

Biorefinery for sustainable Reliable Economical Fuel production from energy crops



Irini Angelidaki

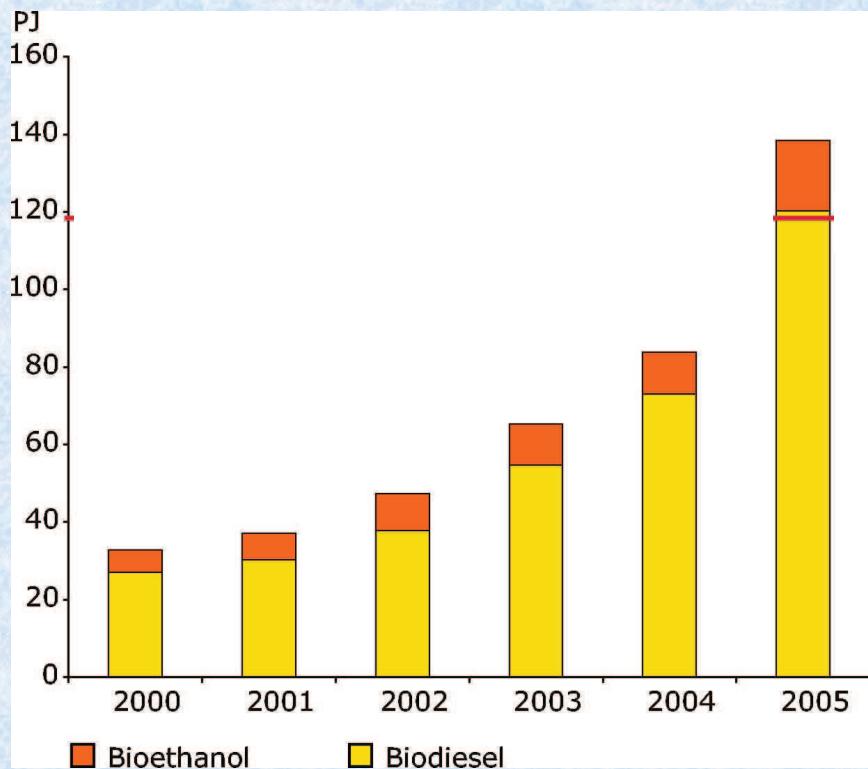
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EU Renewable Energy policy

- European leaders agreed to cut CO₂ emissions by **20%** from 1990 levels by **2020** on their own, and by **30%** if **other nations commit** themselves to comparable reductions.
- They also set a **binding target** of a **20% share of renewable** energies in overall EU energy consumption by 2020 and,
- a **10% binding minimum target** to be achieved by all Member States for the share of **biofuels** in overall EU transport gasoline and diesel consumption by 2020.

