Biomass logistics – supply chains for heat generation
Overview

- Solid biofuels
  - Feedstock
    - Wood
    - Agricultural residues
    - Energy crops
- Biomass Logistics and supply chains (harvesting, handling and storage)
  - Woody biomass
  - Agricultural biomass
  - Security of supply
  - Safety aspects
  - Quality control and standardization
- Modelling of biomass supply chains
- Best practice examples
Overview

- Solid biofuels
  - Feedstock
    - Wood
    - Agricultural residues
    - Energy crops
  - Biomass Logistics and supply chains (harvesting, handling and storage)
    - Woody biomass
    - Agricultural biomass
  - Security of supply
  - Safety aspects
  - Quality control and standardization
  - Modelling of biomass supply chains
- Best practice examples
Solid biofuels

- Different types of biomass
  - Wood based
  - Agricultural residues
  - Energy crops

- Different shapes
  - Pellets
  - Briquettes
  - Chips
  - Bales
  - Loose
  - Powdered
Wood based biofuels

- Woody biomass
  - Forest / plantation wood
    - Whole trees
    - Stemwood
    - Logging residues
    - Stumps / roots
    - Bark
  - By products from wood processing industry
    - Saw dust / shavings
    - Treated and untreated
- Used wood
  - Building / construction material / furniture etc...
Feedstock for wood based biofuels

Forest map of Europe
- Highest forest density in North-East
- But forest grow much slower in the North than in South of Europe
- Forest density is not the same as availability
- Many different applications for wood
  - Construction material
  - Furniture
  - Pulp & paper
  - Energy

Forest map of Europe - Source: European Forest Institute, 2011
Feedstock for wood based biofuels

Biggest potentials of available wood for energy production in:

- Germany
- France
- Finland
- Sweden
- Poland

Outside EU
- Russia
- Canada
- US

Wood potential in Europe

Technical wood potential in EU-27. Those marked by beige color are less than 20 PJ. (Source: VTT, Finland)
Feedstock for wood based biofuels

Total wood Potential is a sum of available:

- Stem wood
- Primary forest residues
- By products
- Used wood

<table>
<thead>
<tr>
<th>Country</th>
<th>Stem wood</th>
<th>Primary forest residues</th>
<th>By-products from forest industries</th>
<th>Used wood</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>8 104</td>
<td>5 735</td>
<td>5 525</td>
<td>1 100</td>
<td>20 464</td>
</tr>
<tr>
<td>Belgium</td>
<td>6 688</td>
<td>1 012</td>
<td>1 638</td>
<td>2 100</td>
<td>5 418</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>4 262</td>
<td>4 072</td>
<td>785</td>
<td>100</td>
<td>9 219</td>
</tr>
<tr>
<td>Cyprus</td>
<td>19</td>
<td>9</td>
<td>2</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>1 272</td>
<td>4 351</td>
<td>3 445</td>
<td>700</td>
<td>9 768</td>
</tr>
<tr>
<td>Denmark</td>
<td>2 407</td>
<td>1 038</td>
<td>295</td>
<td>1 300</td>
<td>5 040</td>
</tr>
<tr>
<td>Estonia</td>
<td>3 538</td>
<td>2 140</td>
<td>908</td>
<td>200</td>
<td>6 786</td>
</tr>
<tr>
<td>Finland</td>
<td>19 320</td>
<td>23 434</td>
<td>14 207</td>
<td>1 200</td>
<td>58 161</td>
</tr>
<tr>
<td>France</td>
<td>40 311</td>
<td>21 050</td>
<td>6 725</td>
<td>6 300</td>
<td>74 386</td>
</tr>
<tr>
<td>Germany</td>
<td>27 749</td>
<td>25 903</td>
<td>12 942</td>
<td>8 700</td>
<td>75 294</td>
</tr>
<tr>
<td>Greece</td>
<td>2 012</td>
<td>1 076</td>
<td>280</td>
<td>900</td>
<td>4 268</td>
</tr>
<tr>
<td>Hungary</td>
<td>5 908</td>
<td>2 407</td>
<td>505</td>
<td>500</td>
<td>9 320</td>
</tr>
<tr>
<td>Ireland</td>
<td>34</td>
<td>883</td>
<td>607</td>
<td>600</td>
<td>2 124</td>
</tr>
<tr>
<td>Italy</td>
<td>23 833</td>
<td>5 982</td>
<td>1 712</td>
<td>6 200</td>
<td>37 727</td>
</tr>
<tr>
<td>Latvia</td>
<td>2 106</td>
<td>3 409</td>
<td>1 987</td>
<td>300</td>
<td>7 802</td>
</tr>
<tr>
<td>Lithuania</td>
<td>2 117</td>
<td>1 971</td>
<td>886</td>
<td>300</td>
<td>5 274</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>213</td>
<td>124</td>
<td>121</td>
<td>0</td>
<td>458</td>
</tr>
<tr>
<td>Malta</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Netherlands</td>
<td>704</td>
<td>419</td>
<td>156</td>
<td>2 500</td>
<td>3 779</td>
</tr>
<tr>
<td>Poland</td>
<td>13 394</td>
<td>14 477</td>
<td>7 912</td>
<td>3 500</td>
<td>39 283</td>
</tr>
<tr>
<td>Portugal</td>
<td>577</td>
<td>2 810</td>
<td>2 334</td>
<td>700</td>
<td>6 421</td>
</tr>
<tr>
<td>Romania</td>
<td>11 683</td>
<td>6 658</td>
<td>2 650</td>
<td>1 700</td>
<td>22 691</td>
</tr>
<tr>
<td>Slovakia</td>
<td>6 086</td>
<td>2 850</td>
<td>1 728</td>
<td>200</td>
<td>5 386</td>
</tr>
<tr>
<td>Slovenia</td>
<td>2 699</td>
<td>1 370</td>
<td>459</td>
<td>100</td>
<td>4 628</td>
</tr>
<tr>
<td>Spain</td>
<td>6 763</td>
<td>7 222</td>
<td>3 995</td>
<td>4 200</td>
<td>22 180</td>
</tr>
<tr>
<td>Sweden</td>
<td>10 089</td>
<td>21 506</td>
<td>18 382</td>
<td>1 000</td>
<td>50 977</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>5 264</td>
<td>4 528</td>
<td>1 984</td>
<td>7 500</td>
<td>19 276</td>
</tr>
<tr>
<td><strong>EU-27</strong></td>
<td><strong>195 656</strong></td>
<td><strong>166 438</strong></td>
<td><strong>92 164</strong></td>
<td><strong>52 000</strong></td>
<td><strong>506 258</strong></td>
</tr>
</tbody>
</table>

