Large Scale Utilisation of Biomass in Fossil Fired Boilers

By

Erik Gjernes, Hans Henrik Poulsen
& Nicholas Kristensen

Burmeister & Wain Energy A/S
Jægersborg Allé 164
DK 2820 Gentofte
Denmark

www.bwe.dk

Power-Gen Europe 2007
Madrid, Spain

1. Introduction

Biomass for heat and power production has traditionally been used in small boilers where the electrical efficiency is below 30%. Co-firing biomass and fossil fuel is an alternative approach where existing large utility boilers with only minor modifications can utilise 10 to 15% biomass. This scheme ensures low investment costs, high efficiency and fuel flexibility.

The present paper reports three cases were biomass is replacing fossil fuel in the range of 45 to 100% of the total fuel input. The first case, Herningværket, is based on wood chips in combination with natural gas while the next two cases, Avedøre unit 2 and Amager unit 1, are based on the use of biomass pellets. The combustion systems and boilers are now developed to a stage where the fuel mix can go from 100% coal to 100% biomass pellets. This allows for large scale utilisation of biomass in fossil fired boilers.

Today biomass remains dependent on e.g. subsidies, green certificates in order to compete with coal. However, the upcoming costs of CO_2 allowances and carbon capture and storage (CCS) will change this. The following section on fuel properties discusses the CO_2 costs.

2. Fuel properties and CO2 costs

In Table 1 fossil and biomass fuels are compared.

Table **1** *Properties of coal, gas, straw and wood. The fuel prices are 2006 (Danish) values published by the Danish Energy Authority and are without tax and with transport.*

Fuel	LHV	Relative LHV	Density	Moisture	Ash	Price
	MJ/kg	-	Kg/m3	%	% (dry)	€/GJ
Coal	24.1	1.0	850	10	14.4	2.0
Natural gas	48.5	2.0	-	-	-	5.7
Straw bales	14.5	0.6	130	15	5	4.5
Straw pellets	14.5	0.6	600	10	5	6.5
Wood chips	9.5	0.4	250	40	0.5	4.4
Wood pellets	17.5	0.7	650	10	0.5	5.8

Straw bales and wood chips are characterised by a low density so that storage and transport are expensive compared to pellets. Therefore straw bales and wood chips are typically supplied from local satellite storages and are cheaper than the more refined wood and straw pellets. However, the biomass pellets can be used in the existing burners with minor changes, whereas the straw bales or wood chips require installation of a bottom grate system in the boiler.

By processing wood or straw to produce pellets a standardised fuel that can be used in a wide range of applications from small fireplaces in private homes to large heat and/or power plants is obtained. As table 1 shows the wood and straw volume is reduced by a factor of 2.5 to 5 by producing pellets, significantly reducing the cost of transport and storage.

In Denmark Dong Energy A/S operates a pellet production facility with a capacity of 180,000 tons of wood pellets and 110,000 tons of straw pellets per year.

Wood logs are processes in a wood chipper and then grinded to small particles with a size of roughly 2 mm. The moisture content of the fresh wood logs is approximately 40%, and in the facility the wood particles are dried in a closed loop with superheated steam. The dried wood particles are compacted into pellets with a diameter of 8 mm and a length of 25 to 40 mm.

The moisture content in straw bales is so low that no drying is needed. The straw is processed by a hammer mill and the end product is pellets with size and properties similar to those of wood pellets.

The fuel prices in Table 1 have been compiled and issued by the Danish Energy Authority and are valid for Denmark in the year 2006. The prices include transport to the power station but are exclusive of any taxes. Using the lower heating value as the reference, natural gas and biomass are found to be 2 to 3 times more expensive than coal.

Compared to natural gas, the less refined fuels i.e. straw bales and wood chips are less expensive while wood pellets are at the same price level and straw pellets are more expensive.

The use of coal and natural gas will be influenced by CO_2 obligations. Figure 1 shows the consequences of either purchasing CO_2 allowances or installing carbon capture and storage (CCS) facilities. Figure 1 is based on CO_2 emissions of 95 kg CO_2/GJ and 57 kg CO_2/GJ for coal and natural gas, respectively. These emission ratios are based on thermal input.

The EU driver for the price of emitting CO2 emissions is the directive implementing the Kyoto Project Mechanisms. The two main factors are:

1. Establishment of the EU Emissions Trading Scheme (EU-ETS)
2. Submittal of the National Application Plan (NAP) by each member states for each trading period.

