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Conceptual Process Design of an Organosolv-Based Wheat Straw Biorefinery for the Co-Production of Bioethanol, Furfural and Lignin

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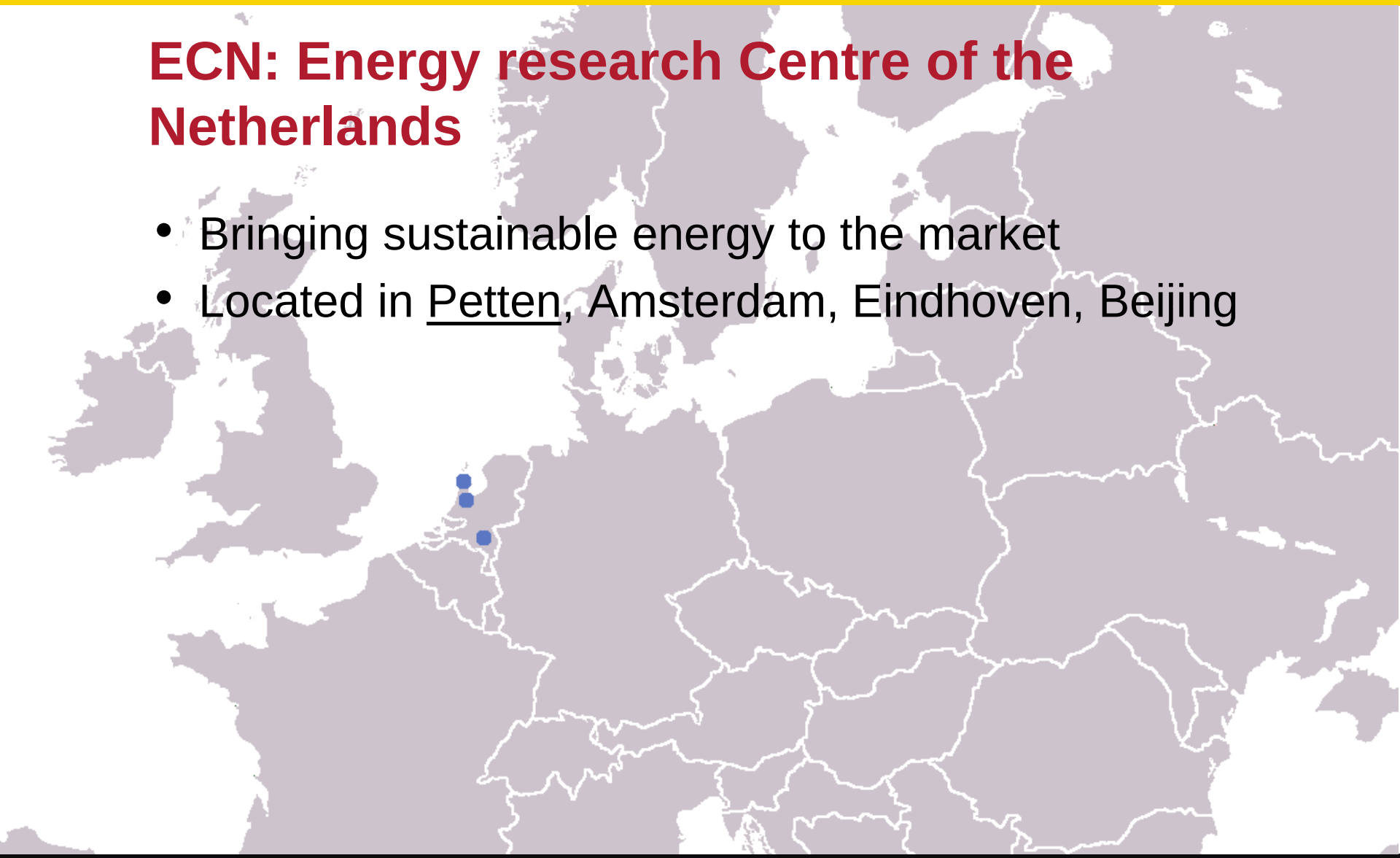
Outline

- Introduction
  - ECN
  - Goal of this presentation
  - Lignocellulosic biorefinery
  - Organosolv
- Process description
- Mass and energy balances
- Economic analysis
- Conclusions and outlooks

