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Process design and evaluation of butanol production from lignocellulosic biomass

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PROCESS DESIGN AND EVALUATION OF BUTANOL PRODUCTION FROM LIGNOCELLULOSIC BIOMASS

Claudia Daza Montaño

Presentation Outline

- Why Butanol?
- ABE (acetone, butanol, ethanol) fermentation background and state of the art
- Developed conceptual process design
- Economic evaluation
- Environmental Impact assessment (LCA)
- Conclusions

BUTANOL (C_4H_9OH): Bulk chemical and fuel

Butanol is better biofuel than ethanol due to its more favorable chemical/physical properties. But even more valuable as chemical

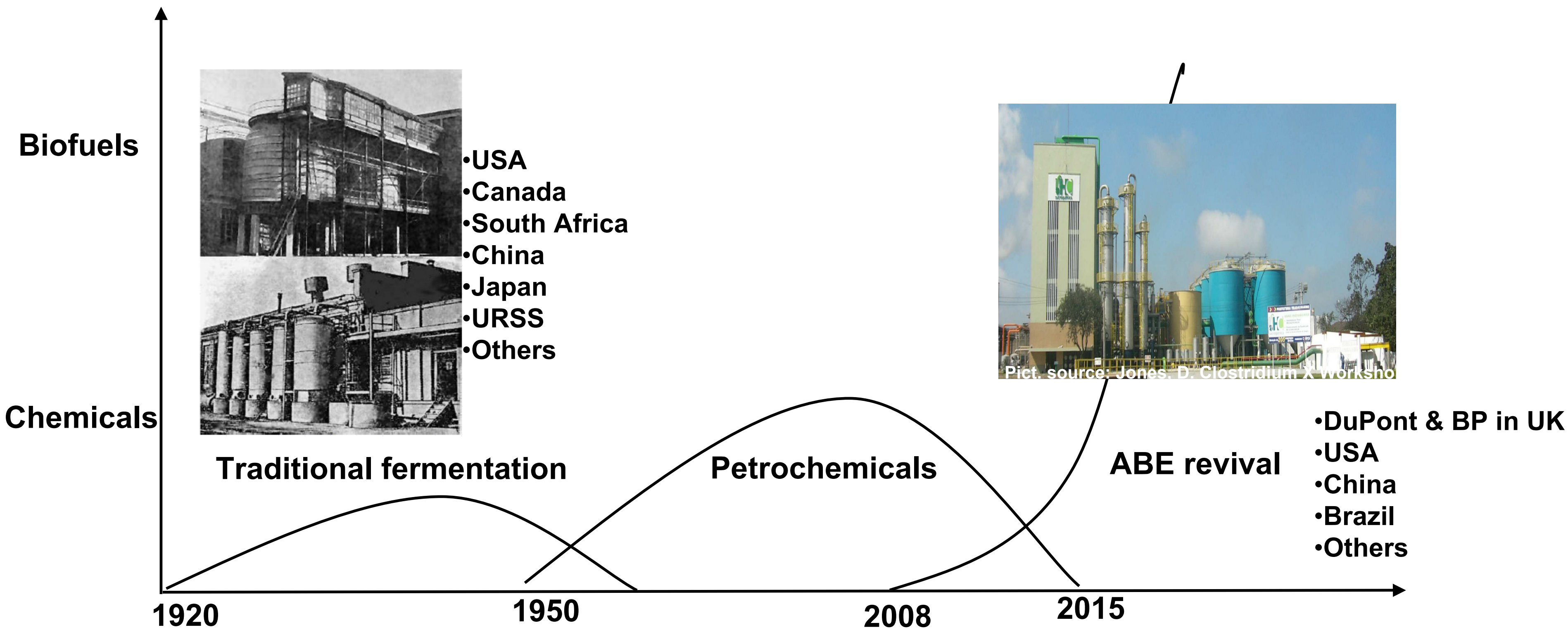
Properties	1-Butanol C_4H_9OH	Ethanol C_2H_5OH
LHV (MJth/kg)	33	27
Solubility (ml/100 ml H_2O)	9	miscible
Vapor pressure (mmHg)	5	44
Flash point (^oC)	37	15

- **Butanol can be shipped and distributed through existing pipelines and filling stations**
- **Butanol can be blended with diesel and with gasoline**
- **Butanol is a widely used solvent in industry**

