8. CHP- and Power Plants

In 1986, the Danish Government entered into an energy policy agreement including, e.g., that decentralised CHP plants with a total power output of 450 MW fired with domestic fuels like straw, wood, waste, biogas, and natural gas shall be constructed up to 1995. In 1990, the government entered into another agreement on increased use of natural gas and biofuels, primarily by constructing new CHP plants and converting the existing coal- and oil-fired district heating plants to natural gas and biomass-based CHP production.


photo: burmeister & wain energi

Masnedø Kraftvarmeværk (CHP plant) was started up in 1996 and consumes approx. 40,000 tonnes of straw per annum. In addition, an amount of approx. 8,000 tonnes of wood chips is consumed.

CHP Plant Principle

At a traditional coal-fired power plant (condensation), 40-45% of the energy input is converted into electrical power. The remaining energy is not utilised. It vanishes with the hot flue gas from the boiler through the chimney into thin air and with the cooling water out into the sea (see Figure 20).

At a CHP plant, electrical power is generated in the same way as at a power plant, but instead of discharging the condensation heat from the steam together with the cooling water into the sea, the steam is cooled by means of the recycling water from a district heating distribution net which in turn is heated.

The advantages of a CHP plant is, e.g., that is does not require sea water for cooling and can therefore be located near large towns (decentralised) where there is a sufficiently great requirement for district heating and a distribution net. Another advantage is that the energy generated by the fuel can be utilised up to 85-90% (see Figure 20).

On the other hand, it is not possible to at a CHP plant together with district heating production achieve as high electrical power efficiency, i.e., the ratio between the electrical power generated and the energy input, as that of a power plant. The electrical power efficiency for a straw-fired plant is 20-30%.

By operating a CHP plant, the annual electrical power efficiency (on average over a year) is not necessarily an expression of what is technically possible. Requirements in respect of process steam supply, priority of district heating supply, and electrical power generation according to certain tariffs result in a lower efficiency than the full-load electrical power efficiency. See Table 6.

At the CHP plant, it is possible to with certain limits regulate the turbine so that the ratio between electrical power and heat production is changed, but in principle, the greater heating requirement the more steam can be cooled by the district heating water, and the more steam can be produced by the boiler with the subsequently greater electrical power generation. At a power plant, there is not this dependence, since there is always sufficient cooling capacity in the sea. In order to make the electrical power generation at a CHP plant more independent of the district heating requirement, all plants are equipped with a storage tank where the condensation heat can be stored when the district heating requirement is low.

Combined heat and power production is given high priority in Denmark, also when it comes to power

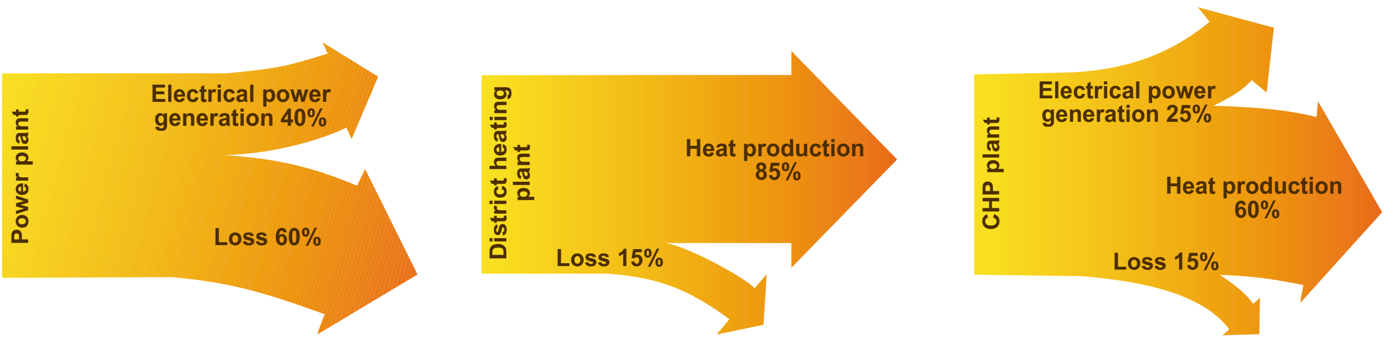


Figure 20: By separate electrical power generation and heat production at a power plant and a district heating plant, the losses are much larger than by combined heat and power production at a CHP plant. Losses include own consumption at the plant

	Rudkøbing	Haslev	Slagelse	Masnedø	Grenå	Måbjerg	Maribo/ Sakskøbing
Electrical power output (net)	2.3 MW	5.0 MW	11.7 MW	8.3 MW	18.6 MW	28 MW	9.3 MW
Heat output	7.0 MJ/s	13.0 MJ/s	28.0 MJ/s	20.8 MJ/s	60.0 MJ/s	67 MJ/s	20.3 MJ/s
Full load electrical efficiency (net)	21%	23%	27%	26%	18%	27%	29%
Electrical efficiency per annum	17%	17%	22%	23%	14%	20%	26%