Biofuels production in EU



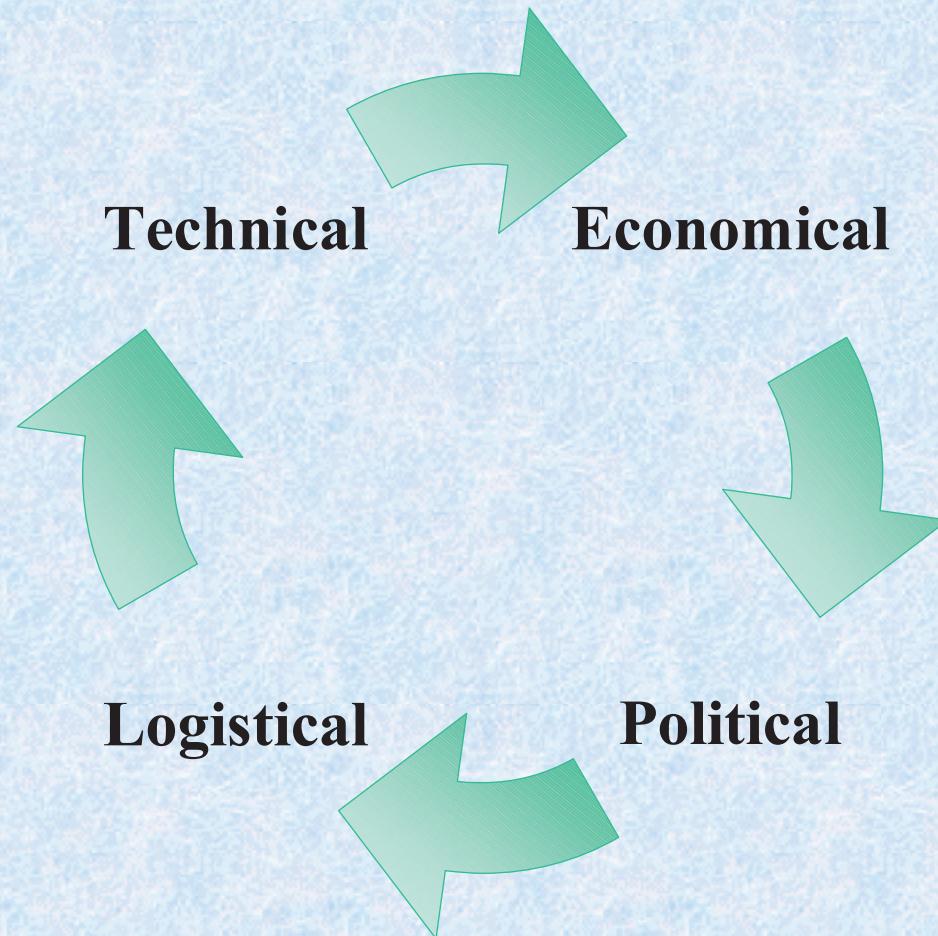
Source: EU-statistics



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Interactions



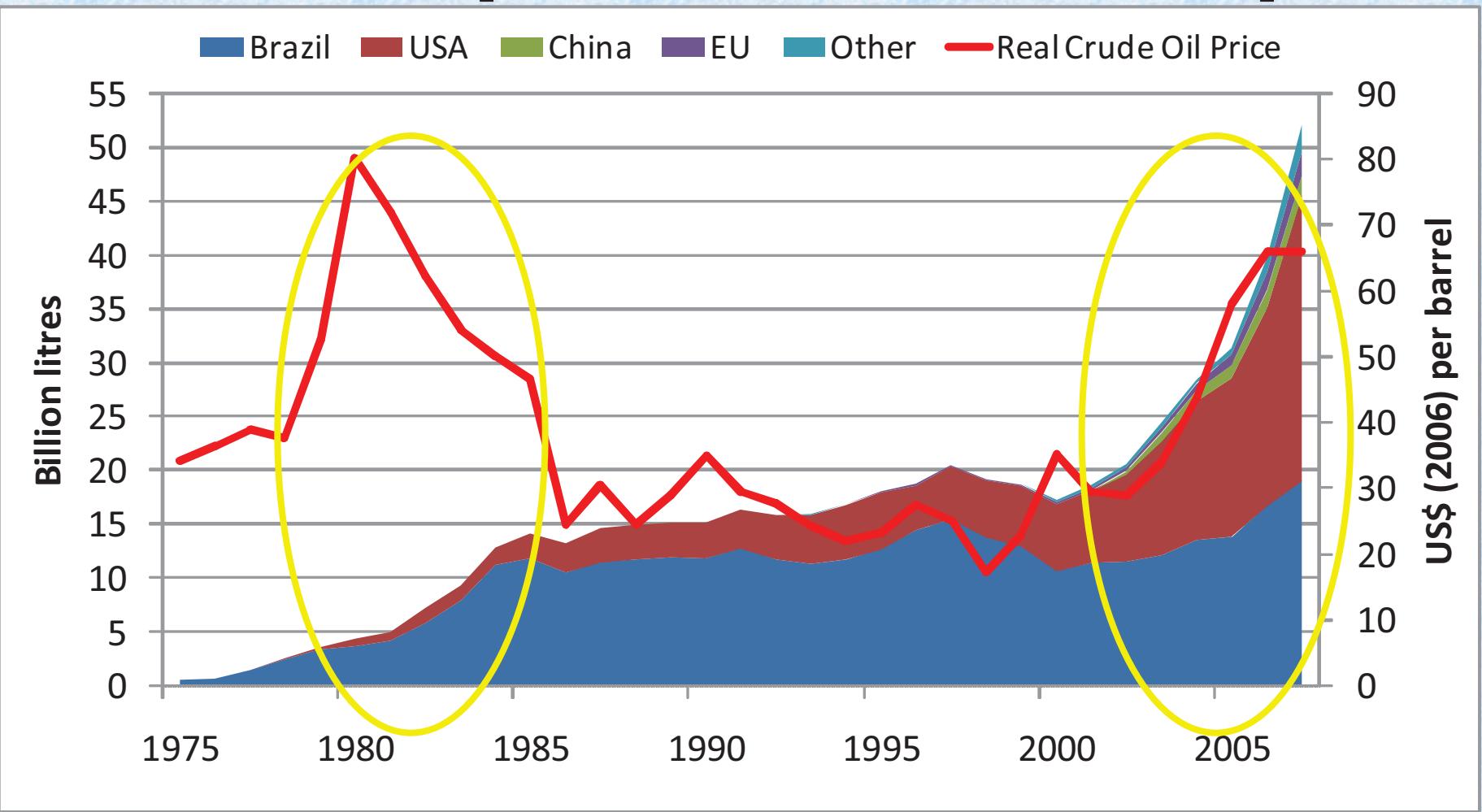
Economical aspects



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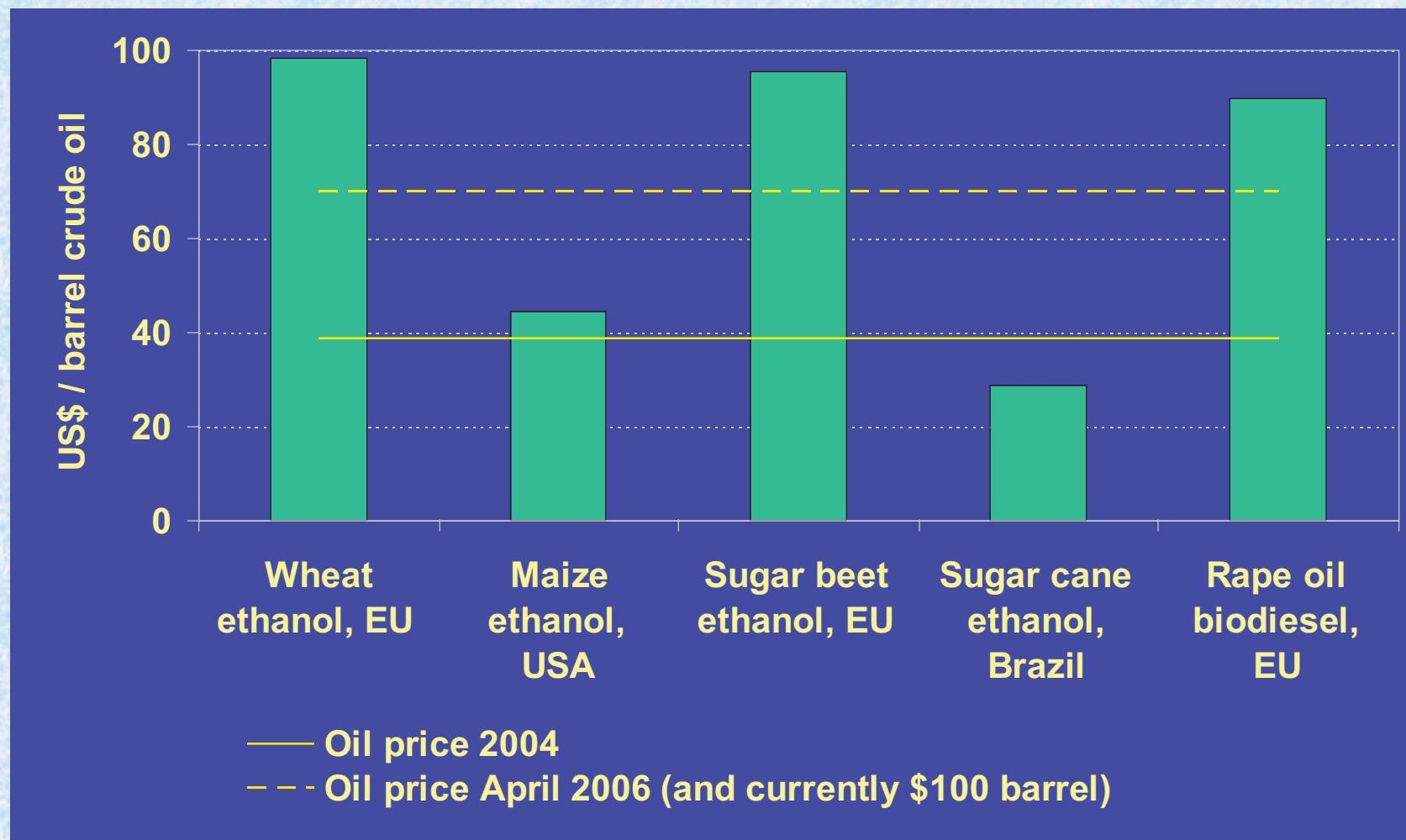
Changing interests in biofuels: Fuel ethanol production and crude prices



Source: F.O. Licht's , St. Luis Fed



Crude oil and bioenergy prices



Source: Wilfred Six. OECD

Costs of biofuel production

- Large differences across countries and processes:
 - Current costs of ethanol from Brazilian sugar cane are half as much per litre of gasoline equivalent as from EU wheat
 - Feedstocks are the largest cost component:
 - half to two thirds of ethanol costs
 - 90% in biodiesel costs

Source: Wilfred Six, OECD



...and meeting biofuel policy targets...

- To meet bio-fuel policy targets in EU and US requires substantial additional quantities of agricultural commodities
- Large area requirements in OECD countries: to achieve a 10% increase in the share of biofuels in transport requires between 30% (US) and 52% (EU) share in crop area, whereas in Brazil it could be achieved with less than 5% area
- Substantial changes in trade patterns
- Price effects modest for grains, but substantial for vegetable oils, sugar

