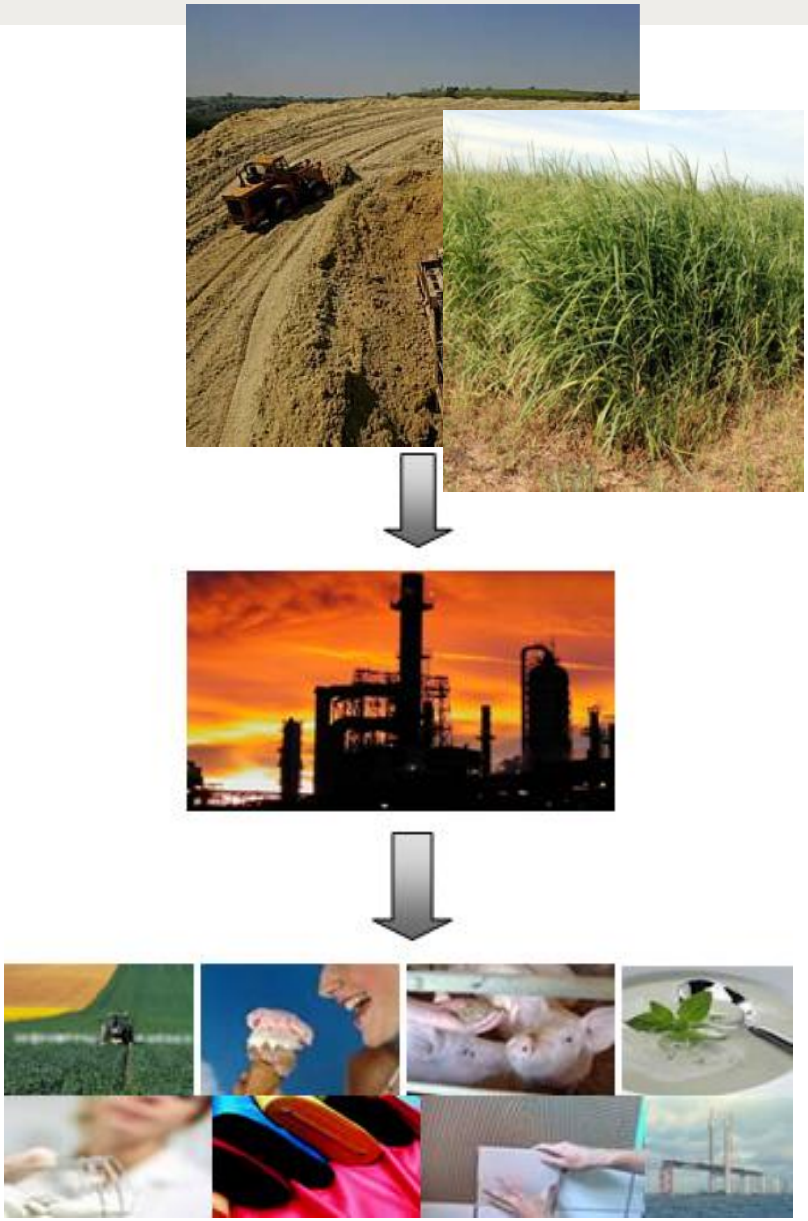

The Biorefinery approach to production of lignocellulosic ethanol and chemicals from lignocellulosic biomass

IEA Bioenergy Conference, Vienna
13-14.11.2012

Gisle L Johansen
Senior Vice President R&D and NBD

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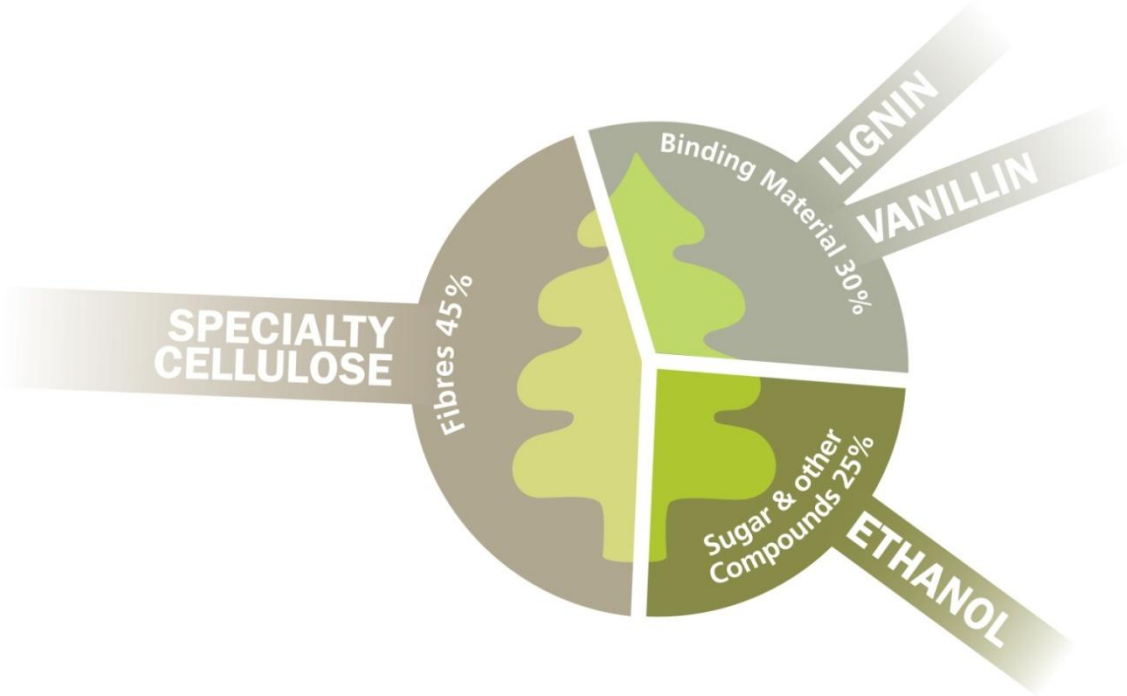
Borregaard
The Sustainable Biorefinery