Acetone-butanol-ethanol (ABE) fermentation

***Clostridia* strains A:B:E≈ 3:6:1 wt.**

Sugars and starch



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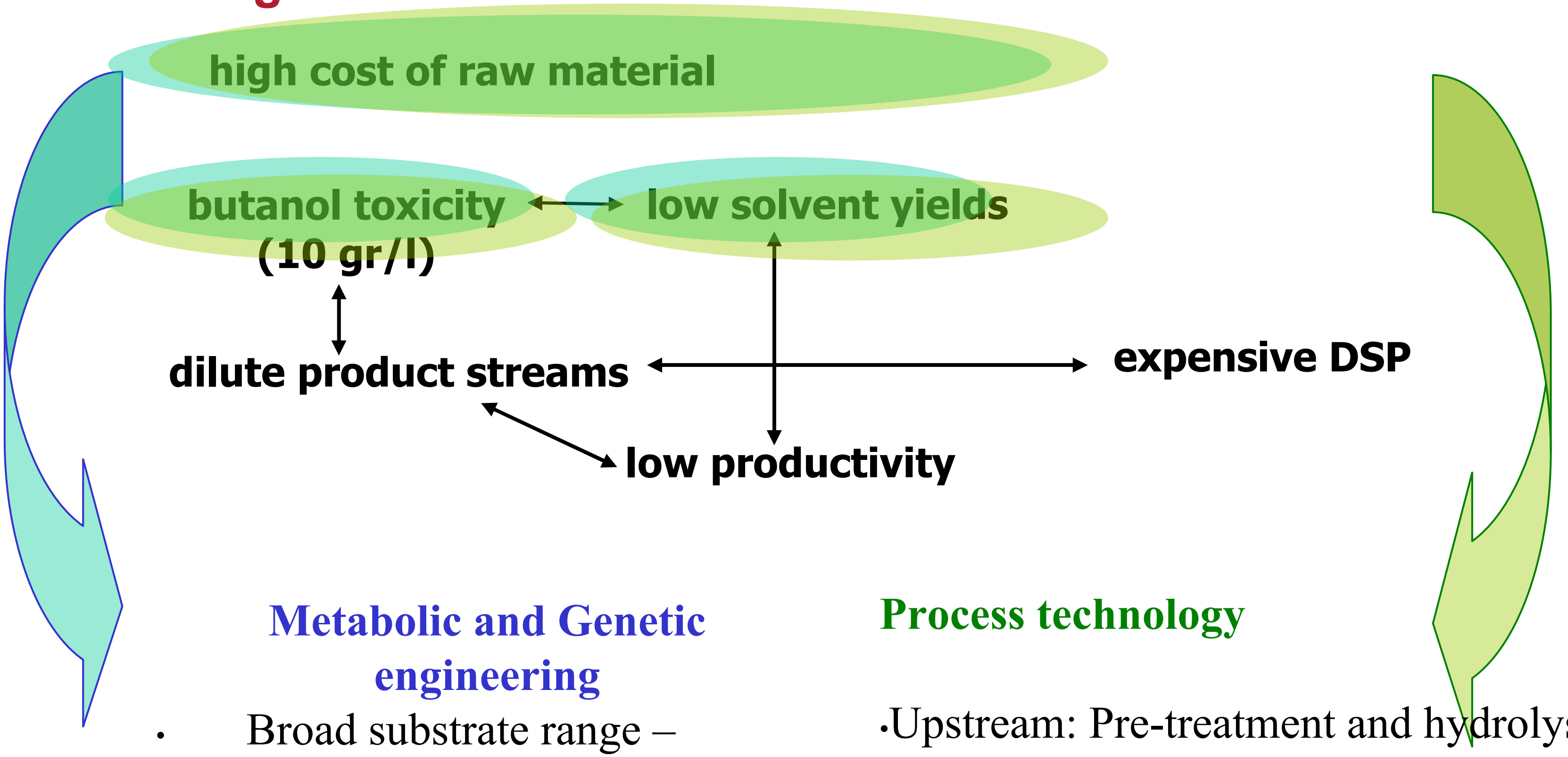
Challenges and research on butanol fermentation



Metabolic and Genetic engineering

- Broad substrate range – agricultural and food industry residues
- Solvent tolerant strains
- Thermophilic strains
- Selective product formation

Process technology

- Upstream: Pre-treatment and hydrolysis
- Fermentation configuration
- In Situ Product Removal *ISPR*
- DSP and process integration

Definition of process designed

- **Plant capacity ➔** 100 kton/year bio-butanol (167 kton/year ABE)
- **Lignocellulosic feedstock ➔**Wheat straw

