

Case study:

Straw fired district heating in Thorsager, Denmark

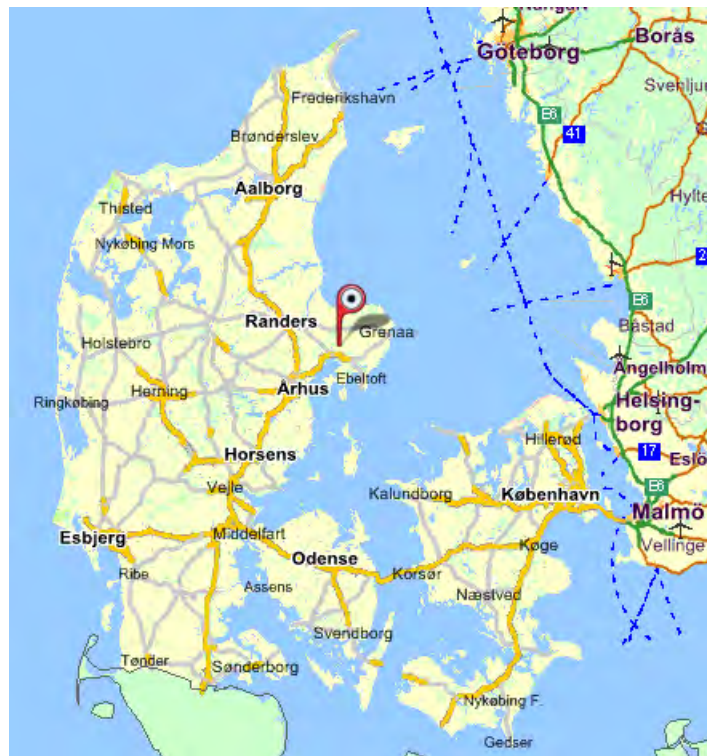
Introduction

For more than 20 years agricultural residues, mainly in the form of straw, have been used for energy generation in Denmark. In farm scale several thousand small scale boilers provide heat for the farm houses, for grain drying etc. In the heating sector straw competes with wood chips, wood pellets and natural gas to supply heat from central boiler installations connected to consumers through district heating networks. And in the larger scale straw is now also being used for power production in combined heat and power plants, either in dedicated straw boilers, or in a mixture with other fuels such as wood or coal.

In the following, we provide a description of one of the straw fired boilers providing heat for district heating systems.

Location

The plant is located in the small town Thorsager near Aarhus in the Eastern part of Jutland in Denmark.



Plant location in Denmark

The climate in Denmark is relatively mild due to the location near the Gulf Stream. Average winter temperature is about 0°C, and summers about 17°C. Due to the need for heating of indoor space for 7-8 months a year and due to relatively high costs for heating based on government taxes on fossil fuels such as heating oil and natural gas for private heating purposes, district heating has developed into a success story in Denmark. Today about 60 % of all homes in the country are hooked up to a district heating network.

The heating plant is located in an area of the town occupied by small commercial businesses and light industry. The nearest neighbor property is 50 m from the property line of the heating plant.

Application

The heating plant in Thorsager is a typical straw fired boiler system for this size range. Heat is supplied into a district heating network, with 384 connected heat consumers that cover most of the town. The boiler plant receives straw from nearby farmers as 500 kg Hesston bales, which are shredded before combustion on a moving grate.

A typical biomass district heating plant in Denmark may have 1000 hookups; the majority would lie between 100 and 10,000 connections.

Plant capacity

The straw boiler has a nominal heat production capacity of 3.15 MW thermal output.

As spare capacity and for peak load heat demand during the coldest periods of winter, an additional oil fired boiler of exactly the same capacity, nominal 3.15 MW thermal output is installed.

A thermal heat storage consisting of a cylindrical water tank can even out load variations on the heat demand side. This way the boiler can be operated under more optimal combustion conditions, and straw fired heat can cover the demand, even when the demand - for shorter periods - exceeds the boiler capacity.

The straw boiler is typical for Danish district heating plants, where the average is about 4 MW thermal output, and where virtually all plant are between 1 and 10 MW.

Fuel type

The main fuel for the district heating plant is agricultural residues in the form of straw from nearby grain producing farms.