Biorefinery – a Business Model Based on Biomass

Borregaard's biochemicals are sustainable and environmentally friendly substitutes to petrochemicals



Borregaard is a global leader in bio based chemicals.
Strong innovation efforts increase the value added to our customers.

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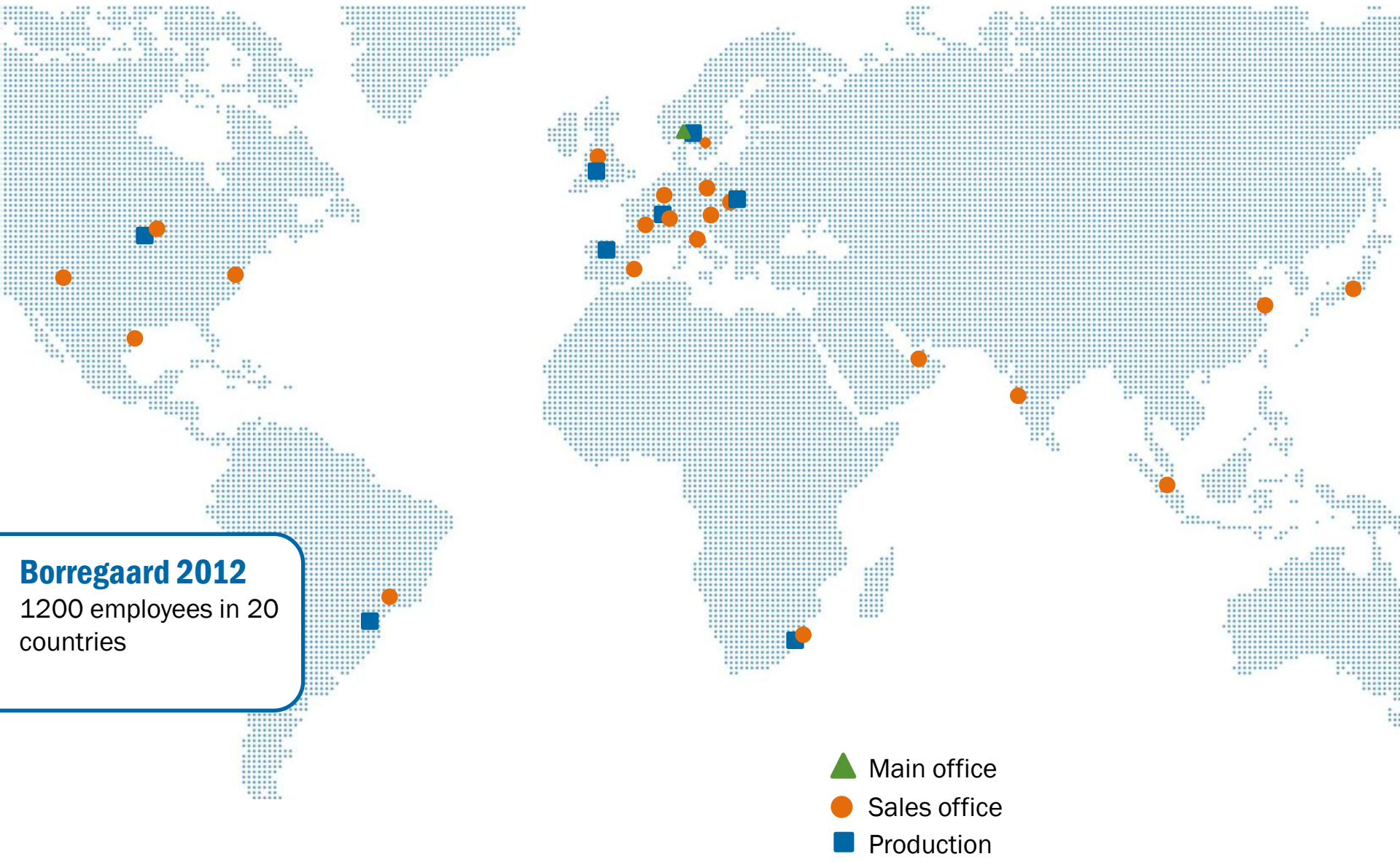
(Still) The world’s largest production of cellulosic ethanol

