Experience with straw firing in Danish combined heat and power plants
Ørsted develops energy systems that are green, independent and economically viable

- Revenue (2017): EUR 8.0bn
- EBITDA (2016): EUR 3.0bn
- ~5,900 employees
- Active in Scandinavia, United Kingdom, Germany, The Netherlands, USA and Taiwan

Major Shareholders:
- Danish State 50.1%
- Seas NVE 9.5%
- Capital Group >5%

Wind Power
- Global leader in offshore wind with 3.8GW installed
- Active in all parts of the value chain - develop, construct, own and operate offshore wind farms
- Significant and attractive build out plan of 5GW towards 2022
- Ambition of 11 -12GW installed offshore wind capacity by 2025

Distribution & Customer Solutions
- Largest power distributor in Denmark with 1 mill. customers
- Largest energy solutions provider in Denmark with 900,000 residential and industrial customers
- Developing green, innovative and cost efficient customer solutions

Bioenergy
- #1 in Danish heat and power generation with 25% of market
- Converting heat and power plants from coal and gas to biomass
- Innovative waste to energy technology (Renescience)
- Energy storage solutions

Note
1 Ørsted was named DONG Energy A/S until 2017. DONG Energy A/S was a merger in 2006 of six Danish production and distribution companies of power, heat, oil and gas.
Bioenergy will exit coal by 2023

Biomass conversions facilitate zero coal from 2023

Ørsted fuel consumption (PJ)

<table>
<thead>
<tr>
<th>Year</th>
<th>Waste</th>
<th>Biomass</th>
<th>Natural gas</th>
<th>Oil</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>7%</td>
<td>66%</td>
<td>18%</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>2015</td>
<td>3%</td>
<td>48%</td>
<td>24%</td>
<td>1%</td>
<td>26%</td>
</tr>
<tr>
<td>2016</td>
<td>1%</td>
<td>46%</td>
<td>26%</td>
<td>1%</td>
<td>27%</td>
</tr>
<tr>
<td>2017</td>
<td>27%</td>
<td>30%</td>
<td>1%</td>
<td>1%</td>
<td>42%</td>
</tr>
<tr>
<td>2023</td>
<td>95%</td>
<td>5%</td>
<td>1%</td>
<td>1%</td>
<td>5%</td>
</tr>
</tbody>
</table>

First major utility to fully exit coal

- Putting further action behind Ørsted’s vision of leading the energy transformation
- Heat customers support early coal phase-out

Coal may be used in force majeure circumstances
Background for straw firing in Denmark in combined heat and power plants

- CO₂-reduction in Denmark by replacing coal based power production by wind power, biomass and natural gas
- Political agreement in 1993 to obligate power plants to apply 1.4 million tons of biomass (mainly straw) for power production in year 2000
- Limited national and international experience with straw combustion in 1993
- Large development program for development and demonstration of straw combustion technology initiated
- Obligation to be fulfilled in 2008
Facts about Denmark

*Denmark*
- 5.8 million inhabitants
- Total area 43,000 km²
- Farmland 26,000 km² (62%)
- Straw crops 14,000 km² (40%)
- Straw production 5.8 million tonnes
- Straw for energy 1.6 million tonnes
- Straw for energy 24 PJ

Source: Danmarks Statistik, 2018
Crop distribution in Denmark:
- Wheat: 36%
- Barley: 41%
- Rye: 7%
- Triticale: 4%
- Oat: 1%
- Rape seed: 11%
- Grass seed: 0%

Energy consumption for straw transportation:
- < 1% assuming
- 1 bale approx. 500 kg
- Transportation by truck, 24 bales per truck
- Average distance from pick-up area: 50 km
Renewable energy production in Denmark

Straw consumption for energy purposes increased from 12 to 24 PJ from 1990 to 2016

Renewable covered 25% of the total energy consumption in 2016
Straw as fuel for power production

Technical challenges:
- low energy density – large volumes
- potassium and chlorine
  - slagging, fouling and corrosion
  - flue gas cleaning
  - utilization of residues

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Water content</th>
<th>Calorific value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>10%</td>
<td>25MJ/kg</td>
</tr>
<tr>
<td>Wood pellets</td>
<td>8%</td>
<td>17.5MJ/kg</td>
</tr>
<tr>
<td>Straw</td>
<td>14%</td>
<td>15MJ/kg</td>
</tr>
<tr>
<td>Wood chips</td>
<td>45%</td>
<td>9.5MJ/kg</td>
</tr>
</tbody>
</table>
Handling of straw

4 tonnes straw per hectare
500 kg big bales
24 bales on each truck
# Overview of straw fired CHP plants in Denmark