Source: Wilfred Six, OECD

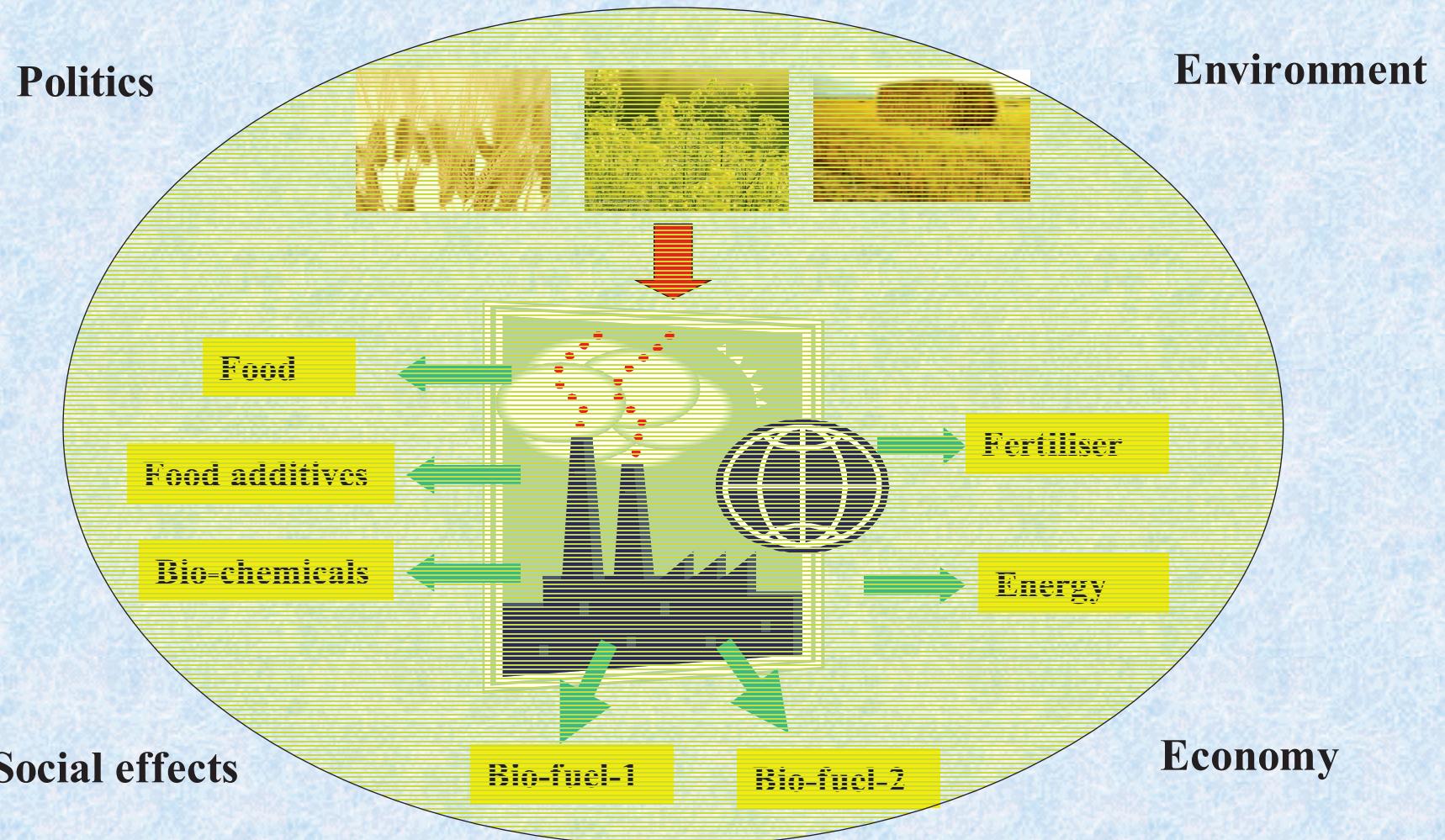


Solutions

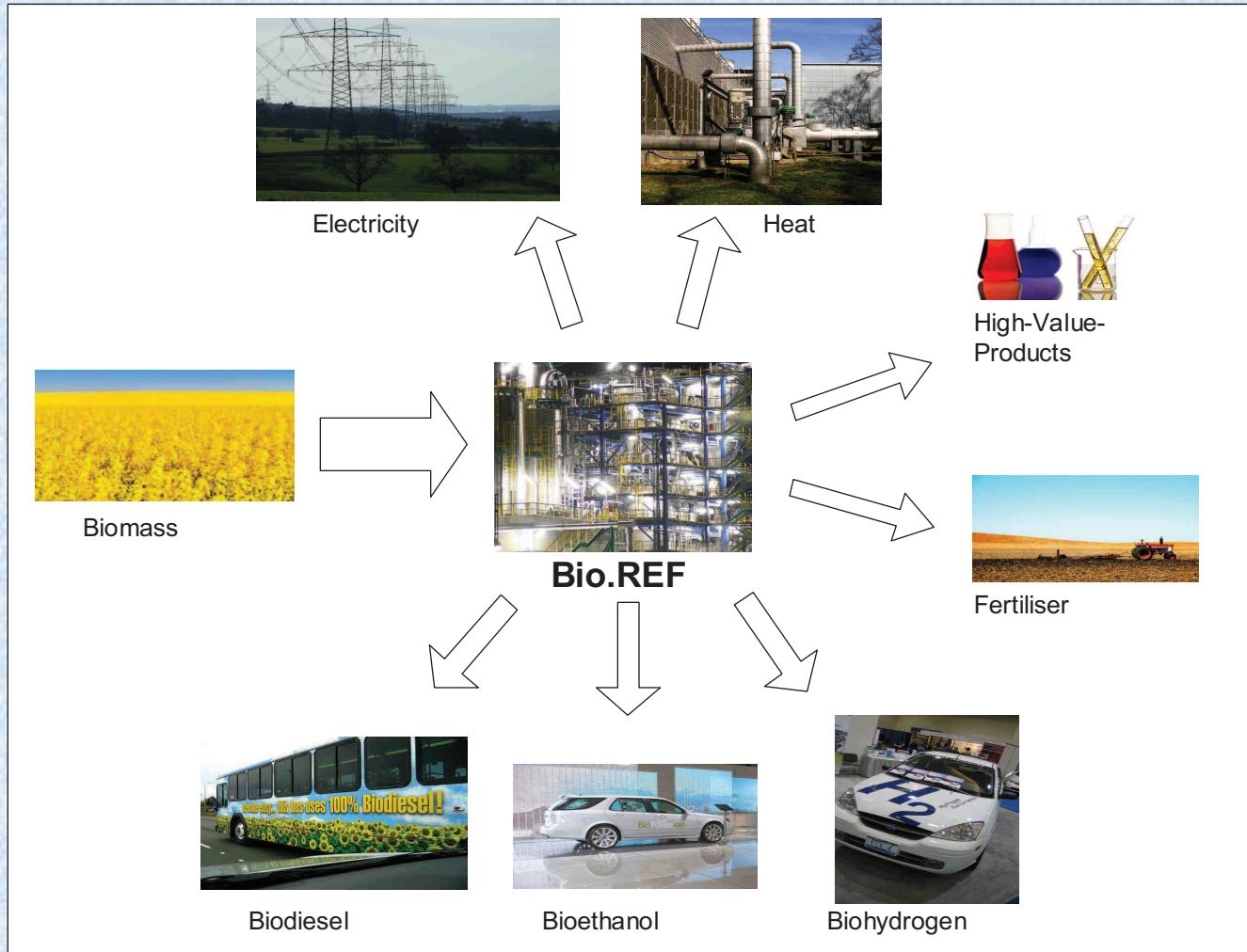
- Whole plant utilisation
- Multi-product process: Biorefineries
 - Food
 - Feed
 - Chemicals
 - Energy



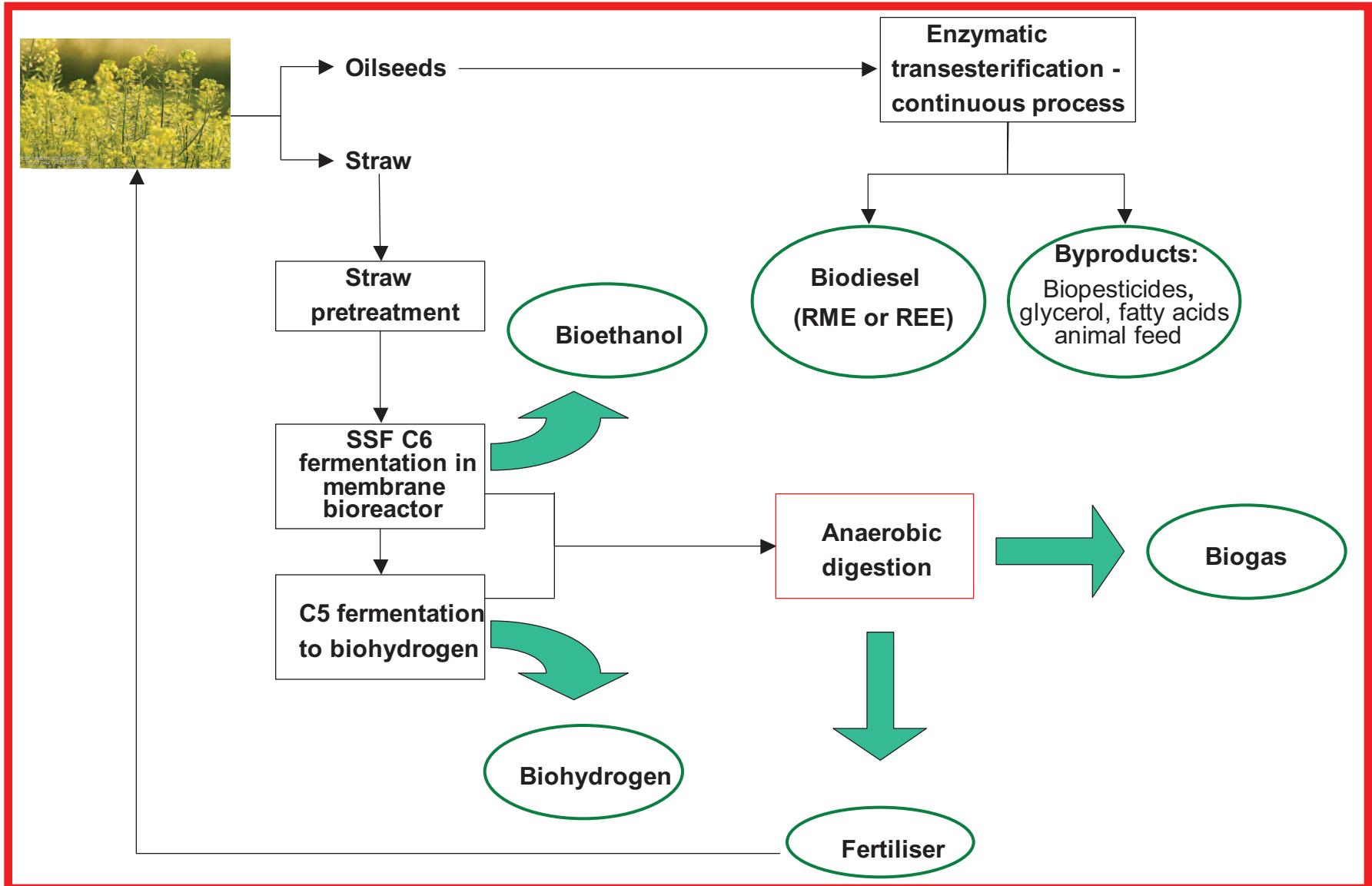
What is a biorefinery?



The Bio.REF concept



BioRef



System analysis, and evaluation



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Partners

Partner 1. E&R-Bioenergy Group, Technical University of Denmark, (DTU-1): *Key persons:* Irini Angelidaki, Prasad Kaparaju and Prawit Konjgan

Partner 2. Technical Faculty, Institute of Chemical, Bio.- and Environ. Technology (CBE), SDU: *Key Persons:* Birgir Nordahl, Knud Christensen, Eivind Schou, Ivan Karup Nielsen.

Partner 3. Biosystems, Risø National Laboratory, (RISØ): *Key persons:* Anne Belinda Thomsen, Mette Hedegaard Thomsen.

Partner 4. Danish Institute of Agricultural Sciences, (DIAS): *Key persons:* Claus Grøn Sørensen and Erik Fløjgård Christensen.

Partner 5. The Royal Veterinary and Agricultural University (KVL-IGV): *Key persons:* Jens Christian Sørensen, Keld Ejdrup Andersen and Hilmer Sørensen

Partner 6. E&R-Solid-waste group, Technical University of Denmark, (DTU-2): *Key persons:* Thomas Astrup.