Wood potential in Europe. Technical potential in 1000m$^3$. Source: VTT, Finland

$m^3$ is solid cubic meter.
## Feedstock for wood based biofuels

### Most common feedstock for heating applications:

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Average Water content</th>
<th>Origin</th>
<th>Used for:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saw mill residues</td>
<td>15 – 50%</td>
<td>Regional saw mills</td>
<td>Premium wood chip production, pellets</td>
</tr>
<tr>
<td>Round wood</td>
<td>20 – 50%</td>
<td>Forest, regional saw mills</td>
<td>Premium wood chip production</td>
</tr>
<tr>
<td>Forest residues</td>
<td>45 – 55%</td>
<td>Private and municipal and federal forests</td>
<td>Industrial wood chips, and maybe premium wood chips</td>
</tr>
<tr>
<td>Landscaping material</td>
<td>45 – 60%</td>
<td>Private and municipal landscaping companies</td>
<td>Industrial wood chips</td>
</tr>
<tr>
<td>Short rotation coppices</td>
<td>45 – 55%</td>
<td>Short rotation coppices</td>
<td>Industrial wood chips, and premium wood chips</td>
</tr>
<tr>
<td>Stalk material</td>
<td>15 – 20%</td>
<td>Agricultural byproducts</td>
<td>Straw fired plant</td>
</tr>
</tbody>
</table>

Source: B4B project 2nd brochure
Biofuels based on agricultural residues

- Agricultural residues
  - Cereal crops and grasses
    - Whole plant
    - Straw part
  - Seeds
  - Shells
  - Stones / kernels
- For heat and power production straw is the most important agricultural feedstock
Straw as a bioenergy feedstock

Available straw potential in Europe in 1,000 tons. Monforti et al. (2013)

Technical potential of straw residues in Europe (Böttcher et al. 2010)

<table>
<thead>
<tr>
<th>Country</th>
<th>Available potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>6.4PJ/a</td>
</tr>
<tr>
<td>Belgium</td>
<td>5.2PJ/a</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>12.1PJ/a</td>
</tr>
<tr>
<td>Cyprus</td>
<td>0PJ/a</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>15.8PJ/a</td>
</tr>
<tr>
<td>Denmark</td>
<td>19.3PJ/a</td>
</tr>
<tr>
<td>Estonia</td>
<td>1.8PJ/a</td>
</tr>
<tr>
<td>Finland</td>
<td>8.9PJ/a</td>
</tr>
<tr>
<td>France</td>
<td>111.5PJ/a</td>
</tr>
<tr>
<td>Germany</td>
<td>92.9PJ/a</td>
</tr>
<tr>
<td>Greece</td>
<td>8.7PJ/a</td>
</tr>
<tr>
<td>Hungary</td>
<td>15.7PJ/a</td>
</tr>
<tr>
<td>Ireland</td>
<td>5.1PJ/a</td>
</tr>
<tr>
<td>Italy</td>
<td>40.3PJ/a</td>
</tr>
<tr>
<td>Latvia</td>
<td>3.5PJ/a</td>
</tr>
<tr>
<td>Lithuania</td>
<td>6.6PJ/a</td>
</tr>
<tr>
<td>Luxemburg</td>
<td>0.4PJ/a</td>
</tr>
<tr>
<td>Malta</td>
<td>0PJ/a</td>
</tr>
<tr>
<td>Netherlands</td>
<td>3.6PJ/a</td>
</tr>
<tr>
<td>Poland</td>
<td>39PJ/a</td>
</tr>
<tr>
<td>Portugal</td>
<td>1.5PJ/a</td>
</tr>
<tr>
<td>Romania</td>
<td>18.7PJ/a</td>
</tr>
<tr>
<td>Slovakia</td>
<td>6PJ/a</td>
</tr>
<tr>
<td>Slovenia</td>
<td>0.5PJ/a</td>
</tr>
<tr>
<td>Spain</td>
<td>74.4PJ/a</td>
</tr>
<tr>
<td>Sweden</td>
<td>10.5PJ/a</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>52PJ/a</td>
</tr>
</tbody>
</table>
| EU-27 TOTAL      | 560.4PJ/a
Energy crops as a feedstock

