Utilization of straw for mid-scale heat applications
Overview

- Straw as energy resource
- Handling and storage of straw
- In-house heating applications of straw
- Straw for small scale district heating applications
- Straw for large scale heat and power generation (optional)
- Residual products
Overview

- **Straw as energy resource**
- Handling and storage of straw
- In-house heating applications of straw
- Straw for small scale district heating applications
- Straw for large scale heat and power generation (optional)
- Residual products
Straw as energy resource

**Straw production**
- Straw is a by product from cereal grain production
- Straw yield depends on the crop
- Usually 35 and 53 kg straw per 100 kg grain
- Yield per ha are ca.
  - 3.5 t/ha for wheat straw
  - 2.75 t/ha for barley straw
  - 1.5 t/ha for rape straw
- Variation due to climatic conditions can be up to 30%
- Variation due to geographic location, soil quality and farming technology
- Only minor part is used for energy production
- Major part of the straw harvest is used in agricultural sector i.e. animal bedding, forage
- Unutilized straw surplus makes out a potential fuel reserve
- Some years ago it was common to burn unutilized straw directly on the field
Straw as energy resource

Technical potential of straw residues in Europe

Available straw potential in Europe in 1,000 tons [4]

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

Technical potential of straw residues in Europe [5]
**Straw as energy resource**

**Straw as a fuel**
- Most important arguments for using straw as a biofuel are lower CO$_2$ emissions compared to fossil fuels
- Low cost and good availability, especially in agricultural regions

**Benchmark of straw to other fuel types:**

<table>
<thead>
<tr>
<th></th>
<th>Yellow straw</th>
<th>Grey straw</th>
<th>Wood chips</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content</td>
<td>10-20%</td>
<td>10-20%</td>
<td>40-50%</td>
<td>12%</td>
</tr>
<tr>
<td>Ash</td>
<td>4%</td>
<td>3%</td>
<td>1%</td>
<td>12%</td>
</tr>
<tr>
<td>Carbon</td>
<td>42%</td>
<td>43%</td>
<td>50%</td>
<td>59%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>5%</td>
<td>5%</td>
<td>6%</td>
<td>4%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>37%</td>
<td>38%</td>
<td>38%</td>
<td>7%</td>
</tr>
<tr>
<td>Chloride</td>
<td>0.75%</td>
<td>0.20%</td>
<td>0.02%</td>
<td>0.08%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.35%</td>
<td>0.41%</td>
<td>0.30%</td>
<td>1.00%</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.16%</td>
<td>0.13%</td>
<td>0.05%</td>
<td>0.80%</td>
</tr>
<tr>
<td>Heating value</td>
<td>14.4 MJ/kg</td>
<td>15.0 MJ/kg</td>
<td>10.4 MJ/kg</td>
<td>25.0 MJ/kg</td>
</tr>
</tbody>
</table>
Straw as energy resource

Straw as a fuel

- Straw is not an easy to use fuel
- High content of alkali and chlorine result in the formation of highly corrosive chloride species during the combustion process
- Corrosion of steel surface in boiler and piping is a serious problem
- The softening temperature of ash is relatively low compared to other fuel types (just 800-850 degrees) in some cases 600 degrees → risk of deposit formation
- Ideal combustion of straw is obtained at excess air ratios of 1.4 to 1.6
Straw as energy resource

Pre-treatment of straw and traded forms

- Straw has a very low bulk density after the harvest (just 40-70 kg/m³)
- Density is increased by baling, briquetting or palletization
  - Bales 100-200 kg/m³
  - Briquettes 400-500 kg/m³
  - Pellets 600-680 kg/m³
- Most common form for energy straw are bales, either round bales or cubes

Curing on the field: Exposure to sun and rain turns fresh “yellow straw” into “gray straw”
- Grey straw has better combustion properties (less ash content)
- Straw has to be dry before bailing (ca. 15% moisture content)
Overview

- Straw as energy resource
- **Handling and storage of straw**
- In-house heating applications of straw
- Straw for small scale district heating applications
- Straw for large scale heat and power generation (optional)
- Residual products
Handling and transport of straw

[Danish Technological Institute]
Handling and transport of straw

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
Handling and transport of straw

