District heating: a precondition for an acceptable use of low-grade fuels

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Many countries or regions have abundant resources of low-grade fuels, which can be explored locally at a very low cost, using local labour and thus saving import of expensive fuels. Naturally, the use of these fuels for heating has a high priority both for the politicians and for the households. The challenge is how to utilize these fuels in an efficient and environmentally friendly way. This article presents three cases where biomass and coal are utilized with respect regarding the environment.

Low-grade fuels

Some countries, e.g. China, Poland and regions in Russia, have indigenous resources of peat, coal and lignite, which have the highest priority for economical reasons. Many countries have in fact an unattended number of resources of a large variety of CO_2 neutral fuels such as:

- straw, wood chips and wood pellets
- waste from the agricultural and wood processing industry
- waste from households

all of which could be utilised if the technology and the financial resources are available.

Fuels such as straw and other agricultural waste products, wood, peat, lignite, coal and domestic waste are all low-grade compared to fossil fuels such as natural gas and fuel oils. These low-grade fuel types are all relatively difficult to use for combustion compared to natural gas and oil, but they are relative cheap and some of them are CO_2 neutral.

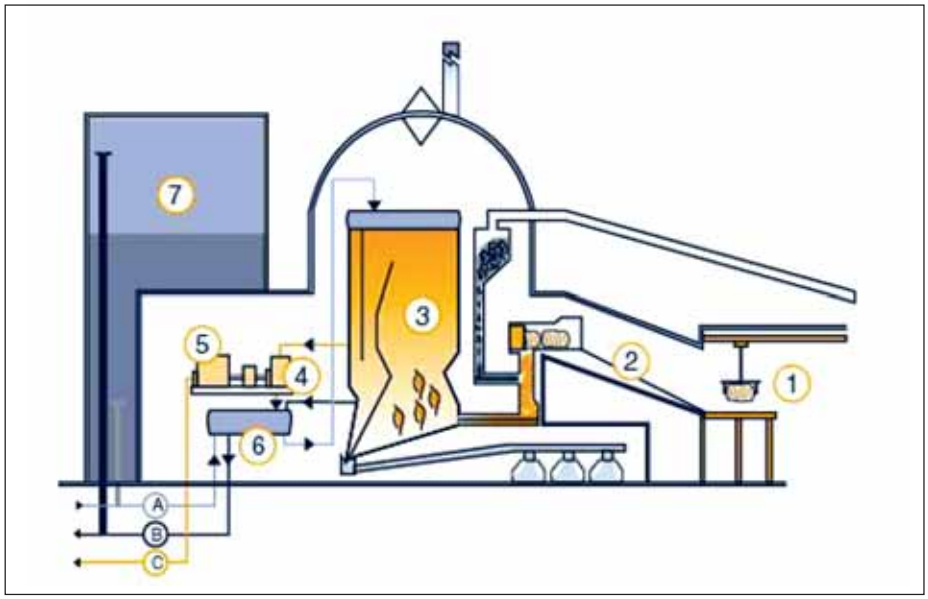
Some of the fuels in individual stoves and small boilers cannot be used in an environmentally safe way; nevertheless, for economic reasons they are still being used in many places. The result is well known:

- a low efficiency
- a large emission of toxic gasses compared to the production
- a high level of emmission (concentration of pollutants in the air) in living areas

In order to use these fuels efficiently and in an environmentally safe manner, it is absolutely necessary to use them in relatively large units (large heat-only boilers or CHP plants for district heating).

In other words: district heating is a precondition for an acceptable use of the low-grade fuels.

Figure 1. 1. Straw storage. 2. Straw transport. 3. Boiler. 4. Turbine. 5. Generator. 6. District heating. 7. Heat accumulator tank.



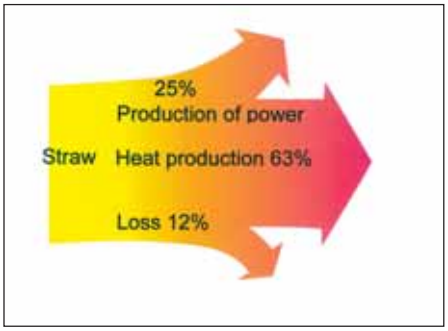


Figure 2. Typical heat flow at Masnedø CHP.