Table 6: Electrical power output, heat output, and electrical power efficiency for the seven decentralised CHP plants. As explained in the text, the annual electrical power efficiency is lower than the efficiency at full load. The annual electrical power efficiency is calculated on the basis of production figures for 1997 except for Maribo/Sakskøbing that is an estimated figure. The high figures for Slagelse are caused by the fact that the steam from the waste boiler plant is not included in the boiler loss. The low figures for Grenaa Kraftvarmeværk (CHP plant) are caused by supplies of process steam for industrial purposes. All figures stated are net figures, i.e., the plant's own consumption of electrical power has been deducted. See also Table 7.

plants located near large cities like Copenhagen, Aarhus, Aalborg, Odense and others. At these power plants, part of the loss of approx. 60% as shown in Figure 20 is utilised for district heating production.

The six straw-fired decentralised CHP plants that are already in operation and the planned plant in Maribo/Sakskøbing are all based on the CHP principle described. As the plants are partly constructed as demonstration plants for the purpose of demonstrating the straw-based technologies, they are rather different in construction design. Comparable data on the seven plants appear from Tables 6, 7, 8, and 9.

Rudkøbing, Haslev, Slagelse, Masnedø, and Maribo/Sakskøbing

The CHP plants in Haslev and Rudkøbing were started up in 1989 and 1990 and are Denmark's and probably the world's first electrical power generating plants exclusively fired with straw. The plant at Masnedø near Vordingborg that was started up in 1996 is also exclusively straw-fired, but at the same time designed for wood chips up to 20% of the total input. The plant near Maribo/Sakskøbing is planned to start up at the beginning of the year 2000 and is exclusively straw-fired.

The plants are owned and run by the electrical power companies: I/S Sjællandske Kraftværker, SK Energi, and I/S Fynsværket. The electricity generated is supplied to the public utility companies' main distribution network, and the heat is supplied to the district heating systems of the towns.

Size of Plant

The outputs at the plants of Rudkøbing, Haslev, and Masnedø are: 2.3, 5, and 8.3 MW electrical power (MW electricity). With a heat output of 7.0, 13, and 20.8 MJ/s respectively, the annual consumption of straw is approx. 12,500, 25,000, and 40,000 tonnes. Electrical output and heat output

