PRESENTATION

• New built biomass plants and retrofits
• Biomass in the firing system
  o Types, systems and preparation
• Biomass in the boiler
  o Corrosion, fouling, designs, geometry
• Biomass in the flue gas cleaning system
  o Catalyst lifetime, fly ash, DeSOx, waste water
• Example plants
  o MSK, HEV, ENV, AVV2
• District heating
• Monitoring and follow-up
2 ‘SMALL-SCALE’ BASIC PROVEN CONCEPTS FOR 100% BIO FUELS MAX~150 MW HEAT INPUT

either
a straw-fired boiler
with possible co-firing of wood-chips up to 50%

or
a chips-fired boiler
with pneumatic spreader
LARGE-SCALE CONCEPT > 150 MW THERMAL - PF FIRING. AVV2

• Combined design, well-proven operation for more than 6 years

Design for USC main boiler:
100% on coal (800 MJ/s)
100% on natural gas
100% on heavy fuel oil (HFO)
70% on biomass
(wood pellets)

USC combined with
2 x 50MW gas turbine
Increased output 150MWe
Total plant efficiency 51%

Plant concept by DONG Energy, visited by delegations during COP15
BIOMASS POWER PLANTS IN DENMARK

Some of the biomass plants Ramboll has engineered:

- **Avedøre 2**, 370 MW/450 MJ/s on wood, 100 MJ/s straw firing (new)
- **Amager 1**, 71 MWe & 250 MJ/s~150 MWe wood and straw (retrofit/semi new)
- **Maribo-Saxkøbing**, 11.4 MW/22.4 MJ/s, straw fired (new)
- **Bio-Ensted 2**, 40MW/47MJ/s, on straw and wood chips, new addition to a central 640 MW coal fired plant, steam cycle coupled
- **Asnæs 2**, a pre-coupled LT-CFB gasifier for straw & wood ~ 5+ MWthermal, experimental
- **Herning** from coal to N-gas to straw/wood chips to wood dust (retrofits)
- **Masnedø**, 8.5/21 MWe/MJ
BIOMASS IN THE FIRING SYSTEM, BASIC CONCEPTS

- Straw stored on a long-term basis with the farmers. Transported on trucks to local barn holding 2-3 days of consumption. Handled by automated crane and storage systems

- Straw and wood chips burned on a grate (smaller plants)
  - Straw bales must be pre-cut before entering the combustion chamber
  - Different options for couplings with a large power plant or stand-alone

- Wood pellets, shipped and stored in a large on-site storage tank. AVV: 100,000 m³, 1,000 m³/hr. Fire and auto ignition observed in the design, fire protection & Atex.

- Wood pellets grinded for PF suspension firing (central plant)
  - Existing coal mills might be used when adequately modified

- Pre-coupled gasifier (LT-CFB) for straw - experimental
STORAGE TANK FOR WOOD PELLETS
100,000 M³ AT 600 T/H – WORLD’S LARGEST

Outer
Wall ~40 m,
12 chain extract
BIOMASS FLEXIBILITY, IN – BOILER OBSERVATIONS

• **Retrofit:** re-use of most of the original construction but consider a re-design of parts where
  • remaining lifetime is too small
  • High Temperature Corrosion (HTC) load will be too high on existing boiler design

• **New constructions:** design of super heaters with
  • low heat flux
  • focus on materials with high HTC resistance
  • non-compact geometry (slagging, fouling, bridging, easy cleaning)
  • additional material (high wear/corrosion) and quick turnaround replacement
  • controlling build-up of a protective fouling layer
BIOMASS AND FLUE GAS CLEANING

• SCR catalyst for DeNOx deactivates faster, in particular with straw firing. Deactivation ~ could be less than 2,000 hrs if uncontrolled.

• Fly ash from straw firing is not easily caught by the ESP – high resistivity = ESP assessment needed.

• Difficult to maintain normal operation on a wet tail end gypsum DeSOx process when firing low-Sulphur biomass.

• Waste water from the tail end wet gypsum DeSOx process may contain inadmissible amounts of Nitrogen (and others).