  Input 1416 kton/year (d.m)

  Cost: 31€/ton (d.m.)
- **Mode of operation ➔** Continuous
- **In situ product removal technique ➔**Gas stripping

ABE fermentation parameters

Solvent-producing *Clostridia beijerinckii NACIMB 8052*

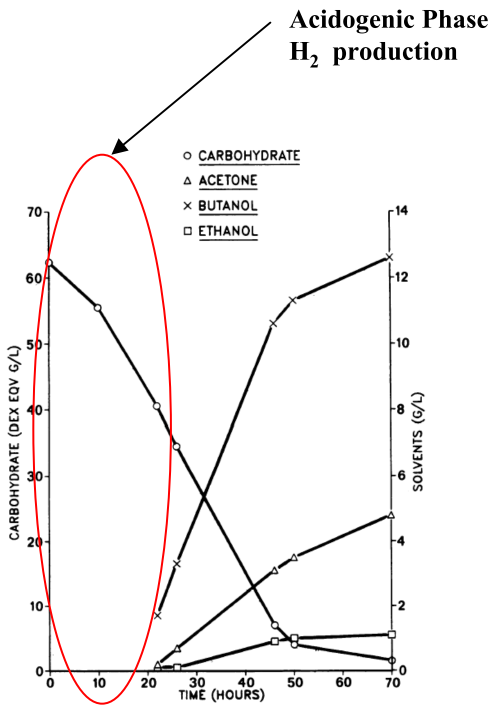
M.W. Beijerinck

- Wild type - Anaerobic bacteria

•Saccharolytic: C6 (glucose) and C5 (xylose) and sugar polymers (starch, xylan)

•Typical yield: 0.3 kg A.B.E/kg_{sugar} with 3:6:1mass ratio

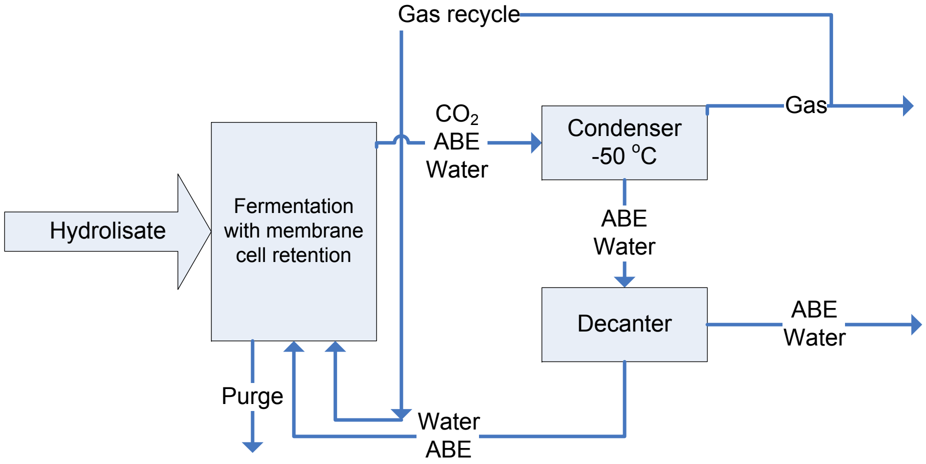
Compound	Formula	wt %
Sugars	CH_2O	-
Acetone	C_3H_6O	9
Butanol	C_4H_9OH	18
Ethanol	C_2H_5OH	3
Acetic acid	CH_3COOH	1.5
Butyric acid	C_4H_8O2	1.5
Hydrogen	H_2	1.6
Microbial cells	$CH_{1.8}O_{0.5}N_{0.2}$	12.7
Carbon dioxide	CO_2	49.7