Straw is commonly used this way in Denmark, where about 50 district heating plants use straw as a boiler fuel. A total of 236,000 ton of straw is utilized this way; this corresponds to about 22 % of the overall 1.06 million ton of straw used for energy in the country.

Other fuels used in similar plants are wood chips, wood pellets and other wooden residues. A total of 120 district heating plants use solid biomass fuels as the main fuel source.

The straw used in Thorsager could be from any grain production. In practice, about 90 % of the annual consumption is wheat straw; the rest is divided between straw from winter rye, oats and other crops.

Fuel supply system

Straw is supplied by the farmers to the heating plant as Hesston bales, measuring approximately 1.2 x 1.3 x 2.2 meter (h x w x l) and weighing about 500 kg each. More recent bale presses can make more dense bales at up to 750 kg weight with same geometry. The plant can handle such bales; however, none of the farmers supplying straw presently have introduced these newer presses.

Bales are pressed in mobile big bale presses, most often of the brand Hesston, thus the name of the bales. Pressing are done in the field by mobile equipment. Larger farms would own their own press,

but most of the smaller ones would contract an agricultural machinery service company to perform the actual baling.

Storage takes place at the individual farm in a straw barn often erected solely for this purpose. Under roof storage is not exactly a requirement in the delivery contract with the district heating plant, but the requirement to supply dry straw with no soil can be met this way, and experiments with cheaper solutions such as open air storage with plastic covers has been abandoned.

The farmers store the straw from harvest in late summer (August) until it is needed at the heating plant (between September and July the following year).

The 50 farmers who supply straw to the heating plant is organized in a straw supply association, which supplies straw to Thorsager as well as the neighboring town of Rønne. Formally the contract for straw supply is between this association and the district heating company.

The 50 farmers take turns in who supplies first to the plant. One year a farmer will supply all his straw in September, next year moving on to October etc.

The majority of the supply takes place on small farm trailers with a tractor; each load would take between 12 and 26 bales. A few farmers transport the bales on trucks.

Straw consumption

The annual consumption of straw is approximately 2,500 ton.

Fuel reception

Bales are unloaded from the trailers by the heating plant personnel using a fork lift truck equipped with special spikes to catch the bales. The truck is equipped with an on board weighing system that weighs each bale; these data are later on used for settling the payment for the delivery.

Moisture is measured in each bale using a portable spear type moisture detector, which is jabbed into each bale in 3 different positions. If the load seems to be acceptable in terms of moisture, a less rigorous scheme for moisture detection is used; and on the other hand when the first measurements gives rise for suspicion, that the load may be too wet, more measurements are taken.

Each bale must be less than 22 % of total weight moisture content, otherwise it is rejected at reception. Rejection is very rare today, where the farmers have learned the necessary lessons on how to achieve acceptable straw moisture through indoor storage etc.

Onsite storage

The plant can store up to 250 bales, which could cover up to about 10 days during winter, where consumption may be up to 26 bales a day. During summer, where daily consumption may be as low as 5 bales a day, the storage can cover more than a month of operation.



The main straw onsite storage (not covered by the crane) with at total capacity of about 250 bales (125 metric ton)

Fuel transport system

The bales are placed under a unirail crane, which is automatically controlled by call for fuel from the boiler. A sensor on the crane reads the position of bales in the line, pick up a bale and lift it to the feeding line, where transport chains move the bale into the string cutter and further into the shredder.



Bales in line (left) for automatic lift by the crane (top) to the feeding table (centre, in red)

The shredder is manufactured by the Danish company Weiss, who also supplied the boiler and most of the auxiliary systems in the plant.

From the shredder, straw fall in a more or less loose form into a feeding bin, from where it is pushed into the feeding canal, a rectangular 0.3 by 1.0 meter confined space, where the straw form an airtight plug between the furnace and the feeding system. The end of the feeding canal leads the straw directly onto the combustion grate.

The feeding system is protected against backfire with two independent thermostatic water sprinkling systems and a fire gate.

Combustion system

Combustion takes place on an inclining step grate, about 1.2 m wide, and 3.5 to 4 m long.

Primary air for combustion on the grate is blown through the grate from the bottom. Secondary air is blown in from the sides of the furnace above the grate, supplying most of the oxygen needed for the gas phase combustion.