Global presence



Borregaard 2012
1200 employees in 20 countries

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Borregaard then and now

Edward Partington

Karl August Kellner

- Competitive edge in 1889
  - cheap timber
  - cheap energy
  - cheap labor

- Austrian technology
- British capital

- High cost
  - raw materials
  - energy
  - labor

- Competitive edge in 2012
  - technology
  - market
  - innovation pipeline

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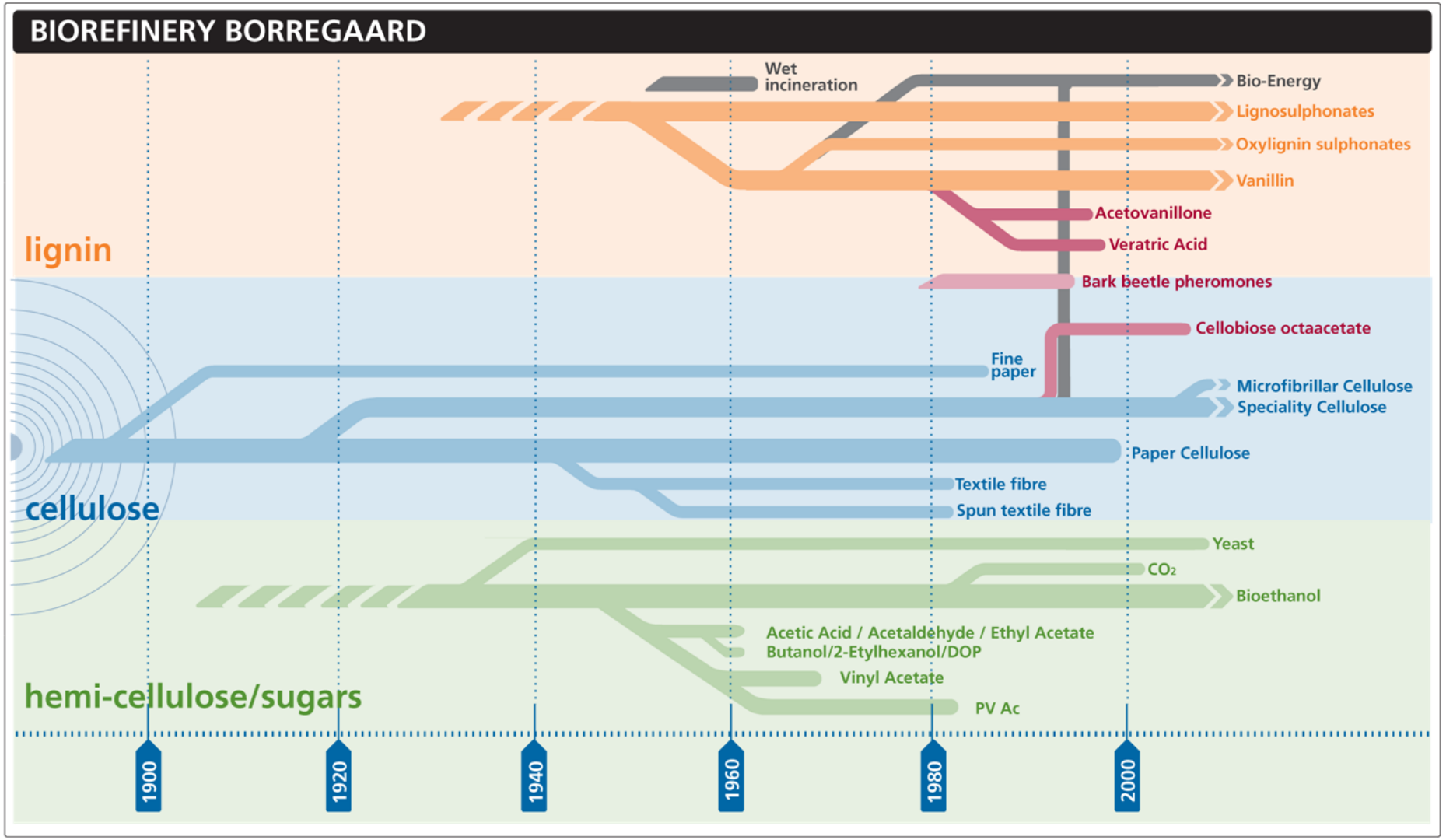
Borregaard site in Sarpsborg, Norway

From paper mill to biorefinery



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Further development of the biorefinery concept