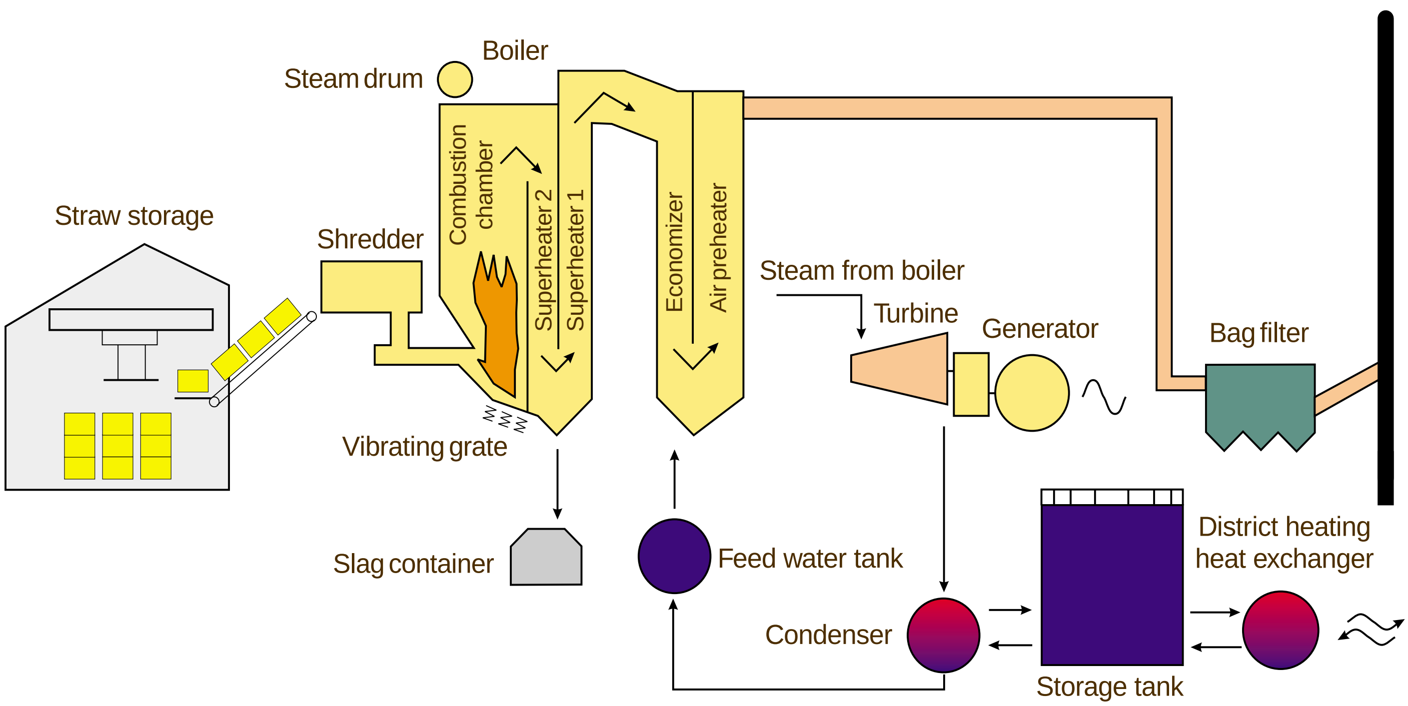


Figure 21. Simplified diagram of Rudkøbing Kraftvarmeværk (CHP plant). The flue gas passes through the combustion chamber to the superheater section and further through an economiser and air preheater and is cleaned in a bag filter before being released through the chimney at 110°C.

are net figures, i.e., the plants' own consumption of electrical power and heat are deducted.

As the plant in Slagelse is a combination between a waste-fired and a straw-fired boiler that produces steam for the same turbine, the data in Tables 6 and 7 for the entire plant are 11.7 MW electrical power and 28 MJ/s heat, respectively. An amount of 65-70% of the production output is based on straw which is equal to an annual consumption of straw of approx. 25,000 tonnes.

The plant near Maribo/Sakskøbing is designed for an electrical power output of 9.3 MW and a heat production of 20.3 MJ/s. The annual consumption of straw is approx. 40,000 tonnes.

Firing and Combustion System
At the plant in Slagelse, two automatic cranes handle the transport of the big bales from the rows in the storage to three parallel feeding system. The bales are passed via a closed fireproof tunnel system (that prevents a possible backfire/burn-back from spreading to the straw storage) towards the straw shredder of the same type as that used at Grenaa Kraftvarmeværk (CHP plant). The strings that hold the bales together are automatically cut and removed.

The shredder consists of three rotating cylinders positioned above each other equipped with kind of a disc separator. The loose straw falls off the shredder on to a rotary valve and from there to the screw stokers which for each of the three firing systems consist of three screws. The screw stokers press the straw through the feeding tunnel on to the grate that consists of an inclined movable push grate followed by a short horizontal push grate. After burning out, the ash/slag falls via a slag hopper into a slag bath filled with water from where a conveyor system conveys the wet ash/slag to containers.

At Rudkøbing Kraftvarmeværk (CHP plant) with a firing capacity of 10.7 MW, only one firing system is required. After shredding, the straw falls down into a stoker system consisting of one single rectangular ram stoker that by forward and backward movements pushes the straw through a water-cooled feeding tunnel on to the

Data	Unit	Rudkøbing	Haslev	Slagelse[3)]	Masnedø	Grenå	Måbjerg[1)]	Maribo Sakskøbing
Electrical power (net)	MW	2.3	5.0	11.7[4)]	8.3	18.6	28[2)]	9.3
Heat output	MJ/s	7.0	13	28[4)]	20.8	60.0[5)]	67[2)]	20.3
Steam pressure	bar	60	67	67	92	92	67	93
Steam temp.	°C	450	450	450	522	505	410/520	542
Max. Steam flow	tonnes/h	13.9	26	40.5	43.2	104	125	43.2
Storage tank	m^3	2,500	3,200	3.500	5,000	4,000	5,000	5,600
Flue gas flow, max.	kg/s	6.8	9.9	13.4	14	39	71	14
Flue gas temp.	°C	110	120	120	120	135	110	110
Straw storage	tonnes	350	350	550	1,000	1,100	432	1,000
Straw consumption	tonnes/year	12,500	25,000	25,000	40,000	55,000	35,000	40,000
Water content, straw	%	10-25	10-25	10-25	max 25	10-23	10-25	max 25
Filter type		Bag filter	Bag filter	Elec. filter	Elec. filter	Elec. filter	Bag filter	Bag filter
Firing system		Shredded/ stoker	Cigar burner	Shredded/ stoker	Shredded/ stoker	Shredded/ pneumatic	Cigar burner	Shredded/ stoker
Boiler plant costs	DKK	64 mill.	100 mill.	140[6)] mill.	240 mill.	365 mill.	600 mill.	240 mill.
Started up	year	1990	1989	1990	1996	1992	1993	2000
Specific 1995-price[7)]	DKK/MW_{el}	30 mill.	23 mill.	21 mill.	28 mill.	21 mill.	22 mill.	23 mill.