The present spot price for a CO_2 Emission Allowance Units (EUA) is less than 1 €/ton CO_2, basically because the Phase I NAPs valid until the end of 2007 easily meet the demand.

Phase II of the EU ETS reduction process starts on January 1, 2008 and runs until 2012. The projected price for Phase II CO_2 Emission Allowance Units (EUA) remains uncertain, but since the release of the Phase National Allocation Plans (NAP) the Dec-2008 forward price has climbed steadily and recently reached 23 €/ton CO_2 as a result of the reduced allocations compared to Phase I. For the purpose of our estimates we assume a range of 15 to 25 €/ton CO_2. Please refer to Figure 1.

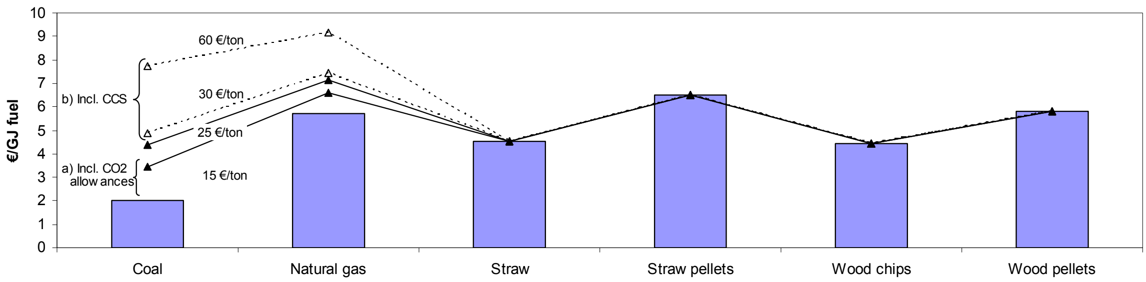

Figure 1 *Fuel price for coal and natural gas are compared with CO2 neutral biomass fuels. The total price for the fossil fuels are shown in the case of*
a) including purchase of allowances for 15 to 25 €/ton CO2
b) including carbon capture and storage(CCS) at a price level of 30 to 60 €/ton CO2.

The current spot price of Phase I EAUs at less than 1 €/ton CO_2 is to small to change the relation between fossil fuels and biomass

Applying a lower EAU price of 15 €/ton for Phase II the cost of firing with coal will increase by 71% and the cost of firing with natural gas will increase by 15%. The cost of natural gas and pellets will come down to less than twice the cost of coal, while the cost of straw bales and wood chips will approach the cost of coal. The cost of natural gas will become slightly higher than that of both straw pellets and wood pellets. In effect an EAU price of 15 €/ton CO_2 will change the position of natural gas compared to biomass, while coal still will be the fuel with the lowest overall cost.

Applying instead the higher EAU price of 25 €/ton for Phase II the cost of firing with coal will increase by 118% and the cost of firing with natural gas will increase by 25%. The cost of natural gas and pellets will come down further compared to coal, while the cost of straw bales and wood chips will be almost identical to the coal cost. The cost of natural gas will become significantly higher than that of both straw pellets and wood pellets. In conclusion an EAU price of 25 €/ton CO_2 will make biomass pellets the cheaper option compared to natural gas. Coal still will be the fuel with the lowest overall cost in this scenario.

An alternative approach is carbon capture and sequestration (CCS), but since the relevant technologies are still in development the cost is rather uncertain. The current best estimate is a cost range from 30 to 60 €/ton CO_2. At 30 €/ton all biomass fuels will have a lower cost than natural gas while straw bales and wood chips will even be a cheaper option than coal. At 60 €/ton coal and gas will be more expensive than any of the biomass variants.

The present gap between the projected cost of CCS and the EAU cost is an obstruction for implementation of CCS. As the technologies are expected to be mature during Phase III of the EU ETS, and as a further reduction of allocations is expected in Phase III this is likely to change the balance..

However, both schemes will increase the cost of using fossil fuels and will make biomass more competitive even at moderate CO_2 costs. Biomass pellets can replace coal in large utility boilers as described below but with the present fuel prices coal will be the cheapest option compared to straw pellets as long as the cost of CO2 is less than 47 €/t, while for wood pellets the break-even is at 40 €/ton CO_2.

For straw bales and wood chips the break-even cost of CO_2 is approximately 25 €/ton. However, due to the need for a special firing system straw bales and wood chips are more likely to compete with natural gas in smaller boilers.