High

Cost/price

Low

BIOREFINERY

BioMaterials
- *Polymers*
- *Composites*

BioChemicals
- *Flavours*
- *Monomers*
- *Proteins*
- *Fine chemicals*
- *Speciality chemicals*

BioFuel
- *Bioethanol*
- *Biodiesel*
- *Biogas*

BioEnergy
- *Electricity/Heat*
- *Liquid Fuels*
- *Pellets*

High

Creating values

Low

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Lignin from biomass - two alternatives

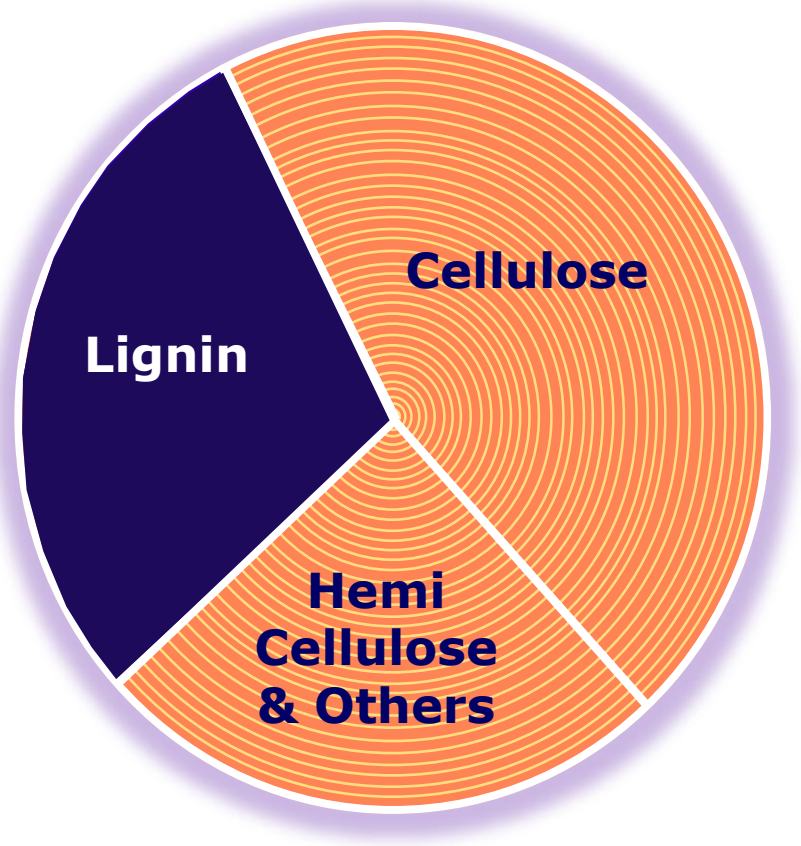
Borregaard BALI process:

Lignin

specialty chemicals

Competing 2G processes:

Energy – heat and power



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BALI™ process in a nutshell - pretreatment

Bagasse

Pretreated and ”reactive” pulp

Water soluble lignin

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Borregaard LignoTech

World leader in lignin based products

Production

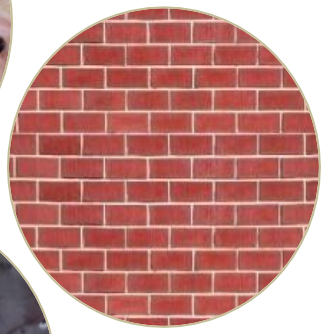
Norway, England, Germany
Spain, Czech Republic, USA,
South Africa, Brazil

Products

A broad range of dispersing and binding agents and other performance chemicals

Applications

- Construction
- Agro chemicals
- Animal feed
- Bricks & tiles
- Lead batteries
- Soil conditioner
- Mining
- Gypsum board



