Re-use of Residual Hemp Biomass from Textile Production

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**External Partner:** Mr. Martin Kloeti, Mr. Erich Chiavi

**Teaching Assistant:** Dr. Bhavish Pate
Introduction
Chemical composition of hemp straws

<table>
<thead>
<tr>
<th>Hemp Straw</th>
<th>Fiber part</th>
<th>Woody part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose (%)</td>
<td>73-77</td>
<td>48</td>
</tr>
<tr>
<td>Hemicellulose (%)</td>
<td>7-9</td>
<td>21-25</td>
</tr>
<tr>
<td>Lignin (%)</td>
<td>4-6</td>
<td>17-19</td>
</tr>
</tbody>
</table>
Applications

Hemp Straw

- long fibers
- quality papers
- technical fibre bundles
- textiles & tech-textiles
- composites, automotive
- construction materials
- paper
- animal bedding, absorbent, mulch
- energy
- biodiesel, biofuel
- environment

short fiber, wood
Potential Products
### Hemp Concrete

- Third class straw
  - 50% fiber
  - 50% wood
- Hemp straw
- Lime-based binder
  - 70% Ca(OH)_2
  - 15% pozzolanic
  - 15% hydraulic binder
- Mechanical treatment
- Hempcrete
  - setting and drying
  - carbonation

### Hemp Paper

- Hemp straw
- Mechanical pre-treatment
  - grounding
  - drying
- Pulping
  - soda pulping
  - Kraft pulping
  - water retting
- Paper
  - pulp with water
  - flattened
  - dried, and cut
New Product

➢ Hemp-based CNF

Hemp straw
- 50% fiber
- 50% wood

Mechanical pre-treatment
- grounding
- blending
- refining

Chemical treatment
- alkaline
- ozonation

Mechanical treatment
- bleaching
- agitation
- defibrillation

Cellulose nanofiber
- a promising material
- high value
- emerging applications

Third class straw
Hemp Concrete

Import

- lime-based binder
- Raw hemp (100% 8t/d)

Mixing

- Water

Projection

Setting and drying (carbonation)

Hempcrete 90%

Export

Diagram:
- Operator
- Substrate
- Lime + hemp
- Water
- Deposition concrete
- Projection distance
Hemp Paper

**Import**
Raw hemp
100% (8t/d)

**Process**
- **Ground into**
  - Rough powder
  - 98% moisture

- **Oven dried**
  - 60°C, until devoid of moisture

- **Soda pulping**
  - 90°C, 90min
  - 12% w/t NaOH
  - 10 times liquor
  - Dry powder
  - 80% moisture

- **Cooling Filtering Washing Drying**
  - Waste water

- **Flattening Drying Cutting**
  - 21% pulp
  - 20% water
  - Waste water

**Export**
Paper
Hemp-based CNF Design Project

**Process**

**Import**
- Raw hemp: 100% (8t/d)
- Ground into Rough powder: 98%
  - Hemicellulose, lignin, non-cellulosic substances

**Alkaline treatment**
- 80°C, 500rpm, 3h, 3 times
- 4% w/v NaOH solution
- Microfibrils: 70%
  - Waste water

**Sodium chlorite bleaching**
- 80°C, 500rpm, 4h, 3times
- NaOH, acetic acid, 0.6% w/v NaClO₂, distilled water
- Microfibrils: 60%
  - Residual lignin, phenolic compounds, by-products
  - Waste water

**High speed agitation**
- 38,000 rpm, 10min
- Microfibrils
- Distilled water: 60%
- Suspension of hemp fiber

**Defibrillation by microfluidizer**
- 20,000 psi, 25°C, 120min
- Distilled water: 60%
- Waste water

**Export**
- Cellulose nanofiber: 60%
## Calculation

### Hemp Concrete

<table>
<thead>
<tr>
<th>Item</th>
<th>Consumption (ton/ton hemp)</th>
<th>Unit price (CHF/ton)</th>
<th>Cost (CHF/ton hemp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pozzolanic</td>
<td>0.4</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>Hydraulic binder</td>
<td>0.4</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>Calcium hydroxide</td>
<td>1.5</td>
<td>55</td>
<td>82.5</td>
</tr>
<tr>
<td>Water</td>
<td>3.2</td>
<td>0.5</td>
<td>1.6</td>
</tr>
<tr>
<td>total</td>
<td>-</td>
<td>-</td>
<td>116.1</td>
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</tbody>
</table>

### Hemp Paper

<table>
<thead>
<tr>
<th>Item</th>
<th>Consumption (ton/ton hemp)</th>
<th>Unit price (CHF/ton)</th>
<th>Cost (CHF/ton hemp)</th>
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</thead>
<tbody>
<tr>
<td>NaOH</td>
<td>0.48</td>
<td>300</td>
<td>144</td>
</tr>
<tr>
<td>Na₂S</td>
<td>0.48</td>
<td>300</td>
<td>144</td>
</tr>
<tr>
<td>Water</td>
<td>10</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>total</td>
<td>-</td>
<td>-</td>
<td>293</td>
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</table>
## Calculation