Partner 7. NOVOZYMES A/S: *Key persons:* Steffan Ernst

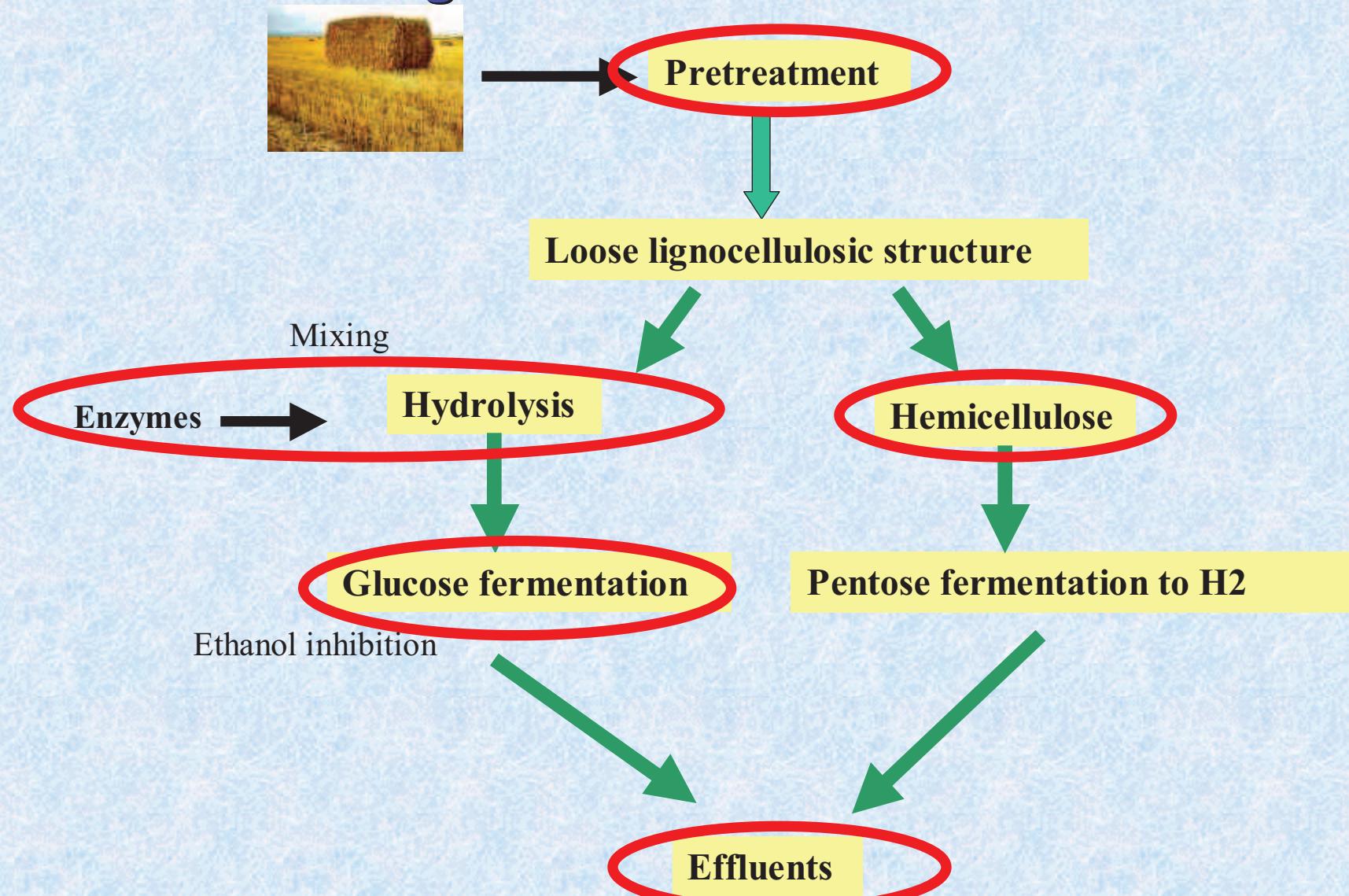
Partner 8. Emmelev A/S is a family own industrial company. *Key person:* Morten Simonsen

Workpackages

- WP1. Harvesting, transportation and fertilizing evaluations and logistics (DIAS/Emmelev). WC: DIAS
- WP2. Biodiesel production by enzymatic transesterification (SDU/NOVOZYMES/Emmelev). WC: SDU
- WP 3. Pre-treatment of the oilseed crops and agricultural residues and bioethanol production with *in-situ* ethanol membrane extraction (RISØ/DTU-1/NOVOZYMES). WC: RISØ
- WP 4. Pentose conversion to biohydrogen (DTU-1). WC: DTU-1
- WP 5. Optimisation of codigestion of process wastewaters (DTU-1, RISØ). WC: DTU-1
- WP 6. Production and use of by-products from oilseed bioprocessing (KVL). WC: KVL
- WP 7. Environmental impact assessment (DTU-2). WC: DTU-2



Key technological improvements for conversion of lignocellulose to biofuels

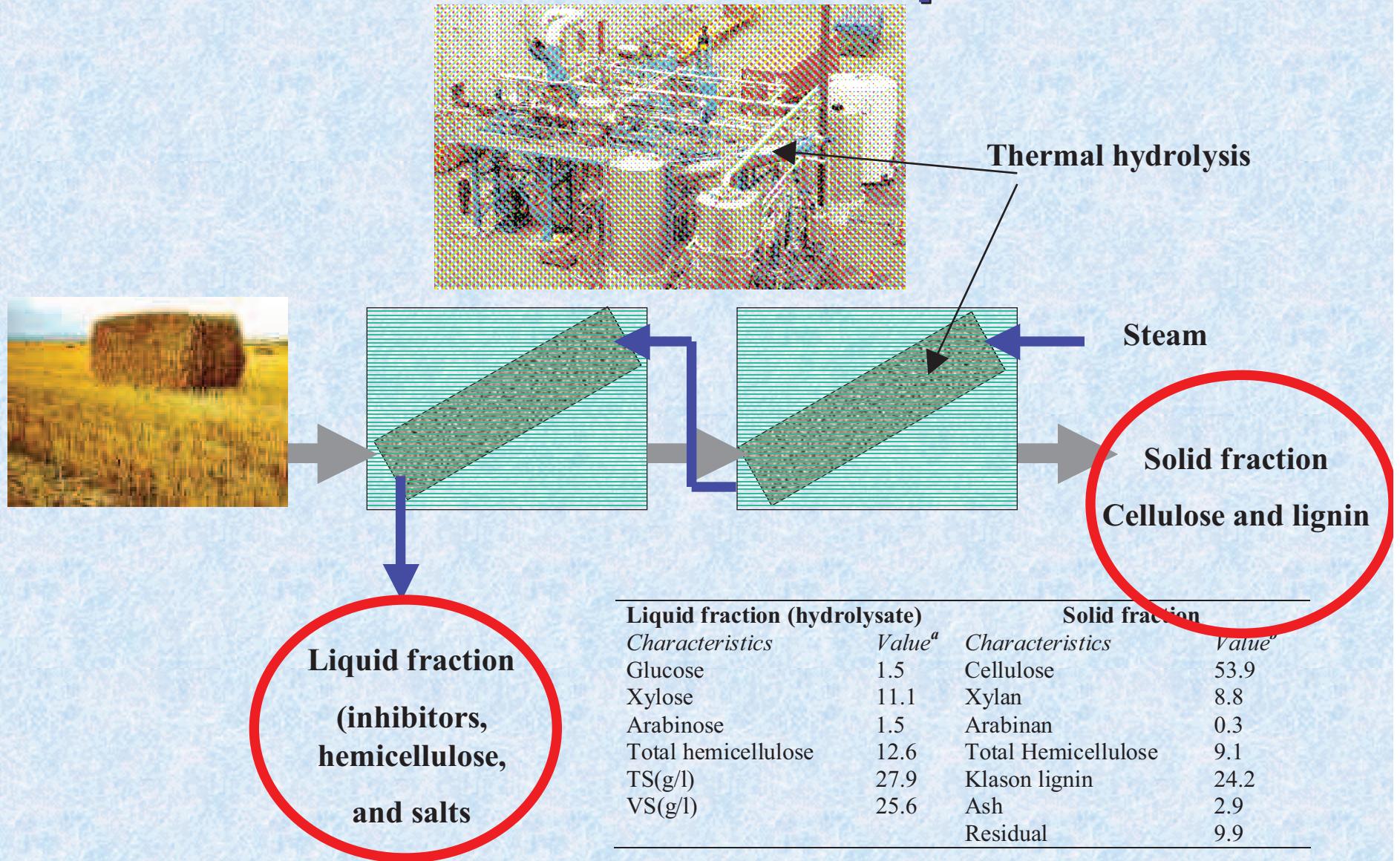


Some innovations concerning ethanol production in the BioREF concept

- Pretreatment – Thermal hydrolysis (continuous high TS treatment system)
- Mixing enzymes with pretreated material (continuous high TS system)
- Fermentation with in situ ethanol membrane separation (effective fermentation due to ethanol removal)



Possible utilisation routes for the pretreated straw



Case 1

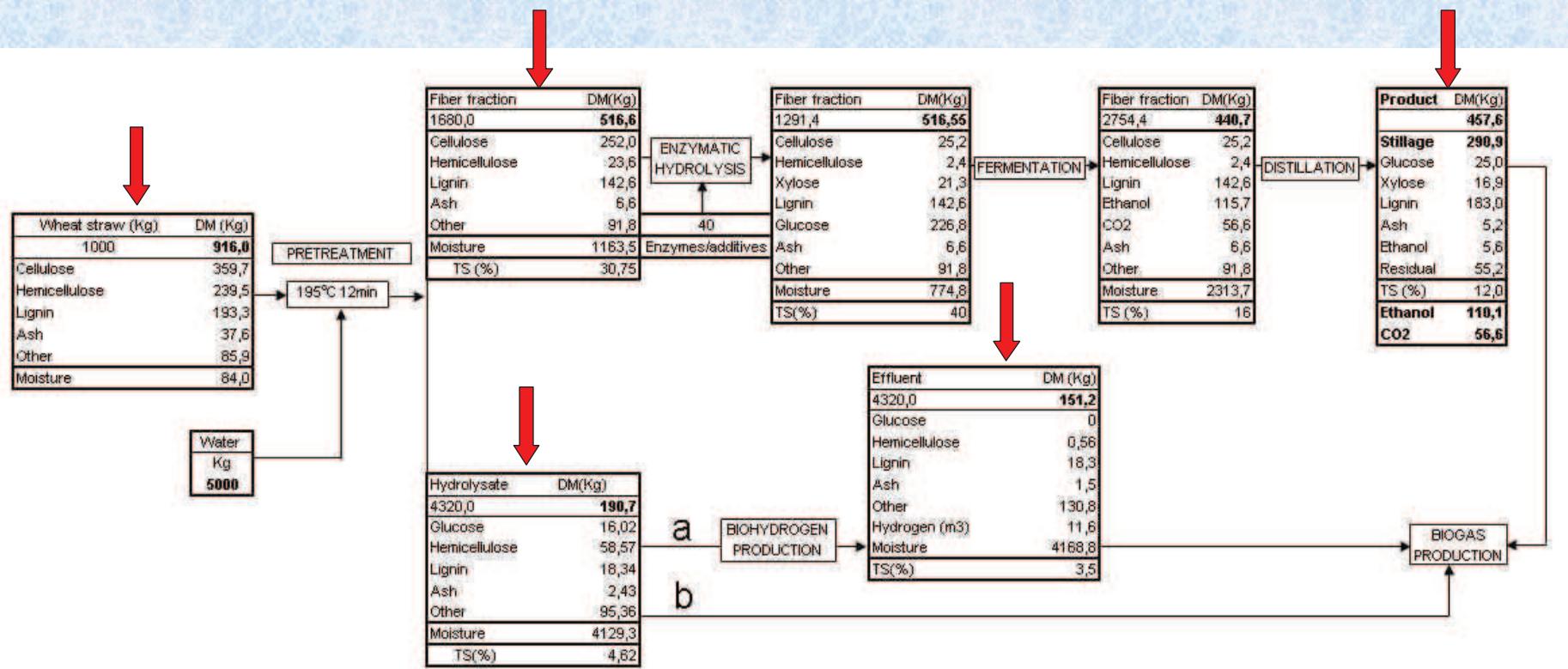
Energy yields for different scenario for utilisation of the components in straw