<table>
<thead>
<tr>
<th>Plant</th>
<th>Technology</th>
<th>Commissioned</th>
<th>Consumption tonnes/year</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haslev CHP-plant</td>
<td>Grate firing of straw</td>
<td>1989</td>
<td>26.000</td>
<td></td>
</tr>
<tr>
<td>Rudkøbing CHP-plant</td>
<td>Grate firing of straw</td>
<td>1990</td>
<td>14.000</td>
<td></td>
</tr>
<tr>
<td>Slagelse CHP-plant</td>
<td>Grate firing of straw</td>
<td>1990</td>
<td>30.000</td>
<td></td>
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<tr>
<td>Grenå CHP-plant</td>
<td>CFB combustion of straw and coal</td>
<td>1992</td>
<td>40.000</td>
<td>Decommissioned</td>
</tr>
<tr>
<td>Måbjerg bio boiler</td>
<td>Grate firing of straw and wood</td>
<td>1993</td>
<td>65.000</td>
<td></td>
</tr>
<tr>
<td>Masnedø CHP-plant</td>
<td>Grate firing of straw and wood</td>
<td>1996</td>
<td>45.000</td>
<td></td>
</tr>
<tr>
<td>Ensted bio boiler</td>
<td>Grate firing of straw and wood</td>
<td>1998</td>
<td>150.000</td>
<td>Decommissioned</td>
</tr>
<tr>
<td>Maribo-Sakskøbing CHP-plant</td>
<td>Grate firing of straw</td>
<td>2000</td>
<td>45.000</td>
<td></td>
</tr>
<tr>
<td>Avedore unit 2 bio boiler</td>
<td>Grate firing of straw</td>
<td>2001</td>
<td>150.000</td>
<td></td>
</tr>
<tr>
<td>Studstrupværket unit 4</td>
<td>Bio-dust co-firing of straw to coal</td>
<td>2002</td>
<td>10.000</td>
<td>Plant in reserve</td>
</tr>
<tr>
<td>Amager CHP-plant unit 2</td>
<td>Bio-dust firing of straw and coal</td>
<td>2003</td>
<td>130.000</td>
<td>Plant in reserve</td>
</tr>
<tr>
<td>Studstrupværket unit 3</td>
<td>Bio-dust co-firing of straw to coal</td>
<td>2005</td>
<td>30.000</td>
<td>From 2016 also wood pellets</td>
</tr>
<tr>
<td>Fynsværket unit 9</td>
<td>Grate firing of straw</td>
<td>2009</td>
<td>150.000</td>
<td></td>
</tr>
<tr>
<td>Amager CHP-plant unit 1</td>
<td>Bio-dust firing of straw and wood</td>
<td>2009</td>
<td>350.000</td>
<td>Currently wood pellets</td>
</tr>
<tr>
<td>Affald Varme Århus</td>
<td>Grate firing of straw</td>
<td>2016</td>
<td>230.000</td>
<td></td>
</tr>
</tbody>
</table>

**Notes**
- **Plants in Bold text:** Constructed and/or operated by Ørsted/DONG Energy A/S or merging companies

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10
Grate firing of straw – 10 plants
Bio dust firing – 2 plants co-firing of straw to coal plants and 2 plants co-firing of straw and wood pellets
Co-firing of straw and coal in fluidized bed – 1 plant
Learning elements from the small scale CHP plants

Straw fired (grate) boilers

- Local fuel (max. 100 km), Hesston bales (standard size)
- Max. 2 days storage at plant
- Crane (measure weight and moisture content)
- Scredder system and boiler screw feeder
- Boiler design
  - Slag
    - Slagging superheater
    - Reduce temp. before convective part
  - High temperature corrosion
    - Selection of materials
    - Additives (not used)
  - Low temperature corrosion
- Ash utilization
  - Bottom ash (80%) recycled to farmland but fly ash (20%) cannot be recycled due to the cadmium content
- NOx considerations
  - Limited experience with SCR/SNCR, one plant with low dust SCR is taken into operation in 2016
Superheater design allowing slagging operation
<table>
<thead>
<tr>
<th>Air preheater</th>
<th>District heating flue gas cooler</th>
</tr>
</thead>
</table>

Challenge with cold end corrosion for straw fired boiler
Conclusion – experience with straw firing in Danish CHP

Resources
There is a surplus of approx. 2 million tons straw per year. However, distance to source and yearly variation in yield might limit further growth in straw fired capacity in Denmark

Main technologies
- grate fired boilers: 100% straw is possible
- co-firing of straw in pulverized coal -fired power plants:
  - approx. 15 % is possible if high -dust SCR deNOx technology is applied
  - approx. 50% is possible in CFB technology is applied
- pulverized fired boilers: 100% straw is possible, if straw is processed in hammer mills for pellets or direct firing. However, 100% straw firing requires either SNCR or low dust SCR and a suitable boiler design for slagging operation of the superheaters

Challenges
- utilization of fly ash
- deNOx technologies
- improvement in bale density
Biomass publication available

Bioenergy for electricity and heat
- experiences from biomass-fired CHP plants in Denmark

2007
Thank you for your attention!