Avedøre unit 2 - the world's largest biomass-fuelled CHP plant

Since November 2001, the “multi-fuel” CHP plant Avedøre, unit 2 has operated as the main heat source for the Copenhagen district heating system. The CHP plant is one of the world’s most efficient, fuel-flexible and environmentally optimal CHP plants. Fuels like natural gas, bio fuels, such as straw and wood pellets, and heavy fuel-oil can be used with high efficiency. The plant was presented in News from DBDH 1/2004. In the following, we present an update of the experience with utilisation of biomass.

**Avedøre unit 2**
The heart of Avedøre unit 2 is a large USC (ultra super critical) boiler plant originally prepared to burn natural gas and heavy fuel oil. This USC plant consists of two boilers, a steam turbine, two gas turbines, two electrical generators and a flue gas cleaning system.

The CHP unit can operate in pure condensing mode, in pure back pressure mode and in any combination in between. Operating in pure condensing mode, the net electrical efficiency is 48% if it is fuelled with biomass at maximum capacity and 51% if the gas turbines are in operation too. Operating in pure back pressure mode utilizing all the thermal energy in the condensed steam for district heating, the total efficiency is 94%.

The basic idea of the multi-fuel concept is shown in figure 1. Each fuel is burnt separately in combustion systems optimized for the specific fuel in order to achieve maximum efficiency. Therefore the fuels are not blended and burnt in a combined boiler. Straw is burnt separately in a biomass boiler. Natural gas, heavy oil and wood pellets are burnt in the main boiler designed for pulverized fuel (prepared for burning hard coal). Natural gas is used in the two gas turbines which provide peak load electricity generation and which are also used to preheat the feed water to the main boiler via exhaust heat recovery units. The steam output from the boilers is integrated and fed to a single modern high efficiency steam turbine.

**Straw boiler**
The straw boiler is the world’s largest boiler of its kind. The maximal boiler capacity is 100 MW steam at 305 bars. At maximal load the boiler is fuelled with 50 bales of straw every hour (each 500 kg). The plant is capable of burning 150,000 tons straw annually.

**Why utilise bio fuels?**
CHP plants have an estimated lifetime of approx. 40 years, but the conditions – political as well as regards supply – are changing much faster. It is therefore very important to have the necessary fuel flexibility, which ensures that political, economical and environmental requirements can be fulfilled at any time.

Originally the main boiler was designed for burning hard coal, but due to the market conditions and a strong interest in increasing the use of biomass as fuel in the power sector to meet CO₂ emission objectives (the Kyoto Agreement), it was decided to retrofit the plant to burn wood pellets in combination with natural gas. This was fairly simple, as the boiler was designed for using coal dust as fuel, and as wood pellets have many similarities with coal dust regarding combustion and fuel handling. This retrofit consists of three new mills for wood pellets, made as modified coal mills. Also new facilities for storage of pellets and a covered fuel transport system were built.

Only a modest part of the energy content in the biomass is consumed in the process where straw is converted to straw pellets and wood chips are converted to wood pellets. The benefit of this conversion is that the bio pellets can be used in large, dust-fired CHP boilers with high efficiency compared to smaller decentralised units. Therefore it is economically attractive to
convert straw and wood into pellets, when biomass has to be utilised in larger scale.

Wood pellet factory
In the city of Køge – situated 30 km from Copenhagen – the company Energi E2, which is the owner of Avedøre, unit 2, established a bio pellet factory. The factory is situated close to the company Junckers Industri, which – among other products – produces parquet floors and table tops. Waste wood from the processes are utilised for CHP production as well for production of wood pellets.

The production of straw pellets starts with big bales of straw – 500 kg each. Up to 36 pieces of these bales of straw – with water contents up to 15% - are cut into small pieces. After this the straw material is grinded. The grinded straw is converted to pellets by adding steam and, if necessary, binder under pressure. After the cooling process – now with water contents of 10% - the straw pellets are ready for shipping. The annual production is 130,000 tons of straw pellets which are all used at the CHP plant Amager, unit 2 in Copenhagen – owned by Energi E2. In connection with the production of the straw pellets, only 1.5 % of the energy contents in the straw material is consumed by the production of the pellets.

The production of wood pellets is a little bit complicated, as the water contents in the wood chips – used as raw material – have to be reduced from 45% to 10%. To begin with, the wood chips are grinded and dried. The grinded wood chips are converted to pellets under high pressure by adding steam at a temperature of 250°C. A system for waste heat recovery ensures that almost 85% of the energy used for drying the wood chips can be recovered. With that only 6.7% of the energy contests in the wood chips is spent in the process for producing wood pellets. Of this, almost 5% of the energy contests is spent for the drying process. Then the wood chips are converted to pellets – now with water contents of 10% - by adding steam and binder if necessary. After cooling, the wood pellets are ready for shipping. The annual production is 180,000 tons of wood pellets which all are used at the CHP plant Avedøre, unit 2. The remaining amount of wood pellets demanded by Avedøre unit 2, - 120,000 tons annually - is bought at the world market.

Biomass-fired CHP plants
Energi E2 has a long tradition for using biomass as fuel. In 1989, the world’s first straw-fired CHP plant was commissioned in the town of Haslev. Today, Energi E2 also operates straw-fired CHP plants in the towns of Slagelse, Masnede, Ringsted, Køge and Maribo-Sakskebing. These plants consume some 280,000 tonnes of different types of biomass annually.

The experience of operation
Several problems have risen from the incineration of straw pellets at Amager unit 2. The advantage is that the content of carbon in the flue gas is less than 3.5 % which indicates a fine combustion. The disadvantage is that the combustion of straw pellets has caused some coating of the heating surfaces, but the problems are expected to be solved by installing spot blowers in the boiler. Dust handling from combustion of straw is difficult as well.

At Avedøre unit 2, the combustion of wood pellets has caused only minor problems, because the pellets are combusted together with natural gas or heavy fuel oil. It would have been much easier to combust the wood pellets together with coal, but when the plant was designed, the political decision was that coal was not allowed to be used at the plant. One way to solve the problems could be to add coal ash to the wood pellets in order to stabilise the boiler and reduce the wear and tear of the boiler installation.

Summary
At first it sounds like a story about the wise men of Gotham: One takes a heap of wood chips and a heap of straw; grinds the material to almost dust in a hammer mill; and at last – under pressure – makes pellets out of the dust. After this the pellets are shipped to two CHP plants, where they are pulverized. The pellets cannot be utilised directly as fuel at the CHP plants – they have to be pulverized to dust, which can be blown directly into the boiler as coal dust at coal-fired plants.

However, as this article shows, the concept is indeed a sensible one. It is cheaper and more flexible to produce bio pellets which can be utilised in large existing plants than to build new smaller CHP plants where the biomass from the agriculture and forestry industry can be utilised directly. The large CHP plants are much more efficient than the smaller plants, where bales of straw and wood chips can be used directly. Hence the power efficiency at Avedøre unit 2 is almost 50%, while the power efficiency at smaller plants using the biomass directly, is less than 40%.

It is obvious that the increasing demands to fuel flexibility and the increasing need for reduction of the CO₂ emissions will result in an expanding use of biomass in the power and heat sector. The most economical way to meet these demands is to increase the utilisation of biomass in larger CHP plants.

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News from DBDH 3/2005

Annual use of biomass fuels distributed at the eight plants on Sealand (Eastern Denmark).