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Mass flow in the bioethanol biohydrogen biomethanation processes



Substrates characterization

	Wheat Straw	Hydrosate	Fiber fraction	Hydrogen Effluents	Stillage (Risoe)	Stillage (Sweden)
pH	-	4.9 ± 0.1	-	5.6 ± 0.1	3.6 ± 0.1	4.0 ± 0.1
TS (%)	91.6 ± 0.02	4.4 ± 0.01	28.2 ± 0.57	3.5 ± 0.01	12.0 ± 0.03	19.6 ± 0.18
VS (%)	87.5 ± 0.02	3.4 ± 0.01	26.9 ± 0.40	1.6 ± 0.01	10.2 ± 0.03	17.8 ± 0.18
Ash content (%)	4.1 ± 0.02	1 ± 0.01	1.3 ± 0.49	1.9 ± 0.01	1.8 ± 0.03	1.8 ± 0.18
SS (g/L)	-	0.16 ± 0.05	-	0.05 ± 0.02	1.4 ± 0.2	0.81 ± 0.1
VSS (mg/L)	-	0.32 ± 0.1	-	0.74 ± 0.1	69.1 ± 2.5	92.4 ± 1.7
COD (g/L)	-	37.9 ± 1.31	-	15.2 ± 0.30	149.8 ± 3.59	170.7 ± 0.38
SCOD (g/L)	-	32.05 ± 2.22	-	8.9 ± 1.23	60.9 ± 4.36	85.08 ± 0.13
VFA (g/L)	0.13 ± 0.02	0.7 ± 0.14	0.61 ± 0.04	0.6 ± 0.04	0.18 ± 0.02	0.37 ± 0.02
Ethanol (g/L)	N.D.	N.D.	N.D.	N.D.	2.3 ± 0.13	0.8 ± 0.10 ¹
Total nitrogen (g/L)	1.3 ± 0.04	0.2 ± 0.01	0.40 ± 0.01	0.32 ± 0.02	1.4 ± 0.02	6.2 ± 0.20
Ammonia (g/L)	0.31 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.15 ± 0.01	0.16 ± 0.01	1.3 ± 0.02
Proteins ² (g/L)	6.5 ± 0.17	1.1 ± 0.03	2.3 ± 0.2	1.1 ± 0.04	7.7 ± 0.09	38.8 ± 1.15
Lipids (%)	1.5	0.24	1.2	0.02	0.99	0.93
Carbohydrates ³ (g/L)	853.1	30.5	265.6	14.2	84.5	129.3
Furfurals (g/L)	-	0.25 ± 0.04	-	N.D.	N.D.	N.D.
HMF (g/L)	-	0.14 ± 0.02	-	N.D.	N.D.	0.02 ± 0.005
Phenols (g/L)	-	0.14	-	0.015	0.06	0.08
Lignin (g/L)	193.3	-	77.8	-	75.6	32.3
Arabinose (g/L)	25.8	1.3	0.00	0.02	0.00	13.7
Xylose (g/L)	213.7	9.3	12.9	0.11	6.9	41.7
Glucose (g/L)	359.7	2.9	137.5	0.00	10.3	58.5

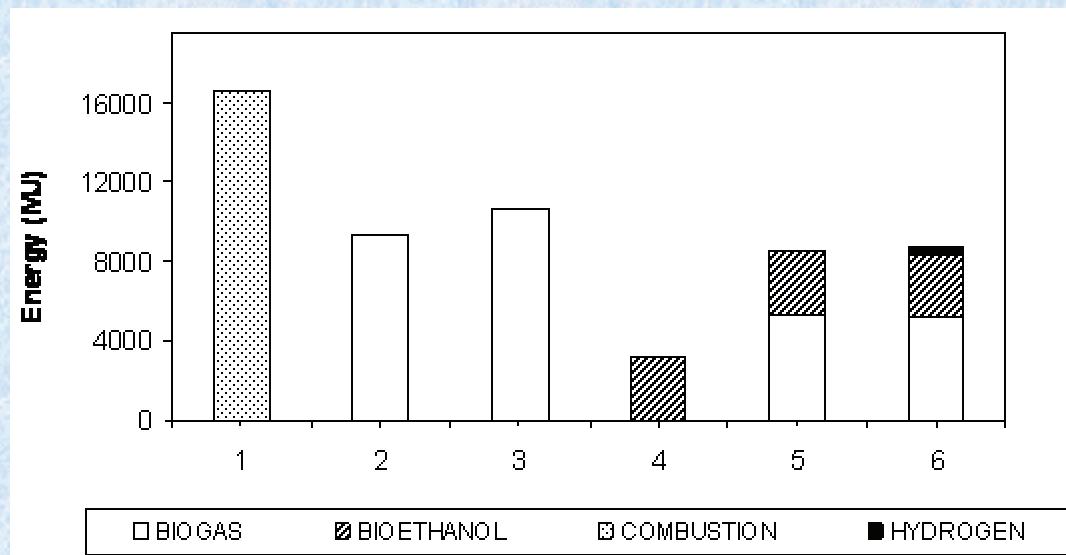
¹ After stripping the ethanol. Swedish stillage obtained from industrial plant producing ethanol from wheat straw and grains.
 N.D., not detected.

² Proteins = 6.25 x (TKN-NH₄⁺)

³ CHO = VS-proteins-lipids-VFA

Energy output from each studied scenario

SCENARIO	
Wheat straw → Incineration	1
Wheat straw → Biogas	2
Wheat straw → Pretreatment → Biogas	3
Wheat straw → Bioethanol	4
Wheat straw → Bioethanol → Biogas	5
Wheat straw → Bioethanol → Biohydrogen → Biogas	6



Conclusions

- Multiple biofuels such as bioethanol, biohydrogen and biogas can be produced from wheat straw in an integrated biorefinery process.
- Pretreatment was efficient to liquefy straw and release sugars
- Losses due to pretreatment resulted in loss of energy potential
- Cellulose could efficiently 98% be converted to ethanol
- Bioconversion of hydrolysate to H₂ could produce at an efficiency of 30%
- All streams could be completely converted to biogas

- Energy optimisation is according to the following the ranking list:
 - combustion
 - biogas
 - co-production
 - Mono-product biofuel



Case 2

New technological developments for efficient bioethanol production from straw



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High TS material

Effective – low cost process ➤ high solids content in biomass

Preferably > 50% TS in hydrolysed material

Problems with incorporation of enzymes and yeast



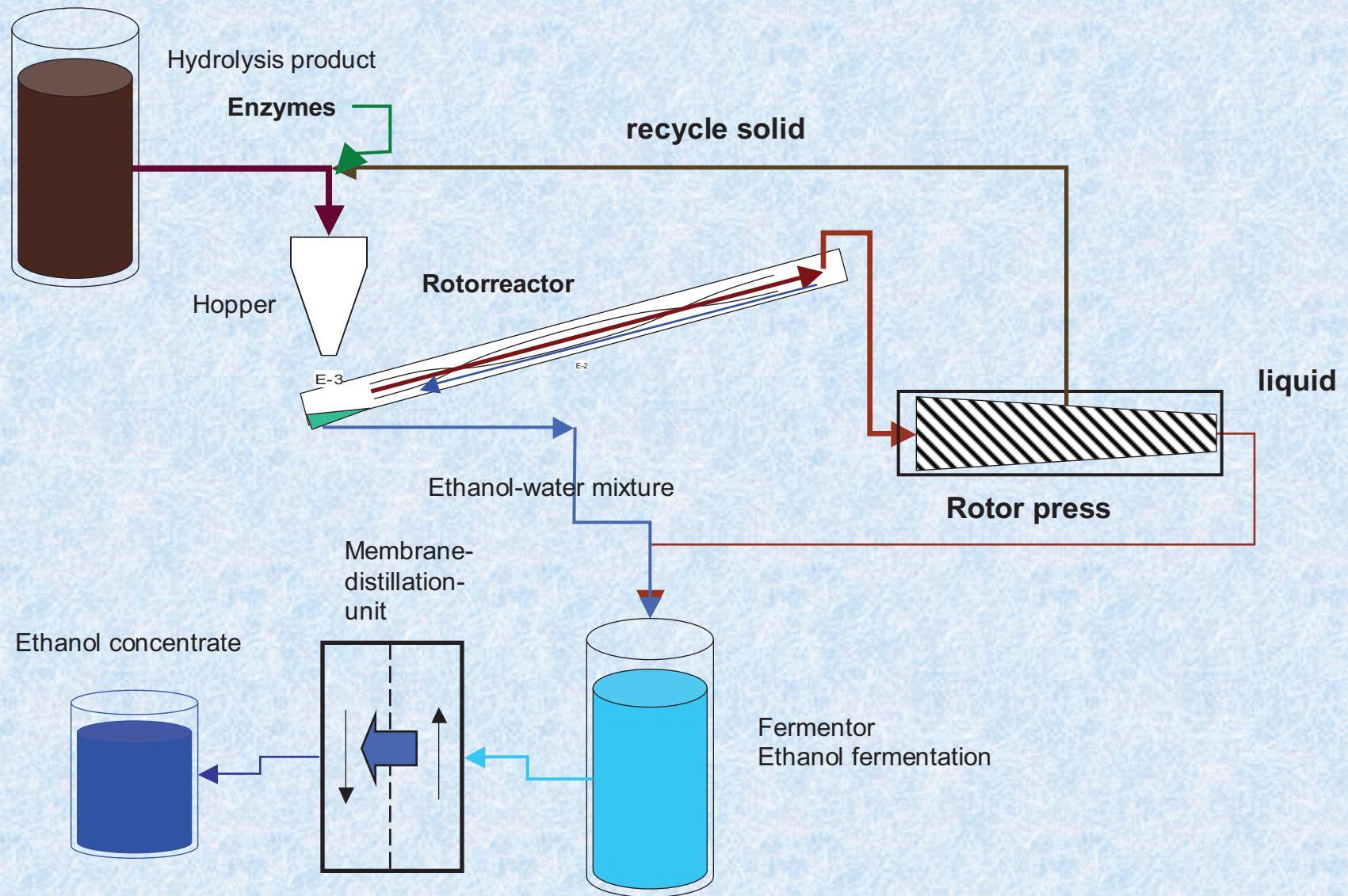
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Efficient mixing of pretreated high TS material with enzymes