1): The plant consists of two waste-fired and one straw/wood chips-fired boiler that produces steam for the same turbine.
2): Data are the total production output of electrical power and heat of the straw/wood chips- and the waste-fired boilers of which the straw/wood chips-fired boiler produces approx. 27%.
3):The plant consists of a waste-fired and a straw-fired boiler that produces steam for the same turbine.
4): Data are the total production of electrical power and heat of the straw- and waste-fired boilers of which the straw-fired boiler generates/produces approx. 66%.
5): Distributed between district heating (max. 32 MJ/s) and process steam (max. 53 MJ/s).
6): The cost of construction only for the straw-boiler.
7): The specific price is only normative, since it varies how much the cost of construction shall include. As a comparison with other types of CHP plants, it should be informed that here the net output has formed the basis of the calculation of the specific price and not the gross electrical power output (gross figures include own consumption at the plant).

Table 7: Data for the seven straw-fired, decentralised CHP plants.

grate. By means of the ram stoker movements, the straw is pressed together in the feeding tunnel to a gas-proof plug that prevents backfire/burn-back. The straw burns out on a vibrating grate, and the ash/slag falls into a water-cooled slag bath from where it passes to the container.

At Haslev Kraftvarmeværk (CHP plant), the big bales are fired without shredding in four parallel cigar burner systems. The cigar burner is described under Section 7 on district heating plants.

At Masnedø Kraftvarmeværk (CHP plant), the straw is stored and handled to the firing system via crane and feeding lines. A completely new system has been developed for the feeding of the straw whereby the straw bale is pushed against two vertical screws which by means of their rotation shred the straw and pass it to a horizontal set of screw stokers that by means of counter rotation press the straw into the form of a gas-proof plug through an almost rectangular feeding tunnel and then on to the grate. With two of these systems, the plant is capable of at full load consuming 19 big bales, equal to 10 tonnes of straw, per hour. Each of the two firing systems have been designed so as to be fed wood chips simultaneously with the straw. Preliminary experiments show that the wood chips can make out up to 40% of the overall energy input. The plant has been designed for 20% wood chips.

photo: weiss a/s

A water tube boiler of a CHP plant is being welded. The tubes are equipped with small longitudinal fins so that they can be welded together to a gas-proof wall making out the sides, top and bottom of the boiler.

Ash and Slag Handling

At all plants, the slag and ash from the bottom of the boiler are separated from the fly ash from the filter. The slag and ash from the bottom of the boiler are returned to the farmer so as to be applied as a manure/fertiliser supplement whereas the fly ash due to its too high content of heavy metals may either be deposited on a controlled waste disposal site or be used for mixing with fertilisers. For further details, see under Section 11 “Residual Products”.

Boiler Output, Steam Data, and Heat Storage

All the boilers are water tube boilers with steam drum and natural circulation in the vaporiser system. For reasons of plant efficiency, it is necessary with a high electrical power generation. This preconditions a high steam pressure and steam temperature. In order for the boiler to withstand the high pressure, the boiler water passes through water/steam tubes that make out the walls (and top and bottom) of the boiler. From the steam drum where water and steam are separated, the steam passes to the superheaters which, e.g., can be clustered either like festoons vertically from the ceiling or be set in vertical banks of pipes in independent superheater passes after the combustion chamber. After the superheater passes, there is a pass with the economiser and the air preheater where the feed water and combustion air are heated. Due to the relative high content of alkali metals in the straw ash (potassium and sodium) and chlorine, the flue gas is corrosive, particularly at high temperatures (above 450°C), and thus as a consequence of the low ash temperature of fusion, the ash particles may cause slagging problems in the boiler. If the slag becomes solid and viscid, it is difficult to remove during operating and will obstruct the heat transfer from the flue gas to the steam in the tubes, and in severe cases, it may shut off the free movement of the flue gas to an extent that the negative pressure and thus the load on the boiler cannot be maintained. At the plants in Haslev, Slagelse, and Rudkøbing, it has been tried to avoid these problems by limiting the superheater temperature to a maximum of 450°C. In Haslev and Slagelse, this has been done by pulling the superheater sections that far back in the boiler system that the flue gas temperature is reduced to approx. 650-700°C before its contact with the first superheater section.

At Masnedø Kraftvarmeværk (CHP plant), the steam temperature has been increased to 522°C as an experiment. As mentioned, the higher temperature increases the risk of heavy corrosion and slagging problems. The superheater and the top of the boiler is therefore constructed so that it is relatively easy to replace possible corroded superheater tubes.

Other fuels	Unit	Masnedø	Grenå	Måbjerg	Slagelse
Waste	tonnes/year	-	-	150,000	20,000
Coal	tonnes/year	-	40,000	-	-
Gas	Nm^3/year	-	-	4 million	-
Wood chips	tonnes/year	8,000	-	25,000	-

Table 8: Four of the plants are designed for co-firing with other fuels.

At the planned CHP plant in Maribo/Sakskøbing that will be started up at the beginning of the year 2000, the steam temperature will be designed to 542°C. A range of experiments will show how serious the corrosion problems will be.

