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Pretreatment for cellulosic ethanol production in the developing world

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Welcome

And a big thanks to:

• The funding body Danida – for funding the 2GBIONRG project (DFC journal no. 10-018RISØ) www.2gbionrg.dk

• Colleagues at the Technical University of Denmark, project partners, and especially my co-authors

• The audience – thank you all for coming
Introduction

• Ongoing project concerning production of residue-based biofuels in Ghana

• Several criterias shape the possible biofuels solutions
  – Infrastructure
  – Biomasses
  – Labor
  – Economics

• Screening of suitable pretreatment methods low-tech conditions on Ghanaian biomasses
Plantain

Cassava

Maize

Oil palm

Sugarcane

Yam

Plantain

Cassava

Source: Andreas Kamp
Cocoa
The Betarenewables full-scale plant in Crescentino, Italy Utilize more than 700 tons of biomass per day

Source: www.betarenewables.com
Therefore...

• Pretreatment for cellulosic ethanol should be optimized within the constraints of a significant smaller scale

• Methods that are more labor intensive than methods developed for the industrialized world

• We investigated three alternative pretreatment methods applicable for small-scale low-tech conditions
Pretreatment: Investigated methods

• Soaking in aqueous ammonia (SAA)

• Boiling pretreatment (BP)

• White rot fungi pretreatment (WRF)

Benchmarked against

• Hydrothermal treatment (HTT)
Soaking in aqueous ammonia (SAA)

- Can be done with long retention times and at ambient temperatures.
- Highly scalable thus suited for low-tech solution
- Swelling of cellulose and delignification
  - Cleavage of ether bonds in lignin
  - Cleavage ether and ester bonds coupling lignin to hemicellulose
- A recovery system for the ammonia is needed

SAA pretreated maize stalks solid to liquid loadings of 1:4 (w/w). After soaking for 10 days at 30°C
Boiling pretreatment (BP)

- Very simple method
- Solubilizes some non-structural components such as proteins, waxes, and inorganic compounds
- When BP has been applied as lignocellulose pretreatment method, it has been with a limited effect
- Starch fractions swell and become exposed for enzymatic breakdown
White rot fungi pretreatment (WRF)

- White rot fungi degrades lignin and carbohydrates through extracellular enzymes over an extended time
- Strain: *Ceriporiopsis subvermispora*
  - Degrades mainly lignin and metabolizes only a little C5 sugars and no C6
- Time consuming and labor intensive but scaleable and suitable for low-tech

Moist straw inoculated with *C. subvermispora*

- 25% initial TS (sterilised biomass)
- 30 days at 28° C, 90% relative humidity
Hydrothermal treatment (HTT)

- Autohydrolysis with water at 160-230°C
- High pressure
- High temperature
- High efficiency
- High costs

- Applied by e.g.
  - Inbicon
  - Betarenewables

MINI IBUS:
1 kg HTT facility at DTU
A downscaled version of the process at the Inbicon demonstration plant

190°C
10 minutes
Investigated agricultural residues from West Africa

- Cassava
- Plantain
- Maize
- Rice
- Oil palm
- Groundnut
- Cocoa

- Stalks
- Peelings
- Trunks
- Leaves
- Cobs
- Stalks
- Straw
- EFB
- Straw
- Pods
- Husks
### Chemical composition