- Plants grown for energy production
  - Reed canary grass
  - Miscanthus
  - Woody energy crops
    - Poplar
    - Short rotation coppice
Solid biofuels

- Biomass is often converted into an energy carrier of defined size and shape to ease trade and handling of biofuels
  - Pellet
  - Briquettes
  - Chips
  - Logs
  - Bales
Pelletization of biomass

- Conversion of a low density bulk material into pellets
  - Increase of density (straw: 40 kg/m$^3$ → 750 kg/m$^3$)
  - Decrease of transportation, storage, handling costs
  - Standardized size → International standards
  - more homogeneous material → process automatization

Danish Technological Institute
Briquetting of biomass

- Alternative process to compact biomass into a solid energy carrier
- Robust and easy to implement process
- Increase the density / lower the volume of the biomass for cheaper transportation and storage of biomass
- Used for all types of biomass: wood, straw, husks, peels
Overview

- Solid biofuels
  - Feedstock
    - Wood
    - Agricultural residues
    - Energy crops
  - Biomass Logistics and supply chains (harvesting, handling and storage)
    - Woody biomass
    - Agricultural biomass
  - Security of supply
  - Safety aspects
  - Quality control and standardization
  - Modelling of biomass supply chains
- Best practice examples
Biomass logistics and supply chains

- Biomass logistics and biomass supply chains are important for
  - Stable supply of biomass fuels around the year
  - Predictable price
  - Stable quality
  - Trade and contracting
  - Planning and maintenance of the heating system
## Biomass demand of bioenergy systems

### Typical scale of operation for various sizes and types of bioenergy plants

<table>
<thead>
<tr>
<th>Type of plant</th>
<th>Heat capacity ranges, and annual hours of operation.</th>
<th>Biomass fuel required (oven dry tonnes/year)</th>
<th>Vehicle movements for biomass delivery to the plant</th>
<th>Land area required to produce the biomass (% of total within a given radius)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small heat</td>
<td>100 - 250 kW\textsubscript{th} 2 000 hr</td>
<td>40 - 60</td>
<td>3 - 5 / yr</td>
<td>1 - 3% within 1 km radius</td>
</tr>
<tr>
<td>Large heat</td>
<td>250 kW\textsubscript{th} - 1 MW\textsubscript{th} 3 000 hr</td>
<td>100 - 1200</td>
<td>10 - 140 / yr</td>
<td>5 - 10% within 2 km radius</td>
</tr>
<tr>
<td>Small CHP</td>
<td>500 kW\textsubscript{e} - 2 MW\textsubscript{e} 4 000 hr</td>
<td>1 000 - 5 000</td>
<td>150 - 500 / yr</td>
<td>1 - 3% within 5 km radius</td>
</tr>
<tr>
<td>Medium CHP</td>
<td>5 - 10 MW\textsubscript{e} 5 000 hr</td>
<td>30 000 - 60 000</td>
<td>5 - 10 / day</td>
<td>5 - 10% within 10 km radius</td>
</tr>
<tr>
<td>Large power plant</td>
<td>20 - 30 MW\textsubscript{e} 7 000 hr</td>
<td>90 000 - 150 000</td>
<td>25 - 50 / day and night</td>
<td>2 - 5% within 50 km radius</td>
</tr>
</tbody>
</table>