The prospects for Danish trade and industry gaining a foothold in foreign markets with straw-fired CHP plants preconditions high electrical power efficiencies and thus high steam data in the range of 580°C as at the most recently constructed pulverised coal-fired power plants. At temperatures that high, it will, in addition to the problems in connection with corrosion and slag deposits, also be necessary to equip the plant with turbines of a different and more expensive quality than that previously used on the CHP plants described in the above sections.

Grenaa and Maabjerg

The CHP plants in Grenaa and Maabjerg near Holstebro are owned and run by the electricity utility companies I/S Midtkraft and I/S Vestkraft.

The Grenaa plant was started up in 1992, and the plant in Maabjerg in 1993. Both plants are designed for firing with combinations of straw and other fuels.

The CHP Plant in Grenaa
The CHP plant in Grenaa is coal- and straw-fired, and in addition to electrical power, it shall together with a municipality run refuse incineration plant, and waste heat from the industrial enterprises nearby, cover 90% of the district heating consumption in Grenaa and 90% of the process steam consumption by the industrial enterprise Danisco Paper. As from 1997, the industrial steam system is developed so as to also cover the process steam consumption by Danisco Distillers. So far being the only biomass-fired plant in Denmark, the boiler type used in Grenaa is designed as a circulating fluidized bed system.

Fluidized Bed
A fluidized bed boiler consists of a cylindrical vertically set combustion chamber where air passes through the solid particles consisting of fuel and a fluidizing medium, e.g., sand, thereby fluidizing the mixture (the bed) and thus attain properties as a liquid.

An advantage of the fluidized bed boiler is that it is suitable for firing with co-fuels.

The fluidized bed principle is seen in a variety of types, but roughly there are two main principles:

- Bubbling fluidized bed (BFB)
- Circulating fluidized bed (CFB)

The boiler in Grenaa is a circulating fluidized bed type. From the fluidized bed section, the heated flue gas circulates together with solid particles into an separator cyclone where the solid particles are extracted and re-circulated in the fluidized bed. The flue gas passes from the cyclone to a pass where the economiser and air preheater are positioned. Between the cyclone outlet and the economiser, the flue gas passes 2 tube sections which together with a bank of pipes in the bed itself make out the superheater. In 1996, the superheater was extended with a section positioned in the ash re-circulation system.

Handling and Firing System

At the CHP plant in Grenaa as with the other plants, the straw is delivered in the form of big bales. With an annual supply of 55,000 tonnes of straw, it has been necessary to automate weighing and measuring of the water content on delivery to the plant. An

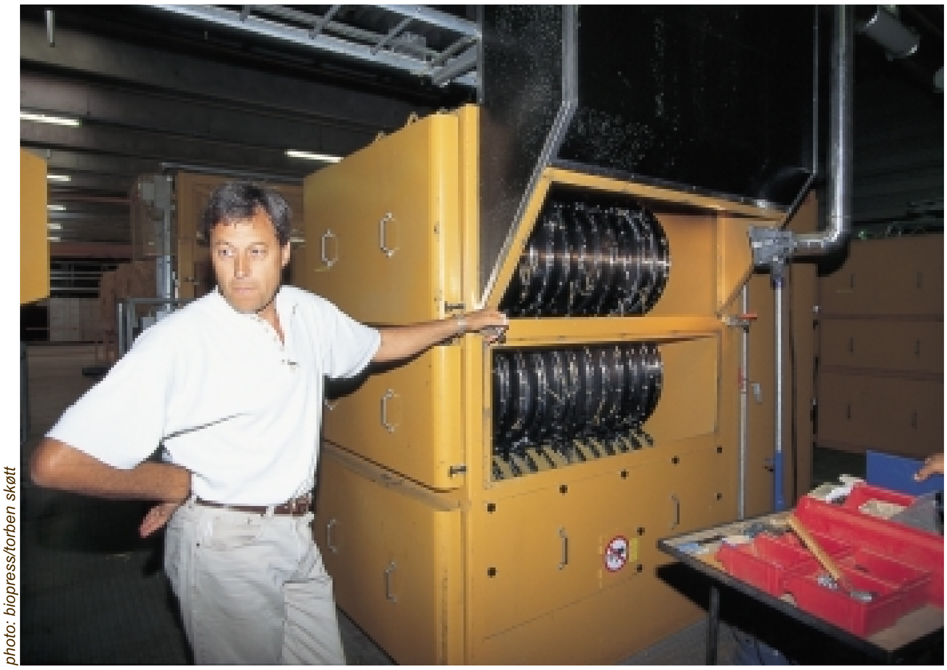
photo: biopress/torben skøtt

Maabjergværket (CHP plant). On the left, the storage tank of 5,000 m^3. The straw storage is the low building on the right. Outermost on the right the outdoor wood chips storage.

automatic crane is equipped with grip-hooks that can lift 12 bales at a time off the truck. By means of microwaves that are sent through the bales from one grip-hook to the other one, and by means of a weighing cell between grip-hooks and crane, the average water content and the weight are being measured and recorded by a computer.