A special system for tertiary air has been fitted in this, and other similar boilers installed during the last few years. All combustion products are drawn through a circular nozzle, where additional combustion air is added while the gases are still very hot, and under turbulent mixing conditions. This way this boiler achieves significantly better combustion with less emissions and higher efficiency than earlier generations. This system was developed by Weiss in co-operation with FORCE Technology.



Furnace and boiler section to the right, and bag filter to the left

Boiler section

After the furnace flue gases are lead into the boiler section, which consist of 5 vertical sections of tubes, flues gas in the tubes, boiler water on the outside. Flue gases leave the boiler section at about 120°C.

Ash deposition in furnace and boiler is an important issue when using agricultural residues as a fuel. The boiler sections are equipped with an automatic cleaning system that blows pressurized air into the pipes in brief shots at set intervals. Further, the furnace and boiler sections have several hatches which give access for manual cleaning.

Flue gas cleaning

Dust in flue gas consists of the fuel ashes carried with the flue gasses through the system as well as aerosols created through nucleation from gaseous mineral compounds in the flue gas.

Coarse particles are mostly removed in the inlet part of the bag filter, where the outer layer functions as a cyclone. The finer particles are then removed in the bag filter, also supplied by Weiss, with 291 individual bag elements and a total surface areal of 345 m². Compared to earlier systems on straw fired boilers, this more recent bag filter has much less load pr. m², and the expected life time for the bags are more than doubled.

The bag filter has a maximum operating temperature of 125°C; if this value is exceeded, a bypass on the flue gas side is opened automatically.

Ash handling

Bottom ash from the grate falls into a wet ash conveyor system.

Fly ash from the bag filter is collected under the filter and transported in a screw conveyor to the bottom ash system, where the two ash fractions are mixed.

The mixed ashes go into a container.

According to national legislation in Denmark, ashes from the combustion of uncontaminated agricultural residues are allowed to be distributed back into farmland. The conditions require analysis of ash samples a couple of times pr. year, and that the farm who takes back the ashes integrate the distribution of the nutrients in his planning for fertilizer use in his fields.

The general principle is that distribution of ashes is allowed in an amount per hectare that corresponds to the ash content in the amount of straw originally harvested from the area.

The main concern behind the rules are trace elements, first of all Cadmium, in the ashes. These compounds originate from the fields, but are recycled in a concentrated form.

Heat storage

A heat storage tank of 1000 m³ is used to even out heat load variations. This way the boiler can be operated under more optimal conditions - partial load is avoided as it is never run at less than 50 % capacity. The tank is filled with boiler water at 98°C (the boiler water is warmer than the water circulated in the street pipelines) and has a total capacity to store 68 MWh of heat. During most weekends, the tank is utilized to full capacity, thus it can often be avoided to run the straw boiler at all when no personnel is available at the plant. During summer, the tank can cover the heat demand in the town for up to 5 days.

The heat storage has improved the efficiency in the plant significantly.

Other equipment

The stack is 27 meter high with two pipes, one for the straw boiler, and one for the oil boiler.

Other equipment includes frequency controlled fans for combustion air and flue gas, a hydraulics system and pressurized air for boiler cleaning

Control and monitoring systems including computers and monitors, and a remote control system, that gives the operator complete control over the plant from his home. The plant is capable of unmanned operation as long as there is fuel in the storage. Alarms go to the operators' mobile phone.

Buildings

The building contains the straw storage, the boiler room, a room for noisy equipment, a control room with electrical and electronic installations, an office with two office work desks, a meeting room (mostly used for board meetings) and a toilets and shower section.



The heating plant with straw storage to the right, boiler building in the center, stack to the left, and the heat storage tank behind

Manning

One operational manager, full time employed, runs virtually all daily operation at the plant: straw reception including weighing and moisture determination, maintenance of boiler and transport equipment, operation and maintenance in the district heating network, reading (remote reading) of heat meters, consumer contact, office work, daily accounting etc. Some of the accounting is performed by an assistant, who comes by a few hours every week. Also during vacation or illness, the manager is substituted by an assistant.

District heating system

The whole system consists of two parallel pipes, one for forwarding the hot water from the central, and one for return water after cooling at the consumers. The forwarding temperature is 75°C all year round, while the return line is about 35°C during winter and 45°C during summer.