Cases from Denmark

Advanced use of low-grade fuels - biomass and coal - has been taking place in Denmark during many years. For many years now, biomass-fuelled CHP plants have been a common part of the Danish power and district heating supply. The installation of new biomass CHP plants continues steadily and the CHP systems are constantly undergoing a development towards an even higher efficiency.

Case 1

The straw-fired Masnedø CHP plant on the island of Masnedø was commissioned in 1996. It produces electricity for the grid supplying Eastern Denmark and it produces heat for the town of Vordingborg. The plant has a capacity of 8.3 MW electricity and 21 MJ/s heat, corresponding to the electricity consumption of around 18,000 households and about 90% of the district heat consumption in Vordingborg. The straw is supplied by farmers in the surrounding country, who later buy the residual products - bottom ash and fly ash - for fertilising their fields. The plant's annual straw consumption is approx. 40,000 tonnes. Its straw store has a capacity of 2,000 bales, which is sufficient for three days' fuel consumption at full production.

Masnedø CHP plant has a total efficiency of 25% for the production of electricity and 63% for the production of heat. Firing with straw has several environmental benefits as less SO_2 and NO_x are produced during combustion than when fossil fuels such as oil and coal are used.

Figure 1 shows the process diagram for the Masnedø CHP plant.

Case 2

The coal-fired CHP plants Amager unit 3 (AMV3) and Avedøre unit 1 (AVV1) were

put into service in 1989 and 1990. Both units are connected to the district heating transmission system in the Copenhagen region.

The units are highly efficient coal-fired CHP units with a coal dust-fuelled steam boiler and with highly efficient equipment for cleaning the flue gas for SO_2, NO_x and dust. The emissions are significantly below the standards for emission.

The waste products from the flue gas cleaning, mainly gypsum, fly ash and slag are utilised by associated industries. The few percent of the waste products not utilised are deposited in controlled land fills.

The CHP units 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 40%. Operating in pure back-pressure mode utilising all the thermal energy in the condensed steam for district heating, the total efficiency is 90 % (with reference to the lower calorific value). Figure 3 shows the concept of this type of large coal-fired CHP plant.

Case 3

The multi-fuelled CHP plant Avedøre unit 2 (AVV2) started commercial operation in late 2001. The plant is one of the world's most efficient, fuel flexible and environment-friendly CHP plants and can utilise as much as up to 94% of the energy in the fuel. AVV2 has a capacity of 570 MW electricity and 570 MW district heating, corresponding to the power consumption of some 800,000 households and the district heating consumption of approx. 110,000 households.