ECN: Energy research Centre of the Netherlands

- Bringing sustainable energy to the market
- Located in Petten, Amsterdam, Eindhoven, Beijing



ECN: Energy research Centre of the Netherlands

- Bringing sustainable energy to the market
- Located in Petten, Amsterdam, Eindhoven, Beijing
- Business units:
  - Biomass, coal and environmental research
  - Solar energy
  - Wind energy
  - Policy studies
  - Efficiency and infrastructure
  - Engineering and services

Goal of this presentation

- Evaluation of organosolv biorefinery for the production of ethanol, furfural and lignin
  - Mass and energy balances
  - Heat integration
  - Economic analysis

- All necessary process equipment included

Biorefinery

- Processing of biomass into multiple products
- The core of the bio-based economy

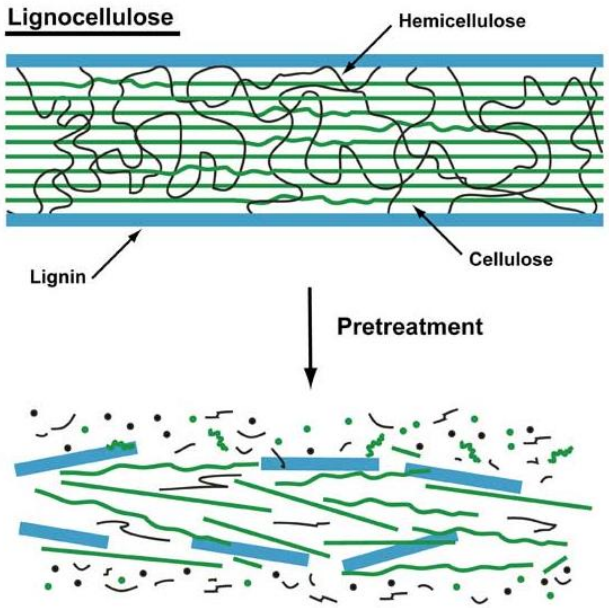
- *Biorefinery is the sustainable processing of biomass into a spectrum of marketable products and energy (IEA Definition)*

Goals fractionation

- Fractionation of lignocellulosic biomass into its main constituents with sufficient quality for production of (bio)chemicals (including lignin)
- Enhancement (enzymatic) degradability of cellulose to fermentable sugars

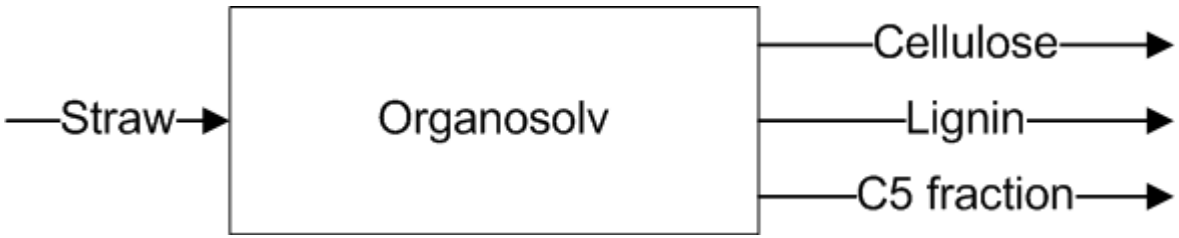
Organosolv (general)

- Feedstock: lignocellulosic biomass
- Extraction of lignin with organic solvent and water
- Hydrolysis hemicellulose into sugars and derivatives
- Liberate cellulose fibres (make pulp)



Organosolv Biorefinery

- Feedstock: wheat straw
- Solvent: ethanol + water
- Marketable products: ethanol, furfural and lignin



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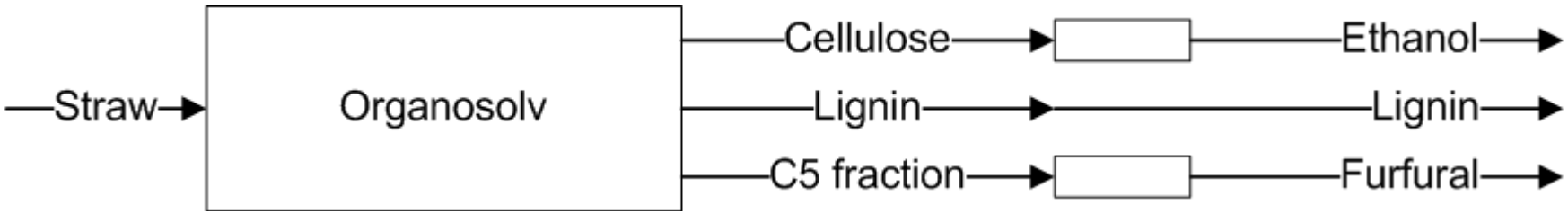