The district heating pipeline system consists of 9.2 km double main street pipelines, and 6.0 km connection pipes (double) to the consumers. Most inner pipes are made of steel, preinsulated and with an outer lining of plastic. In smaller dimensions, and for all hookup lines, plastic inner pipes (PEX) are used, also preinsulated.

There are 384 metering points, where the heat consumption in the house is measured. The meters include a radio transmitter and are read remotely by the plant operator 3-4 times a year.

Most consumers are private households. Thorsager does not have much business and industry, and few of these are connected to the system. The largest individual consumer is the school, which takes up about 350 MWh a year, second is the local grocery store at about 40 MWh a year. Most individual homes are detached houses in the 100 to 150 m² range and would typically take 12-25 MWh. Only a

few hookups are attached houses or apartments. Roughly 90 % of the heat demand is used by private homes.

This picture is fairly normal for Danish conditions, where most district heat plants have the majority of hook-ups as private homes, say 9 out of 10. The last 10 % of hook-ups is larger buildings like the town hall, schools, sports complex and other public buildings. Commercial sector (shops, smaller service businesses) often count relatively little, and proper industries are rarely an important part of the heat demand in district heating in Denmark.

Heat losses in the district heating system in Thorsager account to a total of 33 % of the heat produced at the district heating plant. This may seem like a high figure, and other systems in Denmark actually perform better, down to 20 % or even 15 % for the very best. The heat losses are very dependent on the how close the heat consumers are to each other and how big the consumption is in each hookup. In this context Thorsager is a widespread town with long pipeline length as compared to heat sales.

A continuous effort is ongoing to lower the losses. Return water temperature is lowered by installing more heating surface (radiators) in the homes that have too high return water temperature. Pipelines are replaced with new ones with better insulation. Temperatures in the system are monitored at all times, and lowered whenever possible. Leaks are investigated and repaired. Correct metering is tested.

Ownership and economic strategy

The district heating plant and the district heating pipeline system is owned and operated by a private entity owned by the heat consumers. The legal organization is co-operative society, but the liability of the individual consumers is limited.

The municipality guarantees for loans taken by the company.

The company is lead by an annual general assembly, where the board is elected. The 6 person board is then responsible for employment of the plant manager and any assistance required, for the annual accounting, for budget and tariffs, and for the strategic development including investments in new equipment.

The purpose of the company is to supply heat to connected consumers in Thorsager on a non-profit basis. The company will need to seek optimized solutions for the production and distribution of heat, which is the background for choosing straw as a fuel. Danish legislation protects consumers connected to a monopoly supply system, and the company is simply not allowed to make a profit.

Tariffs for connection fees and heat costs are settled annually based on a budget for the costs for straw, financial costs, manning costs etc. at the plant for the following year.

Heat tariff

Initially the company settled the tariff solely on the consumption of heat. This lead to high variable cost for the consumers, so some where inclined to take up individual wood heating. At the same time the plant was very sensitive to seasonal variations in climate: in a warm heating season there were simply insufficient income to pay the fixed costs for finance, manning etc. at the plant.

Today the tariff consists more or less equally of a variable element dependent on the metered heat consumption, and a fixed element which is independent of consumption. A few has complained, but generally, consumers accept the necessity of this tariff structure, and are satisfied as long as the total heating bill is lower than comparable heating by oil (which is always the case).

Investment

The first straw plant was installed in Thorsager in 1989. At that time, the investment was 20 million DKK (4.3 million CAD; exchange rate: 1 DKK = 0.21 CAD, November 2009), which included the straw fired boiler plant including storage, buildings etc. and the complete district heating system.

Government support was granted for the first investment back then in the order of 15 % of the investment.

When the new plant was installed in 2007, the total investment in boilers, new building, new storage and the heat storage tank - but exclusive of the district heating system - was 15 million DKK (3.2 million CAD). There were no subsidies given for the new plant, however the loans were again guaranteed by the municipality at favorable conditions.

Straw price

The present straw price is 550 DKK (117 CAD) pr. metric ton, recently up from 420 DKK (90 CAD), a level maintained almost constant for 20 years.

The straw price is the same independent of moisture content between 14 and 17.9 %. Outside these limits a compensation or deduction is made for drier or more moist straw.