- Harvesting with a combined harvester chaff cutter
- Drying, raking and turning of swaths
- Tractor propelled bale press
Handling and transport of straw

- Loading and unloading of transport truck/trailer to storage
- Truck/Trailer transport to storage
- Plastic covered outside storage

[1]
Handling and transport of straw

Truck transport to end-user

Unloading and storage at end user site
Handling and transport of straw

Delivery contracts for straw fuels

- The crop delivery contract for straw may include the following terms and conditions:
  - Term of contract and notice of termination
  - The amount of straw agreed upon, including provisions in the event of increase/decrease in the consumption of straw, non-delivery due to decrease in crop yield etc.
  - Terms of delivery, including the type of bale, the dimensions and weight of bales, water content, and other grade determinations
  - Basic price and the regulation of price in proportion to water content and time of delivery
Handling and transport of straw

Major cost factors

Source: The Bioenergy System Planners Handbook - BISYPLAN
Overview

- Straw as energy resource
- Handling and storage of straw
- **In-house heating applications of straw**
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In-house heating applications of straw

Boiler types

**Batch fired boilers:**
- Always installed in combination with a storage tank that can absorb the heat energy from the firing → Boiler can operate at full load
- Fuel types
  - Small straw bales
  - Medium sized bales
  - Big bales
  - Round bales
- Most widely used boiler size is a boiler for one medium sized bale or 8-10 small bales
- Typical applications are heating of farm buildings, estates building complexes
In-house heating applications of straw

Boiler types

Batch fired boilers

The principle in a batch-fired boiler:

The storage tank is big enough to contain the energy generated by combustion of the straw that the combustion chamber will hold.

Source: Center for Biomass Technology
In-house heating applications of straw

Boiler types

Batch fired boilers: - Control of firing

- Combustion air fans
- Amount of air and distribution of air between primary and secondary air is controlled electronically by a control unit
- Flue gas temperature and oxygen content are used as control parameter
  - Lambda probe
  - Oxygen concentration of 6-7 % in flue gas (Lambda 1.5)
  - Electronic control unit steers primary/secondary air to keep oxygen level constant
- Air nozzles designed and positioned to maintain a proper turbulence in the combustion zone
- Storage tank (60-80 liters of water per kg of straw) to maintain maximum boiler load throughout all combustion stages

[1]
In-house heating applications of straw

Boiler types

**Automated boiler**
- Ease the work of firing with straw
- Mainly designed for small bales

**Automatic boiler:** The straw is being shredded by a slow-speed shredder and fed via screw stoker on to the grate where the combustion takes place. The forward and backward movements of the grate pushes the ash towards the ash chute and further out with the ash conveyor. The flue gases are cooled by passing several passes where the fire tubes are surrounded by boiler water.

Source: Center for Biomass Technology
In-house heating applications of straw

Boiler types

Automated boiler
- Bale conveyor: 10-20 meter length is filled with straw bales once every 24 hours
- Before firing straw is disintegrated by a shredder/cutter
- Worm conveyor or blower transports straw into the boiler
- Blower is most common systems (high security against backfire/burn back
- Continues firing results in a more stable combustion and thus a higher efficiency and reduced emissions
- The boiler heat transmission is adjusted by on/off operation, controlled by a thermostat that controls the boiler water temperature

An automatic boiler. The chaffed straw is sucked into the lower, bright tube of the cyclone. The upper tube is the cyclone exit air. The straw is separated from the transport air in the cyclone and is dosed via a rotary valve under the cyclone down on to the screw stoker that passes the straw into the boiler. The flue gas fan is seen on the back of the boiler

Source: Center for Biomass Technology [1]
In-house heating applications of straw

Boiler types

Automated boiler – combustion control
- Amount of straw fired is adapted to amount of combustion air
- Constant straw fed is applied by an oxygen controlled screw stoker
- Oxygen content in flue gas is recorded by a lambda probe and straw amount is controlled by turning on/off the screw stoker
- Aim is to maintain the oxygen content at approximately 7%

The gate is open to the combustion chamber of an automatically fed fire tube boiler. The straw is fed by screw stoker behind the flames, and the flue gas passes through the four tubes and further through the boiler vessel. Below on the right, the gear motor of the ash conveyor is seen.