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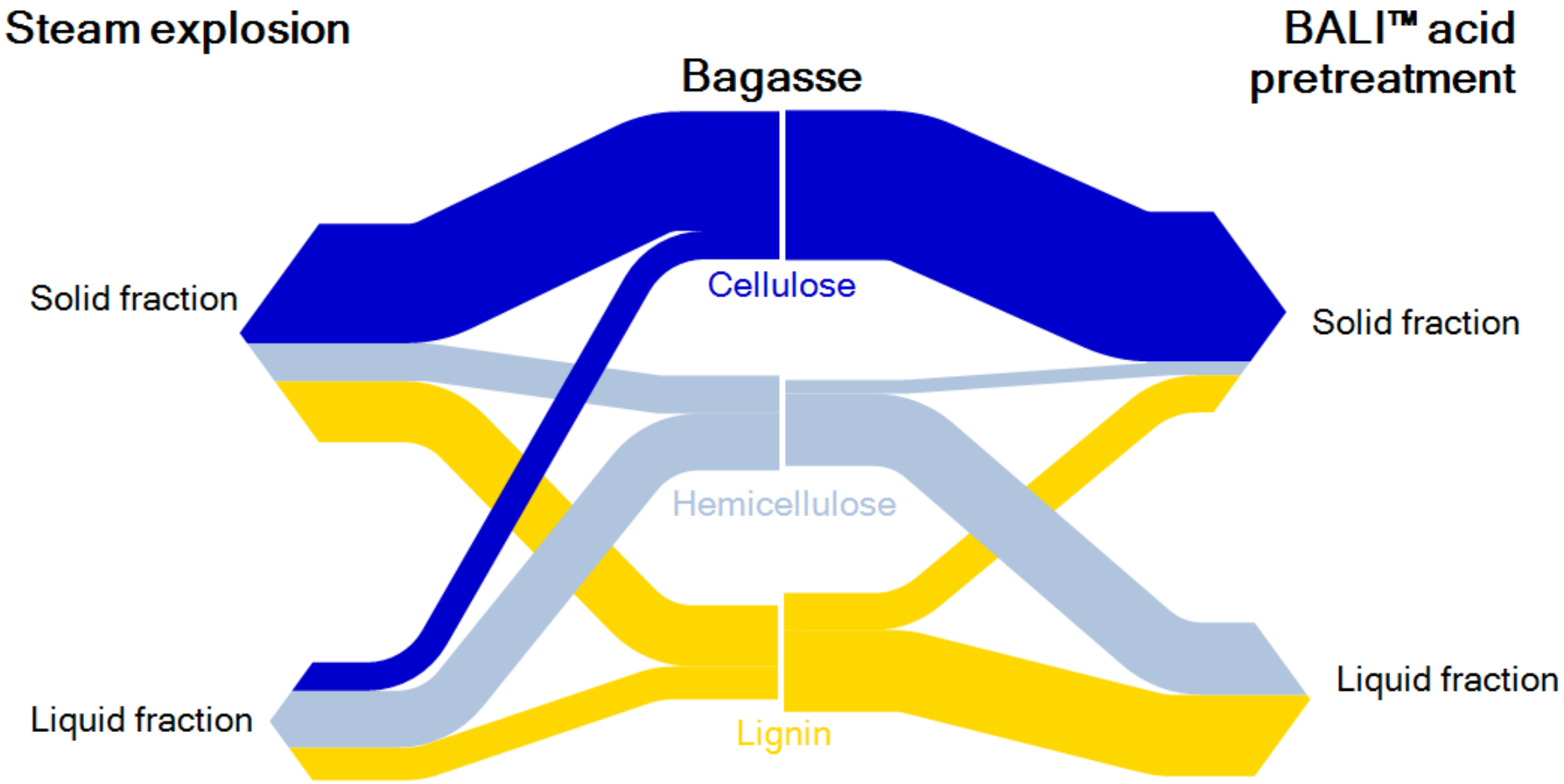
Bagasse mass balance (only C/H/L shown)



SE data from Martin et al. *BioRes* **2008**, 607.

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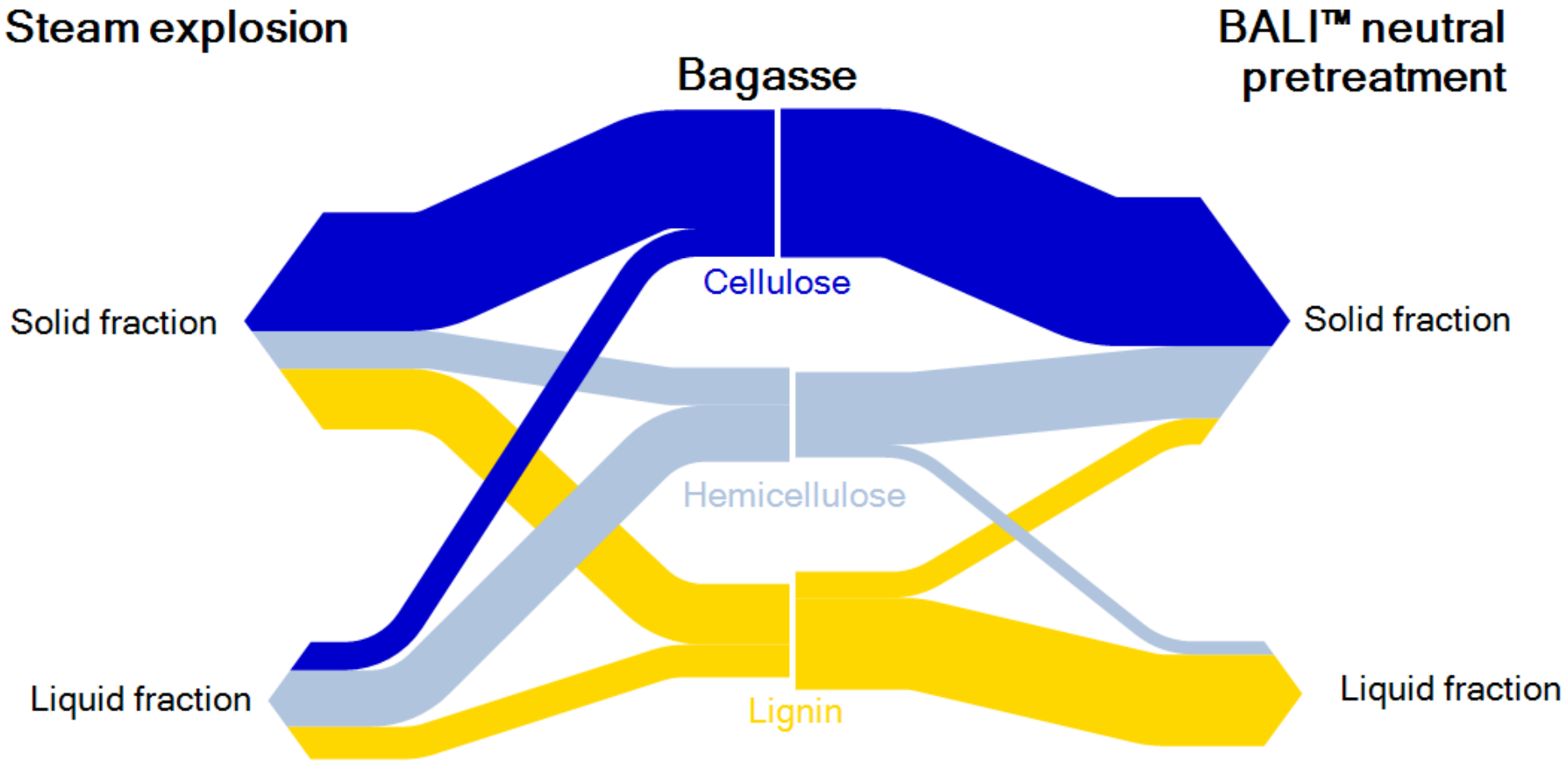
Bagasse mass balance (only C/H/L shown)