## Solid biomass fuels supply chain options according to end-user sector

<table>
<thead>
<tr>
<th>End-user and average annual fuel consumption</th>
<th>Biomass fuel</th>
<th>Quality requirements</th>
<th>Technology for energy conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Households (&lt;50 kWh)</strong></td>
<td>Wood pellets</td>
<td>Good mechanical durability</td>
<td>Pellet boilers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low ash content</td>
<td>Pellet stoves</td>
</tr>
<tr>
<td><strong>Annual fuel consumption &lt;30 MWh</strong></td>
<td>Wood briquettes</td>
<td>Low ash content, packaged</td>
<td>Stoves and fireplaces</td>
</tr>
<tr>
<td></td>
<td>Wood chips</td>
<td>Low moisture content, &lt; 35w-%</td>
<td>Stoker boiler</td>
</tr>
<tr>
<td></td>
<td>Log wood</td>
<td>Low moisture content, 15-20 w-%</td>
<td>Stoves and fireplaces, boilers</td>
</tr>
<tr>
<td><strong>Farms, large buildings (&lt;1 MWh)</strong></td>
<td>Wood chips from whole trees or delimbed trees</td>
<td>Low moisture content, less than 35 w-%</td>
<td>Stoker burners, Grate firing</td>
</tr>
<tr>
<td><strong>Annual fuel consumption &lt; 3 GWh</strong></td>
<td>Straw bales</td>
<td>High quality bales, low moisture content (&lt; 18 w-%)</td>
<td>Grate combustion, also whole bales</td>
</tr>
<tr>
<td></td>
<td>Wood pellets</td>
<td>Good mechanical durability</td>
<td>Pellet boilers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low ash content</td>
<td>Stoker boilers</td>
</tr>
<tr>
<td><strong>District heating plants (&lt;5 MW&lt;sub&gt;H&lt;/sub&gt; or power plants (&lt;5 MW&lt;sub&gt;e&lt;/sub&gt;)</strong></td>
<td>Wood chips from forest residues or whole trees</td>
<td>Moisture content usually less than 40 w-%</td>
<td>Grate combustion, Fluidised bed combustion, Gasification</td>
</tr>
<tr>
<td><strong>Annual fuel consumption &lt;35 GWh (DH, CHP) or 85 GWh (power only)</strong></td>
<td>Straw or energy grass bales</td>
<td>Moisture content, less 20 w-%</td>
<td>Cigar combustion, Grate combustion, also whole bales</td>
</tr>
<tr>
<td><strong>CHP and power plants (&gt;5 MW&lt;sub&gt;e&lt;/sub&gt;)</strong></td>
<td>Wood fuels from forest residues, stumps</td>
<td>Boiler and handling equipment based requirements</td>
<td>Usually cofiring with coal or peat, Fluidised bed combustion, Gasification</td>
</tr>
<tr>
<td><strong>Annual fuel consumption from 85 GWh to several TWh</strong></td>
<td>Wood or straw pellets</td>
<td>Boiler and handling equipment based requirements</td>
<td>Cofiring with coal, Pulverised combustion</td>
</tr>
<tr>
<td></td>
<td>Herbaceous biomass (straw or energy grasses, like miscanthus and reed canary grass)</td>
<td>Big bales, moisture content less than 20 w-%</td>
<td>Cigar combustion, Grate combustion, Fluidised bed combustion, Cofiring with coal</td>
</tr>
<tr>
<td></td>
<td>Olive residues</td>
<td>Boiler and handling equipment based requirements</td>
<td>Grate firing, Cofiring with coal in fluidised bed boiler</td>
</tr>
</tbody>
</table>

Source: E. Alakangas, VTT, Finland - EUBIONET II project
Biomass supply chains

- Biomass supply chains
  - Cultivation
  - Harvesting
  - Drying
  - Pre-treatment
  - Loading and un-loading operations
  - Transport
    - Short distance
    - Long distance
  - Storage
    - Intermediate
    - Longterm
Biomass supply chains