Source: Center for Biomass Technology
Overview

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Small scale district heating

- Small heating plant without power production
- 1-9 MW (usually around 3 MW)
- Maximum boiler temperature of 120 C and 6 bar pressure
- Most common type of straw utilization for energy production
- Designed for big bales

Design
- The boiler rating is fixed on the basis of the maximum heat amount to be supplied to the distribution net on the coldest day of the year
- Distribution loss 16-42 %
- Straw boiler with back-up boiler
- See B4B dimensioning tool for further info
Small scale district heating

The duration curve for a 3 MW boiler plant with a 2 MW straw-fired boiler. Peak load and stand-by load by a 3 MW oil-fired boiler.

Source: Center for Biomass Technology [1]
Small scale district heating

Handling & Storage
- Space consuming
- 8 days full operation is minimum requirement
- 400 big bales for a 3,7 MW plant (600 m²)
- Weighing of the bales upon arrival
- Reject if more than 20% moisture content
- Crane for moving the bales
- Chaff cutting and shredding before firing

Source: Center for Biomass Technology [1]
Small scale district heating

**Boiler**
- Boiler for sliced bales
  - Bale is sliced by hydraulic knife
  - Pushed into boiler by a ram stoker
- Boiler for continues firing
  - Instead of cutting the bale is pressed continuously into the boiler
  - Burning from the end
  - Cigar burner principle
- Boiler for firing of whole bales
  - Whole bale is placed into the boilers pre-heating chamber by crane
  - Bale is ignited by the burning fuel already present in the chamber
  - Burns partly from the from and top
  - Air inlet is controlled by flue gas temperature

**Flue gas cleaning**
- Multi-cyclone
- Bag filter
- Electrostatic filter
- Flue gas scrubber
- Flue gas condensation
Small scale district heating

Storage tank

The advantages of installing a tank are the following:

- Peak load morning and evening during the winter season can be smoothed out, thereby avoiding oil firing.
- During suspension of operations, the heat consumption can be drawn from the storage tank, thereby avoiding oil firing.
- A 400 m³ tank can supply heat for 7 hours at full load at an average plant.
- At off-peak load during summer, the boiler can operate at full load for a short period while the storage tank is filled, and then boiler is closed. The result is improved efficiency and lower emissions compared to continuous operating at off-peak load.
- The personnel’s roster becomes more flexible, since, e.g., the boiler can be closed over the week-end during summer.

Drawbacks are increased expenses for investments and maintenance of the tank
Overview

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Straw use in CHP and powerplants

**CHP plant principle and advantages**
- Higher efficiency: 85-90 % of the fuel energy are used for heat and power production
- Ratio between heat production and power production can be changed

By separate electrical power generation and heat production at a power plant and a district heating plant, the losses are much larger than by combined heat and power production at a CHP plant. Losses include own consumption at the plant