### Hemp-based CNF

<table>
<thead>
<tr>
<th>Stage</th>
<th>Water (m$^3$)</th>
<th>NaOH (ton)</th>
<th>NaClO$_2$ (ton)</th>
<th>HAc (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretreatment</td>
<td>6</td>
<td>0.24</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bleaching</td>
<td>6</td>
<td>0.054</td>
<td>0.036</td>
<td>0.15</td>
</tr>
<tr>
<td>Agitation</td>
<td>85</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Defibrillation</td>
<td>85</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>182</strong></td>
<td><strong>0.294</strong></td>
<td><strong>0.036</strong></td>
<td><strong>0.15</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consumption (ton/ton hemp)</th>
<th>Unit price (CHF/ton)</th>
<th>Cost (CHF/ton hemp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>182</td>
<td>0.5</td>
</tr>
<tr>
<td>NaOH</td>
<td>0.294</td>
<td>300</td>
</tr>
<tr>
<td>NaClO$_2$</td>
<td>0.036</td>
<td>2000</td>
</tr>
<tr>
<td>HAc</td>
<td>0.015</td>
<td>500</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
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</tbody>
</table>
Multi-Criteria Analysis
Identify Criteria

Selection of the Best Pathway

Environment
- Energy Consumption
- CO₂ Emissions

Economic
- Operation Costs
- Value of Products
- Market Demand

Technology
- Risks
- Technology Maturity

Standardization Scale

<table>
<thead>
<tr>
<th>Extremely bad</th>
<th>Very bad</th>
<th>Bad</th>
<th>More or less bad</th>
<th>Moderate</th>
<th>More or less good</th>
<th>Good</th>
<th>Very good</th>
<th>Extremely good</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
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</tbody>
</table>
# Evaluation Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Goals</th>
<th>Units</th>
<th>Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CNF</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy consumption</td>
<td>↓</td>
<td>MJ/ton</td>
<td>87000</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>↓</td>
<td>kg CO₂ eq/ton</td>
<td>790</td>
</tr>
<tr>
<td>Operation costs</td>
<td>↓</td>
<td>CHF/ton</td>
<td>431.2</td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value of products</td>
<td>↑</td>
<td>CHF/ton</td>
<td>3000</td>
</tr>
<tr>
<td>Market demand</td>
<td>↑</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risks</td>
<td>↓</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Technology maturity</td>
<td>↑</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>

- **Environment**
  - LCA from literature
- **Economic**
  - Mass flow analysis
- **Qualitative criteria**
  - Standardized scale
Normalization Evaluation Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Goals</th>
<th>Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CNF</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>↓</td>
<td></td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Operation costs</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Value of products</td>
<td>↑</td>
<td></td>
</tr>
<tr>
<td>Market demand</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Technology</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Risks</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Technology maturity</td>
<td>↑</td>
<td></td>
</tr>
</tbody>
</table>

- standardization scale
- linear regression
## Weighted Matrix

<table>
<thead>
<tr>
<th>Domain</th>
<th>Weight&lt;sub&gt;1&lt;/sub&gt;</th>
<th>Criteria</th>
<th>Weight&lt;sub&gt;2&lt;/sub&gt;</th>
<th>CNF</th>
<th>Hemp concrete</th>
<th>Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>0.4</td>
<td>Energy consumption</td>
<td>0.5</td>
<td>0.2</td>
<td>1.8</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO&lt;sub&gt;2&lt;/sub&gt; emissions</td>
<td>0.5</td>
<td>0.2</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation costs</td>
<td>0.4</td>
<td>0.16</td>
<td>0.16</td>
<td>0.48</td>
</tr>
<tr>
<td>Economic</td>
<td>0.4</td>
<td>Value of products</td>
<td>0.4</td>
<td>1.44</td>
<td>1.44</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Market demand</td>
<td>0.2</td>
<td>0.32</td>
<td>0.32</td>
<td>0.2</td>
</tr>
<tr>
<td>Technology</td>
<td>0.2</td>
<td>Risks</td>
<td>0.6</td>
<td>0.96</td>
<td>0.96</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technology maturity</td>
<td>0.4</td>
<td>0.16</td>
<td>0.16</td>
<td>0.56</td>
</tr>
<tr>
<td>Total Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td>3.44</td>
<td>4.56</td>
<td>4.88</td>
<td></td>
</tr>
</tbody>
</table>

➢ Weighted score = Score of normalized table * Weight<sub>1</sub>* Weight<sub>2</sub>
➢ Production of CNF performs worst
   - high operation and energy cost
   - high value
   - emerging market, a promising pathway

➢ Producing concrete is simple and traditional
   - low cost and environment impact
   - little economic benefit

➢ Production of paper performs the best
   - the most suitable pathway nowadays
Thanks for your attention!

Q&A session