Typical steps in a biomass supply chain

Rotter and Rohrhofer (2013)
Biomass supply chains

Logistic chains can look very different, and vary greatly in their costs

# Cost factors of biomass supply chains by country

<table>
<thead>
<tr>
<th>Country Code</th>
<th>Country</th>
<th>Index for</th>
<th>Labor costs</th>
<th>Fuel costs</th>
<th>Vehicle investment costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE</td>
<td>Belgium</td>
<td>39.3</td>
<td>47%</td>
<td>57.8</td>
<td>1.44</td>
</tr>
<tr>
<td>SE</td>
<td>Sweden</td>
<td>39.1</td>
<td>52%</td>
<td>59.4</td>
<td>1.49</td>
</tr>
<tr>
<td>DK</td>
<td>Denmark</td>
<td>38.9</td>
<td>15%</td>
<td>44.7</td>
<td>1.12</td>
</tr>
<tr>
<td>FR</td>
<td>France</td>
<td>34.2</td>
<td>50%</td>
<td>51.3</td>
<td>1.28</td>
</tr>
<tr>
<td>LU</td>
<td>Luxembourg</td>
<td>33.7</td>
<td>15%</td>
<td>38.8</td>
<td>0.97</td>
</tr>
<tr>
<td>NL</td>
<td>Netherlands</td>
<td>31.1</td>
<td>30%</td>
<td>40.4</td>
<td>1.01</td>
</tr>
<tr>
<td>DE</td>
<td>Germany</td>
<td>30.1</td>
<td>28%</td>
<td>38.5</td>
<td>0.96</td>
</tr>
<tr>
<td>FI</td>
<td>Finland</td>
<td>29.7</td>
<td>28%</td>
<td>38.0</td>
<td>0.95</td>
</tr>
<tr>
<td>AT</td>
<td>Austria</td>
<td>29.2</td>
<td>37%</td>
<td>40.0</td>
<td>1.00</td>
</tr>
<tr>
<td>IE</td>
<td>Ireland</td>
<td>27.4</td>
<td>18%</td>
<td>32.3</td>
<td>0.81</td>
</tr>
<tr>
<td>IT</td>
<td>Italy</td>
<td>26.7</td>
<td>41%</td>
<td>37.6</td>
<td>0.94</td>
</tr>
<tr>
<td>ES</td>
<td>Spain</td>
<td>20.6</td>
<td>37%</td>
<td>28.2</td>
<td>0.71</td>
</tr>
<tr>
<td>UK</td>
<td>Great Britain</td>
<td>20.1</td>
<td>16%</td>
<td>23.3</td>
<td>0.58</td>
</tr>
<tr>
<td>CY</td>
<td>Cyprus</td>
<td>16.5</td>
<td>21%</td>
<td>20.0</td>
<td>0.50</td>
</tr>
<tr>
<td>GR</td>
<td>Greece</td>
<td>16.4</td>
<td>29%</td>
<td>21.2</td>
<td>0.53</td>
</tr>
<tr>
<td>SI</td>
<td>Slovenia</td>
<td>14.4</td>
<td>17%</td>
<td>16.8</td>
<td>0.42</td>
</tr>
<tr>
<td>PT</td>
<td>Portugal</td>
<td>12.1</td>
<td>26%</td>
<td>15.2</td>
<td>0.38</td>
</tr>
<tr>
<td>MT</td>
<td>Malta</td>
<td>11.9</td>
<td>10%</td>
<td>13.1</td>
<td>0.33</td>
</tr>
<tr>
<td>CZ</td>
<td>Czech Rep.</td>
<td>10.5</td>
<td>37%</td>
<td>14.4</td>
<td>0.36</td>
</tr>
<tr>
<td>SK</td>
<td>Slovakia</td>
<td>8.4</td>
<td>36%</td>
<td>11.4</td>
<td>0.29</td>
</tr>
<tr>
<td>EE</td>
<td>Estonia</td>
<td>8.1</td>
<td>37%</td>
<td>11.1</td>
<td>0.28</td>
</tr>
<tr>
<td>HU</td>
<td>Hungary</td>
<td>7.6</td>
<td>34%</td>
<td>10.2</td>
<td>0.25</td>
</tr>
<tr>
<td>PL</td>
<td>Poland</td>
<td>7.1</td>
<td>20%</td>
<td>8.5</td>
<td>0.21</td>
</tr>
<tr>
<td>LV</td>
<td>Latvia</td>
<td>5.9</td>
<td>27%</td>
<td>7.5</td>
<td>0.19</td>
</tr>
<tr>
<td>LT</td>
<td>Lithuania</td>
<td>5.5</td>
<td>40%</td>
<td>7.7</td>
<td>0.19</td>
</tr>
<tr>
<td>RO</td>
<td>Romania</td>
<td>4.5</td>
<td>31%</td>
<td>5.9</td>
<td>0.15</td>
</tr>
<tr>
<td>BG</td>
<td>Bulgaria</td>
<td>3.5</td>
<td>19%</td>
<td>4.2</td>
<td>0.10</td>
</tr>
<tr>
<td>CH</td>
<td>Switzerland</td>
<td>41.9</td>
<td>20%</td>
<td>50.3</td>
<td>1.26</td>
</tr>
</tbody>
</table>

Rotter and Rohrhofer (2013)
Wood fuel supply chain

[Diagram showing the supply chain for firewood.]

Supply chain for firewood. Source: VTT
Wood fuel supply chain

Example: thinning in coniferous stand:

- Felling
- Full tree skidding
- Mechanized processing at the landing site
- Loading logs on truck and trailer
- Transporting logs to biomass trade center (90 km)
- Unloading logs from truck and trailer
- Natural seasoning
- Chipping logs
- Delivery of chips (90 km one way)
Wood fuel supply chain

<table>
<thead>
<tr>
<th>Working phase</th>
<th>Equipment</th>
<th>Productivity (bulk m³/h)</th>
<th>Cost (€/bulk m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felling</td>
<td>2 chainsaws</td>
<td>35</td>
<td>0.5</td>
</tr>
<tr>
<td>Full tree skidding</td>
<td>2 tractors and winch</td>
<td>17</td>
<td>5.9</td>
</tr>
<tr>
<td>Mechanized processing at the landing site</td>
<td>processor on tractor</td>
<td>24.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Loading logs on the truck and trailer</td>
<td>truck and trailer</td>
<td>121.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Transporting logs to the biomass trade centre (back&amp;forth 90 km)</td>
<td>truck and trailer</td>
<td>36.5</td>
<td>2</td>
</tr>
<tr>
<td>Unloading logs from the truck and trailer</td>
<td>truck and trailer</td>
<td>145.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Natural seasoning</td>
<td>—</td>
<td>—</td>
<td>0.3</td>
</tr>
<tr>
<td>Chipping logs</td>
<td>high power chipper</td>
<td>100</td>
<td>1.4</td>
</tr>
<tr>
<td>Delivery of chips (back&amp;forth 90 km)</td>
<td>truck and trailer</td>
<td>24.4**</td>
<td>2.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>14.6</td>
</tr>
</tbody>
</table>

