

CO-PRODUCTION OF CELLULOSIC BIO-ETHANOL, POWER AND HEAT

Techno-economic feasibility and follow-up R&D

J.H. Reith, H. den Uil and R. van Ree, *Energy research Centre of the Netherlands (ECN), Unit Biomass*
 P.O. Box 1, 1755 ZG Petten, the Netherlands, tel. (31) 224-564371, fax (31) 224-568487, e-mail: reith@ecn.nl
 W.T.A.M. de Laat and J.J. Niessen, *Royal Nedalco BV, Bergen op Zoom, The Netherlands*
 E. de Jong, H.W. Elbersen and R. Weusthuis, *Agrotechnological Research Institute ATO BV, Wageningen, The Netherlands*
 J.P. van Dijken and L. Raamsdonk, *Kluyver Laboratory of Biotechnology, Technical University Delft, Delft, The Netherlands*.

INTRODUCTION

The use of low-cost (ligno)cellulosic biomass and residues as feedstock for bio-ethanol production is expected to reduce production costs and cause a sizeable increase of production volume. A consortium from industry and R&D institutes in the Netherlands performed an evaluation to identify R&D approaches towards commercial implementation. Based on the results¹⁾ a 4 year R&D project (2003-2006) is currently underway.

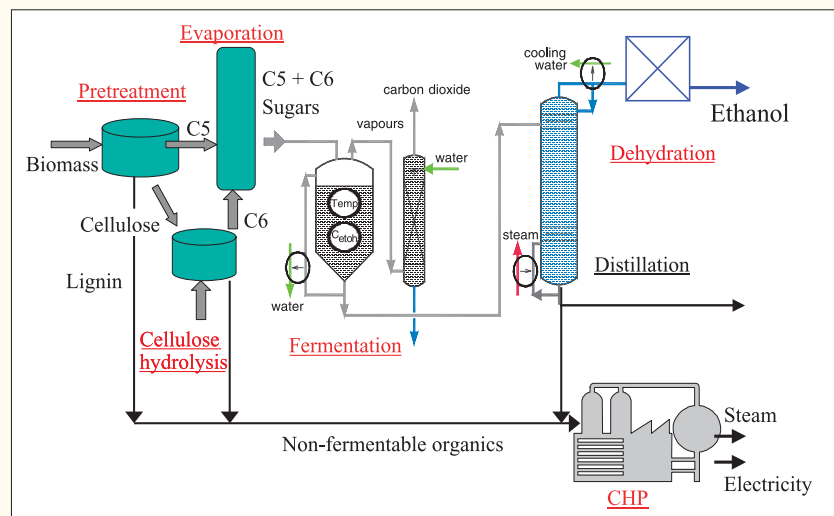


Figure 1. Process scheme for co-production of bio-ethanol, electricity and heat from ligno-cellulose.

RESULTS

Feedstock

- The total amount of lignocellulosic biomass and residues in the Netherlands is estimated at 12 million dry tonnes/year. This is sufficient for a (potential) production of 2.5 million tonnes bio-ethanol (65 PJ_{th})/year.
- In the near term a focus on agricultural and agro-industrial residues is a good strategy; in the long term the feedstock range should be broadened with (imported) energy crops.

Critical process steps

- Production of fermentable sugars from lignocellulose is a critical issue. Mild alkaline extraction at low temperature and weak acid hydrolysis in pressurized hot water have been selected for further development²⁾.
- A substantial reduction in the costs of industrial enzymes for cellulose hydrolysis is required.
- No suitable fermentation system is available for ethanol fermentation of pentoses from hemicellulose. A possible approach is through genetic modification of the industrial ethanol producing yeast *Saccharomyces*. An alternative approach (chosen in the current project) is to explore strains of anaerobic, thermophilic bacteria showing potential to convert all (hemi)cellulose components into ethanol.