• Recycling of fly ashes should be considered, avoidance of contamination from fossil ash.
DENOX, HIGH DUST SCR

Fuel → Boiler → SCR → NH₃ → Flue gas → GGH

EXTENDING FLEXIBILITY FOR EXISTING BIOMASS PLANTS
NOVEMBER 2011
AVV1, DENOX ASH DEPOSIT IN A SHORT SOOT BLOWER DOWN TIME
DEACTIVATION OF SCR CATALYST WHEN FIRING BIOMASS

No solid solution – straw is even worse
DIFFERENT SIZES, FUELS AND CONFIGURATIONS
NO SINGLE SOLUTION FITS ALL

- Stand-alone straw-fired decentralized plant
- 11.4 MW + 22.4 MJ/s, grate fired
- Central coal fired plant (89 MW + 174 MJ/s) converted to biomass and other fuels
- Straw and woodchips grate fired plant (40 MW + 47 MJ/s), integrated into a central plant
- New central CHP plant (370 MW + 450 MJ/s) fired on wood pellets (suspension firing) with integrated straw fired (grate) boiler
PLANT I: MARIBO-SAKSKØBING, A STRAW-FIRED BOILER

Prerequisites and design data

- **Operation scheme**
  - 8,000 h/y planned operation
  - 24 h unmanned operation with remote surveillance
  - Power: 10 MW(e) with backpressure turbine
  - Heat: 20.2 MJ/s eq. to 90% of demand from Maribo and Sakskøbing

- **Fuel**
  - 40,000 t/y domestic cereal straw (wheat, barley, rye, grass) supplied as big bales (1.2 x 1.3 x 2.5 m)
  - Storage: Indoor capacity for 2-3 days full plant load. Outdoor by farmers

- **Boiler**
  - 43.2 t/h live steam at 92 bar and 540° C, natural circulation

- **District heating**
  - *Heat storage tank essential* for optimized operation in seasons with lower heat demand (4-5,000 h/y eq. full load)
BIOMASS FIRING, PLANT DYNAMICS

**Issues:**
- Ramping vs. sustained load change
- Load dynamics – Load vs. efficiency sacrifices
- Lifetime – plant and components
- The handles:
  - Steam side (quick response – Ramping)
    - sliding pressure, throttling
    - District heat cut off
    - HP heater cut off
    - Condensate cut off
- All of those impact on the firing and component equipment capabilities
PLANT AND COMPONENT CAPABILITIES INFLUENCING DYNAMICS

- Fuel change and capacity dynamics
- Milling performance can be suffered short term to gain dynamics
- Boiler construction – energy accumulation (speicherfähigkeit)
- Loss of protective combustion chamber layers
- Thermal stress, $\Delta t$ monitoring/controls on critical thick boiler parts
- Feeder step up capacity
- Multifuel plants can make use of excess firing capacity (combined firing)
- Control capacity on critical components dampers, valves etc.
- Advanced C&I in order to keep stable and safe operation during a dynamic operation, the combustion, the steam cycle, emissions control etc.
THE PLANTS: PLANT I: MSK – STRAW-FIRED BOILER
PLANT I: MSK – STRAW-FIRED BOILER

Realized operation scheme

- 4-5,000 h/y eq. full load due to power tariffs
  - Uneconomical operation with low heat demand, i.e. in part load operation
  - Economical operation only when load is >70%, which leads to on/off operation
  - Intermittent operation in spring/autumn season: 1 day on with loading of heat accumulator followed by 1 day off (boiler pressurized for warm start)

- 8 h manned/16 unmanned operation on daily basis

- Performance upgraded by 15% due to higher heat demand
  - Power: 11.3 MW<sub>e</sub> - Heat: 22.8 MJ/s
  - Achieved through utilizing design reserves as well as changes in control system and safety valve settings
  - Live steam now 49.7 t/h live steam still at 92 bar and 542° C
PLANT I: MSK – STRAW-FIRED BOILER
LESSONS LEARNED

- Availability
  - 7,600-7,900 hours per year

- Performance
  - Electrical efficiency: 29% net
  - Energy utilization (with district heating): 89% net

- Fuel logistic
  - Most frequent cause for stop is of bales out of spec dropped by the automatic crane in storage building

- Combustion
  - Homogeneous fuel feed (feed rate, texture, moisture) is essential for efficient combustion with low emissions
  - Design of staged combustion air distribution is essential for efficient combustion with low emissions
PLANT I: MSK – STRAW-FIRED BOILER
LESSONS LEARNED

- Corrosion and fouling
  - Platen type (suspended) superheater banks with appropriate material selection and tube/bank pitch designed for condensation of gaseous alkali ($\text{K}_2\text{SO}_4$, $\text{KCl}$) proved satisfactory. *No replacement of tubes in final superheater stages after more than 11 years of operation*
  - Part of first stage superheater (coil type) replaced after 10 years due to corrosion and wear. Likely caused by higher flue gas temperature than anticipated leading to deposit of sticky fly ash particles on tubes
  - High live steam temperature is possible without excessive corrosion rates
  - Severe corrosion in platen type air preheater. Mild steel and enamelled sheets replaced with stainless steel sheets (254SMO) and inlet air temperature raised
  - Wear observed
    - In fuel feeding tunnels – replaced 2011
    - On furnace side walls from slag moving down the vibration grate – repaired with weld cladding
PLANT I: MSK – STRAW-FIRED BOILER
LESSONS LEARNED

Typical fouling of superheater banks located in top of furnace.