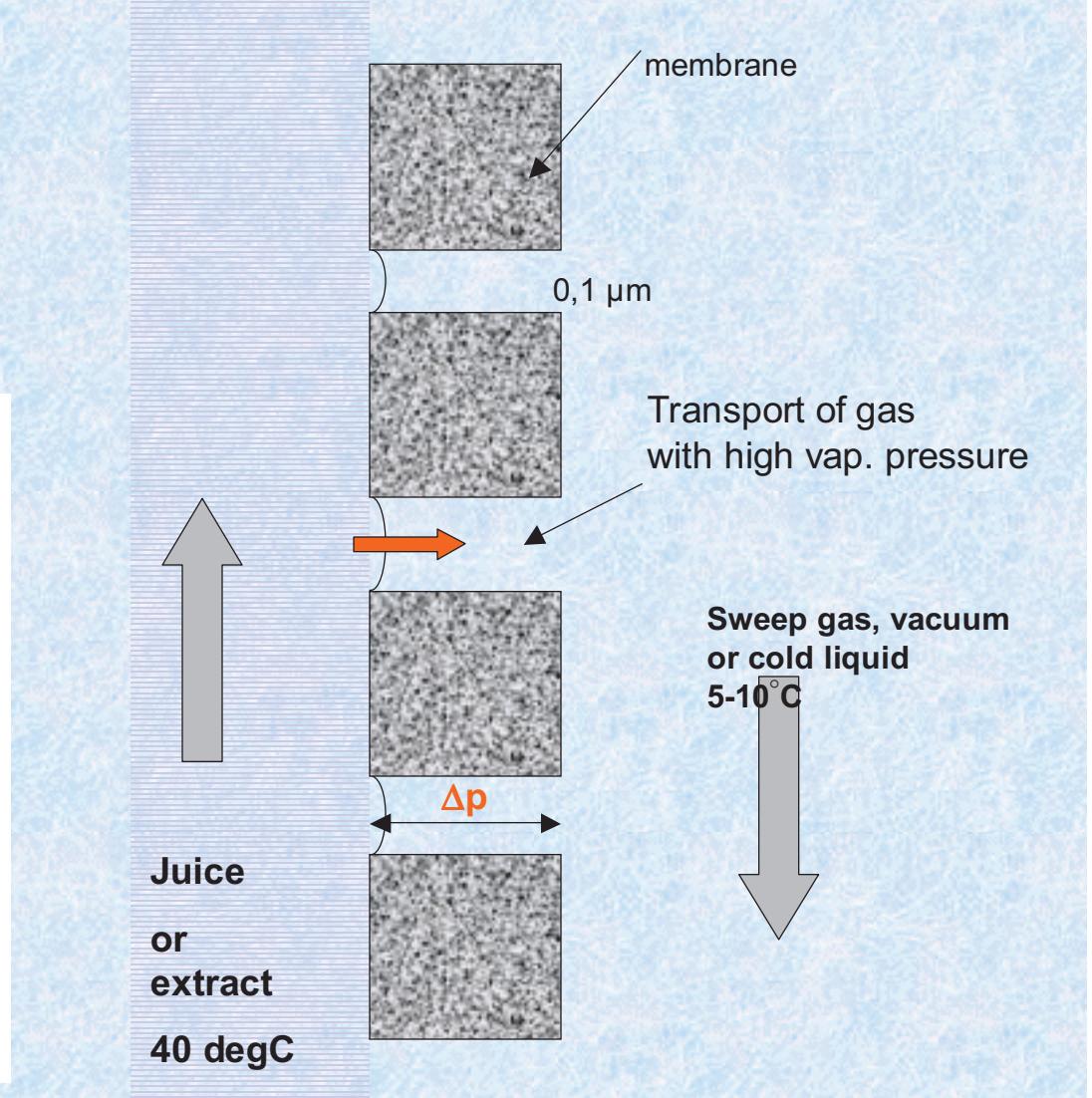
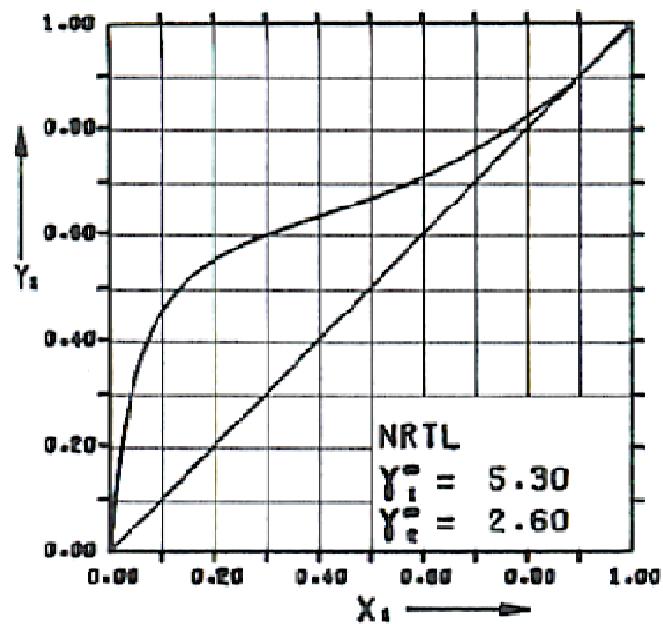