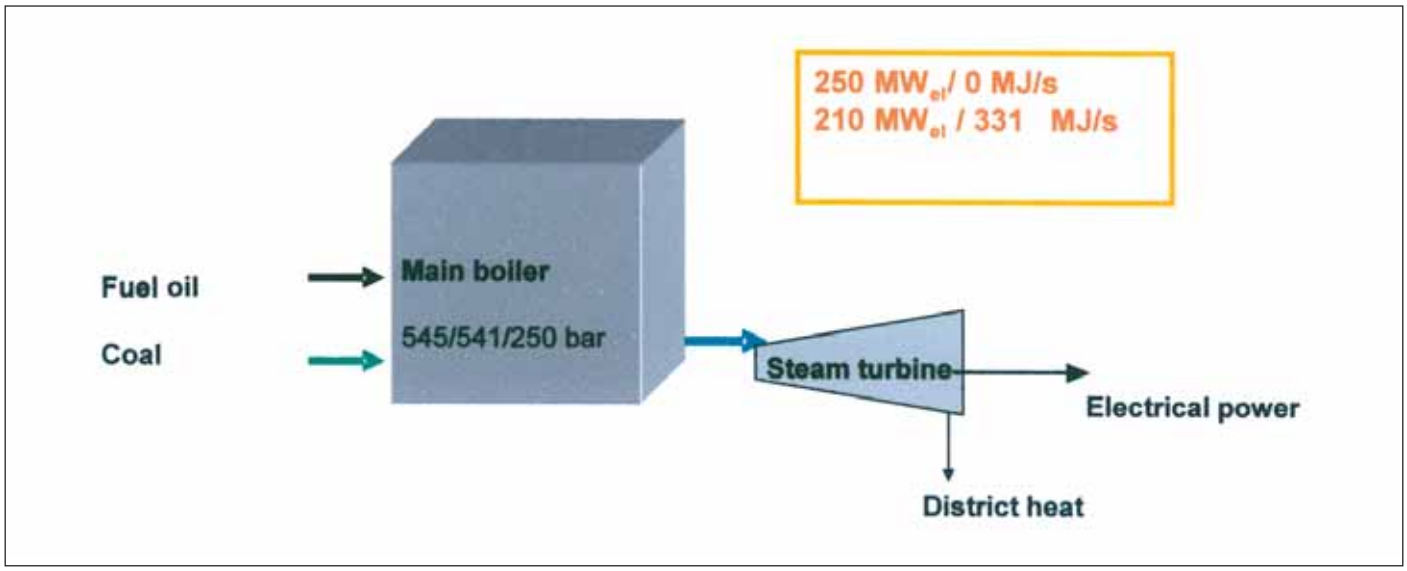


Figure 3. Process diagram for Avedøre unit 1 and Amager unit 3. Live steam data: 545 degr. C, 250 bar.

The plant can efficiently burn natural gas, heavy fuel oil and biofuels, such as straw in bales and wood pellets. The wood pellets are CO_2-neutral and with a total of 300,000 tonnes annually, they will make up almost half of the fuel used at AVV2. The wood pellets will be produced at a factory 20 km from the plant. They are, among other things, made from surplus wood from a manufacturer of hardwood flooring. The wood pellets are shipped from the pellet factory to AVV2's harbour.

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 48-51%. Operating in pure back-pressure mode utilising all the thermal energy in the condensed steam for district heating, the total efficiency is 94 %.

The idea behind the multi-fuel concept is shown in figure 4.

The AVV2 CHP plant comprises several units which, in combination, offer a record-high utilisation of the enrgy in the fuels. Each fuel is burnt seperately in combustion systems optimized for the specific fuel in order to achieve maximum efficiency.

The heart of AVV2 is an approx. 80 m high USC (ultra super critical steam-data) main boiler, originally prepared to burn natural gas and heavy fuel oil. The boiler is prepared for burning hard coal in case gas prices increase. The USC boiler is connected to a 30 m long steam turbine with a generator of 13 m.

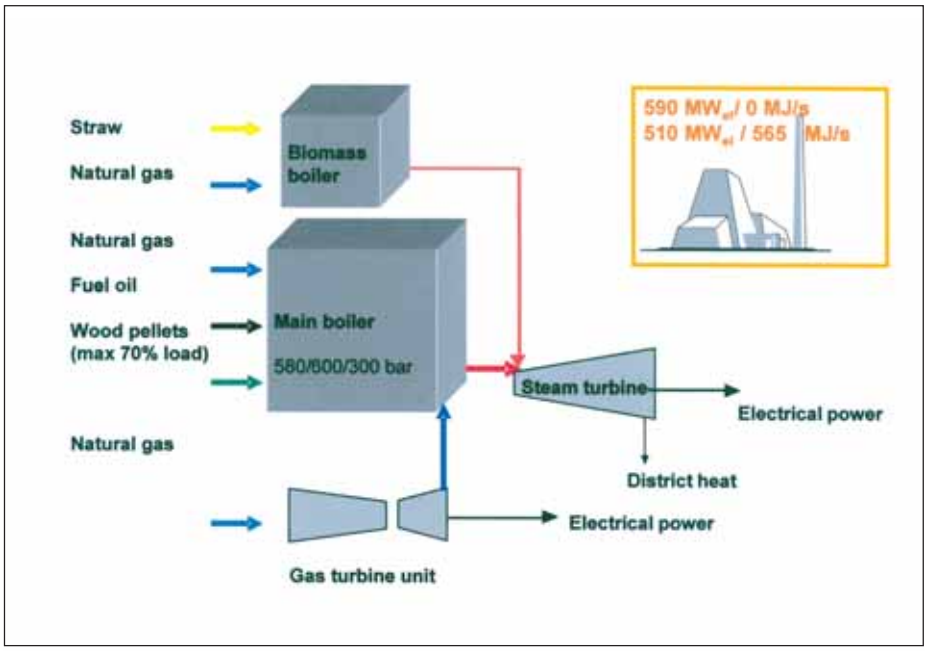


Figure 4. Process diagram for Avedøre unit 2. Live steam data: 580 degr. C, 300 bar.

