Co-firing biomass with fossil fuels – technological and economic evaluation based on Austrian experiences

Dr. Ingwald Obernberger

Overview

- Introduction
- Framework conditions for electricity production from biomass in Austria
- Technologies for co-firing biomass with fossil fuels
- Economic evaluation of the technologies investigated
- Sensitivity analyses regarding important parameters
- Summary
Advantages of biomass co-firing

- Reduction of CO$_2$ emissions
- Potential for reduction of SO$_x$ and NO$_x$ emissions given (especially when wood fuels are utilised)
- Rapid creation of a large renewable energy market
- Efficient utilisation of biomass fuel resources
- Reduced capital costs in comparison to new biomass power or CHP plants

Challenges of biomass co-firing

- Risk of ash deposition problems
- Risk of high-temperature corrosion
- Problems regarding the deactivation of SCR catalysts
- Reduced ash disposal / utilisation options
- Increase in carbon carryover or unburned carbon
- Problems regarding biomass fuel supply may occur
- An increase of the fuel costs can occur
- Substantial increase in volumetric feeding and fuel storage areas
- Thermal biomass utilisation in decentralised plants is perhaps more effective regarding the limited resources of biomass fuels available
Electricity production using biomass fuels in Austria (1)

Utilities

- St. Andrä
- Zeltweg
- ~ 9 coal fired power plants
- ~ 20 small-scale biomass CHP plants
- ~ 3 medium-scale biomass & waste fired CHP plants

Industrial plants

- Pulp and paper industry
- ~ 3 medium-scale biomass & waste fired CHP plants
- ~ 20 small-scale biomass CHP plants

Co-Combustion:
- Coal boiler with separate biomass grate
- Coal boiler using gas from biomass gasifier (shut down)

Electricity production in Austria (2)

Utilities

- St. Andrä ~ 7.5
- Zeitweg (shut down) (~ 5)
- ~ 9 coal fired power plants (potential for co-combustion) ~ 500

Industrial plants

Wood processing industry
- ~ 20 small-scale biomass CHP plants ~ 100

Pulp and paper industry
- ~ 3 medium-scale biomass & waste fired CHP plants ~ 300
- 9 co-combustion CHP plants ~ 1,000

- Total electricity production in Austria: ~50,000 GWh/a
- Electricity production from thermal power plants in Austria: ~14,000 GWh/a
Description of the different co-firing technologies according to the following evaluation criteria:

- Operating principle
- Influence of the biomass fuel on the overall system
- State of development and experiences already achieved
- Electricity production costs
  (calculation of the electricity production costs according to the guideline VDI 2067)

Technologies for co-firing biomass with fossil fuels

- Biomass co-firing in existing pulverised coal combustion (PCC) systems
  - Co-firing of biomass on a separate grate directly under the coal boiler
  - Co-firing of finely milled biomass mingled with coal
  - Co-firing of finely milled biomass by separate injection
- Biomass co-firing in fluidised bed combustion (CFB and BFB) systems
- Biomass co-firing by using separate combustion units and junction of steam
- Biomass gasification and utilisation of the product gas as fuel in a coal combustion system
Co-firing of biomass on a separate grate directly under the coal boiler

+ Large variety of biomass fuels to be used
  (especially regarding particle size and water content)
+ High biomass and coal carbon conversion
  - Limited applicability due to space available under the boiler
  - Mingled biomass and coal bottom and fly ash

Austrian application: St. Andrä
  - Nominal capacity 124 MWel / 284 MWth
  - Biomass contribution 3 % of the fuel input (NCV)

Co-firing of finely milled biomass mingled with coal

+ No significant modifications are necessary
  - Particle size < 3 mm
  - Water content < 30 wt.% (w.b.)
  - Pneumatic delivering system of the fuel to the burner is necessary
  - Corrosion and deposition problems (especially when co-firing straw)
  - Deactivation of DeNOx catalysts
  - Plugging and bridging problems
  - Ash utilisation problems

Applications in operation in DK, FIN, NL and USA
Advantages and disadvantages of separate injection compared to mingled biomass and coal:

+ Optimised biomass handling and preparation due to separate storage
+ Better burner optimisation to the biomass fuel possible
+ Increased fuel flexibility
+ Increased biomass loading
- Increased capital costs
- Formation of stratified flows

Utilisation of biomass with higher particle size possible

High flexibility concerning utilisation of biomass fuels

- Higher risk of bed agglomeration and fouling
- Separate feeding systems for each fuel
- Mixture of coal and biomass ashes

Applications in operation in A, DK, S, FIN, NL and USA
Biomass co-firing by using separate combustion units and junction of steam

- Best adjustment of the boiler and the flue gas cleaning system to the fuels used
- Separate utilisation of biomass and coal ashes
- Higher steam parameters are possible
- Smaller operating costs
- Higher investment costs
- More complex plant design

2 applications in operation in DK

Biomass gasification and utilisation of the product gas as fuel in a PCC unit

- No fuel pre-drying
- Particle size up to 40 mm
- No special demands on the gas
- NOx reduction by fuel staging possible
- High flexibility concerning utilisation of biomass fuels
- Easy application to existing coal-fired power plants
- More complex plant design and operation
- Biomass and coal fly ashes are partially mixed

Austrian application: Zeltweg
- Nominal capacity 137 MWel / 330 MWth
- Biomass contribution 3 % of the fuel input (NCV)

Finnish application: Kymijärvi
- Nominal electric capacity 167 Mwel
- Thermal capacity biomass gasifier 40 – 70 MW (depending on the fuel input)
Calculations are based on additional electricity production from biomass → only the additional costs for power production have to be considered

Economic calculations performed according to VDI guideline 2067

Data gained from comprehensive investigations performed in Austrian wood processing industries and utilities as well as from plant owners.

### Technical data biomass co-firing

<table>
<thead>
<tr>
<th>Technology</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal thermal capacity $P_{th}$</td>
<td>MW</td>
<td>70</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Gross electric capacity $P_{el}$</td>
<td>MW</td>
<td>28</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>4.2</td>
</tr>
<tr>
<td>Full load operating hours $t_{FL}$</td>
<td>h</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Specific internal electricity consumption $kW_{el}/MW_{th}$</td>
<td>8</td>
<td>40</td>
<td>5</td>
<td>5</td>
<td>11</td>
<td>8</td>
<td>11</td>
</tr>
</tbody>
</table>

### Investment costs

| Technical installations | 1,000 € | 8,000 | 8,700 | 700 | 17,000 | 7,300 | 500 | 2,300 |
| Conveying system | 1,000 € | 2,300 | 4,400 | 2,500 | 2,500 | 2,500 | 600 | 600 |
| Construction work (storage, base plate) | 1,000 € | 700 | 1,100 | 400 | 1,100 | 900 | 200 | 300 |
| Control system | 1,000 € | 200 | 600 | 100 | 400 | 400 | 100 | 300 |
| Total investment costs | 1,000 € | 11,200 | 14,800 | 3,700 | 21,000 | 11,100 | 1,400 | 3,500 |

### Specific investment costs $I/P_{el}$

<table>
<thead>
<tr>
<th>1...Biomass grate</th>
<th>2...Co-firing in PCC plant</th>
<th>3...Co-firing CFB</th>
<th>4...Separate biomass boiler</th>
<th>5...Biomass gasification</th>
<th>6...separate biomass grate (pilot plant St. Andrä)</th>
<th>7...biomass gasification (pilot plant Zeltweg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I/P_{el}$</td>
<td>€/kW$_{el}$</td>
<td>400</td>
<td>370</td>
<td>93</td>
<td>525</td>
<td>278</td>
</tr>
</tbody>
</table>
## Economics – framework conditions (3)