From the storage, the bales are picked up by a crane and unloaded on to 4 feeding lines. The straw is shredded by a relatively low energy consumption (1.8 kWh per MWh fired). The shredded straw is conveyed from the 4 lines via rotary valves to 2 feeding systems. Via the feeding systems, the straw is blown on to the ash circulation system from where it passes on to the bed. After having been pulverised to a grain size of maximum 8 mm, the coal is fed either via screw stokers in the bottom of the boiler or via rotary valves on to the ash circulation system.

photo: biopress/torben skøtt



The operations manager at Grenaa Kraftvarmeværk (CHP plant) stands by the straw shredder that is opened for inspection.

Other Data
The boiler in Grenaa has been designed for firing with coal and straw in a mixture of 50% straw on energy basis. At full load (100%), the boiler produces 104 tonnes of steam per hour at 505°C and 92 bar. Of this amount, between 37 and 77 tonnes of steam are drawn off per hour at 210°C and 8.3 bar for process steam for the industrial enterprises Danisco Paper and Danisco Distillers. In addition to 55,000 tonnes of straw, approx. 40,000 tonnes of coal are consumed per annum. The coal storage is capable of supplying coal for 20 days and nights at 100% pure coal firing, and the straw storage is capable of supplying straw for the consumption of 4.2 days and nights at 50/50% fuel mixture. Like the other CHP plants, the boiler plant is equipped with a heat storage tank, and like the plants in Slagelse and Masnedø, the flue gas is cleaned for solid particles by means of an electrostatic filter.

The CHP Plant in Maabjerg
In Maabjerg near Holstebro, I/S Vestkraft (electricity utility) has constructed a CHP plant that is fired with waste, straw, wood chips, and natural gas. The plant is divided into 3 boiler lines, 2 for waste and 1 for straw and wood chips.

All 3 boilers are equipped with separate natural gas-fired superheater that raises the steam temperature from 410°C to 520°C at a pressure of 67 bar. The straw is fired in the form of whole big bales into 6 cigar burners, installed 3 and 3 opposite each other. By means of a pneumatic feeding system, the wood chips are thrown on to a vibrating grate where unburnt straw and wood chips burn out. The flue gas generated by the straw/wood chips-fired boiler is cleaned in a bag filter, and in respect of the waste-fired boilers, the flue gas cleaning system is supplemented by a scrubber system in order to reduce hydrogen chloride-, hydrogen fluoride-, and sulphur oxide emissions. The scrubber system separates at the same time heavy metals from the fly ash to a certain extent.

The straw/wood chips-fired boiler can operate at full load on either straw or wood chips, or on combinations of straw and wood chips. The boiler output is 12 tonnes of straw per hour. Further data are set out in Tables 6, 7, 8, and 9.

Environmental Requirements

In the Danish Environmental Protection Agency Directions No. 6 and 9/1990 on “Industrial Air Pollution Control Guidelines” /ref. 42/, emission levels that are intended as a guide for

Emission	Unit	Rudkøbing	Haslev	Slagelse	Grenå	Aabenraa	Måbjerg	Masnedø	Maribo/ Sakskøbing
CO	volume % dry flue gas	0.2 at 12% CO_2	0.05 at 10% O_2	0.2 at 12% CO_2	None	None	0.05 at 10% O_2 [2)]	0.05 at 10% O_2	0.05 at 10% O_2
Dust	mg/Nm^3	50	50	50	50	50	40	40	40
NO_x	mg/Nm^3	350	340	340	160	400	None	200	400
SO_2	mg/Nm^3	None	300	300	280	2,000 [1)]	None	None	None

Table 9: Maximum emissions from the 7 decentralised CHP plants and the power plant at Aabenraa. The figures are from the environmental approvals of the individual plants.
1): The emission is 100-200 mg SO_2/Nm^3 when operating
2): Calculated on the basis of 650 mg/Nm^3.

straw-fired boiler plants larger than 1 MW input are for dust and CO suggested at 40 mg/Nm^3 and 0.05% CO (volume % at 10% O_2 in the flue gas), respectively. However, concerning the CHP plants described here, the environmental approvals in question stipulate individual requirements to be met, see Table 9.

Cost of Construction and Operating Costs

The cost of construction for the decentralised biomass-fired CHP plants is relatively higher than that of conventional coal-fired power plants measured by the million (DKK) per installed MW electrical power output. For the seven plants, the specific construction investment is in the range of approx. DKK 21 and 30 million per MW electrical power. As will appear from Table 7, the cost of construction is price index-linked to the 1995 level, thereby making it suitable to be compared. The relatively high cost of construction depends first and foremost on the size of the plant, (the smaller the plant, the higher the specific cost of construction). By technological advances in respect of a certain type of plant, the specific price will drop for new plants compared to older plants of the same size. The specific price should be understood as a guide, since the cost of construction varies with the items included, see Table 7. By a comparison with other types of CHP plants, it should be mentioned that the calculation of the specific price forming the basis of Table 7 is based on the net output and not on the gross output. The gross output includes the plant's own consumption of power. The status of being pilot and demonstration plant also contributes to an increase in the cost of construction which contributes to confusing the price.