Product recovery

Product Removal (ISPR) required to optimize fermentation productivity

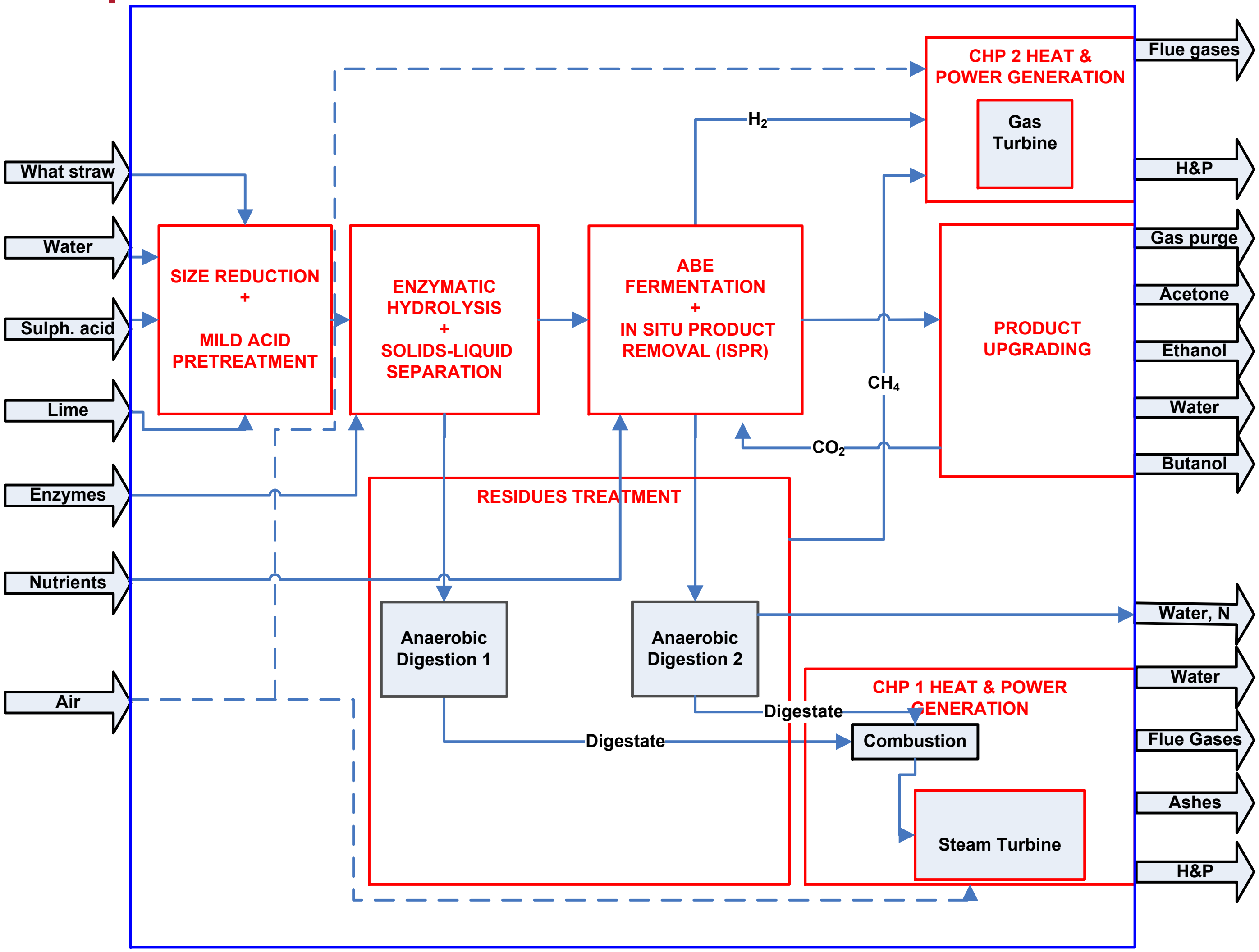
Technology	Efficiency	State of development	Scale	Capital cost	Operating cost	Technology status
Distillation	High	Complete	Commercial	Med	High	Commercial
Gas Stripping	Medium	Research	Lab	High	High	Research
Solvent Extraction	High	Research	Lab	Med	Med	Research
Pervaporation	High	Development	Pilot	High	High	Research
Adsorption	High	Research	Commercial	High	Low	Research



Gas stripping advantages:

- Simple technology
- Selective removal of volatile compounds
- Use of fermentation off gas (CO_2)
- No toxicity to cells

Main process sections



Overall mass & energy balance

Inputs	Kton/year	Value MW
Wheat straw (d.w., 9 wt% ash)	**1416**	**835***
Heat demand		**196**
Electricity demand		**61**
Total input		**1091**
Outputs		
Acetone	**50**	**181 ***
Butanol	**100**	
Ethanol	**17**	
Heat generation in CHP's		**431**
Electricity generation in CHP's		**196**
Total output		**808**
Net heat surplus		**235**
Net electricity surplus		**136**

*(LHV basis)

