Organosolv process
Innovative wood processing for value products

Dr. Markus Wolperdinger
BIO World Congress
Montreal, July 20, 2015
The Linde Group
Organisational structure

The Linde Group

Gases Division
- EMEA
- Asia/Pacific
- Americas

Engineering Division
- 27 Entities worldwide
- 4 Execution hubs:
  - Germany
  - India
  - USA
  - China

Other Activities
- Gist

Revenue (2014): 17,047 m€
No of employees: 65,591

July 20, 2015
Linde Engineering
Leading market position in all segments

Air Separation Plants
Hydrogen and Synthesis Gas Plants
Petrochemical Plants
Natural Gas Plants

Engineering & building production plants
Providing chemistry and energy-related solutions

1,000 process engineering patents and applications
4,000 completed plant projects worldwide

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Linde Engineering
Selected industrial biotechnology reference plants

1. Industrial biotech plant for international client

2. Pilot plant Center for chemical-biotechnological processing of renewable raw materials

3. Fermentation plant for the biotechnological production of C4 chemicals in Germany

4. Plant for production of green hydrogen from raw glycerine in Germany

5. Plant for the production of modified starch in Germany
Introducing a New Biomass Fractionation Process
Extending the pulp & paper industry's value chain

"Organosolv" Production Plant
280,000 tonnes wood(atro) per year
The New Organosolv Process
Extending the pulp & paper industry's value chain

- Declining pulp & paper demand
- Pressure to improve plant economics
- Need to extend existing value chains and/or find alternative use for by-products

Pulp & Paper Industry's Need to Act

Organosolv Process Biorefinery Concept

Wood → Pulp/Paper Mill → Organosolv Plant

- Paper
- Pulp
- Cellulose fibers
- C5 & C6 sugars
- Lignin

Revenue
The New Organosolv Process
Extending the pulp & paper industry's value chain

- Significantly better cost efficiency of wood conversion through high-yield processes
- Favorable process economics with products validated by industry partners
- Fits in with already existing wood logistics
- Flexible process configuration for wide product slate incl. lignin, C5/C6 sugars, cellulose
- Broad feedstock basis, including soft wood, hard wood and other biomass
- Environmentally friendly through recirculation of process media and energy optimization
# The New Organosolv Process
High quality primary products

## Organosolv primary product advantages

<table>
<thead>
<tr>
<th></th>
<th>Organosolv</th>
<th>Kraft</th>
<th>Steam explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin</td>
<td>High purity, low sulphate, low ash, suitable for chemical and other use</td>
<td>Medium purity, mainly for thermal treatment</td>
<td>Very low purity, only thermal treatment</td>
</tr>
<tr>
<td>C5 sugars</td>
<td>Additional product stream</td>
<td>Usually not separated</td>
<td>Mixed fraction</td>
</tr>
<tr>
<td>C6 sugars</td>
<td>Alternative to fiber</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Fiber</td>
<td>Dissolving pulp</td>
<td>High strength Kraft pulp</td>
<td>n.a.</td>
</tr>
</tbody>
</table>
The New Organosolv Process
Market opportunities for high-value Organosolv products

Lignin
- Fiberboard
- Wood composite
- PU foam
- PF resins
- Carbon fiber
- Bioplastics, co-polymer

Cellulose fiber
- Viscose, textile industry
- Cellulose ether & others

C5 Xylose
- Xylitol
- Furfural → Chemicals

C6 Glucose
- Fermentation industry
  - Biofuel
  - Chemicals
The New Organosolv Process  
Systematic process development and scale-up

<table>
<thead>
<tr>
<th>Stage</th>
<th>Activities</th>
<th>Probability of Success</th>
</tr>
</thead>
</table>
| Pre-feasibility | Check technical principles theoretically  
|              | Estimate market potential and competitive advantage of technology          | 20%                    |
| Feasibility  | Prove technical principles and define critical technical concepts  
|              | Establish IP protection and check for freedom to operate  
|              | Assess economic viability of product                                       | 40%                    |
| Development  | Define technical concepts in all relevant details  
|              | Confirm IP protection and freedom to operate  
|              | Confirm economic viability of product                                       | 60%                    |
| Piloting     | Qualify technology by verification and testing of prototype/pilot  
|              | Define product ready for launch                                            | 80%                    |
| Launch       | Prove commercial application and economic viability of product             | >90%                   |

approx. 5 years

Probability of success:
- Pre-feasibility: 20%
- Feasibility: 40%
- Development: 60%
- Piloting: 80%
- Launch: >90%

Launch:
- Feasibility: 20%
- Pre-feasibility: 40%
- Development: 60%
- Piloting: 80%
- Launch: >90%

Approximately 5 years

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The New Organosolv Process
Systematic technology development

Pilot plant engineered, constructed and commissioned by Linde Engineering. Successfully operated for 2 years.