The price actually paid to the farmer varies over the season. The basic price above applies in January. For earlier deliveries the price is slightly lower, and for later deliveries slightly higher. This is to compensate the farmer for his costs with straw storage.

Economic performance

An indirect subsidy element exist in the high energy taxes and carbon-dioxide taxes on fossil fuels (heating oil and natural gas) for heating in private homes in Denmark. As the alternative costs are artificially high, the consumers are prepared to pay a relatively high price for heat supply from the straw fired district heating plant.

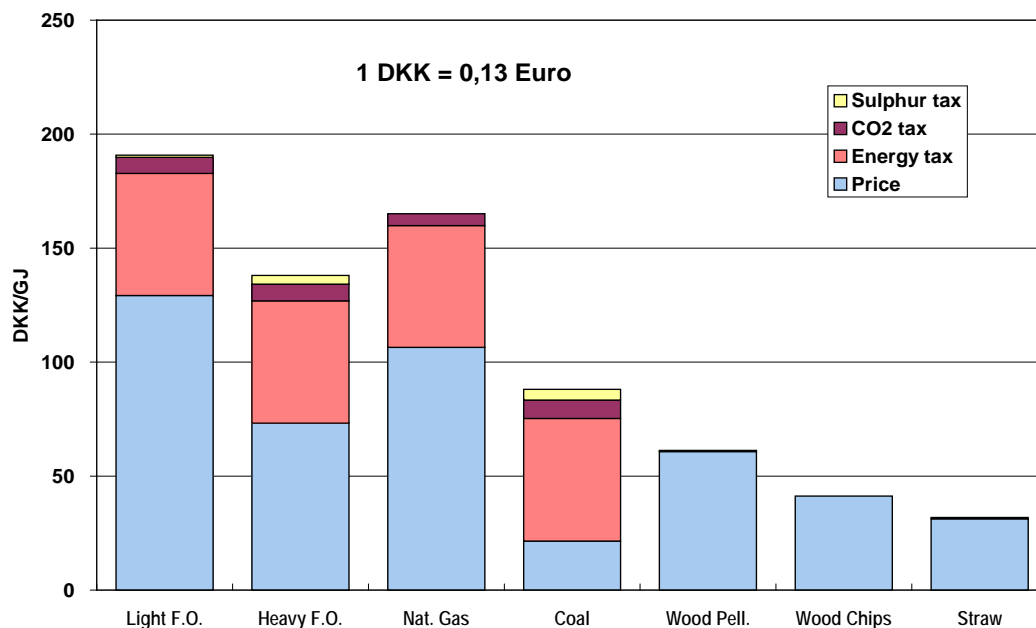


Illustration of costs for fuels in Denmark, including the heavy energy and carbondioxide taxes on natural gas, fuel oil and coal. There are no such taxes on solid biomass fuels.

A rough annual operational budget is:

Straw procurement	1.25 mio. DKK	0.27 mio. CAD
Manning	0.50 mio. DKK	0.11 mio. CAD
Operation and maintenance	0.25 mio. DKK	0.05 mio. CAD
Power, water and chemicals	0.16 mio. DKK	0.03 mio. CAD
Administration	0.26 mio. DKK	0.06 mio. CAD

Interest payment on loans	0.58 mio. DKK	0.12 mio. CAD
Depreciation on investments	2.10 mio. DKK	0.45 mio. CAD
Total	5.10 mio. DKK	1.09 mio. CAD

Income from heat sales and fixed tariff elements balance the annual costs.

As a consequence of the non-profit principle set out in legislation for heat supply, the plant is in principle not allowed to make a profit. In practice some years may provide a small margin which is then paid back to consumers through reduced tariff the following year.

Environmental performance

According to the environmental approval, the stack emission of dust is not allowed to exceed 40 mg pr. normal m³ at 10 % reference oxygen level in flue gas.

Regular measurement during the past few years document this limiting value met at all times.

The plant does not have other limitations on emissions such as CO or NO_x. This is due to the relatively small size of the plant; for plants above 5 MW such limits normally apply.

The environmental approval for the plant includes a limit for noise, 40 dB at property border line during night time. During the engineering phase it was decided to put fans and compressors in a separate sound insulated room within the plant. There are no problems, neither with reaching the set limit, nor with complaints from neighbors.

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