The volumetric calorific value of straw is a factor 10-15 times lower than that of coal at the same time of straw being physically more difficult to handle, thus the costs for storage, handling and firing systems contribute to increasing the plants' high specific cost of construction. With a straw price of approx. DKK 0.45 per kg or approx. DKK 0.11 per kWh, straw is three times as expensive as coal for electrical power production, see Figure 1, Section 1.

Straw at Power Plants

In 1993, the Danish parliament "Folketinget" ordered the Danish power plants to use 1.2 million tonnes of straw (it was later decided that 0.2 million tonnes of wood chips can be substituted by wood or willow chips) and 0.2 million tonnes of wood chips as fuels at the centralised power plants not later than 2000 as a result of the energy policy target in respect of CO_2 reduction.

The Electricity Utility Group ELSAM and ELKRAFT Power Company Ltd. therefore implemented a wide range of activities in order to subject the problems of firing very large amounts of straw at power plants to a critical analysis. Among the important issues in that respect were:

- High-temperature corrosion of superheaters at high steam temperatures
- Industrial application of mixed ash by co-firing of straw and coal
- Flue gas cleaning by co-firing of straw and coal
- Resource statements and straw supply safety
- Costs

There are several overall concepts for solutions:

1. Separate firing: Straw fired in a separate biomass-based boiler that supplies steam for the coal-fired boiler.
2. Co-firing: Straw and coal fired together in power plant boiler
3. Coupled-gasifier-combustor. Gasification of straw, the gas burns in a boiler that may be designed for co-firing of straw gas and pulverised coal. This concept is undergoing further development.

By separate firing, problems in respect of high-temperature corrosion are avoided because the steam temperature in the biomass boiler is kept under a critical level. Industrial application of ash from the coal boiler is no problem because the ash from the two boilers are not mixed. The drawback to separate firing is first and foremost the high cost of construction. By co-firing, solutions should be found to the problems of high-temperature corrosion and industrial application of mixed ash. At power plants that are equipped with desulphurization- and nitrogen reduction units (deNO_x plants), the content of alkali metals (potassium and sodium) and chlorine in the straw ash causes operating problems. A major advantage of co-firing is the low cost of construction.

The interest for coupled-gasifier-combustors is due to both the low cost of construction and the prospects of low alkali and chlorine contents in the gas. So far, a straw-fired boiler plant has been established at a power plant within a framework managed by the Electricity Utility Group ELSAM. In the autumn of 1997, Sønderjyllands Højspændingsværk (electricity utility) has started up a separate biomass-fired boiler at the Enstedværket (power plant) running parallel with the pulverised coal-fired Unit 3 of the Enstedværket. Since 1995, I/S Midtkraft (electricity utility) has carried out ex-

photo: sønderjyllands højspændingsværk

3 of 4 feeding lines at Enstedværket (power plant). The big bales are collected via a conveyor belt in the storage and are distributed to the 4 lines via a traversing vehicle.

