



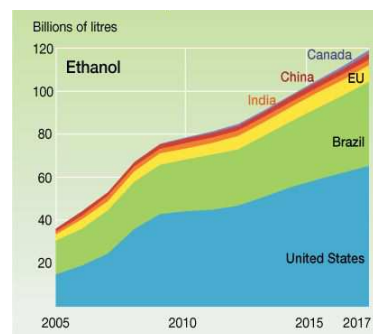
## One-stage saccharification and fermentation of wood into ethanol

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## Ethanol most common biofuel

- ▶ 72.5 million tonnes/a produced (2013) <sup>1)</sup>
  - ▶ 84% is used as biofuel
- ▶ Spark-ignition engines
  - ▶ E5, E10
  - ▶ E85
- ▶ Compression-ignition engine
  - ▶ ED95



2)

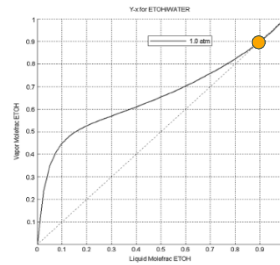
1) Merchant Research & Consulting, Ltd., U.K.

2) [www.grida.no](http://www.grida.no)

## ED95

Substance	Amount
Aqueous ethanol	95%
Additive	5%

- ▶ Additive:
  - ▶ Ignition improver
  - ▶ Anticorrosive agent
  - ▶ Lubricant
  - ▶ (denaturant)



1) Scania Schweiz AG

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## Biochemical production processes of bio-EtOH

## 1st generation

- ▶ Based on sugar/starch
- ▶ Single-substrate
- ▶ Granulate/liquid educt
- ▶ High carbohydrate content
- ▶ Allows for high titers
- ▶ Food

## 2nd generation

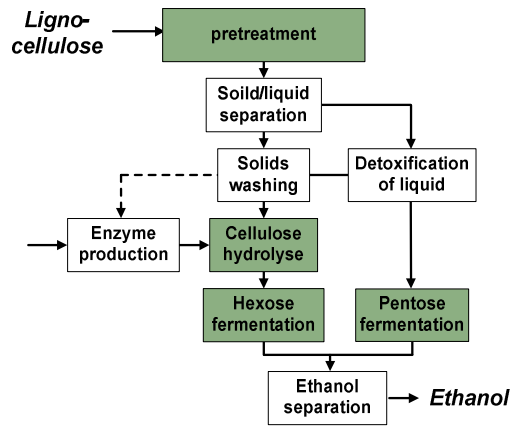
- ▶ Based on lignocellulose
- ▶ Complex composition
- ▶ Contains up to 25% lignin
- ▶ Bulky material
- ▶ Max. 60% carbohydrates
- ▶ Difficult to achieve 4% EtOH concentration
- ▶ None edible/(feed)

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## Standard lignocellulose-ethanol-process

- ▶ Elaborate process
  - ▶ High CAPEX and OPEX
  - ▶ Various unit operations
- ▶ 3 Main unit operations
  - ▶ Pretreatment
  - ▶ Cellulose hydrolysis
  - ▶ Sugar fermentation

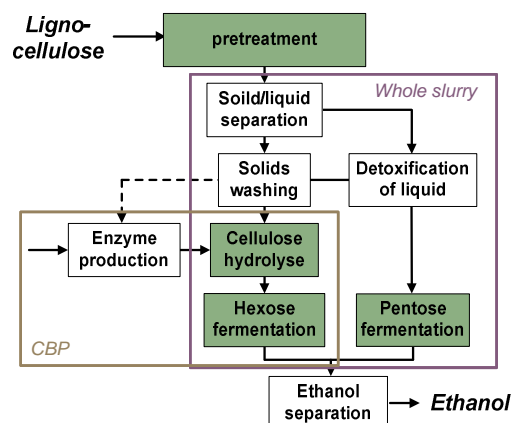


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## Advanced process integrations

