Biofuel production technologies in young stands, forest infrastructure, from undergrowth trees and stumps
Results of Latvian case studies

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Andis Lazdiņš, Dagnija Lazdiņa
Latvian State Forestry Research Institute “Silava”
Forest biofuel potential in Latvia

- Theoretical yearly stock (*according to round-wood harvesting stock in in 2007*) – 4.1 milt.t\(_{\text{dry}}\).
- Available yearly stock (*excluding wet soils and poor forest types*) – 3.5 mill.t\(_{\text{dry}}\).
- Technically available stock (*excluding production losses*) – 2.6 milj.t\(_{\text{dry}}\);
  - 63 % of theoretical stock;
  - small trees & stumps – 1.09 mill.t\(_{\text{dry}}\).

<table>
<thead>
<tr>
<th>Type of resources</th>
<th>Firewood</th>
<th>Clear-cuts</th>
<th>Thinning</th>
<th>Forest infrastructure</th>
<th>Non-forest lands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>undergrowth</td>
<td>slash</td>
<td>small trees</td>
<td></td>
</tr>
<tr>
<td>Theoretical stock (t(_{\text{dry yearly}}))</td>
<td>550 537</td>
<td>81 467</td>
<td>969 652</td>
<td>1 349 572</td>
<td>229 985</td>
</tr>
<tr>
<td>Available stock (t(_{\text{dry yearly}}))</td>
<td>550 537</td>
<td>61 612</td>
<td>767 429</td>
<td>1 231 979</td>
<td>154 997</td>
</tr>
<tr>
<td>Technically available stock (t(_{\text{dry yearly}}))</td>
<td>545 031</td>
<td>43 128</td>
<td>537 201</td>
<td>739 187</td>
<td>108 498</td>
</tr>
<tr>
<td>Harvest-able area (ha yearly)</td>
<td>107 312</td>
<td>25 672</td>
<td>25 672</td>
<td>31 062</td>
<td>45 172</td>
</tr>
<tr>
<td>Stock (t(_{\text{dry ha}^{-1} \text{ yearly}}))</td>
<td>5</td>
<td>2</td>
<td>21</td>
<td>24</td>
<td>2</td>
</tr>
</tbody>
</table>
Studies on small trees

- Delayed pre-commercial thinning
- Removal of woody vegetation from forest infrastructure (drainage systems)
- Removal of undergrowth trees (before clear-cut)
Studied machine concepts and applications

<table>
<thead>
<tr>
<th>Machine concept</th>
<th>Application</th>
</tr>
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<tbody>
<tr>
<td>Ponsse EH25 guillotine head on a forwarder base</td>
<td>Pre-commercial thinning</td>
</tr>
<tr>
<td></td>
<td>Cleaning of forest infrastructure</td>
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<tr>
<td></td>
<td>Terrain transport in all studies</td>
</tr>
<tr>
<td>Bracke C16.a cutting head on a harvester base</td>
<td>Pre-commercial thinning</td>
</tr>
<tr>
<td></td>
<td>Cleaning of forest infrastructure</td>
</tr>
<tr>
<td></td>
<td>Cleaning of undergrowth</td>
</tr>
</tbody>
</table>
Characteristics of the pre-commercial thinning study

- **Pine stand:**
  - stand characteristics;
    - average H – 12 m,
    - average Ø – 13.5 cm,
    - basal area – 42 m$^2$ ha$^{-1}$
      $(4.8 \, \text{th. trees ha}^{-1})$,
    - basal area after thinning – 15 m$^2$ ha$^{-1}$,
    - growing stock – 103 t$_{\text{dry}}$ ha$^{-1}$,
  - results of experiment;
    - Ponsse EH25 – 53-118 trees per E$_0$h or 10.3 LVm$^3$ E$_{15}$h$^{-1}$,
    - Bracke C16.a – 120 trees per E$_0$h or 14.1 LVm$^3$ E$_{15}$h$^{-1}$.

- **Mixed spruce stand:**
  - stand characteristics;
    - average H – 10 m,
    - average Ø – 12 cm,
    - basal area – 25 m$^2$ ha$^{-1}$
      $(4.3 \, \text{th. trees ha}^{-1})$,
    - basal area after thinning – 15 m$^2$ ha$^{-1}$,
    - growing stock – 69 t$_{\text{dry}}$ ha$^{-1}$,
  - results of experiment;
    - Ponsse EH25 – 119 trees per E$_0$h or 6.7 LVm$^3$ E$_{15}$h$^{-1}$,
    - Bracke C16.a – 203 trees per E$_0$h or 12.1 LVm$^3$ E$_{15}$h$^{-1}$.
Characteristics of sample plots for forest infrastructure cleaning

- Plot No.1 – partially covered with vegetation:
  - average H – 7.9 m;
  - average Ø – 5.7 cm;
  - number of trees - 3 014 ha\(^{-1}\);
  - basal area - 12.9 m\(^2\) ha\(^{-1}\);
  - growing stock – 18.8 t\(_{\text{dry}}\) ha\(^{-1}\).