Aebiom, 2009
Wood fuel supply chain – Equipment and Machinery

Chainsaw
purchase cost: 500-900 €
productivity in high forest:
1-1.2 solid m³/h (thinning)
2-2.5 solid m³/h (main felling)
productivity in coppice:
0.4-0.7 stacked m³/h (average cond.)
0.8-1.8 stacked m³/h (good cond.)
fuel consumption per hour:
0.6-1 l (petrol and oil mixture)
hourly cost: ≈ 18-20 €

Tractor and winch
tractor purchase cost: 45,000-60,000 €
winch purchase cost: 3000-4200 €
productivity in high forest: 2.5-6 solid m³/h
productivity in coppice: 3-7 stacked m³/h
fuel consumption per hour: 4-9 l
hourly cost: ≈ 45-50 € (2 operators)

Tractor and trailer
tractor purchase cost: 45,000-60,000 €
trailer purchase cost: 8,000-25,000 €
loading capacity: 5-15 t
productivity: 5-12 solid m³/h
(depending on hauling distance)
fuel consumption per hour: 5-10 l
hourly cost: ≈ 40-50 €
Wood fuel supply chain – Equipment and Machinery

Cable crane with mobile tower yarder
light
purchase cost: 40000-120,000 €
max traction power: 2,000 daN
productivity: 3-6 solid m³/h
fuel hourly consumption: 5-6 l
hourly cost: ≈ 25-40 €

medium
purchase cost: 100,000-220,000 €
max traction power: 5000 daN
productivity: 3-12 solid m³/h
fuel consumption per hour: 6-10 l
hourly cost: ≈ 40-80 €

Harvester
purchase cost: 300,000-370,000 €
max cutting diameter: 65-70 cm
max deliming diameter: 45-60 cm
max negotiable slope: 35% (wheels)
60% (tracks)
(with optimal soil bearing capacity)
productivity in high forest: 8-20 solid m³/h
fuel consumption per hour: 11-16 l
hourly cost: ≈ 90-120 €

Forwarder
purchase cost: 180,000 – 270,000 €
loading capacity: 10 - 14 t
max negotiable slope: 30 - 35%
logs length: up to 6 m
productivity: 12-20 solid m³/h
(depending on hauling distance)
fuel consumption per hour: 7-11 l
hourly cost: ≈ 65 - 80 €

Woodfuels Handbook, Aebiom, 2009
Wood fuel supply chain – Equipment and Machinery

**Hybrid harvester**
purchase cost: 240,000 €
max cutting diameter: 55 cm
max delimbing diameter: 50 cm
max negotiable slope: 45-50%
productivity: 10-15 solid m³/h
fuel consumption per hour: 10-12 l
hourly cost: ≈ 80 €

**Skidder**
purchase cost: 120,000 – 150,000 €
skidding capacity: up to 3 t
max negotiable slope: 20%
productivity: 8 - 12 solid m³/h
(depending on hauling distance)
fuel consumption per hour: 6-10 l
hourly cost: ≈ 55 - 65 €

**Tractor-mounted processor**
tractor purchase cost: 30,000 €
processor purchase cost: 45,000 €
max cutting diameter: 48 cm
max delimbing diameter: 40 cm
productivity: 10-15 solid m³/h
fuel consumption per hour: 4-5 l
hourly cost: ≈ 35 €

Wood fuel supply chain – Equipment and Machinery

Excavator-based processor
excavator purchase cost: 170,000 €
processor purchase cost: 60,000 €
max cutting diameter: 65 cm
max deliming diameter: 60 cm
productivity: 15-40 solid m³/h
fuel consumption per hour: 15 - 17 l
hourly cost: ≈ 85 €

Chipper
small power
purchase cost: 3,500-35,000 €
working diameter: max 20 cm
productivity: 2-3 t/h
fuel consumption per hour: 5-8 l
medium power
purchase cost: 15,000-75,000 €
working diameter: max 30 cm
productivity: 4-7 t/h
fuel consumption per hour: 10-14 l
high power
purchase cost: 31,000-250,000 €
working diameter: > 30 cm
productivity: 13-20 t/h
fuel consumption per hour: 34-38 l
hourly cost: ≈ 150-190 €
Wood fuel supply chain – Equipment and Machinery

**Saw wood**
*purchase cost: 600-2,000 €*
*working diameter: 14-25 cm*

**Split wood**
*purchase cost: 1,500-14,000 €*
*working log length: 0.3-4 m*

**Combined (saw-split wood)**
*purchase cost: 7,000-70,000 €*
*working diameter: 25-60 cm*
*working log length: 2-6 m*
*hourly cost: \( \approx 70-150 \) €