- ▶ Whole slurry hydrolysis and fermentation
  - ▶ Accept enzyme inhibition
  - ▶ Often GMO to co-ferment C5 and C6-sugars
  - ▶ External enzyme production
- ▶ Consolidated bioprocessing
  - ▶ GMO <sup>1)</sup>
  - ▶ Low titers and yields <sup>1)</sup>
  - ▶ External enzymes necessary <sup>1)</sup>
  - ▶ Pure substrates <sup>1)</sup>
  - ▶ Only cellulose fraction



<sup>1)</sup> Brethauer and Studer; CHIMIA 2015, 69, No. 10

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## First 2<sup>nd</sup> generation full-scale bio-ethanol plant



- ▶ Ethanol Production: 40'000 t/a (= 50 Mio L/a = 1PJ)
- ▶ Biomasse consumption: 180'000 t/a (= 500 t/d)
- ▶ Arundo Donax, wheat straw, corn stover
  - ▶ 280 L<sub>Ethanol</sub>/t<sub>Stroh</sub>
- ▶ 13MW power production
  - ▶ Burning lignin
- ▶ Energy self-sufficient
- ▶ Water Recycling: 100%
- ▶ Investment: 150 Mio €

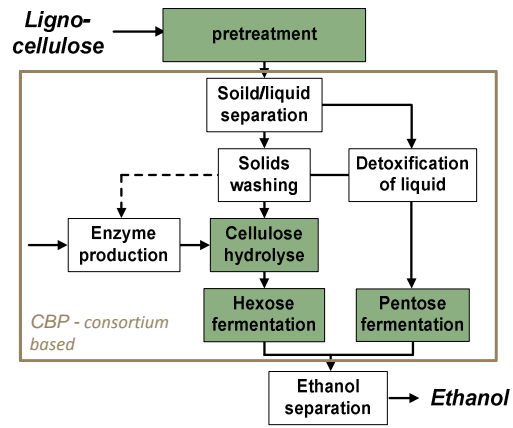


## Challenges for Switzerland

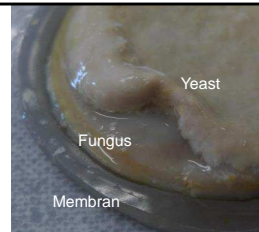
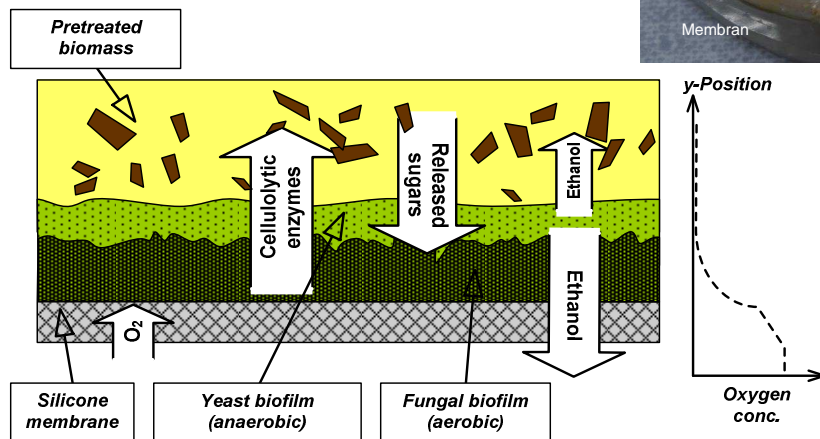
- ▶ Biomass potential in CH:
  - ▶ Ag-residues: 500'000t
  - ▶ Energy wood: 700'000t
  - ▶ 6 such plants in whole Switzerland
    - ▶ Roughly 25 40t-trucks per day
- ▶ Downsize the plant by 10 to 20X:
  - ▶ 10 - 20'000t/a biomasse plant
  - ▶ Decentralized plant
  - ▶ 'Economy of scale'
    - ▶ CAPEX for 50Mio Liter-plant is 100-200Mio €