- Plot No.2 – complete coverage with vegetation:
  - average H – 8.5 m;
  - average Ø – 6.2 cm;
  - number of trees - 6 333 ha\(^{-1}\);
  - basal area - 29.2 m\(^2\) ha\(^{-1}\);
  - growing stock – 67.3 t\(_{\text{dry}}\) ha\(^{-1}\).
Productivity figures in forest infrastructure cleaning

- **Ponsse EH25** (*simultaneous harvesting and forwarding)*:
  - 8.2 LVm³ E₁₅ h⁻¹;
  - 118 trees and bushes E₀ h⁻¹;
  - 1.65 trees per crane cycle.

- **Bracke C16.a** (*only harvesting)*:
  - 13.91 LVm³ E₁₅ h⁻¹;
  - 335 trees and bushes E₀ h⁻¹;
  - system is better fitted to remove trees of smaller dimensions.
Productivity figures of the undergrowth trees removal

- **Stand characteristics:**
  - average $H$ – 5.4 m;
  - average $\varnothing$ – 2.6 cm;
  - basal area – 3.8 m$^2$ ha$^{-1}$;
  - number of stems – 5200 ha$^{-1}$;
  - growing stock – 7.7 t$_{\text{dry}}$ ha$^{-1}$.

- **Results of experiment:**
  - harvesting (*Bracke C16.a*);
    - 221 trees per $E_0$ h$^{-1}$;
    - 1.1 LVm$^3$ $E_{15}$ h$^{-1}$;

- **Some conclusions:**
  - trees are too small to work efficiently;
  - significant time consumption for bush cutting;
  - snaky strip-roads makes further forwarding complicated.
Results of forwarding studies

- Productivity in pre-commercial thinning:
  - pine stand – 12.7 LVm³ E₁₅h⁻¹;
  - mixed stand – 15.5 LVm³ E₁₅h⁻¹;
- Productivity in the forest infrastructure cleaning:
  - deciduous trees – 16.3 LVm³ E₁₅h⁻¹;
- Removal of undergrowth:
  - mixed stand – 2.4 LVm³ E₁₅h⁻¹;
- Significant variability between stands on operators:
  - due to a different experience of operators;
  - smaller and easier to manage trees in mixed stand.
Stump extraction study
Characteristics of forest stands and sample plots in the study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest site</td>
<td>Zemgale forestry, Garozas forest district, block No. 177, parcel No.1 (2.7 ha) and No.5 (1.4 ha)</td>
</tr>
</tbody>
</table>
| Tree species                                   | parcel No.5: 5S1P1B (82 years old) 3P (120 years old) + S (65 years old) in second floor  
|                                                | parcel No.1: 7S2P1B (102 years old) + A, O (102 years old) + S in second floor     |
| Harvested stock                                | parcel No.5 – 279 m³ ha⁻¹                                                        
|                                                | parcel No.1 – 348 m³ ha⁻¹                                                        |
| Average DBH¹ of trees at the breast height     | parcel No.5 – 28 cm                                                            |
|                                                | parcel No.1 – 35 cm                                                             |

¹ DBH – diameter at the breast height (1.3 m)

<table>
<thead>
<tr>
<th></th>
<th>Plot 1</th>
<th>Plot 2</th>
<th>Plot 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil type</td>
<td>Sand (ridge)</td>
<td>Sand (low land)</td>
<td>Peat (40 cm)</td>
</tr>
<tr>
<td>Plot area, m²</td>
<td>2000</td>
<td>1950</td>
<td>1250</td>
</tr>
<tr>
<td>Average DBH of stumps (cm)</td>
<td><strong>36</strong></td>
<td><strong>34</strong></td>
<td><strong>35</strong></td>
</tr>
<tr>
<td>Gross weight of stumps, t⁻¹</td>
<td>8.6</td>
<td>8.4</td>
<td>3.9</td>
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</tbody>
</table>
Field study results – productivity of harvesting

<table>
<thead>
<tr>
<th>Specie</th>
<th>Data</th>
<th>Plot No. 1</th>
<th>Plot No. 2</th>
<th>Plot No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous</td>
<td>Total observation time, cmin</td>
<td>3050</td>
<td>2957</td>
<td>1562</td>
</tr>
<tr>
<td></td>
<td>Stump and root biomass, $t_{\text{dry}}$</td>
<td>1.47</td>
<td>1.47</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Productivity, $t_{\text{dry}} E_0 h^{-1}$</td>
<td>2.9</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Spruce</td>
<td>Total observation time, cmin</td>
<td>3902</td>
<td>6001</td>
<td>2447</td>
</tr>
<tr>
<td></td>
<td>Stump and root biomass, $t_{\text{dry}}$</td>
<td>4.7</td>
<td>5.52</td>
<td>2.74</td>
</tr>
<tr>
<td></td>
<td>Productivity, $t_{\text{dry}} E_0 h^{-1}$</td>
<td>7.2</td>
<td>5.5</td>
<td>6.7</td>
</tr>
<tr>
<td>Pine</td>
<td>Total observation time, cmin</td>
<td>923</td>
<td>1992</td>
<td>972</td>
</tr>
<tr>
<td></td>
<td>Stump and root biomass, $t_{\text{dry}}$</td>
<td>0.79</td>
<td>0.72</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>Productivity, $t_{\text{dry}} E_0 h^{-1}$</td>
<td>5.1</td>
<td>2.2</td>
<td>3.5</td>
</tr>
<tr>
<td>All species</td>
<td>Total observation time, cmin</td>
<td>7875</td>
<td>10950</td>
<td>4981</td>
</tr>
<tr>
<td></td>
<td>Stump and root biomass, $t_{\text{dry}}$</td>
<td>6.96</td>
<td>7.72</td>
<td>3.84</td>
</tr>
<tr>
<td></td>
<td>Productivity, $t_{\text{dry}} E_0 h^{-1}$</td>
<td>5.3</td>
<td>4.2</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Correlation between stump mass and time consumption in extraction