Flow-diagram sketch

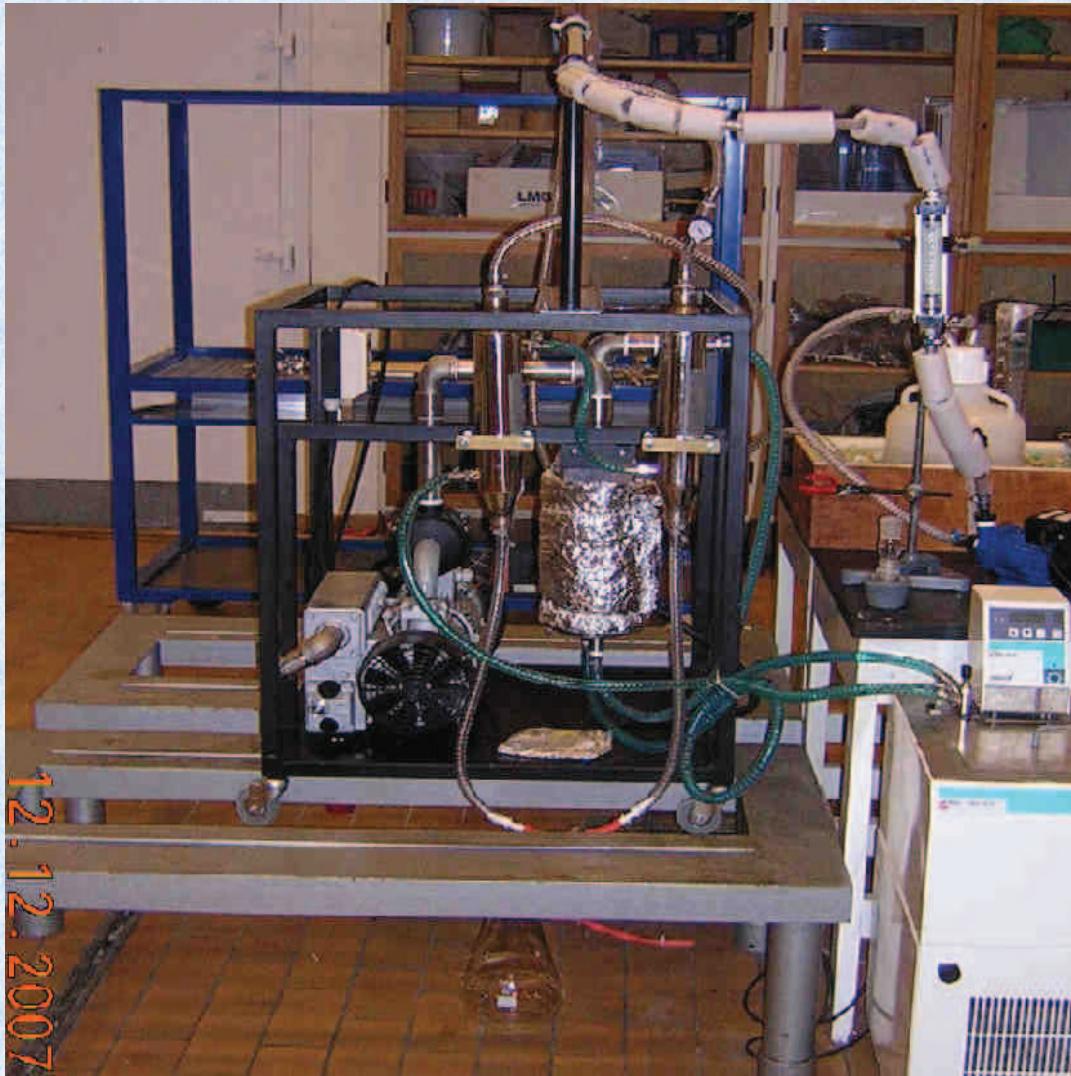


Principle of membrane distillation with a contact membrane water as solvent

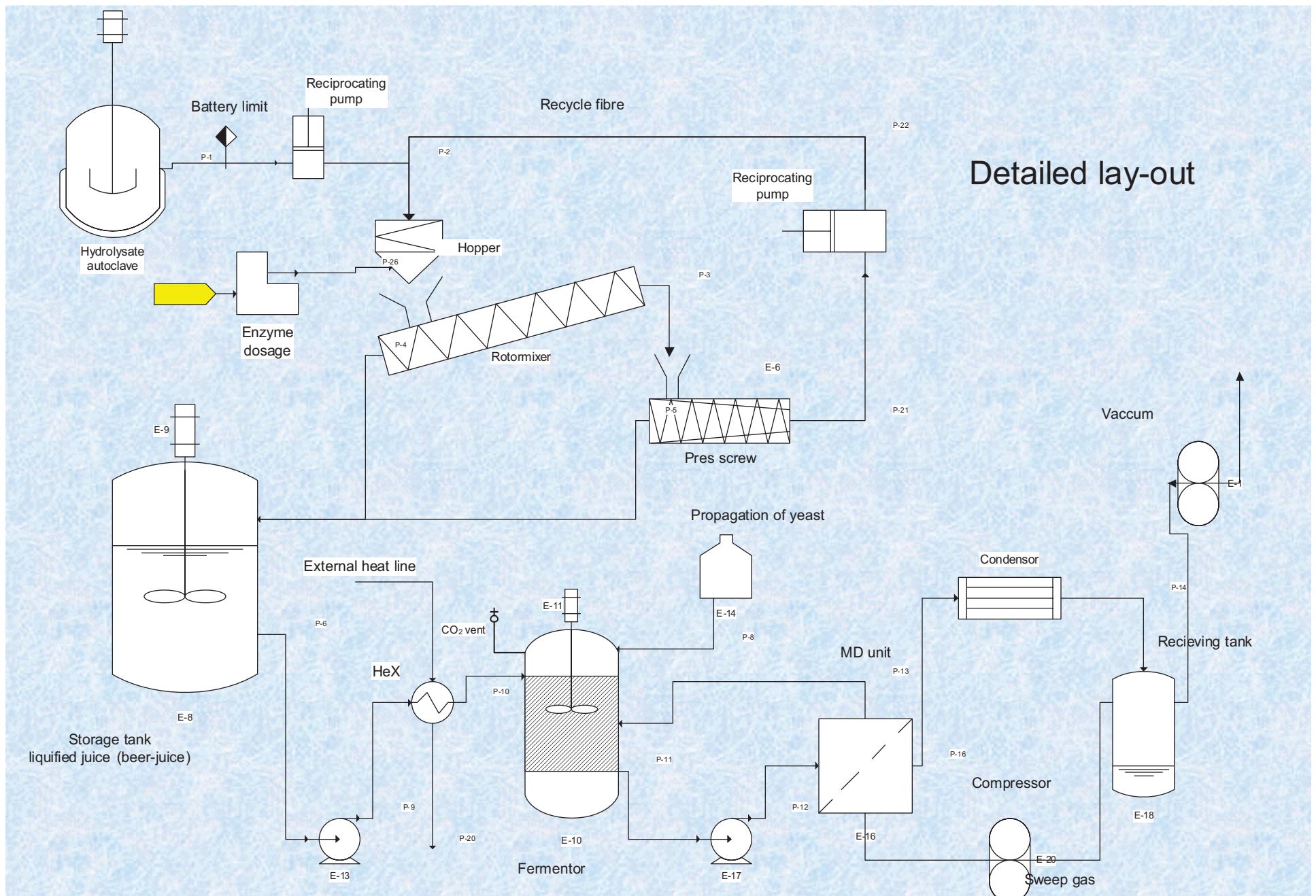
Hydrophilic polymer with holes
f.ex. Polypropylene or PVDF



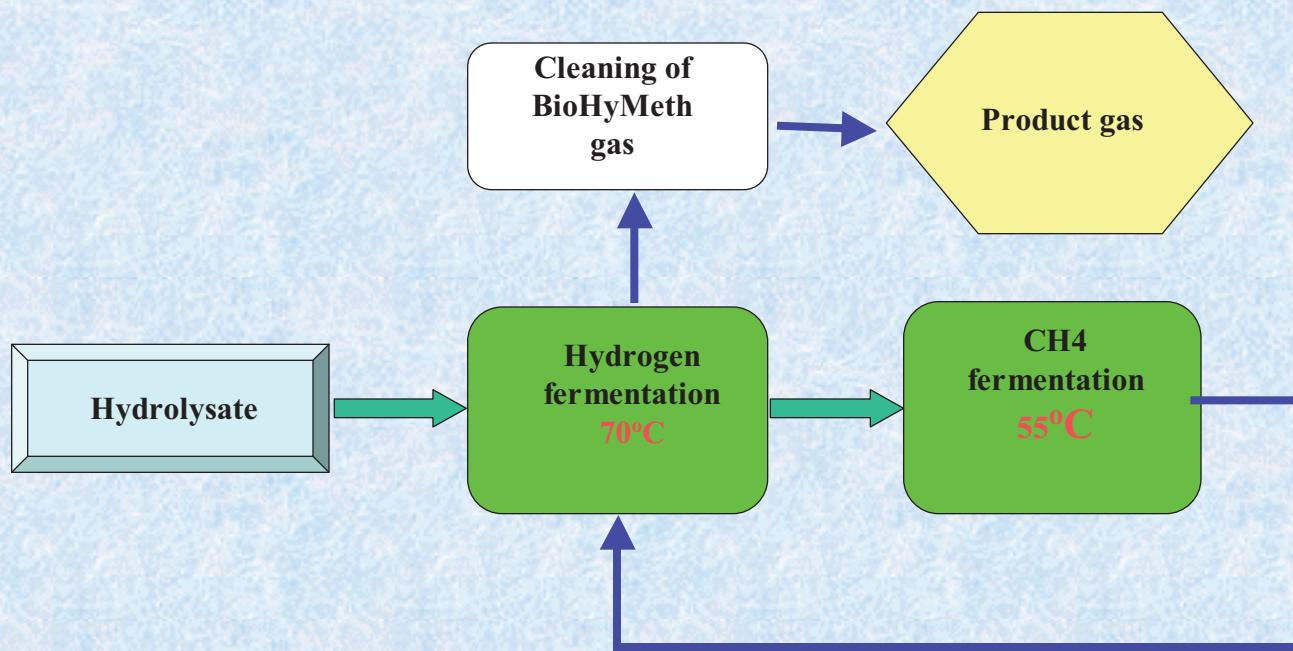
Ethanol Fermentor with membrane distillation unit



Detailed lay-out

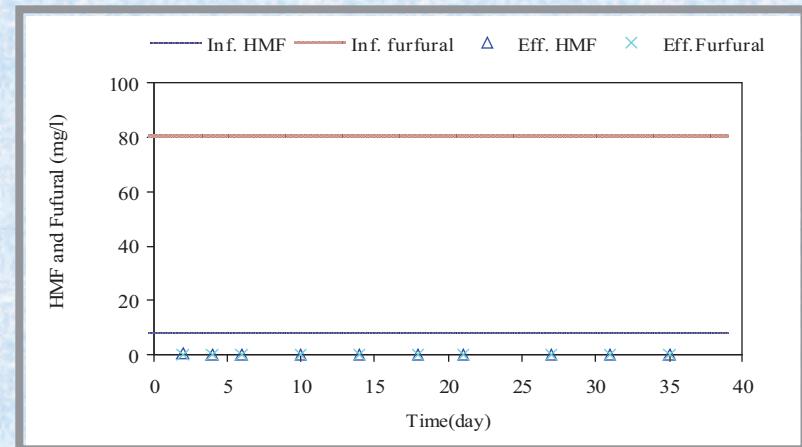
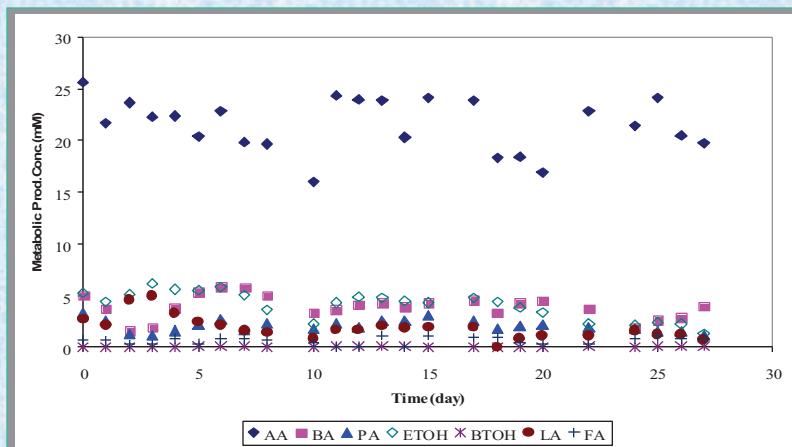
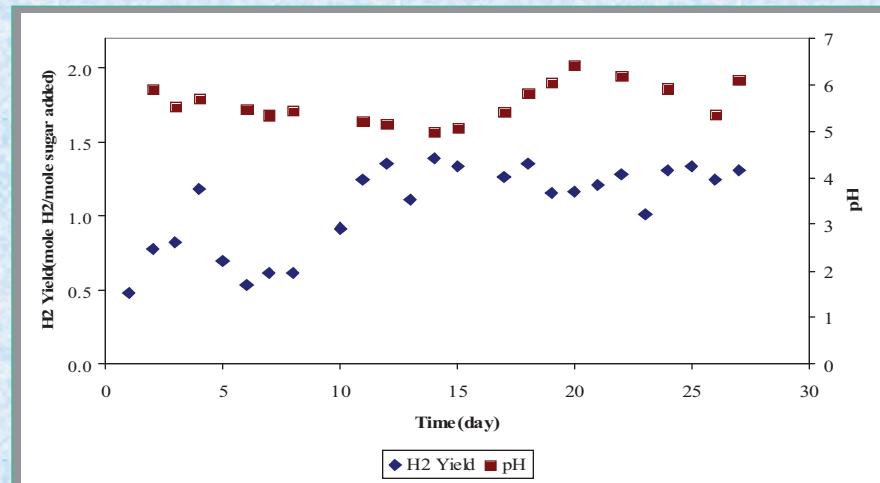