Plant concept for demo and production scale completed by Linde Engineering.

Process economics evaluated w/positive results.

Technology ready for deployment on industrial demo-scale.
- Plant capacity: 315 kg dry wood per week

- Scale-up factor from lab to pilot: approx. 20

- Products: Glucose (approx. 122 kg)
  \[C_5\] Sugar (approx. 31 kg)
  Lignin (approx. 81 kg)

- Organosolv Process:
  - Wood pulping with ethanol and water
  - Disintegration, washing and dewatering of pulp
  - Precipitation, filtration, washing and drying of lignin
  - Enzymatic hydrolysis of cellulose and hemi-cellulose fraction (optional)
  - Concentration of glucose syrup
  - Solvent recovery
The New Organosolv Process
Pilot plant in operation
The New Organosolv Process
Scale-transfer proven from lab- to pilot scale

### Comparison of Molecular Weight Distribution of Lignin**

<table>
<thead>
<tr>
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<th>Pilot Plant</th>
<th>Laboratory</th>
</tr>
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<tbody>
<tr>
<td><strong>Mw (g/mol)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Laboratory</strong></td>
<td>87.8</td>
<td>83.4</td>
</tr>
<tr>
<td><strong>Pilot Plant</strong></td>
<td>83.4</td>
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<tr>
<th>Pulp composition</th>
<th>Lignin composition</th>
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<tr>
<td>Total carbohydrates [%]</td>
<td>Klasson Lignin [%]</td>
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* Actual values are higher due to Klasson test conditions
** GPC method
The New Organosolv Process
Systematic technology development

- Pilot plant engineered, constructed and commissioned by Linde Engineering. Successfully operated for 2 years.
- Plant concept for demo and production scale completed by Linde Engineering.
- Process economics evaluated with positive results.
- Technology ready for deployment on industrial demo-scale.
The New Organosolv Process
Scale-up from pilot plant to industrial scale

Pilot plant

• Processing 280,000 tonnes wood(atro) per year
• Products: Lignin (20%), Fiber (42%), C5 syrup (27%)
• Plot size appr. 50 to 60 acres

Industrial-scale greenfield plant
Pilot plant engineered, constructed and commissioned by Linde Engineering. Successfully operated for 2 years.

Plant concept for demo and production scale completed by Linde Engineering.

Process economics evaluated w/positive results.

Technology ready for deployment on industrial demo-scale.
The New Organosolv Process  
Project economics are attractive

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<th>Project IRR*</th>
<th>Worst</th>
<th>Expected</th>
<th>Best</th>
</tr>
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<tbody>
<tr>
<td>Greenfield plant for 280 kta dry wood</td>
<td>11.7 %</td>
<td>14.7 %</td>
<td>17.5 %</td>
</tr>
<tr>
<td>Core plant for 280 kta dry wood integrated in existing pulp/paper mill</td>
<td>29.4 %</td>
<td>34.7 %</td>
<td>39.7 %</td>
</tr>
</tbody>
</table>

| Biomass: | 50 $/t | Biomass: | 55 $/t | Biomass: | 60 $/t |
| Lignin:  | 630 $/t | Lignin:  | 700 $/t | Lignin:  | 770 $/t |
| Xylose:  | 450 $/t | Xylose:  | 500 $/t | Xylose:  | 550 $/t |
| Fiber:   | 630 $/t | Fiber:   | 700 $/t | Fiber:   | 770 $/t |

Assumptions:
* Pre-tax, pre-finance, discounted payback 10 years, plant lifecycle 15 years
** Feed/Product prices based on general market intelligence
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Systematic technology development

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Thank you for your attention.

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