<table>
<thead>
<tr>
<th>Technology</th>
<th>1</th>
<th>2</th>
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<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electricity production costs of the biomass co-firing unit</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Capital costs</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Interest rate (real)</td>
<td>% p.a.</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Lifetime co-firing unit</td>
<td>a</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
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<tr>
<td>Consumption based costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel price</td>
<td>€/MWh NCV</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Material costs at t(_{FL}) = 8760 h/a</td>
<td>(% of I) p.a.</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Operation based costs</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Personal costs per hour</td>
<td>€/h</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Working hours at t(_{FL}) = 8760 h/a</td>
<td>(% of 8760h) p.a.</td>
<td>30</td>
<td>70</td>
<td>35</td>
<td>45</td>
<td>35</td>
<td>10</td>
</tr>
<tr>
<td>Maintenance costs at t(_{FL}) = 8760 h/a</td>
<td>(% of I) p.a.</td>
<td>1.5</td>
<td>3.5</td>
<td>1.7</td>
<td>1.7</td>
<td>2.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Other costs</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Administration, insurance</td>
<td>(% of I) p.a.</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

1...Biomass grate  
2...Co-firing in PCC plant  
3...Co-firing CFB  
4...Separate biomass boiler  
5...Biomass gasification  
6...separate biomass grate (pilot plant St. Andrä)  
7...biomass gasification (pilot plant Zeltweg)
Economics – sensitivity analysis
electricity production costs vs.
full load operating hours

- Biomass grate
- Co-firing in PCC plant
- Co-firing CFB
- Separate biomass boiler
- Biomass gasification
- St. Andrä
- Zeltweg

- Range for electricity production costs from large-scale nuclear power, coal or natural gas power plants

fuel price = 15 €/MWh NCV
investment subsidies = 0%

Economics – sensitivity analysis
electricity production costs vs.
fuel price

- Biomass grate
- Co-firing in PCC plant
- Co-firing CFB
- Separate biomass boiler
- Biomass gasification
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- Range for electricity production costs from large-scale nuclear power, coal or natural gas power plants

full load operating hours = 3,000 h/a
investment subsidies = 0%
Economics – sensitivity analysis

electricity production costs vs.
investment subsidies

Investment subsidies [%]

Electricity production costs [€/MWh]

0 20 40 60 80 100 120 140

0 10 20 30 40 50

Biomass grate
Co-firing in PCC plant
Co-firing CFB
Separate biomass boiler
Biomass gasification
St. Andrä
Zeltweg

- range for electricity production costs from large-scale nuclear power, coal or natural gas power plants

full load operating hours = 3,000 h/a
fuel price = 15 €/MWh NCV

0 1 0 2 0 3 0 4 0 5 0

Biomass grate
Co-firing in PCC plant
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Biomass gasification
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Zeltweg

- range for electricity production costs from large-scale nuclear power, coal or natural gas power plants

Austrian feed-in tariffs for electricity
production from solid biomass

Price secured for a duration of 13 years after start-up

*...maximum electric capacity

Forestry wood chips

Primary energy source according to Table 2 in the annex to § 5 (1) 5 of the Austrian Electricity Supply Act, e.g. by-products from sawmills

Primary energy source according to Table 1 in the annex to § 5 (1) 5 of the Austrian Electricity Supply Act, e.g. waste wood
Summary (1)

- Co-firing has a high short-term potential for electricity production from biomass and therefore for a substantial reduction of CO₂ emissions (due to large plant capacities of existing power plants)
- Several proven co-firing technologies are available
- Technical barriers can be surmounted by proper attention to boiler design, boiler operation and fuel properties
- Usually NOₓ and SOₓ reduction when using pure wood fuels
- Problems concerning deposition, erosion and corrosion in boilers need additional and critical research

Summary (2)

- Most importantly biomass-coal co-firing using biomass residues as a feedstock represents possibly the lowest cost and lowest risk option (for increased renewable energy production)
- Electricity production costs for the different large-scale co-firing technologies considered are between 50 and 80 €/MWhₑ₁ (54 – 86 US$/MWhₑ₁)
- Biomass co-firing with coal is slightly more economically favourable than power production in large-scale biomass CHP plants (electricity production costs 70 to 100 EUR / MWhₑ₁).
The economy of biomass co-combustion plants is strongly influenced by the annual full load operating hours that can be achieved (> 3,000 h/a are necessary) and by the fuel price (price target: 15 €/MWh_{NCV} (16 US$/MWh_{NCV}) and lower)

Increased and secured feed-in tariffs for electricity from biomass co-combustion plants strongly support this technology
(e.g. regulated in the new Austrian regulation for electricity production from renewables)