SE data from Martin et al. *BioRes* **2008**, 607.

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BALI™ process in a nutshell – fiber hydrolysis

Pretreated bagasse

Decomposition with enzymes yields high purity sugar in solution

Sugar is transformed to bioethanol or chemicals

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Performance evaluation of cellulolytic enzymes

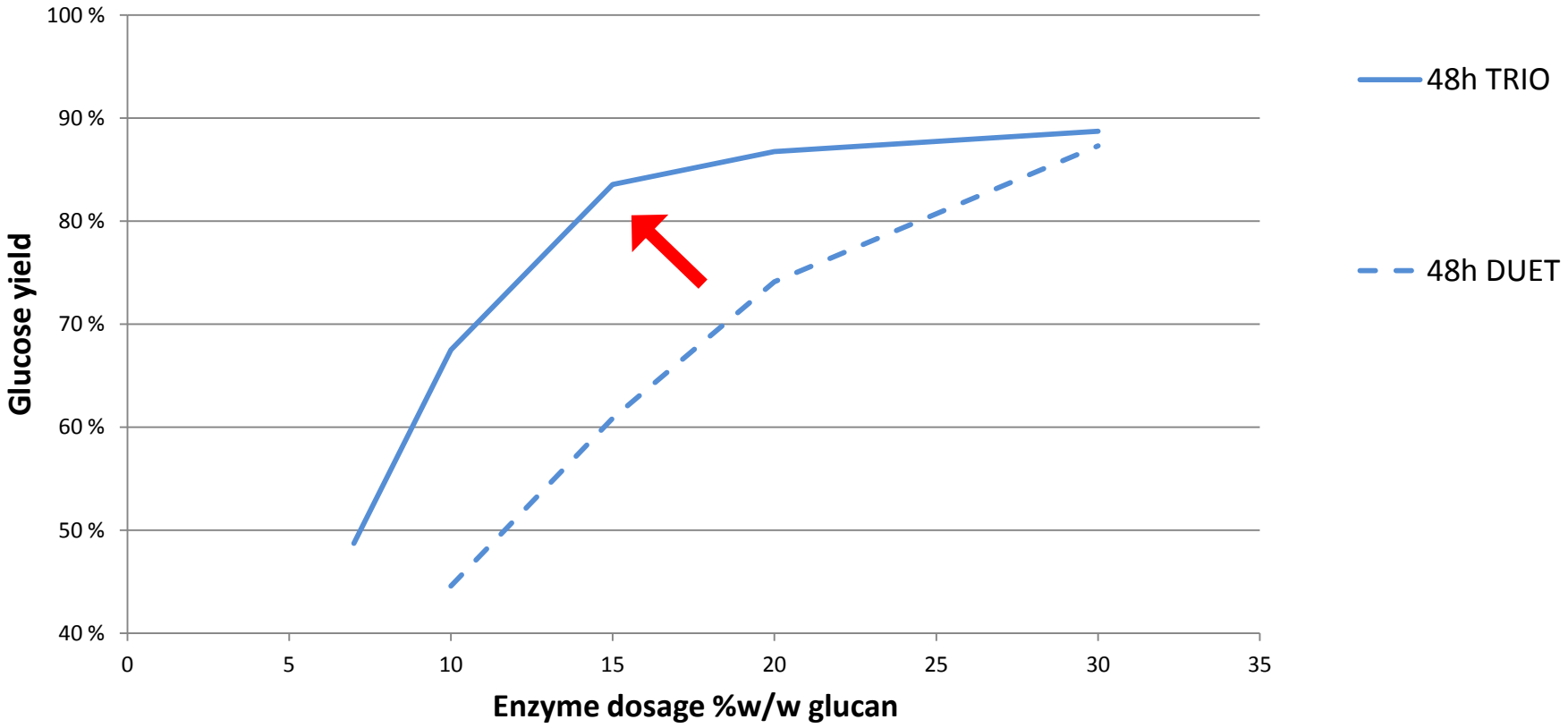
- Many factors affect yields in enzymatic hydrolysis and all need to be taken into account when evaluating and comparing results
  - solids and glucan loading
  - enzyme dosage (on solids or glucan? %w/w or %v/w?)
  - time
  - buffer and concentration of buffer (pH at end of hydrolysis measured?)
  - temperature (mostly at 50 °C, but more stable enzymes are emerging)