3. Biomass in fossil fired boilers

The following three installations represent large scale utilisation of biomass in units deisgned and supplied by Burmeister & Wain Energy A/S (BWE):

- Herningværket - gas, oil and wood chips
- Avedøre unit 2 - gas, oil and wood pellets
- Amager unit 1 – coal, oil, wood- and straw pellets

Table **2** *Key data for Herningværket (HEV), the USC boiler at Avedøre unit 2 (AVV2) and Amager unit 1 (AMV1).*

Plant		HEV	AVV2	AMV1
Commissioned		1982	2001	2009
Plant size	MWe		400	
	MWe/MJ/s	89/174		71/250
Fuel		Gas/HFO wood chips	Gas/HFO wood pellets	Coal/HFO wood/straw pellets
Fuel input	MJ/s	290	800	350
Max biomass	MJ/s	130	560	350/320
Max biomass	ton/h	49	115	72/79
HP steam	kg/s	118	296	139
	bara	115	305	185
	°C	525	582	562
IP steam	kg/s	-	284	123
	bara	-	64	76
	°C	-	600	540

Table 2 provides key data for the three installations.

Herningværket

Herningværket (Dong Energy A/S, Denmark) was commissioned in 1982 as a coal/oil fired 424 t/h boiler supplied by BWE. In 2000 the boiler was converted to natural gas/oil and in 2002 the combustion system was extended by inclusion of a bottom grate for wood chip firing. The boiler can now be operated in co-firing mode with natural gas/oil and wood and in single mode on gas, oil or wood chips. In the latter case wood chips consumption is up to 130 MJ/s or 49 tons of wood chips per hour as indicated in Table 2.

Figure 2 shows the original as well as the retrofitted combustion system at Herningværket.

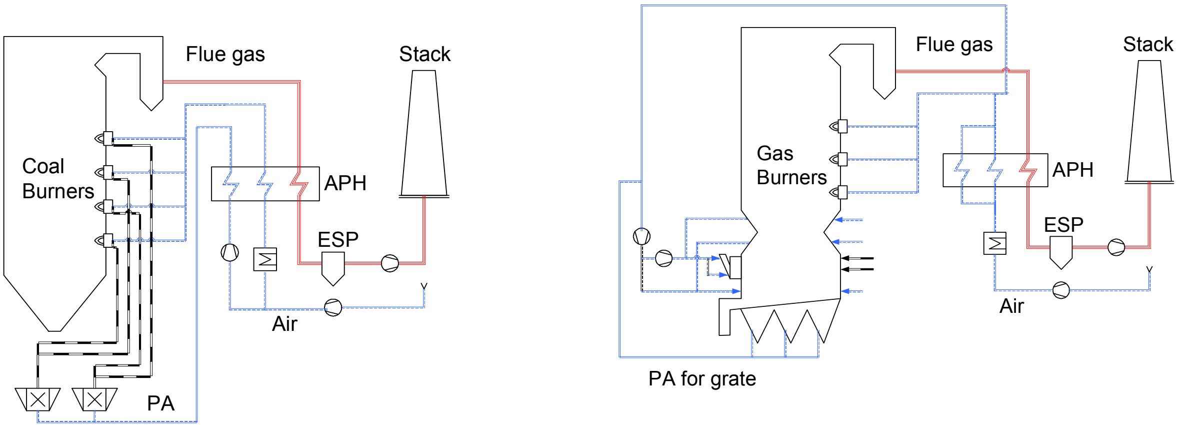

Figure 2 *Herningværket 1982 with coal/oil (left) and retrofitted for wood chips in 2002 (right).*

The biomass system has now been in operation for four years and, in 2006 the annual wood chip consumption reached 263,000 tons. This biomass fuel replaces natural gas and the corresponding CO_2 reduction is more than 140,000 tons. On energy basis biomass represents 70% of the 2006 fuel consumption.

Avedøre unit 2

Avedøre unit 2 (Dong Energy A/S, Denmark) is an advanced multi-fuel unit that includes:

- USC plant: gas, oil and wood pellets (800 MJ/s)
- Biomass plant: straw-fired biomass boiler (105 MJ/s)

- Gas turbines (2 x 50 MWe)

The full load capacity is 570 MWe for power or 545 MJ/s and 485 MWe for heat and power operation (the plant is connected to the Copenhagen area district heating system). Figure 3