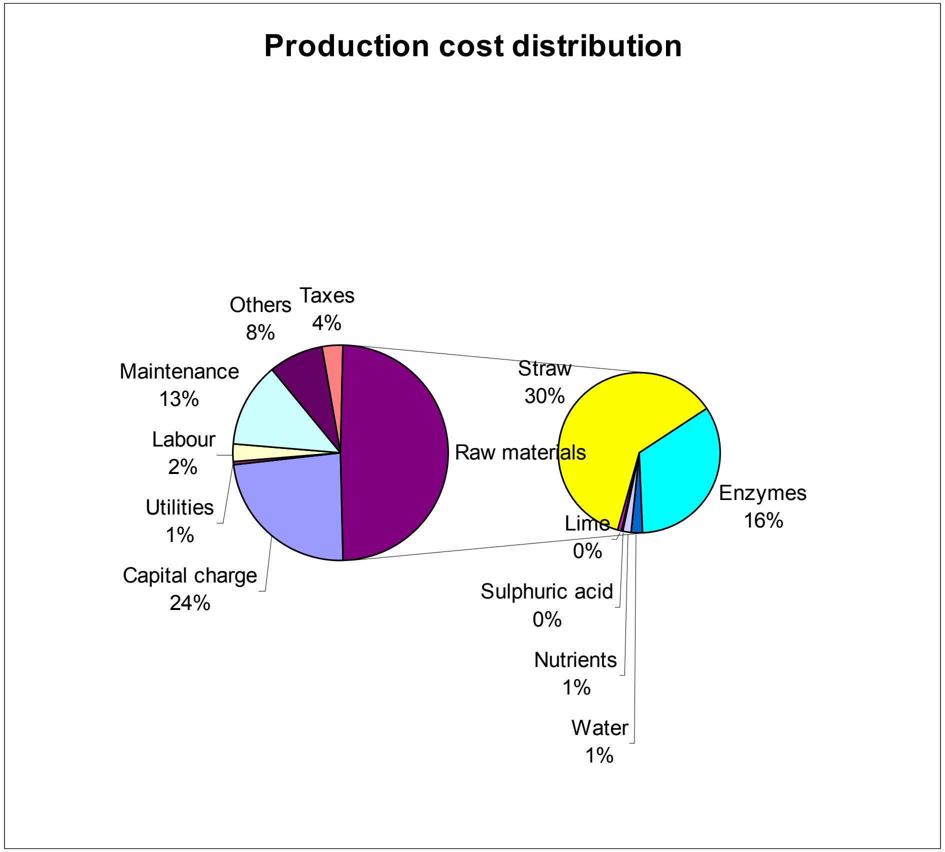
- Process energy demand (steam and electricity) fully covered + large electricity export
- Room for improvement via heat integration
- Surplus heat could be used for sterilization or for cooling generation via Absorption Refrigeration Plant

$$\text{Energy efficiency} = \frac{\text{Energy content in ABE} + \text{Electricity output}}{\text{Energy input (feedstock)}} = 38\%$$

Total production cost

Costs	€/TonABE
Raw materials	421
Utilities	5
Labor	21
Maintenance	110
Others	71
Taxes	30
Capital charge	204
Total gross	862
Total-electricity* sales	408