<table>
<thead>
<tr>
<th></th>
<th>Starch</th>
<th>Cellulose</th>
<th>Xylan</th>
<th>Arabinan</th>
<th>Rhamnan</th>
<th>Galactan</th>
<th>Fructose</th>
<th>Lignin</th>
<th>Ash</th>
<th>Extractives</th>
<th>Protein</th>
<th>Residual</th>
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<td><strong>Yam peelings</strong></td>
<td>70.1</td>
<td>5.7</td>
<td>n.d.</td>
<td>0.6</td>
<td>n.d.</td>
<td>n.d.</td>
<td>4.7</td>
<td>4.1</td>
<td>5.1</td>
<td>5.3</td>
<td>3.2</td>
<td>1.2</td>
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<tr>
<td><strong>Cassava peelings</strong></td>
<td>53.1</td>
<td>12.7</td>
<td>n.d.</td>
<td>1.3</td>
<td>0.8</td>
<td>n.d.</td>
<td>3.4</td>
<td>8.2</td>
<td>4.8</td>
<td>7.2</td>
<td>3.0</td>
<td>5.6</td>
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<tr>
<td><strong>Cassava stalks</strong></td>
<td>1.1</td>
<td>33.1</td>
<td>13.7</td>
<td>0.5</td>
<td>n.d.</td>
<td>n.d.</td>
<td>2.8</td>
<td>28.3</td>
<td>4.1</td>
<td>8.9</td>
<td>2.7</td>
<td>4.8</td>
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<td><strong>Plantain peelings</strong></td>
<td>26.2</td>
<td>8.0</td>
<td>n.d.</td>
<td>2.6</td>
<td>n.d.</td>
<td>2.8</td>
<td>1.0</td>
<td>10.0</td>
<td>14.3</td>
<td>18.3</td>
<td>4.5</td>
<td>12.3</td>
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<tr>
<td><strong>Plantain trunks</strong></td>
<td>0.6</td>
<td>45.6</td>
<td>9.6</td>
<td>2.6</td>
<td>n.d.</td>
<td>1.6</td>
<td>n.d.</td>
<td>12.4</td>
<td>13.7</td>
<td>10.1</td>
<td>3.2</td>
<td>0.5</td>
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<td><strong>Plantain leaves</strong></td>
<td>0.6</td>
<td>21.9</td>
<td>9.0</td>
<td>5.6</td>
<td>1.6</td>
<td>4.1</td>
<td>n.d.</td>
<td>18.3</td>
<td>13.4</td>
<td>16.1</td>
<td>5.6</td>
<td>4.0</td>
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<td><strong>Cocoa husks</strong></td>
<td>3.2</td>
<td>12.9</td>
<td>n.d.</td>
<td>1.5</td>
<td>1.7</td>
<td>6.7</td>
<td>n.d.</td>
<td>24.3</td>
<td>11.6</td>
<td>17.5</td>
<td>12.6</td>
<td>8.0</td>
</tr>
<tr>
<td><strong>Cocoa pods</strong></td>
<td>0.6</td>
<td>19.1</td>
<td>8.7</td>
<td>1.8</td>
<td>1.7</td>
<td>6.5</td>
<td>n.d.</td>
<td>37.2</td>
<td>12.6</td>
<td>5.7</td>
<td>5.9</td>
<td>0.3</td>
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<tr>
<td><strong>Oil palm EFB</strong></td>
<td>0.5</td>
<td>33.0</td>
<td>22.1</td>
<td>0.6</td>
<td>n.d.</td>
<td>0.3</td>
<td>n.d.</td>
<td>23.8</td>
<td>4.8</td>
<td>6.2</td>
<td>2.9</td>
<td>5.8</td>
</tr>
<tr>
<td><strong>Maize cobs</strong></td>
<td>0.7</td>
<td>35.4</td>
<td>31.3</td>
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<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>18.0</td>
<td>1.6</td>
<td>1.7</td>
<td>1.3</td>
<td>6.4</td>
</tr>
<tr>
<td><strong>Maize stalks</strong></td>
<td>1.0</td>
<td>37.5</td>
<td>18.8</td>
<td>2.7</td>
<td>n.d.</td>
<td>0.5</td>
<td>n.d.</td>
<td>17.0</td>
<td>11.2</td>
<td>4.2</td>
<td>2.0</td>
<td>5.3</td>
</tr>
<tr>
<td><strong>Rice straw</strong></td>
<td>1.4</td>
<td>32.5</td>
<td>17.3</td>
<td>2.5</td>
<td>n.d.</td>
<td>0.6</td>
<td>n.d.</td>
<td>11.3</td>
<td>17.8</td>
<td>4.2</td>
<td>2.8</td>
<td>9.7</td>
</tr>
<tr>
<td><strong>Groundnut straw</strong></td>
<td>2.2</td>
<td>18.1</td>
<td>7.7</td>
<td>2.6</td>
<td>1.7</td>
<td>1.7</td>
<td>n.d.</td>
<td>15.4</td>
<td>10.9</td>
<td>10.9</td>
<td>9.4</td>
<td>19.3</td>
</tr>
</tbody>
</table>

All standard deviations were below 5%. Not detected = n.d.