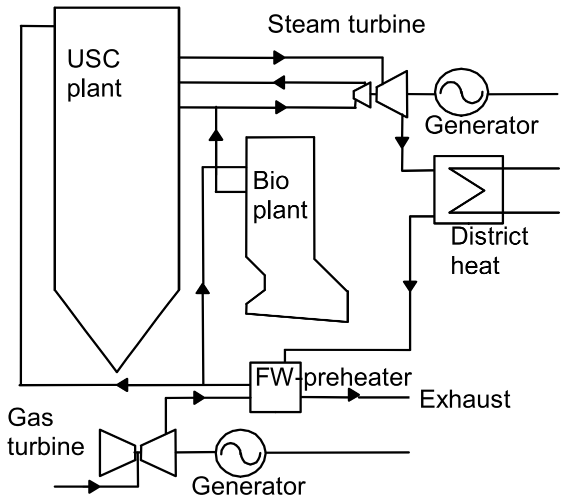

Figure 3 *Schematic view of Avedøre unit 2. The HP-steam from the USC- and biomass-plant are connected and the feed water can be preheated by the gas turbine exhaust gas.*

shows the steam system where the USC boiler and straw fired biomass boiler are connected and that the feed water can be preheated by exhaust gas from the gas turbines.

This discussion will be limited to the USC plant supplied by BWE. The 1.067 t/h corner-fired USC boiler was commissioned in 2001 with oil and natural gas as the base fuels. It was originally designed for coal firing, but as a CO_2 reduction initiative coal was replaced by natural gas during the engineering phase. In 2003 the combustion system was upgraded to include wood pellet facilities while keeping the gas and oil firing capacity unaltered. Three out of the four burner levels, i.e. 12 out of 16 burners were retrofitted for wood dust and the supply included three roller mills, primary air system, and pulverized fuel piping.

At Avedøre the roller mills applied for wood pellet pulverising represent well proven coal milling technology, and the direct firing approach for pneumatic transport of pulverized fuel from the mills to the burners is also a standard PFC solution. The mills are slightly modified for biomass and are operated at cold conditions in order to eliminate the risk of fire.

The maximum wood pellets capacity is equivalent to 70% of the full load fuel input of 800 MJ/s**.** As shown in Table 2 this amounts to 560 MJ/s or 115 ton wood pellets per hour. The yearly pellet consumption is typically in excess of 250,000 tons, or 30% of the annual thermal fuel input. This results in a CO_2 reduction of 250,000 tons per year when wood pellets are replacing natural gas.

Amagerværket, unit 1

This approach is also used at Amagerværket unit 1 (Vattenfall A/S, Denmark), a multi-fuel boiler with a fuel diet of coal, oil, wood or straw pellet. This project is currently in the construction phase. BWE supplies a new 500 t/h Benson boiler that will be fitted inside an existing boiler house. The boiler will be in commercial operation by January 2009. As for Avedøre 2 the biomass supply is based on pellets and a direct type of combustion system. Full load thermal input is 350 MJ/s and this can be maintained either by fossil fuel or biomass.

Due to the slightly lower heating value of straw pellets the maximum capacity with 100% straw pellets is 320 MJ/s. Table 2 shows that the maximum capacities on wood pellets and straw pellets are 79 t/h and 72 t/h, respectively. The somewhat unusual steam parameters are adapted reflects the old steam-based district heating system in central Copenhagen to which the plant is connected.

For the Amagerværket unit 1 project the main measures for proper and safe biomass utilisation are:

- The milling plant uses air for drying and transport; cold air for biomass pellets
- Only one fuel type per mill at any time; i.e. no co-milling
- Load limitations for straw is required avoid slag build-up (due to the low ash softening point for straw firing)
- Increased pitch in tube bundles and limited use of finned tubes in order to avoid slag blocking.
- Enhanced corrosion resistance by the use of austenitic steel in the superheaters.
- Fully enamelled air preheater elements.

The projected yearly consumption of wood and straw pellets is 40,000 and 110,000 tons, respectively. This represents up to 35% of the yearly thermal fuel input, and when replacing coal it represents a CO_2 reduction of 220,000 tons/year.

4. Conclusion

Biomass pellets can be utilised by well proven coal technology. Pellets and coal are milled, pneumatically transported and burned by use of the same equipment. This is a major step towards large scale utilisation of biomass in fossil fired boilers where full fuel flexibility, 100% coal to 100% biomass, can be achieved.

5. References

Erik Gjernes (2006), Fuel Flexibility at Amager Unit 1 using Pulverized Fuels, Power-Gen Europe, May 30 - June 1 2006, Cologne, Germany.

Danish Energy Authoroty, Basis for socioeconomic analyses in the energy sector - January 2007 (only available in Danish)