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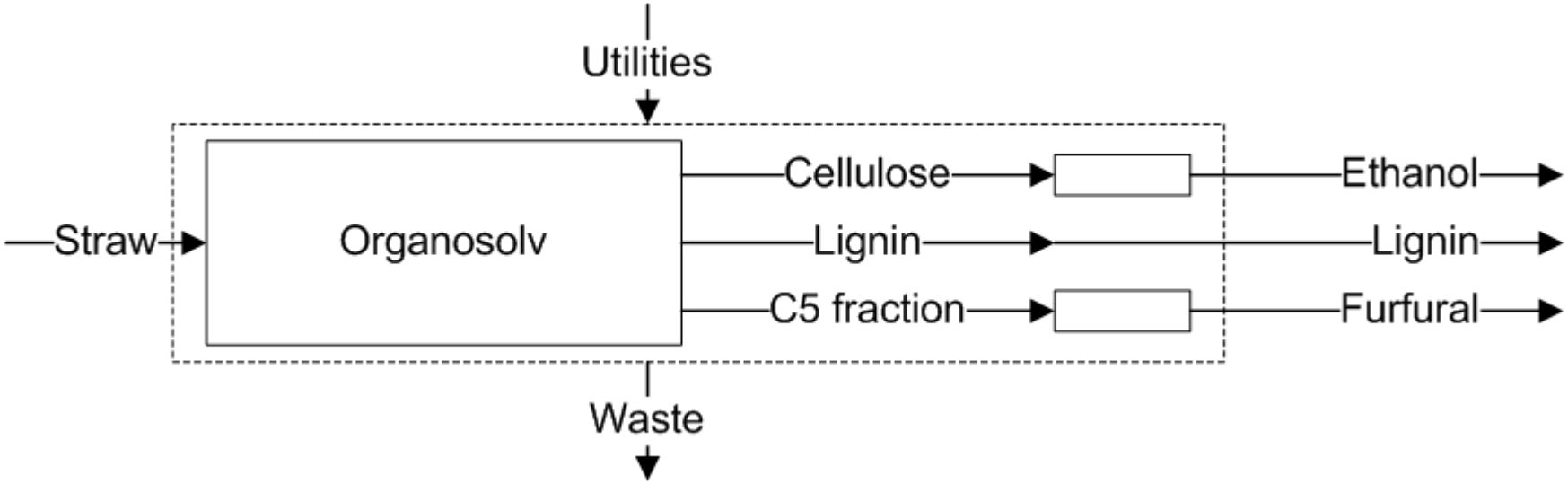


Assumptions Organosolv Process

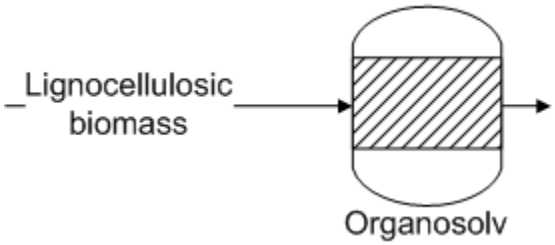
- Lignin removed from pulp 80%
- Hemicellulose hydrolysis 95%
- Cellulose in pulp 95%