* 0.07 €/kWh



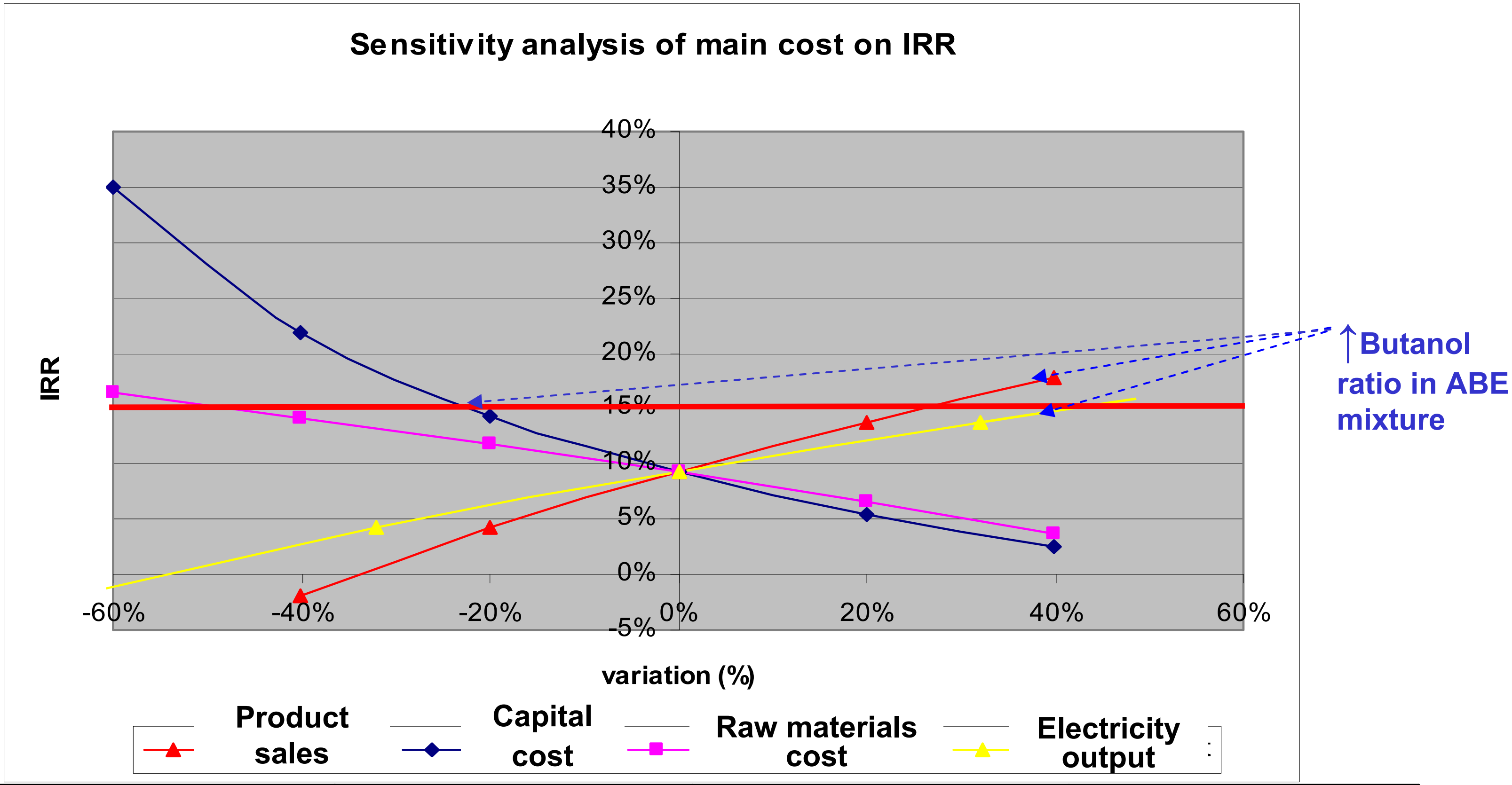
Product sales revenues

PRODUCT	CHEMICALS Selling Price €/Ton	PRODUCTION Kton/year	ANNUAL SALES M€/year	PRODUCT VALUE %
Acetone	571	50	28	20
Butanol	929	100	93	68
Ethanol	857	17	15	12
Total ABE (3:6:1 wt)	**814**	**167**	**136**	**100**

Internal Rate of Return (IRR) = 9,6%

Sensitivity analysis on Internal Rate of Return (IRR)

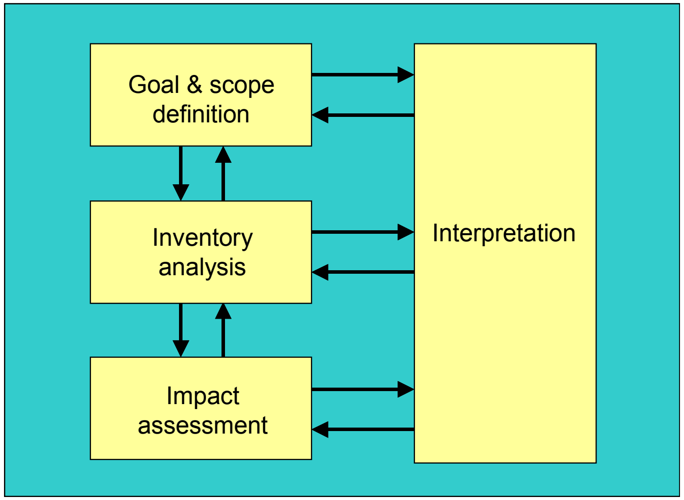
Total ABE sales as chemicals: 136 M€/year
IRR=9,6%



PRODUCTS	LHV (MJth/kg)	FUELS	CHEMICALS
		Fuel value €/Ton*	Market Price €/Ton
Total ABE (3:6:1 wt)	31	440	814