**Truck and trailer (log transport)**
*truck purchase cost: 110,000-150,000 €*
*trailer purchase cost: 20,000-30,000 €*
*loading capacity: 18-20 t*
*fuel consumption: 2.5-3.5 km/l*
*hourly cost: \( \approx 60-75 \) €

**Truck and trailer (wood chips transport)**
*truck purchase cost: 100,000-115,000 €*
*trailer purchase cost: 45,000 €*
*loading capacity: 20-22 t (85-90 bulk m³)*
*fuel consumption: 2.5-3.5 km/l*
*hourly cost: \( \approx 65-70 \) €*
*with clamshell bucket loader*
*purchase cost: 205,000 €*
*loading capacity: 81 bulk m³*
*hourly cost: \( \approx 70-75 \) €

Woodfuels Handbook, Aebiom, 2009
Straw supply chain
Straw fuel supply chain

Example: cereal straw for biomass boiler
- Harvesting of cereal straw
- Drying / turning of swaths
- Baling
- Loading on field
- Transport to field storage / farm storage
- Unloading at storage
- Stacking
- Loading of truck
- Transport to end user
- Storage at end user
- Internal conveying and combustion
Straw fuel supply chain

- Harvesting with a combined harvester chaff cutter
- Drying, raking and turning of swaths
- Tracktor propelled bale press
Straw fuel supply chain

Loading and unloading of transport truck/trailer to storage

Truck/Trailer transport to storage

Plastic covered outside storage

Danish Technological Institute
Straw fuel supply chain

- Truck transport to end-user

- Unloading and storage at end user site

Danish Technological Institute
## Transport

<table>
<thead>
<tr>
<th>Vehicle-trailer combination</th>
<th>Feedstock type</th>
<th>Max. cargo space / payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm tractor and (two) tippers</td>
<td>Wheat straw and wood chips</td>
<td>70 m³ / 21.4 t</td>
</tr>
<tr>
<td>Farm tractor and platform trailer</td>
<td>Wheat straw</td>
<td>89 m³ / 18 t</td>
</tr>
<tr>
<td>Farm tractor and hook lift trailer for roll-off containers</td>
<td>Wood chips</td>
<td>40 m³ / 23 t</td>
</tr>
<tr>
<td>Truck and drawbar trailer</td>
<td>Wheat straw and wood chips</td>
<td>115 m³ / 25 t</td>
</tr>
<tr>
<td>Truck and drawbar/hook lift trailer for roll-off containers</td>
<td>Wood chips</td>
<td>60 m³ / 26 t</td>
</tr>
</tbody>
</table>

Rotter and Röhrhofer (2013)
<table>
<thead>
<tr>
<th>Handling equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front-end loaders (farm tractor)</td>
</tr>
<tr>
<td>Telescopic handler</td>
</tr>
<tr>
<td>Forklift truck</td>
</tr>
<tr>
<td>Gantry crane</td>
</tr>
</tbody>
</table>
# Storage

<table>
<thead>
<tr>
<th>Storage locations (biomass logistics)</th>
<th>Square bales</th>
<th>Wood chips</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Piles/roadside landing</td>
<td><img src="image1.jpg" alt="Image" /></td>
<td><img src="image2.jpg" alt="Image" /></td>
</tr>
<tr>
<td>2  Intermediate depot</td>
<td><img src="image3.jpg" alt="Image" /></td>
<td><img src="image4.jpg" alt="Image" /></td>
</tr>
<tr>
<td>3  Decentral conversion plant</td>
<td><img src="image5.jpg" alt="Image" /></td>
<td><img src="image6.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>
Overview

- Solid biofuels
  - Feedstock
    - Wood
    - Agricultural residues
    - Energy crops
- Biomass Logistics and supply chains (harvesting, handling and storage)
  - Woody biomass
  - Agricultural biomass
  - Security of supply
  - Safety aspects
  - Quality control and standardization
  - Modelling of biomass supply chains
- Best practice examples
Security of supply

- Contracting of biomass suppliers
  - Delivery contacts for biomass fuels
    - Ensuring a timely delivery of the fuel
    - Ensuring the quality of the fuel
    - Ensuring price stability of the fuel
    - Reimbursement in case of contract breach (quality, amounts, time, etc.)