### CBP – based on a microbial consortium

- ▶ Enzyme production, hydrolysis, fermentation (of all sugars) in one reactor
- ▶ Robust industrial strains
- ▶ Microorganisms are protected in a biofilm
- ▶ Large potential cost savings



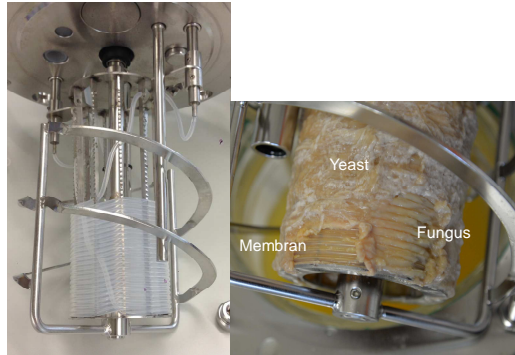
### Multispecies-biofilm-membrane process



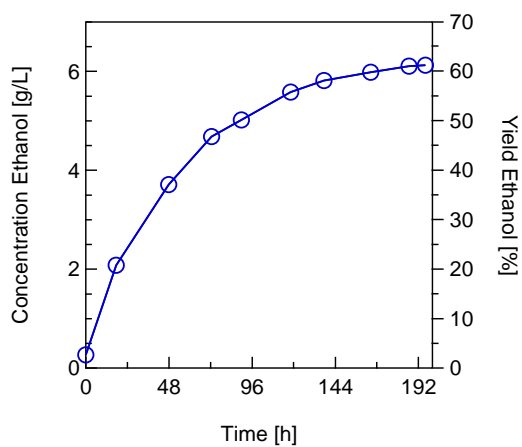
1) Brethauer and Studer; Energy Environ. Sci., 2014, 7,1446

## Upscaling of the CBP based on a microbial consortium

- ▶ Based on 3.6 Liter 'Labfors 5 BioEtOH' Infors-HT fermenter
- ▶ Membrane holder with tubular membrane
  - ▶ 800um thick

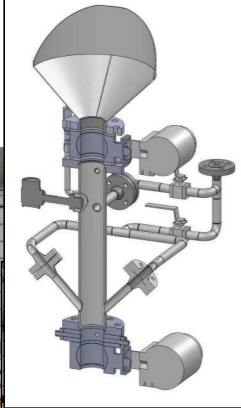


## CBP of pure cellulose to EtOH in a stirred tank reactor



- ▶ Batch run
- ▶ Mandels medium with 17.5 g/L cellulose
- ▶ *T. reesei* Rut C30 inoculation
- ▶ Addition of *S. cerevisiae* and  $\beta$ -glucosidase
  - ▶ 48h after fungi inoculation
- ▶ Yield calculated based on 17.5g/L cellulose

## Steam pretreatment plant

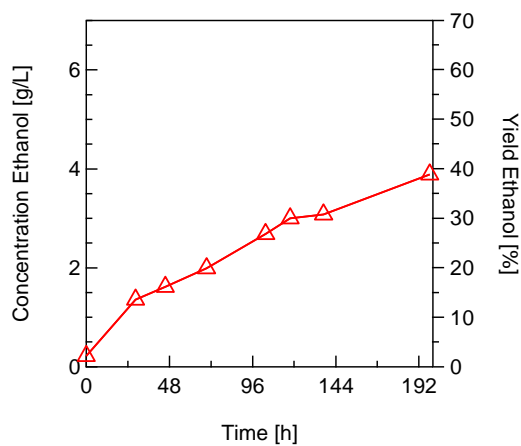


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## CBP of pretreated beech wood to EtOH