- T = 200°C
- P = ~32 bar
- Residence time = ~ 1 hr
- Ethanol/Water = 60/40 wt

Organosolv process description

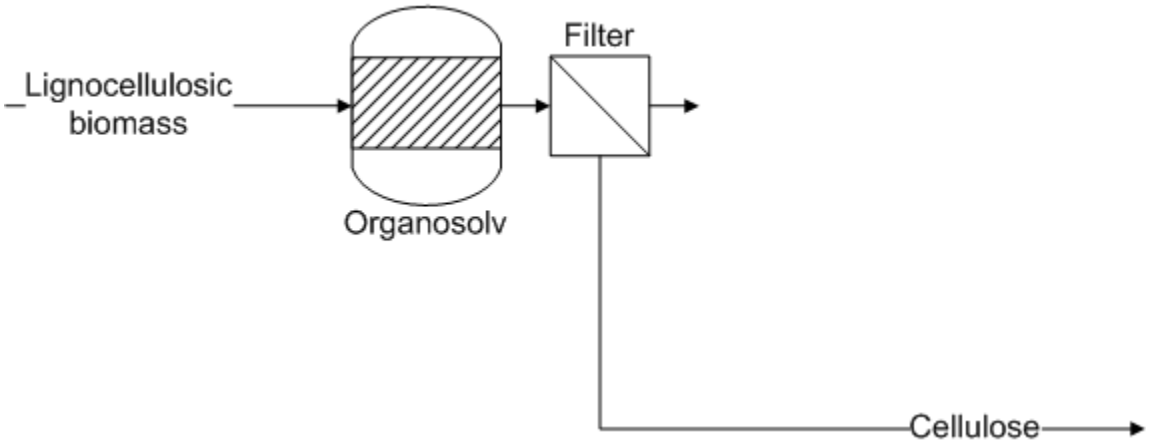
- Organosolv reactor:

$Straw_{(s)} \rightarrow Cellulose_{(s)} + Lignin_{(aq)} + Hemicellulose_{(aq)}$



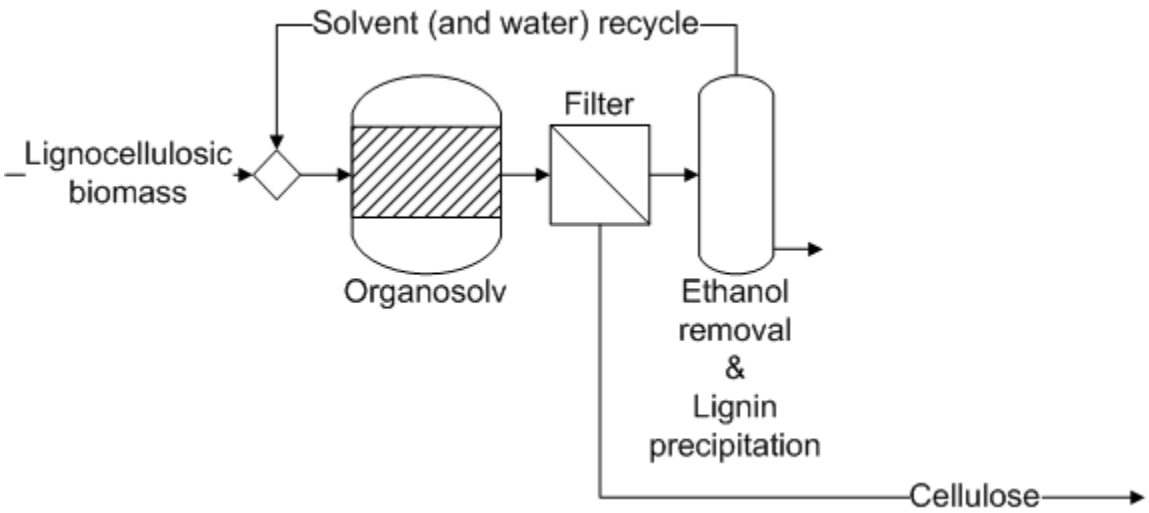
Organosolv process description

- A filter removes cellulose from the liquid mixture



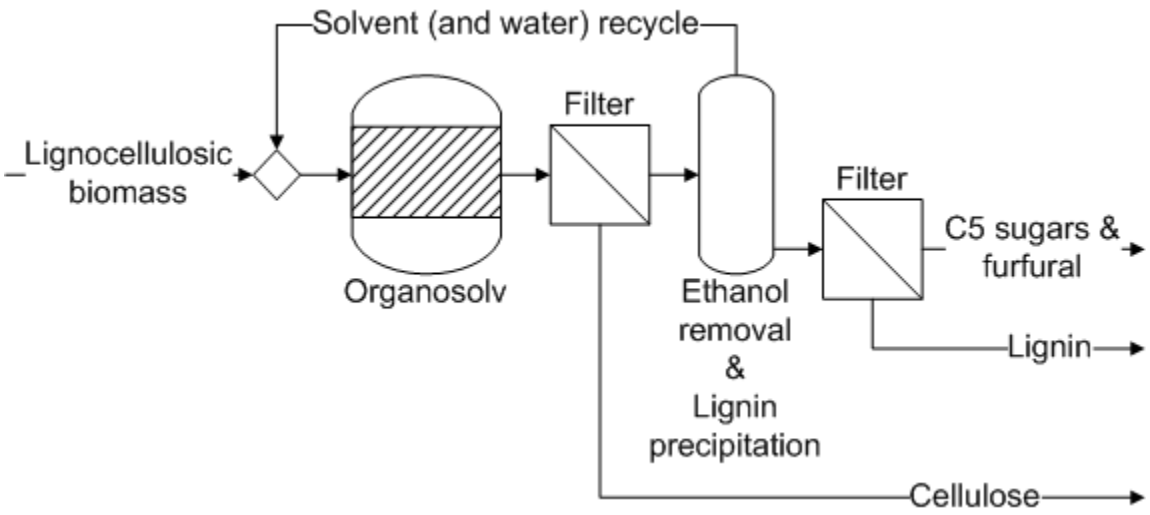
Organosolv process description

- Lignin is precipitated by removing the ethanol (lowering lignin solubility)
- Ethanol recycling is 99.9%; Crucial for economics



Organosolv process description

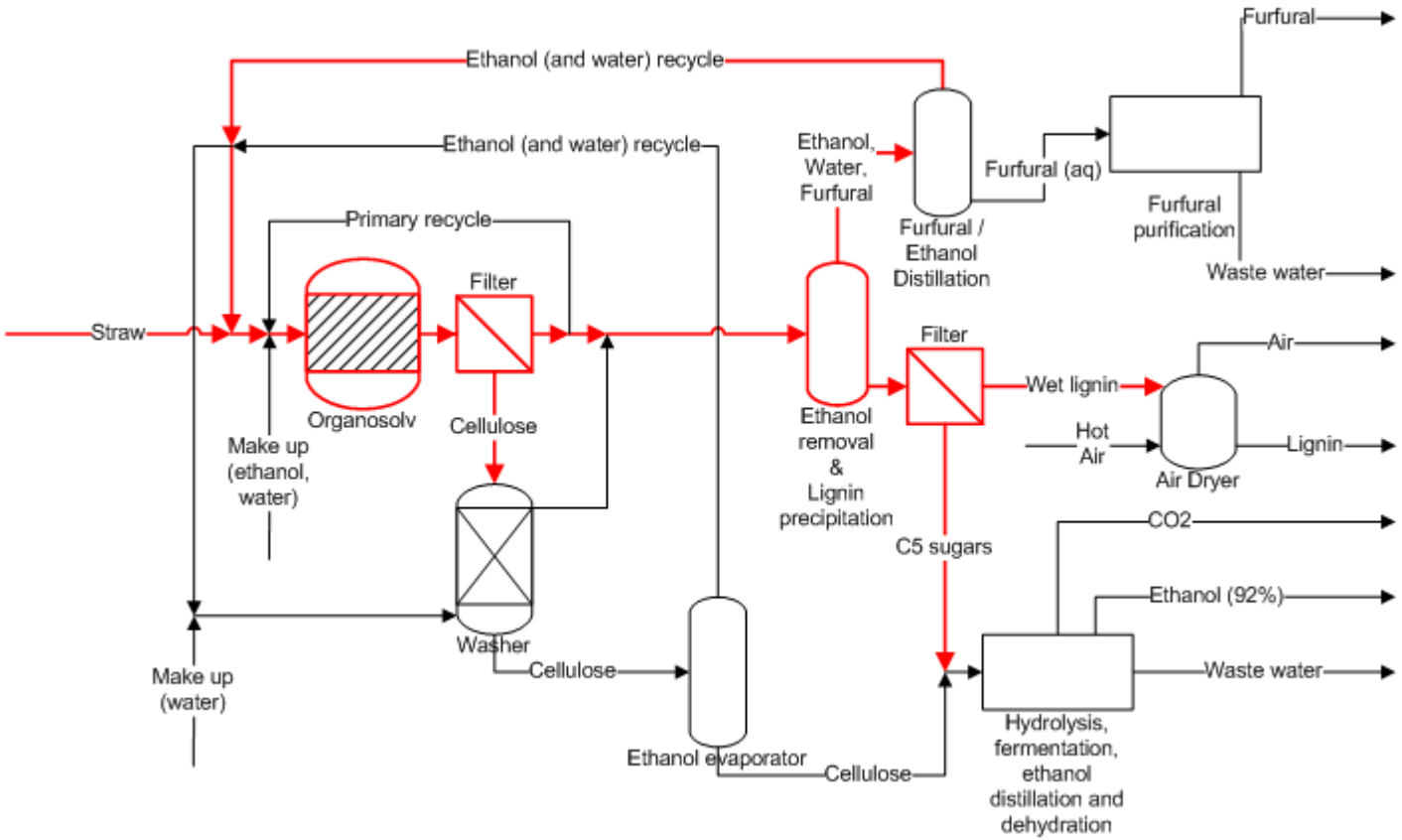
- A filter separates the lignin from the C5 sugars
- Organosolv can fractionate all the three main biomass components into separate streams