- Storage space
  - Trade off between fuel supply security and investment costs
  - Storage should cover a minimum of one week fuel supply.
  - In many cases bigger storage space is recommended to limit the number of transports and to bridge periods without supply possibility
Safety aspects

- Biomass can be a potentially hazardous material if handled incorrect
  - Self heating of biomass in storage (biological reactions, chemical oxidation)
    - Keep biomass dry and monitor temperature on a regular basis
    - Fresh biomass tends to be more reactive than “old” biomass
  - Oxygen depletion and off-gassing
    - Biomass removes oxygen and releases hazardous gases if stored in closed compartments (carbon monoxide, aldehydes)
    - Ventilation of the storage room before entering.
  - Dust formation during handling of biomass
    - Inhalation of dust is very unhealthy for lungs and respiratory system
    - Dust can form explosive atmospheres (dust-explosion)
    - Wear dust masks and prevent open fire/light in dusty zones. ATEX regulations may apply in biomass storage/handling zones
Quality control

- Standards for solid biofuels
  - EN 14961: Technical specifications
  - EN 15234: Quality assurance

- Size, shape
- Mechanical durability (fines and dust formation during handling)
- Moisture content
- Bulk density
- Heating value
- Ash content
- Ash composition / Ash melting behaviour

- Certification schemes for pellets/briquettes i.e. EN-plus certification
Overview

- Solid biofuels
  - Feedstock
    - Wood
    - Agricultural residues
    - Energy crops
- Biomass Logistics and supply chains (harvesting, handling and storage)
  - Woody biomass
  - Agricultural biomass
  - Security of supply
  - Safety aspects
  - Quality control and standardization
  - Modelling of biomass supply chains
- Best practice examples
Modelling of biomass supply chains
Biomass logistics - Challenges

Challenges
- Different types of biomass
- Seasonal variations (amount & quality)
- Limited storage time (decay)
- Low bulk density

Supply chain management to ensure...
- Availability at the right time
- In the right amounts
- In the proper quality

→ Stable and secure biomass supply at predictable (low) costs
Modelling and optimization of biomass supply chains

Evaluation of different scenarios for an optimal supply of biomass to an end-user
- Stable and secure supply
- Quality
- Price

Biomass logistic tool:

- Developed in EUROBIOREF project (EU-FP7 project) by DTI
- Based on Excel and Gams platform
- Tool has been used in different projects and commercial activities
- High flexibility: feedstock, supply chain elements and output parameters
Example: Cereal Straw supply chain Scenario

Cereal straw from field to small scale CHP plant in DK

Field - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - > CHP plant

End user: Hillerød Kraft-Varme Værk (Hillerød, 50 km North of Copenhagen, DK)
Cereal straw harvested 25 km away from plant
Example: Cereal Straw supply chain Scenario

Cereal straw from field to heat and power plant

Supply chain
1. Harvesting
2. Baling
3. Loading
4. Field transport
5. Unloading / Stapling
6. Field storage (covered)
7. Loading
8. Truck transport
9. Delivery at end-user
Example: Cereal Straw supply chain Scenario

Data sheet for each step in supply chain

1. Harvesting
2. Baling
3. Loading
4. Field transport
5. Unloading / Stapling
6. Field storage (covered)
7. Loading
8. Truck transport
9. Delivery at end-user
### Example: Cereal Straw supply chain Scenario

#### Data sheet

- **Process information**
- **Machinery**
- **Alternative uses of machinery**
- **References to literature / manufacturers**
- **Dry matter in and out**
- **Bulk density in and out**
- **Capacity**
- **Efficiency**
- **Losses**
- **Costs** (machine, operation, indirect costs, fuel price, salaries, insurance, loans)
- **CO₂ emissions**
Example: Cereal Straw supply chain Scenario

Harvest: Aug 90% / Sep 10%

End-user: Various amounts 3000-6000 t/month

Maintance break in July

Field storage
Example: Cereal Straw supply chain Scenario

Cost of each supply chain element

- Wheat straw combined harvesting
- Tractor propelled baling (500-600 kg/bale)
- Telescopic wheel loader for big bales
- Telescopic wheel loader for insertion/stacking of big bales
- Covered Cereal Straw big bale outdoor storages at grower's farm
- Telescopic wheel loader for big bales
- Lorry and trailer
- Cereal Straw Reed big bale central indoor storages

Costs - euro per ton DM or end product

- Cost per element excluding supply chain losses
- Cost per element including supply chain losses
Example: Cereal Straw supply chain Scenario

Energy consumption of each supply chain element

- Wheat straw combined harvesting
- Tractor propelled baling (500-600 kg/bale)
- Telescopic wheel loader for big bales
- Tractor and trailer
- Telescopic wheel loader for insertion/stacking of big bales
- Covered Cereal Straw big bale outdoor storages at growers farm
- Lorry and trailer
- Telescopic wheel loader for big bales
- Cereal Straw Reed big bale central indoor storages
Example: Cereal Straw supply chain Scenario

The biomass supply chain modelling tool is available within the project consortium.

The tool can model supply chains for wood and agricultural residues and can be adapted to specific scenarios.

The input data has to be exact, since the modelled data is always just as exact as the data you feed into the model.
References and further reading

- Serup H. et al. (2002). Wood for Energy production. Center for Biomass Technology, Denmark
- Skot T. et al. (2011) Straw to Energy Status, Technologies and Innovation in Denmark. Agro Business Park A/S.
- Alakangas E. et al. (2007) Biomass Fuel Supply Chains for Solid Biofuels. VTT Research Center, Finland