*0.015 €/MJth

Life Cycle Analysis LCA

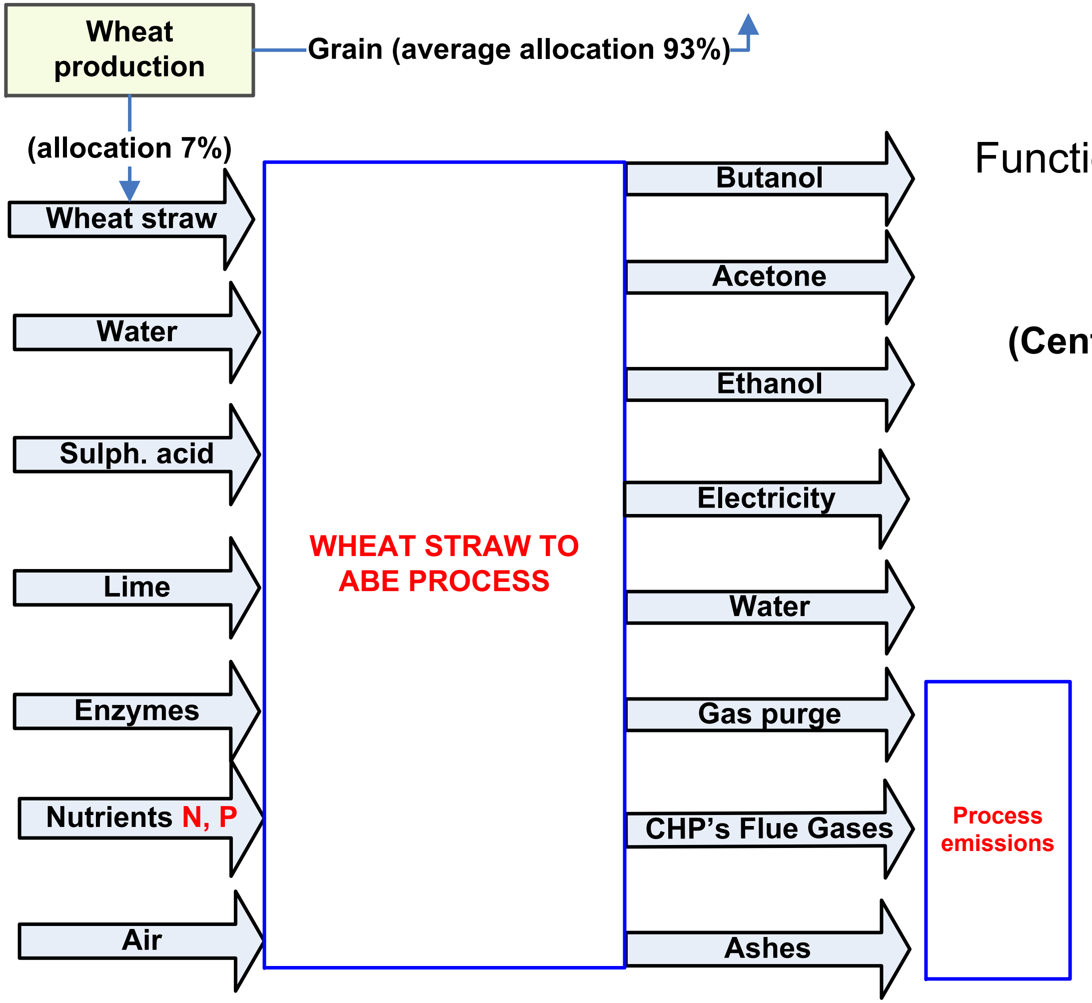


Life Cycle Assessment framework, with different steps of LCA and their interactions according to ISO standards

The goals of the screening LCA are to assess the environmental impacts of ABE production from straw, in a "cradle to gate" analysis and to compare these impacts with those of ABE petrol-based production and with those of gasoline production.