- Potassium chloride KCl
- Potassium sulfate K₂SO₄
PLANT II: HEV - HERNING
A CENTRAL PLANT CONVERTED TO BIOMASS

• Originally commissioned in 1982 as a coal fired CHP plant
  a. 89 MW_e power and 174 MJ/s heat
  b. 425 t/h, 115 bar and 525° C natural circulation boiler

• Converted to 100% natural gas firing in 2000
  a. Performance data maintained

• Rebuild with the addition of wood chip firing in 2002
  a. Installation of wood chip storage and handling facilities
  b. Installation of water cooled vibrating grate under existing furnace
  c. Up to 45% load on wood chip and 100% when added with N-gas

• Rebuild with the addition of PF firing from wood pellets in 2009
  a. 4 gas/oil burners rebuild for biomass-PF/gas/oil firing
  b. Installation of storage, handling and milling facilities for wood pellets
  c. Up to 85% load on max wood chip and when biomass-PF is added
PLANT II: HEV - HERNING
A CENTRAL PLANT CONVERTED TO BIOMASS

1982
100% coal/oil
4 x 2 PF coal/oil burners

2002
100% wood chip/N-gas/oil
Max. 45% wood chip on vibrating grate
3 x 2 N-gas/oil burners
Flue gas recirculation (N-gas)

2000
100% N-gas/oil
4 x 2 N-gas/oil burners
Flue gas recirculation

2009
100% wood chip/pellets/N-gas/oil
Max. 45% wood chip on vibrating grate
Max. 85% biomass
2 x 2 PF wood/N-gas/oil burners
1 x 2 N-gas/oil burners
Flue gas recirculation (N-gas)
PLANT II: HEV - HERNING
A CENTRAL PLANT CONVERTED TO BIOMASS

Lessons learned:
1. Plant performance is maintained
   a. 89 MW\textsubscript{e} power and 174 MJ/s heat
   b. 425 t/h, 115 bar and 525° C
2. CO\textsubscript{2} emission reduced by 325,000 tons/year compared to coal firing
3. NO\textsubscript{x} emission reduced by 45% compared to coal firing
4. Slagging in furnace with combined wood chip and N-gas firing
5. Complex commissioning with mix of several fuels and combustion technologies
6. PF firing of wood pellets still in the learning phase regarding
   a. wood pellets milling technology
   b. correct parameter settings, e.g.
      • fuel-to-air ratio
      • fuel/air velocity in PF piping
      • temperature of PF transport air
   c. PF fuel flow fluctuations from feeding and dosing
   d. design of burner internals for efficient multi-fuel burners
   e. mitigation of fire risk in wood pellets storage and transport systems
AMAGER 1, COPENHAGEN

- CHP – 71 Mwe & 250 MJ/s heat
- (500 t/h steam ~ equivalent to 150 Mwe)
- Front-wall fired
- Fitted into existing building
- HP part 185 bar & 540° C
- Benson boiler
PLANT III: ENV 3 - ENSTED
A CENTRAL PLANT WITH A BIO UNIT

• ENV 3 is a (1979) transcritical central 624 MW coal fired unit

• The BIO unit has,
  a. A grate fired boiler for straw
  b. A specially designed radiative super heater fired with wood chips
  c. The boiler is a Benson boiler with full live steam pressure and temperature. Steam re-heat occurs in the main boiler
  d. Thermal input, 100 MJ/s, Pressure: 210 Bar, Temperature: 510° C
  e. Boiler efficiency: 92%

• The super heater is layered with protective Inconel, welded directly on the tubes to enhance lifetime
PLANT IV: AVV 2. MULTI-FUEL POWER PLANT
BIOMASS IN BOTH MAIN BOILER & GRATE-FIRED SMALL-SCALE BOILER

- AVV 2 - a complex multi-fuel plant
  a. A steam cycle with a main boiler, thermal input 800 MJ/s
  b. The boiler is designed for coal but may be fired as well on oil, Ngas, and wood pellets (suspension)
  c. Gas turbines (2x53 MW) with exhaust boilers for feed water heating; this increases power on the main turbine as well as DH power
  d. A straw-fired (grate) boiler at full steam pressure for additional bio power, thermal input 100 MJ/s; steam re-heat in the main boiler; electrical efficiency around 35%, coupled on the steam side

- Main plant net electrical efficiency 46%, energy utilization 94%
- Supplies district heating to the Copenhagen DH grid, 450-550 MJ/s
- Under strong environmental regulation
- Dynamic operation in a liberalized market
AVV2 FUEL FLEXIBILITY EXAMPLE