Thomsen et al., Compositional analysis and theoretical biofuel potentials from various West African agricultural residues, *Biomass & Bioenergy* (2014)
Glucose yield after enzymatic conversion with cellulase of raw and pretreated agricultural residues

5 %TS, Cellic CTec 2® + HTec 2®, 72h
Threshold for glucose yield after enzymatic conversion

• Based on two criteria:
  – At least 4 w/w % ethanol after fermentation is needed in order to make cost-effective distillation
  – Maximum 25 % TS in prehydrolysis
• These factors can be calculated into a required conversion of glucan of at least 30 g per 100 g of TS
Glucose yield after enzymatic conversion with cellulase of raw and pretreated agricultural residues

5 %TS, Cellic CTec 2® + HTec 2®, 72h
Fermentation* of raw and pretreated residues

<table>
<thead>
<tr>
<th>Type</th>
<th>g ethanol (100 g TS)^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Plantain</td>
<td>11</td>
</tr>
<tr>
<td>BP Plantain</td>
<td>22</td>
</tr>
<tr>
<td>HTT Plantain</td>
<td>25</td>
</tr>
<tr>
<td>WRF Trunks</td>
<td>17</td>
</tr>
<tr>
<td>Raw Maize</td>
<td>5</td>
</tr>
<tr>
<td>HTT Maize</td>
<td>23</td>
</tr>
<tr>
<td>SAA Cobs</td>
<td>15</td>
</tr>
<tr>
<td>Raw Maize Stalks</td>
<td>13</td>
</tr>
</tbody>
</table>

*SSF, 6 days, 10 %TS, Cellic CTeC 2® + HTec 2®, Ethanol Red®
Glucan recovery, ethanol conversion efficiency and overall ethanol yield of raw and pretreated residues

<table>
<thead>
<tr>
<th></th>
<th>Glucan recovery</th>
<th>Ethanol conversion efficiency</th>
<th>Overall ethanol yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w/w %</td>
<td>g eth./100 g potential eth. from pretreated material</td>
<td>g eth./100 g TS raw material</td>
</tr>
<tr>
<td>Plantain peelings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw</td>
<td>100%</td>
<td>59.4</td>
<td>11.5</td>
</tr>
<tr>
<td>BP</td>
<td>81%</td>
<td>85.9</td>
<td>13.4</td>
</tr>
<tr>
<td>Plantain trunks</td>
<td>Raw 100%</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>HTT</td>
<td>77%</td>
<td>74.1</td>
<td>15.0</td>
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<tr>
<td>WRF</td>
<td>89%</td>
<td>63.7</td>
<td>14.8</td>
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<tr>
<td>Maize cobs</td>
<td>Raw 100%</td>
<td>17.3</td>
<td>3.6</td>
</tr>
<tr>
<td>HTT</td>
<td>81%</td>
<td>91.1</td>
<td>15.2</td>
</tr>
<tr>
<td>SAA</td>
<td>81%</td>
<td>92.7</td>
<td>15.2</td>
</tr>
<tr>
<td>Maize stalks</td>
<td>Raw 100%</td>
<td>25.0</td>
<td>5.4</td>
</tr>
<tr>
<td>SAA</td>
<td>90%</td>
<td>72.4</td>
<td>13.7</td>
</tr>
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</table>
Summary

• Pretreatment for cellulosic ethanol should be optimized for smaller scale for most developing world scenarios (exemplified by West African conditions)

• We find that the alternative methods are viable, especially when looking at the overall utilization of the biomasses

• Only less than half of the tested biomasses are suitable for cellulosic ethanol production with sufficiently high yields

• Outlook:
  – Low-tech small-scale distillation
  – Implementation studies on site

References:

• Kemausuor et al., Assessment of biomass residue availability and sustainable bioenergy yields in Ghana, Resources, Conservation and Recycling (2014)

• Thomsen et al., Compositional analysis and theoretical biofuel potentials from various West African agricultural residues, Biomass & Bioenergy (2014)

• Thomsen et al., Screening of pretreatments of common West African lignocellulosic biomass residues for ethanol production, submitted to Renewable Energy (2014)