, furans, anhydrosugars, phenolics (+ char and syngas)

**Challenges**

- Optimisation of individual product or product group yields via catalysis, process conditions: temperature, heating rate, vapour and solid residence times
- Product separation and upgrading
Comparison thermochemical processing straw

Selected chemicals from wheat straw via 1-step BFB pyrolysis, via staged degasification in an auger reactor and via hybrid thermochemical processing involving aquathermolyis and BFB pyrolysis showing the superior performance of the hybrid concept

Separation/upgrading

- Staged condensation for separation of (groups) of chemicals
- Procedures to improve quality of pyrolysis oil (filtration, dewatering)

80-250 kg/hr rotating cone fast pyrolysis pilot plant at BTG
WP3: Advanced biochemical conversion

Objectives
Development of advanced biochemical processes for conversion of sugars and lignin into value-added products or intermediates

- Acetone-butanol-ethanol (ABE) fermentation: IFP-A&F
- Sugar conversion to platform chemicals: VTT
- Production and analysis of functional lignin derivatives: VTT
- Separation of product mixtures by Multiphase Rotating disk Contactors: GIG
ABE fermentation: Preliminary results

• Screening of strains on pure substrates
  ▪ tests in flasks
  ▪ tests in lab-scale reactors

• Production on wheat straw hemicellulose hydrolyzates prepared by steam explosion in mild acidic conditions

ABE fermentation at IFP
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

![Graph showing solvent production](image-url)
Functional lignin derivatives

- procedure for lignin nanoparticles
- enzymatic lignin modification by laccases

Reactivity of Biosynergy lignins with *Trametes hirsuta* laccase
Functional lignin derivatives

Modified lignin polymers have been prepared on lab scale by *Trametes hirsuta* laccase treatment and they have been characterised by chemical and spectroscopic methods.

WP4: Innovative chemical conversion and synthesis

Objectives

- Definition and technical development of reaction chemistries and process designs for a well-defined portfolio of value added products

- Validation of commercial opportunities for the products portfolio in existing and also new industrial and consumer markets and applications

Partners: DOW, A&F, ARD, Bioref, GIG, Chimar, TUD
Production & characterisation platform chemicals

- Products from Lignin, Cellulose and Hemicellulose fractions
- Lignin depolymerisation in supercritical CO₂: A&F
- Hydroxymethylfurfural production from glucose dehydration >> high conversion rates and selectivity
  Biorefinery.de
- Analysis kinetics furfural synthesis from xylose and modelling furfural production process: TUDelft


Scheme of lab scale reactor TUDelft
Added value chemicals from platform chemicals

- Synthesis of 2,5-furandicarboxylic acid (2,5-FDA) starting from methyl furoate (to be obtained from furfural): A&F
- Synthesis of 2,5-FDA from HMF: Biorefinery.de

- Development of technologies for production of Diol-Components
- Evaluate use of resulting chemicals in polymer synthesis
Pentoses valorisation as raw materials for surfactants ARD

- Production of pentoside surfactants by a green technology in order to access the price level of petrol based competitors (1.5 €/kg)

- Development of new technology to directly convert pentoses containing raw material in surfactants in high yields: good progress obtained
Applications testing and market validations

- Successful tests thermosetting phenol-formaldehyde resin for wood-based panel with phenol substitution up to 50% by lignin for lab scale particle board application.

- Use of pentoses based surfactants for paper impregnation in the wood-based industry
WP5: Conceptual design biorefinery plant

Objectives
Basic design for innovative lignocellulose biorefinery plant at an existing cellulose ethanol site: ABNT BCyL plant, Salamanca

- targeted outputs: bio-products (chemicals, materials), bio-ethanol, power and/or heat.
- maximized profit and minimized environmental impact

Partners: ABNT, Aston, ECN

BCyL cellulose ethanol pilot plant ABNT, Salamanca, 5 Million L EtOH / year
WP5: Conceptual design biorefinery plant

Progress to date:

• Integrated 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.

• Draft flowsheeting model for integrated biorefinery
WP6: Biomass-to-products chain design, analysis and optimisation

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

Partners: Aston, ECN, IFP, CRES, JR, JRC, Cepsa, ABNT.
Progress to date:

- Creation and validation of process synthesis methodology and modelling tool to identify the optimum process chain design and literature review;
- Definition of the main structure of the LCA model and Collection of data
- Choice of 10 initial concepts for modelling and LCA
Example: LCA data requirement

**Biorefinery Concept 1**

- **Wheat straw**
- **Auxiliary energy**

**Solid waste**
- CO2
- Others

**Liquid waste**
- Recovered condensate
- Waste water
- Stillage stream

**Air emissions**
- CO2
- Others

**Auxiliary material**
- Steam
- H2SO4
- H2O
- NaOH
- Enzymes
- Yeast
- Others

**Products**
- Bioethanol
- Furfural
- Phenols

**Auxiliary energy**
- Electricity
- Heat

**Outputs**
- Remaining biooil
- Charcoal

**Mass:** t/a
**Energy:** MWh/a
WP7: Demonstration at pilot scale

Objectives
To use pilot-scale facilities to
• produce samples of bio-based intermediates for lab and bench-scale technology developments (WP1-4)
• Examine scale-up potential developed technologies

Partners: A&F, ABNT, Aston, ECN, ARD, BTG, Bioref
WP7: Demonstration at pilot scale

Progress to date:
• Steam pre-treated straw delivered by ABNT
• Pilot-scale pyrolysis 280 kg bio-oil rotating cone reactor BTG

• Scale up developed technologies 2009 & onward
Hybrid Thermochemical processing

- Poplar chips
  - Aquathermolysis steam treatment
  - Aquathermolysed poplar chips
    - (Catalytic) intermediate / fast pyrolysis
      - Furfural
      - Levoglucosan Bio-oil
      - Residu (ash, charcoal)

93 m³ industrial batch thermolyser reactor
1 kg/hr BFB test rig at ECN
80-250 kg/hr rotating cone fast pyrolysis pilot plant at BTG
Pilot scale ABE fermentation at ARD

- Lab-scale (150L)
- Intermediate scale (10 m³)
- Fermentor 80 m³
- Membranes purification
Pentoses Valorization as surfactants

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

- Application testing (Chimar)
• R&D shows good progress
• Development of integrated processes / chain approach is one of the major challenges
• Lignin valorization is an important tool for economic profitability
Thank you for your attention

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