Pine, all plots
\[ f(x) = 0.53x + 83.01 \quad R^2 = 0.03 \]

Spruce, all plots
\[ f(x) = -0.05x + 120.42 \quad R^2 = 0 \]

Deciduous, all plots
\[ f(x) = 0x + 43.47 \quad R^2 = 0 \]

Pine, dry sandy plot (ridge)
\[ f(x) = 0.74x + 30.9 \quad R^2 = 0.62 \]
Productivity of terrain and road transport and comminution

- **Forwarding of stumps** $6.3 \ t_{\text{dry}} \ E_0 \ h^{-1}$ (one way – 300 m):
  - loads are filled by 50 %, in case if 100 % of forwarder capacity is used, productivity would be at least $8.0 \ t_{\text{dry}} \ E_0 \ h^{-1}$

- **Road transport of stumps** $3.5 \ t_{\text{dry}} \ E_0 \ h^{-1}$ (one way 7 km):
  - very inefficient operation, road-side comminution should be introduced to avoid this step.

- **Comminution of stumps** $10 \ t_{\text{dry}} \ E_0 \ h^{-1}$:
  - 3...4 times less than actual capacity of the crusher, proper crushers for irregular biomass should be used instead.

- **Road transport of chips** was $4.2 \ t_{\text{dry}} \ E_0 \ h^{-1}$ (one way 50 km):
  - container systems should be used in case of long transport distance to increase efficiency of utilization of lorries.
Technological cycle of stump biofuel production

1. **Shunt lifting head**
2. **Excavation**
3. **Forwarding**
4. **Slashloader**
5. **Roadside storage (6-12 months)**
6. **Road transport**
7. **Field before and after extraction**
8. **Wood chips**
9. **Confinement**
Biofuel prime cost calculation

<table>
<thead>
<tr>
<th>Costs, EUR LVm$^3$</th>
<th>Harvesting</th>
<th>Forwarding</th>
<th>Stump transport</th>
<th>Crushing</th>
<th>Loading</th>
<th>Road transport</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stump extraction in clear-cuts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Komatsu 210LC-7 head</td>
<td>2.04</td>
<td>1.07</td>
<td>1.67</td>
<td>2.09</td>
<td>0.13</td>
<td>1.51</td>
<td><strong>8.51</strong></td>
</tr>
<tr>
<td><strong>Delayed pre-commercial thinning</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ponsse EH25</td>
<td>2.53</td>
<td>2.71</td>
<td></td>
<td>1.77</td>
<td></td>
<td>1.51</td>
<td><strong>8.53</strong></td>
</tr>
<tr>
<td>Bracke C16.a</td>
<td>2.36</td>
<td>2.71</td>
<td></td>
<td>1.77</td>
<td></td>
<td>1.51</td>
<td><strong>8.36</strong></td>
</tr>
<tr>
<td><strong>Removal of woody vegetation from forest infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ponsse EH25</td>
<td>7.1</td>
<td></td>
<td>1.77</td>
<td></td>
<td>1.51</td>
<td></td>
<td><strong>10.39</strong></td>
</tr>
<tr>
<td>Bracke C16.a</td>
<td>3.34</td>
<td>2.33</td>
<td></td>
<td>1.77</td>
<td></td>
<td>1.51</td>
<td><strong>8.96</strong></td>
</tr>
<tr>
<td><strong>Removal of undergrowth trees before clear-cut</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bracke C16.a</td>
<td>37.83</td>
<td>12.27</td>
<td></td>
<td>1.77</td>
<td></td>
<td>1.51</td>
<td><strong>53.39</strong></td>
</tr>
</tbody>
</table>
Prime costs of biofuel excluding silviculture costs
Environmental footprint of biofuel production

- Total carbon emissions per 1 LVm$^3$ (84-86 kg C):
  - early thinning;
    - Ponsse EH25 2.0 kg, Bracke C16.a 2.5 kg,
  - cleaning of forest infrastructure;
    - Ponsse EH25 2.8 kg, Bracke C16.a 2.7 kg,
  - undergrowth removal;
    - Bracke C16.a 12.5 kg,
  - stump extraction;
    - Komatsu 210LC-7 head 3.34 kg LVm$^{-3}$. 

C emissions during stump extraction

- Excavator 13%
- Forwarder 7%
- Stump truck 20%
- Chip truck 18%
- Loader 1%
- Chipper 40%
Thank you for attention!