Techno-economic assessment (Tables 1 and 2)

A performed system assessment for a bio-ethanol plant (156 kton/yr; Fig. 1) for three feedstocks shows that:

- Bio-ethanol (99.9 vol%) is produced at an energetic efficiency of 40-55%.
- CHP of non-fermentable residues provides the total steam and electricity demand of the plant plus an electricity surplus, giving a total efficiency of 56-68%.
- Water consumption is 2-4 times higher than in current ethanol production, requiring evaporation of the sugar solution prior to fermentation. R&D and process design should focus on reduction of water use.
- Capital costs (31-36 % of production costs) and cellulase costs (36-45%) are the major cost drivers.
- A 30% reduction in capital investments and 10-fold reduced cellulase costs are required to reach bio-ethanol production costs of 16-20 €/GJ, competitive with fuel ethanol from starch crops (approx. 16 €/GJ).
- The potential CO₂ reduction is 3.1 - 3.8 tonne/tonne bio-ethanol. A 50% fulfillment of EU targets³⁾ for 2020 by bio-ethanol will result in a CO₂ reduction of approx. 36 Mtonne/year.

CURRENT R&D PROGRAMME

A 4-year R&D-programme by an extended consortium has started in 2003 developing technology for conversion of lignocellulosic feedstock into ethanol and lactic acid, electricity and heat. Major topics are:

- Pretreatment by mild alkaline extraction and weak acid hydrolysis in pressurized hot water;
- Optimisation of enzymatic (hemi)cellulose hydrolysis using commercially available cellulases;

- Use of lignocellulosic hydrolysates for ethanol and lactic acid fermentation;
- Screening of novel C-5 fermenting organisms;
- CHP development for converting non-fermentables incl. process integration and reduction of water use;
- Application of bio-ethanol in transportation fuels.

Table 1.

Summary of mass- and energy balance for a 156 kton/year bio-ethanol plant.¹⁾

	Verge grass	Willow tops	Wheat milling residue
Feedstock composition:			
- (Hemi)cellulose (wt.%)	61	75	82 ¹⁾
- Lignin (wt.%)	21,5	23	0
- Other organics (wt.%)	10,5	0,5	18 ²⁾
- Ash (wt.%)	7	1,5	0
Feedstock (kton/year)	1295	1110	939
Gross water consumption (l/l ethanol)	54	46	28
Energy efficiency ³⁾			
- Ethanol (% LHV)	40	47	55
- Electricity ⁴⁾ (% LHV)	15	15	12
- Total (% LHV)	56	62	68

1) Including 20% starch. 2) Protein. 3) Net energy output. Internal steam and electricity consumption are fully covered by CHP of non-fermentable biomass fractions. 4) Surplus electricity supplied to the grid.

Table 2. Summary of economic evaluation for a 156 kton/year bio-ethanol plant (IRR 15% over a period of 15 years).¹⁾

	Verge grass	Willow tops	Wheat residue
Feedstock (€/ton d.w.)	20	70	80
Total investment (M€)	313	285	235
O&M costs			
- Feedstock (M€/year)	13	39	38
- Cellulase (M€/year)	102	97	59
- Others ¹⁾ (M€/year)	19	14	11
- Total (M€/year)	134	149	108
Ethanol production cost			
- Feedstock (€/l)	0.06	0.19	0.19
- Cellulase (€/l)	0.51	0.48	0.30
- Other O&M (€/l)	0.09	0.07	0.06
- Capital (€/l)	0.37	0.34	0.28
- Gross ethanol price (€/l)	1.04	1.08	0.82
- Electricity ³⁾ (€/l)	-0.11	-0.10	-0.07
- Net ethanol cost (€/l)	0.92	0.99	0.75

1) Others=Ca(OH)₂, ash disposal, maintenance and labor.
 2) Cellulase costs assumed to be 6,000 €/tonne of enzyme.
 3) Surplus electricity revenues assumed to be €0.051/kWh.

For information and contact see the project website:
<http://bemz.ecn.nl/index.html>

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- EC 'Biofuels directive' 2003/30/EC, 8 May 2003.

ACKNOWLEDGEMENT

This project is supported with a grant of the Dutch Programme EET (Economy, Ecology, Technology) a joint initiative of the Ministries of Economic Affairs, Education, Culture and Sciences and of Housing, Spatial Planning and the Environment. The programme is executed by the EET Programme Office, a partnership of Senter and Novem.

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