Electrical efficiency

Total efficiency %

OperatingHrs/mnth %

Fossil fuel/fuel total %

Avedøre 2, 2005 operations
3 WEEKS OF OPERATION OF AVV 2
FUELS AND PRODUCTS

- Fuel input
- District heating production
- Power from the gas turbines
- Power from the bio boiler
- Steam turbine power from oil
- Steam turbine power from Ngas
- Steam turbine power from wood pellets
POWER PLANT DYNAMICS (AVV 2) (ALSO VALID FOR BIOMASS FIRING)

• Usual control (sliding pressure or throttling)
  o No drying of wood pellets, thus faster mill dynamics

• Shut off district heating
  o Speed (5-10 sec.), lasting (hours, with heat store), amount (max 80 MW), penalty (reduced total efficiency)

• HP pre-heater shut off
  o Speed (30 sec), lasting (inf.), amount (10-30 MWel), penalty (reduced electrical efficiency)

• Condensate build-up in condenser
  o Speed (5-10 sec.), lasting (shortly), amount (10-30 MWel), penalty (reduced electrical efficiency and a later load reduction)
• In Denmark
  o electricity is taxed at the consumer
  o district heating is taxed at the production site, and
  o no tax when DH is made from biomass
  o CO$_2$ reductions are wanted

• DH from biomass is advantageous in Denmark

• To ensure flexible operation, heat accumulators are used to decouple heat and power production
When the production is higher than the consumption, the heat accumulator is charged. The accumulator is discharged when the production is below the consumption.

The atmospheric heat accumulator tank can maintain the static pressure in the district heating network and also function as expansion reservoir.
MONITORING FUELS AND PRODUCTION, KPI MODELS

• On AVV 2, a follow-up on production and fuel consumption is very important/valuable ~ KPI progr.

• For CHP plants a PQ diagram relates Power, Q\text{DH}, and Q\text{input} (a state surface)

• From a computer model this surface and its variations with coolant and DH temperatures (and others) can be determined

• Ramboll is monitoring plants and assess out-of-spec. (Operation – KPI modelling)
MONITORING FUELS AND PRODUCTION

• Due to the complexity of AVV 2
  o 4 different fuels (NGas, wood pellets, coal, oil) that are mixed
  o 3 different process couplings (NGas, coal-wood, oil)
  o 2 gas turbines
  o a biomass boiler
  o district heating production

a special tool (KPI) has been developed in EXCEL/VBA to supplement existing procedures

• The basis is the variation in PQ diagrams due to fuel type/amount, GT, bio-boiler, cooling water and DH temperatures. A PQ diagram contains 600 points and the system manipulates data from 28 diagrams built from approx. 17,000 simulated operation points
MONITORING FUELS AND PRODUCTION

• The KPI tool is to be used both by plant operators and by staff doing production follow-up

• In the KPI-tool you could either

  o display a PQ diagram based on actual operational conditions – changing the conditions will change the PQ diagram data, or

  o go through a month of (verified) operational data and check for deviations in fuel consumptions. Too large deviation will have economic consequences for the plant

• Overall accuracy *within 1%* over the whole load and operating range
POWER PLANT DYNAMICS (AVV 2) (ALSO VALID FOR BIOMASS FIRING)

• Usual control (sliding pressure or throttling)
  o No drying of wood pellets, thus faster mill dynamics 5 %/min 20 MW/min without start of mills

• Shut off district heating
  o Speed (30 sec.), lasting (hours, with heat store), amount (max 80 MW), penalty (reduced total efficiency)

• HP pre-heater shut off
  o Speed (30 sec), lasting (inf.), amount (10-30 MW), penalty (reduced electrical efficiency)

• Condensate stop/build-up in condenser
  o Speed (30 sec.), lasting (shortly), amount (10-40 MW), penalty (reduced electrical efficiency and a later load reduction)
CONCLUSIONS

• Biomasses, and in particular straw types, are variable and difficult fuels.
• It is however possible to use different biomasses for heat and power production equally to coal with the right approach. It just takes some precocious ingenuity and determent investments.
• It requires a deep insight and experience into combustion, materials, processes etc. to be successful.
• Retrofit is normally possible, but can be more of a challenge.
• Some high load parts may require re-design and more frequent replacements, lifetime components may become wear parts.
• The consequences of a conversion of several large scale plants to biomass fuels on climate, economy, electricity prices, fuel market prices etc. are sound, but unpredictable on a scale.
• Total efficiencies when coupled as CHP of is approx. 90%, hence should be the preferred concept if applicable.
THANK YOU FOR YOUR ATTENTION