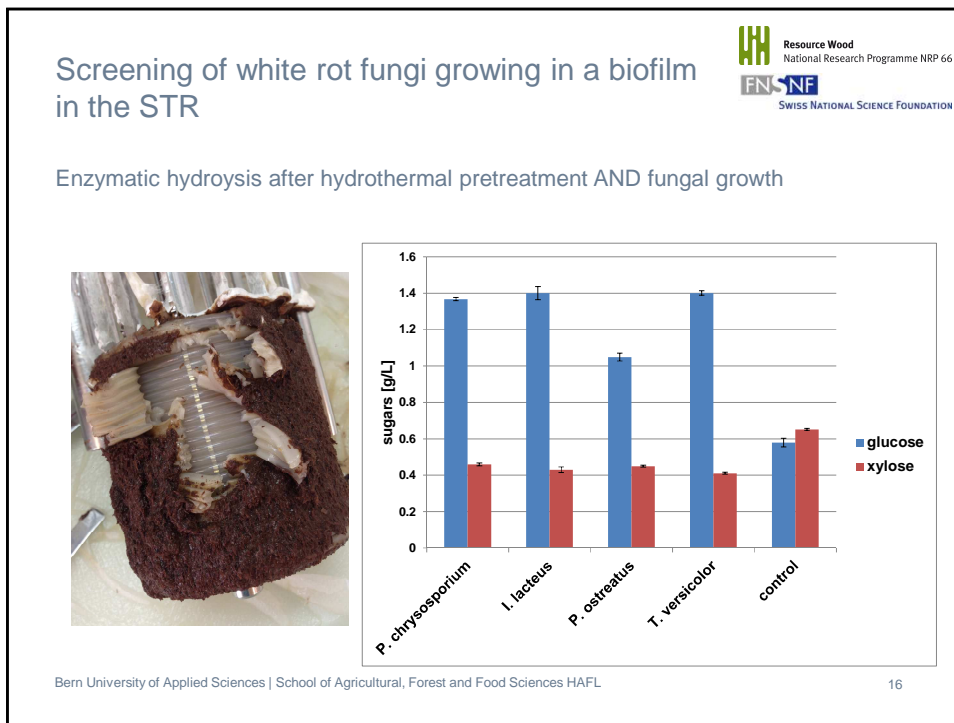
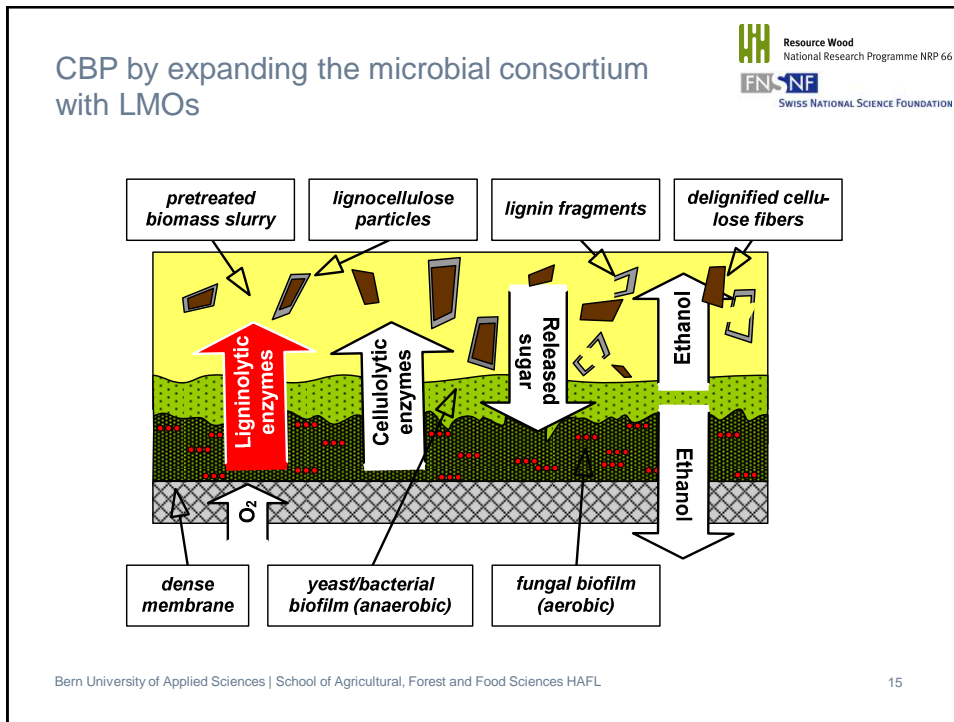