Conversion of the liquid hydrolysate (pentoses) to Hydrogen and Methane in a two stage process



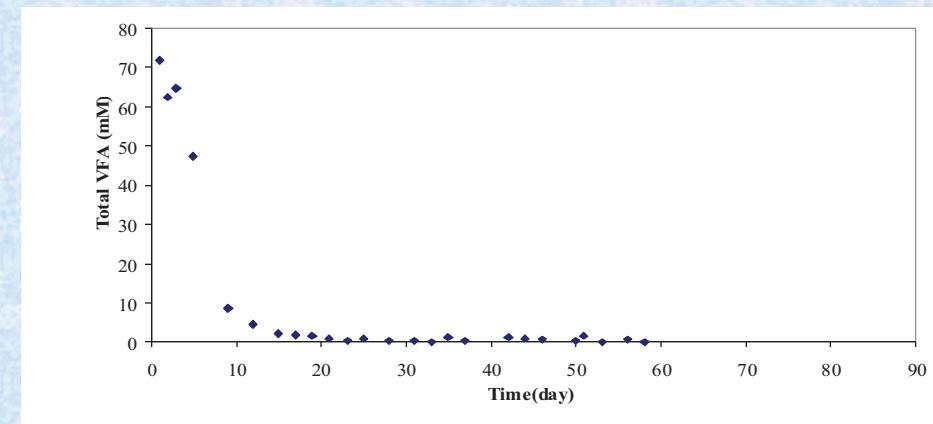
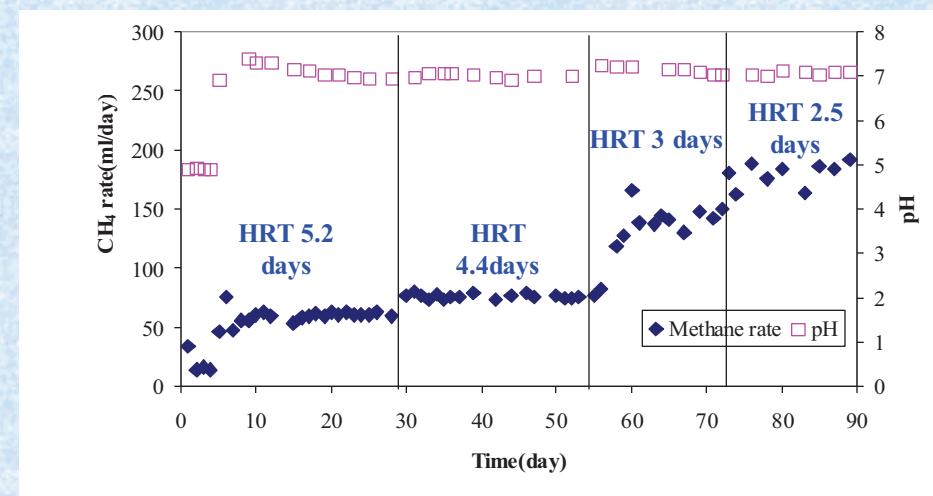
1st stage

Hydrogen production from hydrolysate in UASB reactor (70°C)



2nd stage

Methane production in UASB reactor (55°C)



Hydrogen production at 1 day HRT

Yield = 1.6 mole H₂/mole sugar_{added}

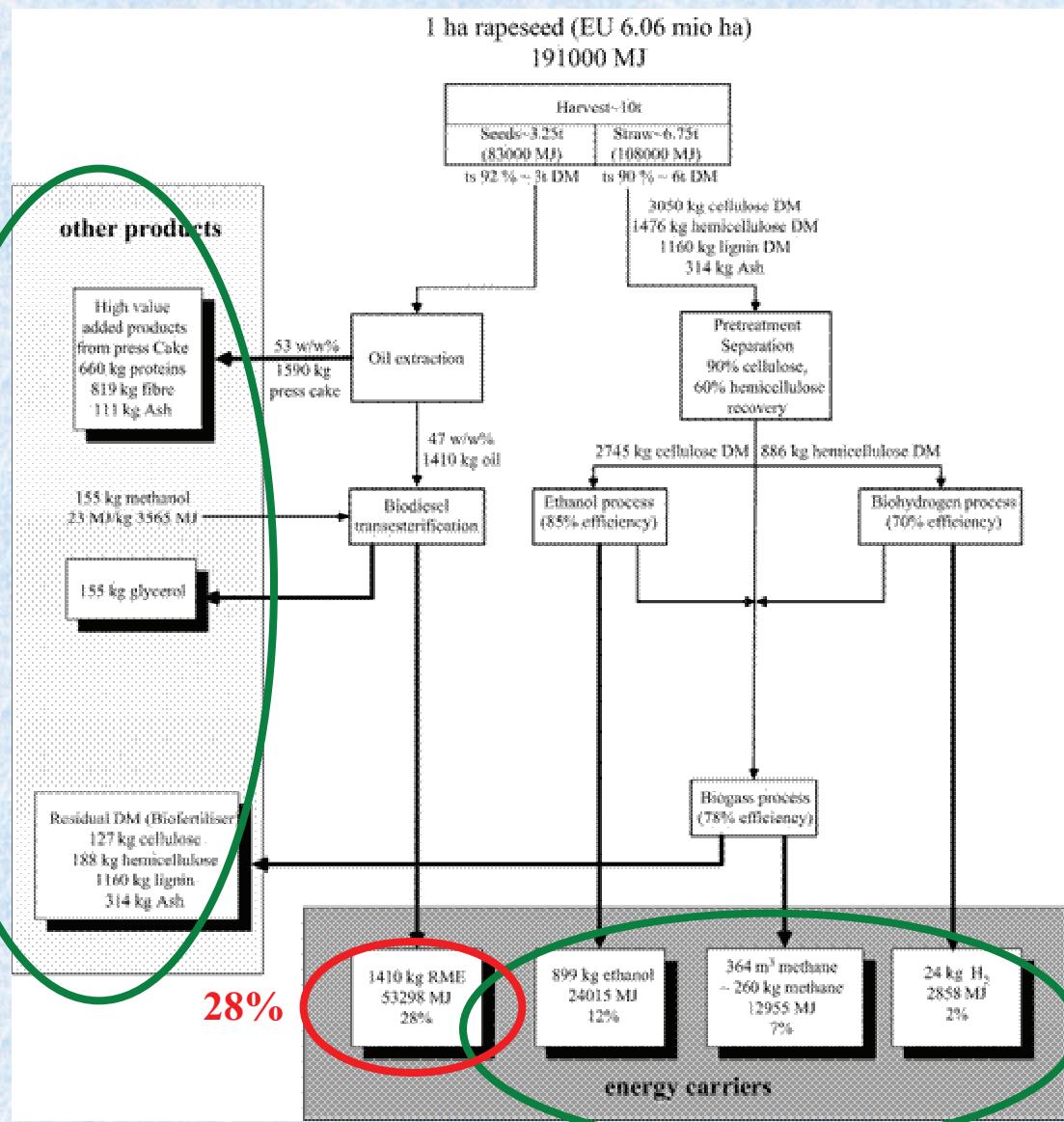
Productivity = 630 (ml/d·l_{reactor})

Methane production at different HRT

HRT(day)	5.2	4.4	3.0	2.5
OLR(g-VS _{added} /d·l _{reactor})	0.86	1.0	1.45	1.77
CH ₄ yield(ml/g-VS _{added})	322	340	439	464
Productivity(ml/d·l _{reactor})	271	347	737	817



Quantities of biofuels and biochemicals produced by the BioREF from 1 ha of rapeseed cultivation



Conclusions

- A new effective **biorefinery** concept for sustainable solution for future biofuels production has been developed
 - Biodiesel
 - H₂
 - Ethanol
 - Methane
 - High value products
 - Biofertilizers
- **High total solids technology** has been developed, which has significantly lower energy demands and with effective recycle give less amounts of effluents
- ***In-situ* ethanol membrane ethanol extraction** is increasing ethanol productivity