Organosolv process description

- Multiple additional process units are needed for:
  - Ethanol removal from:
    - C5 sugars and furfural stream
    - Cellulose pulp
  - Lignin drying
  - Furfural purification
  - Conversion cellulose to fuel-grade bioethanol

Organosolv process flow sheet



Mass balance

IN	kg / kg straw
Straw	1.00
Ethanol	0.0038
Water	2.17
Total	3.17

OUT	kg / kg straw
Ethanol	0.22
Furfural	0.059
Lignin	0.19
Waste water	2.33
CO_2 (*)	0.19
Water vapor	0.18
Total	3.17

(*) from fermentation only

- Straw to products: 52% wt
- Energy efficiency straw to products: 66%, (LHV based)

Energy balance

Unit operation	Heat (MJ/kg straw)
Ethanol removal from lignin	3.4
Ethanol removal from cellulose	0.9
Ethanol product distillation	1.0
Other	1.8
Total	7.1

Unit operation	Cooling (MJ/kg straw)
Ethanol removal from lignin	2.6
Ethanol removal from cellulose	0.6
Ethanol product distillation	0.6
Other	2.8
Total	6.6

- Heat integration is essential

Heat integration

- Coupling coolers and heaters to use heat multiple times
- Changing the pressure in separations to change the boiling points, to allow integration

	No heat integration MJ/kg straw	Heat integrated MJ/kg straw
Heating	7.1	3.3
Cooling	6.6	2.9

- ~20% of LHV of straw

Economic analysis

- Scale:
  - 140 kton/yr straw (dw)
  - Straw from a 50 km radius around plant
- 8000 hrs of operation / yr
- Standard literature methods for cost factors
- Price index: end of 2010
- Location: EU

Income

Product	Flow (kton/yr)	Price (€/ton)	Income (M€/yr)
Ethanol	32.1	750	24.1
Furfural	9.19	625	5.7
Lignin	23.1	500	11.6
Total			41.4

Operating costs, raw materials

Raw materials	Flow (kton/yr)	Price (€/ton)	Costs (M€/yr)
Straw (10% moisture)	156	60	9.33
Ethanol	0.58	750	0.44
Water	337	5	1.68
Enzymes			1.5
Total			12.96

Operating costs, total

Operating costs	Costs (M€/yr)
Raw materials	12.96
Utilities	4.7
Maintenance	6.0
Other	10.34
Total	34.0

Investments

Purchase costs	Cost (M€)
Reactor	5.0
Lignin work-up	1.8
Heat exchangers (all plant)	2.4
Fermentation section	2.3
Other	2.1
Total	13.6

- Physical plant costs: 43 M€
- Total Fixed Capital: 60 M€

Summary economic analysis

- Scale:
  - 140 kton/yr straw (dw)
- Income: 41.4 M€/yr
- Operating costs: 34 M€/yr
- Net revenue: 7.4 M€/yr
- Investment: 60 M€

Economic analysis, discussion

- Very sensitive to feedstock and product prices
- Energy costs are not the main cost factor
- Outlook:
  - Income can be higher if cellulose is used as material
  - Lignin price 500 €/ton: payback time about 8.2 yr
  - Lignin price 750 €/ton: payback time about 4.6 yr

Conclusions

- Organosolv biorefinery wheat straw:
  - Mass efficiency to products: 52%wt
  - Energy efficiency to products: 66%
  - Heat integration crucial, and feasible
  - Overall heat consumption modest
  - Economic return: interesting
  - Good lignin price essential for economics

Thank you for your attention!

More information:
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http://www.biosynergy.eu/

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