The main plant is connected to the world's largest straw-fired boiler which supplies the turbine with additional steam. The straw boiler can burn 150,000 tonnes of hour) which constitutes about 10% of AVV2's fuel consumption. The straw is transported to AVV2 from farmers in Eastern Denmark on some 50 lorries a day. The ash from the straw is returned to the fields due to its fertiliser value.

AVV2 is also connected to two separate gas turbines (two modified aeroplane jet engines) each of which operates its generator with a total capacity of 110 MW. The exhaust gasses from the gas turbines are used for auxiliary heating of water in the plant's main boiler which contributes to a record-high efficiency in the electricty production.

Originally the plant was not designed to burn wood pellets, but due to the market conditions and due to a strong interest in increasing the use of biomass in the power sector to meet CO_2 emission objectives, it was decided to retrofit the plant and burn wood pellets in combination with gas. This was fairly simple as the boiler was prepared for coal dust, which bears a lot of similarities to wood pellets when it comes to combustion and fuel handling.

The AVV2 CHP plant is of great importance to achieving the Danish targets in the energy and environmental fields, as the plant replaces 3 old coal-fired power station units in Eastern Denmark. In that way, AVV2 reduces the CO_2-emissions in the East-Danish power sector by approx. 10%. At the same time, emissions of NO_x are reduced by 20% and SO_2 emissions by 30%.

Conclusion

Use of low-grade solid fuels for heating purposes in small furnaces and in small boilers is very problematic. The energy efficiency is low and the emission is high due to the inefficient combustion. Moreover, due to the lack of flue-gas cleaning and emission in low stacks the air quality is severely threatened.

However, with large boilers based on modern technology this is not a problem. The boilers can be designed and operated for perfect combustion of almost any fuel, the flue gas can be cleaned properly, and the cleaned flue gas will be emitted from tall stacks.

In theory, these fuels could be used in large power-only plants supplying the power grid; however, for economical reasons this would be difficult without large subsidies or compensation for CO_2 emission reduction.

Therefore it is vital for a successful use of low-grade indigenous fuels that sufficiently large district heating systems are maintained and developed to use the heat from plants fuelled by the indigenous fuels.

These plants could be heat-only boilers (in case CHP is not an option due to low electricity prices), while the CHP plants could be fuelled by indigenous fuels, and they should operate as base-load plants in the district heating system supplemented by oil boilers for peak and reserve load. The plants should be designed to operate efficiently both at maximal load in winter and at low load in summer.

Avedøre CHP plant. From right to left: coal storage, unit 1, unit 2, and straw storage. Two heat accumulators behind AVV2. (Photo: Energi E2).

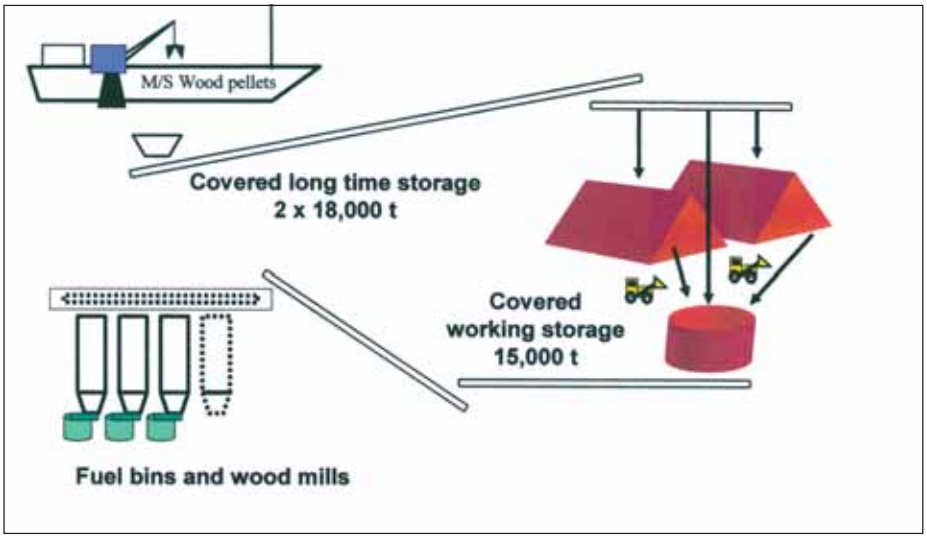


Figure 5. Fuel handling system for wood pellets at AVV2.

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