- Yields >100% (not uncommon as pretreatment and enzyme technology improves) mainly due to underestimation of glucan in the raw material analysis (main challenge is the 2-step quantitative analytic hydrolysis)

- A performance evaluation of feedstock/pretreatment combinations needs to be done on a case-by-case basis for every enzyme product studied due to differences in product formulation and composition.

- In the end only $/kg sugar counts

DuPont Accellerase® DUET vs TRIO



BALI™ neutral pretreated bagasse
15% substrate/8.5% glucan loading
50 °C, 200 rpm
25 g total reaction mass
sodium citrate buffer

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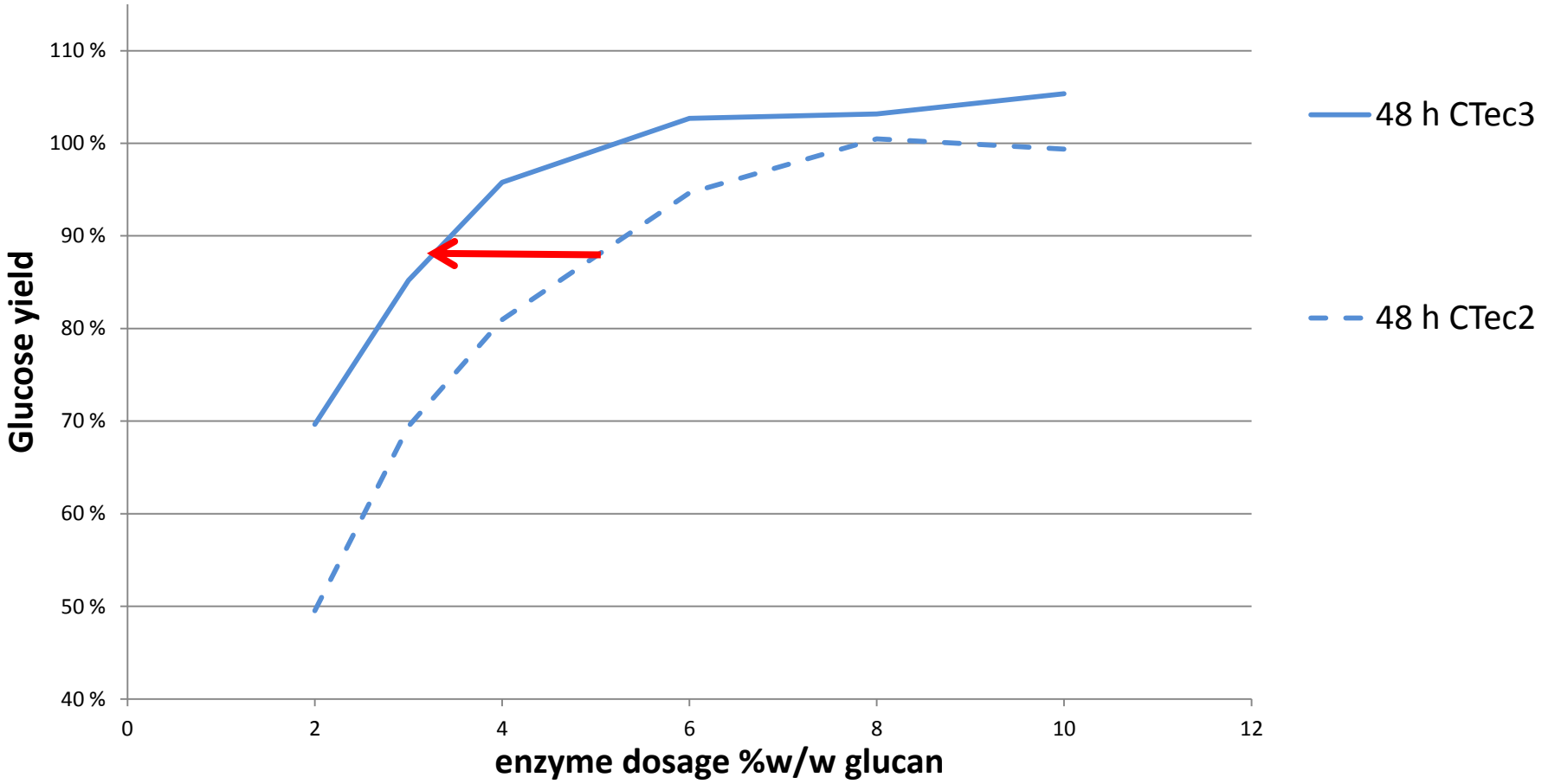
Novozymes Cellic® CTec2 vs CTec3