Software: SimaPro (version 7) www.pre.nl

Inventory analysis and impact assessment



Ecoinvent database

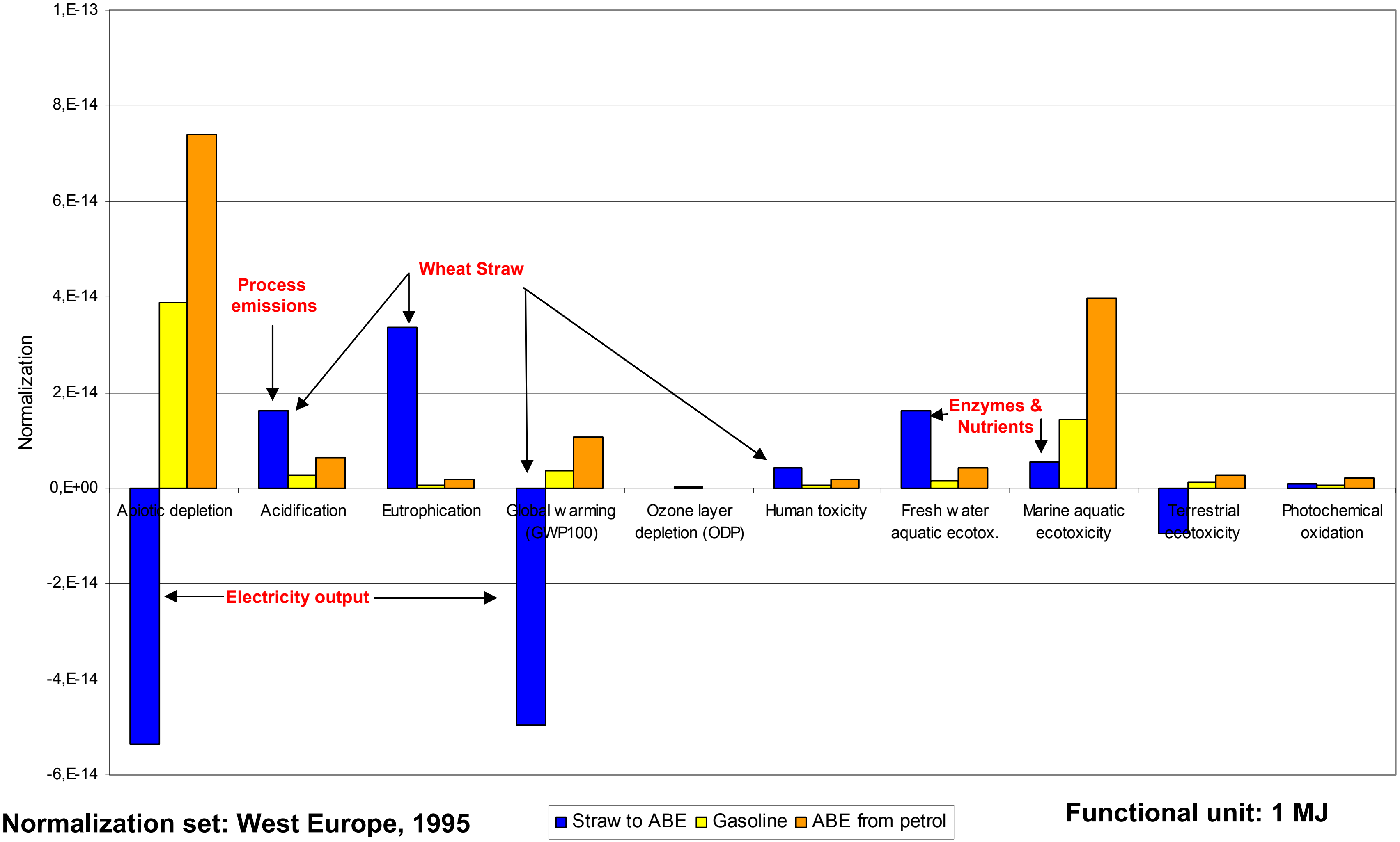
Functional unit 1 MJ ABE =0.032 kg ABE

CML method
(Centrum voor Milieukunde Leiden (CML)

Impact categories

- Abiotic depletion
- Global warming
- Ozone layer depletion
- Human toxicity
- Fresh water aquatic ecotoxicity
- Marine aquatic ecotoxicity
- Terrestrial ecotoxicity
- Photochemical oxidation
- Acidification
- Eutrophication

Comparison ABE from wheat straw with gasoline and with petrochemical ABE



Normalization set: West Europe, 1995

Functional unit: 1 MJ

Overall conclusions and recommendations

- ❖Wheat Straw to ABE as chemicals = CLOSE TO be economically competitive.
  - o Raw materials are the major cost driver
- ❖Increase of butanol ratio to A:E produced improves energy efficiency and economics
- ❖Environmental performance: straw-ABE better than petrol-based ABE
  - o Residues conversion into heat and electricity are a key parameter
  - o Major environmental impacts: eutrophication
  - o Recovery of nutrients and production of useful by-products would improve LCA
- ❖ OPTION: Retrofit existing ethanol plants for butanol production

Thank for your attention

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Project website: www.biobased.nl/eosbiobutanol

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Wageningen University & Research Centre WUR

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