  
 Resource Wood  
 National Research Programme NRP 66  
 SNSF  
 SWISS NATIONAL SCIENCE FOUNDATION



- ▶ Batch run
- ▶ Beech wood
- ▶ Pretreatment conditions: 230° C, 4.7 Min
- ▶ Mandels medium with pretreated beech wood
  - ▶ 17.5 g/L cellulose
- ▶ *T. reesei* Rut C30 inoculation
- ▶ Addition of *S. cerevisiae* and  $\beta$ -glucosidase
  - ▶ 48h after fungi inoculation
- ▶ Yield calculated based on 17.5g/L cellulose

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## Conclusion

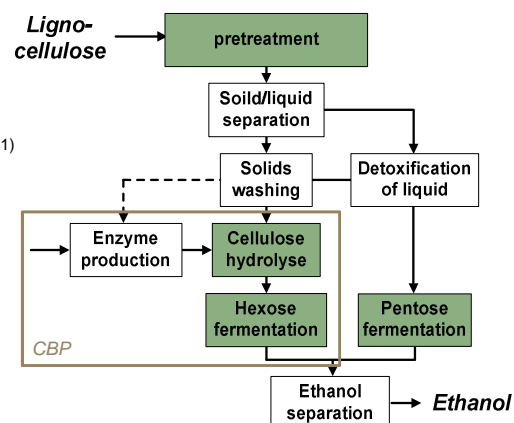
- ▶ EtOH is an established biofuel
  - ▶ Potential to be used more efficiently as ED95
- ▶ Smaller decentralized plants better suited for Switzerland
- ▶ Consortium based CBP features high level of integration
  - ▶ Cope with economy of scale
- ▶ Swiss bio-ethanol production and use as ED95 in heavy-duty transportation seems suitable



## Advanced process integrations (2)

### Consolidated Bioprocessing

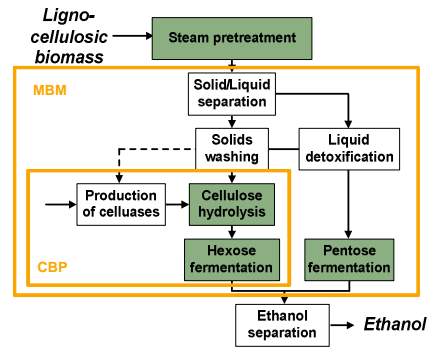
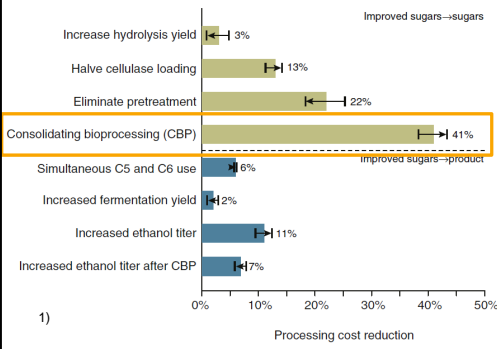
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1) Brethauer and Studer; CHIMIA 2015, 69, No. 10

# Consolidated bioprocessing

## Potential cost savings



<sup>1</sup> L.R. Lynd, et al., How biotech can transform biofuels, NATURE BIOTECHNOLOGY 26 (2), 2008