BALI™ acid pretreated bagasse
15% substrate/9.7% glucan loading
50/53 °C (CTec2/CTec3), 200 rpm
28 g total reaction mass
sodium citrate buffer

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BALI™ produces clean hydrolysates

- BALI™ hydrolysates are easily fermentable to ethanol, indicating the absence of fermentation inhibitors

- Company A (chemical process):
  - ***”Borregaard hydrolysates were converted very efficiently”***

- Company B (fermentation process):
  - ***”Results for conversion of the acid and neutral hydrolysates are the best we have ever observed”***

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Demonstration plant for bioethanol and green chemicals -in operation

Biomass

BALI

Cellulosic ethanol
Biochemicals

Lignin Chemicals

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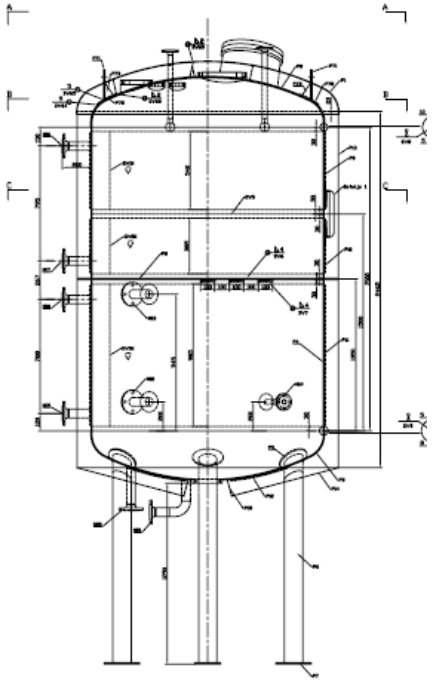
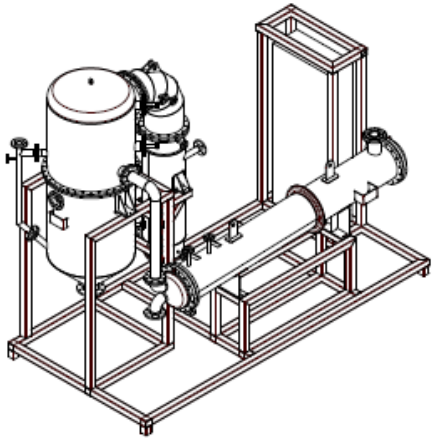
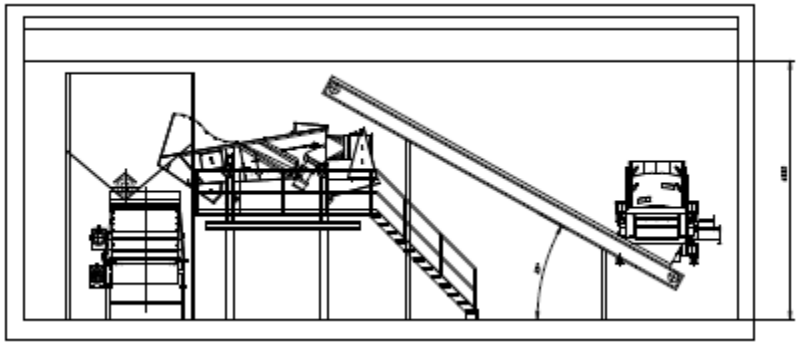
Building the first BALI™ demonstration

- Demonstrate lignin grade/quality
- Serve partners
- Reduction of risk (CAPEX est)
- A real “mini plant”, continuous process, scalable equipment (up to 50 m^3 scale)
- Includes
  - lignin processing
  - continuous polysaccharide hydrolysis
  - fermentation capabilities
- Feed: 2MTDS/day
- Currently in operation
- Location: Sarpsborg, Norway
- Total cost approx 24 mill USD







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Biomass2Products
3.3 MUSD from the Norwegian Research Council (2009 – 2012)

BALI pilot plant
10 MUSD for construction of pilot plant received from Innovation Norway

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