Source: Center for Biomass Technology [1]
Straw use in CHP and powerplants

Examples of straw fired CHP boilers in DK

<table>
<thead>
<tr>
<th>Plant</th>
<th>Technology</th>
<th>Biomass consumption/year</th>
<th>Steam temperature</th>
<th>Steam pressure</th>
<th>Commissioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haslev Kraftvarmeørk</td>
<td>Grate-firing of straw</td>
<td>26,000 tonnes</td>
<td>455°C</td>
<td>67 bar</td>
<td>1989</td>
</tr>
<tr>
<td>Rudkøbing Kraftvarmeørk</td>
<td>Grate-firing of straw</td>
<td>14,000 tonnes</td>
<td>450°C</td>
<td>60 bar</td>
<td>1990</td>
</tr>
<tr>
<td>Slagelse Kraftvarmeørk</td>
<td>Grate-firing of straw</td>
<td>30,000 tonnes</td>
<td>450°C</td>
<td>67 bar</td>
<td>1990</td>
</tr>
<tr>
<td>Maribo-Sakskøbing Kraftvarmeørk</td>
<td>Grate-firing of straw</td>
<td>45,000 tonnes</td>
<td>540°C</td>
<td>93 bar</td>
<td>2000</td>
</tr>
<tr>
<td>Fynsværket</td>
<td>Grate-firing of straw</td>
<td>150,000 tonnes</td>
<td>540°C</td>
<td>110 bar</td>
<td>2009</td>
</tr>
<tr>
<td>Koge Kraftvarmeørk unit 7</td>
<td>Grate-firing of wood</td>
<td>80,000 tonnes</td>
<td>525°C</td>
<td>93 bar</td>
<td>1987</td>
</tr>
<tr>
<td>Koge Kraftvarmeørk unit 8</td>
<td>Grate-firing of wood</td>
<td>120,000 tonnes</td>
<td>525°C</td>
<td>93 bar</td>
<td>1999</td>
</tr>
<tr>
<td>Herningværket</td>
<td>Grate-firing of wood</td>
<td>250,000 tonnes</td>
<td>525°C</td>
<td>115 bar</td>
<td>2002</td>
</tr>
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<td>Assens Kraftvarmeørk</td>
<td>Grate-firing of wood</td>
<td>45,000 tonnes</td>
<td>525°C</td>
<td>77 bar</td>
<td>1999</td>
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<tr>
<td>Randers</td>
<td>Grate-firing of coal and dry biomass</td>
<td>74,000 tonnes</td>
<td>525°C</td>
<td>111 bar</td>
<td>2002*</td>
</tr>
<tr>
<td>Måbjerg bio-boiler</td>
<td>Grate-firing of wood and straw</td>
<td>65,000 tonnes</td>
<td>520°C</td>
<td>67 bar</td>
<td>1993</td>
</tr>
<tr>
<td>Masnedø Kraftvarmeørk</td>
<td>Grate-firing of wood and straw</td>
<td>45,000 tonnes</td>
<td>522°C</td>
<td>92 bar</td>
<td>1996</td>
</tr>
<tr>
<td>Ensted bio-boiler</td>
<td>Grate-firing of wood and straw</td>
<td>150,000 tonnes</td>
<td>510°C</td>
<td>210 bar</td>
<td>1998</td>
</tr>
<tr>
<td>Avedøre 2 bioboiler</td>
<td>Grate-firing of straw</td>
<td>150,000 tonnes</td>
<td>545°C</td>
<td>310 bar</td>
<td>2001</td>
</tr>
<tr>
<td>Studstrupværket unit 4</td>
<td>Co-firing, straw to coal</td>
<td>100,000 tonnes</td>
<td>540°C</td>
<td>270 bar</td>
<td>2002*</td>
</tr>
<tr>
<td>Studstrupværket unit 3</td>
<td>Co-firing, straw to coal</td>
<td>30,000 tonnes</td>
<td>540°C</td>
<td>270 bar</td>
<td>2005*</td>
</tr>
<tr>
<td>Avedøre 2 main boiler</td>
<td>Biodust-firing in power plant boiler</td>
<td>300,000 tonnes</td>
<td>542°C</td>
<td>310 bar</td>
<td>2001</td>
</tr>
<tr>
<td>Amagerværket</td>
<td>Biodust-firing</td>
<td>130,000 tonnes</td>
<td>480°C</td>
<td>120 bar</td>
<td>2003</td>
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<tr>
<td>Grenaa</td>
<td>CFB combustion of straw and coal</td>
<td>40,000 tonnes</td>
<td>505°C</td>
<td>92 bar</td>
<td>1992</td>
</tr>
</tbody>
</table>

Table 5.1. Overview of biomass-fired CHP plants in Denmark. * Converted to biomass.
Straw use in CHP and powerplants

Examples of straw fired CHP boilers in DK

Source: Center for Biomass Technology [1]
Residual products

Ash
- Ash is rich in nutrients, primarily potassium, magnesium and phosphorous and can therefore be used as fertilizer
- Bottom ash can in a number of regulated countries be used as soil improvement or fertilizer directly on farmland in other countries. Limits determined by trace elements.
- Another option is the use in composting together with other plant materials.
- Some bottom ashes may even be used for engineering purposes, e.g. certain road constructions, especially far from major cities.
References and further reading