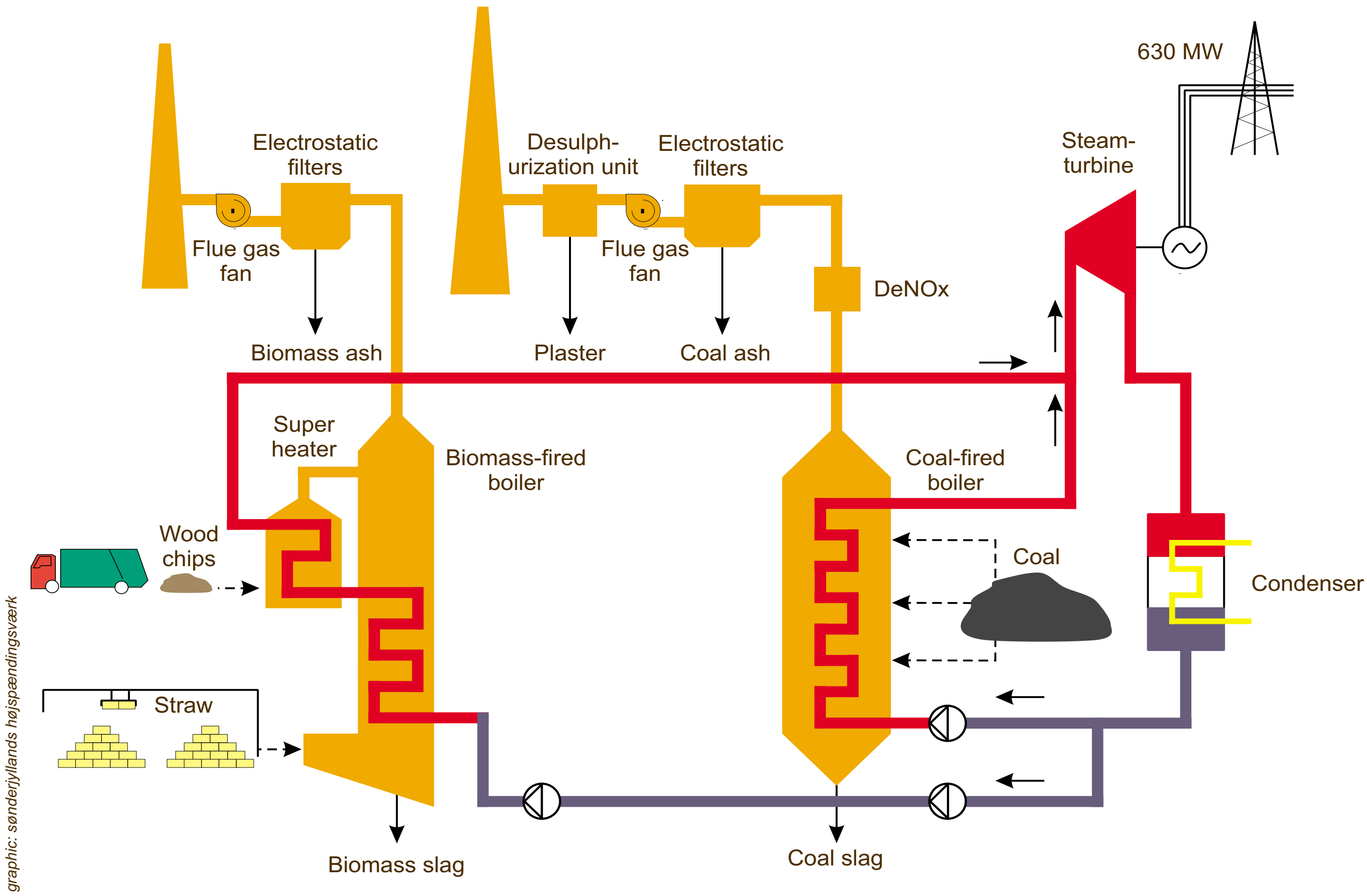


Figure 22: Simplified diagram of Enstedværket's biomass-fired boiler of 40 MW electrical power and the coal-fired boiler of 630 MW electrical power. The biomass-fired boiler substitutes the use of the 80,000 tonnes of coal/year, thereby reducing the amount of CO_2 being released to the atmosphere by 192,000 tonnes/year.

periments on co-firing with straw and pulverised coal in a 150 MW electrical power power plant boiler.

In Zealand, ELKRAFT Power Company Ltd. has planned firing with straw at Avedøreværket (power plant) in a separate biomass-fired boiler.

Enstedværket

The biomass-fired boiler plant at the Enstedværket consists of two boilers, a straw-fired boiler producing heat at 470°C, and a wood chips-fired boiler superheating the steam from the straw-fired boiler to 542°C. The superheated steam is lead to the high-pressure steam system of the Enstedværket Unit 3 (210 bar). With an estimated annual consumption of 120,000 tonnes of straw and 30,000 tonnes of wood chips, equal to an input of 95.2 MJ/s, the biomass-fired boiler produces 88 MW thermic (energy) including 39.7 MW electrical power (approx. 6.6% of the total amount of electrical power generated by Unit 3. Thus the biomass-fired boiler is considerably larger than the largest of the decentralised biomass-fired CHP plants. Net electrical power efficiency being 40%. The annual efficiency is estimated being a bit lower due to the connection with Unit 3 and due to variations in load conditions. The biomass-fired boiler is planned to operate 6,000 hours at full load per annum. With a storage capacity of only 1,008 bales which will allow for approx. 24 hours operation, 914 big bales should be delivered every 24 hours on average, equal to 4 truck loads per hour for 9.5 hours every 24 hours.

The straw-fired boiler is equipped with 4 feeding lines. The plant can operate at a 100% load at only 3 lines, though. Each feeding line consists of a fireproof tunnel, conveyors, straw shredder, fire damper, and a feeding tunnel. As with the plant at Masnedø, the straw shredder is designed as two coupled, conical, vertical screws towards which the straw bale is pressed. From the straw shredder, the shredded straw is dosed via a fire damper on to the screw stoker that presses the straw like a plug through the feeding tunnel and on to the grate. The wood chips-based boiler is equipped with two pneumatic dampers that throws the wood chips on to a grate. The dosing of wood chips is performed by a feeding screw from an intermediate silo.

The flue gas is cleaned by electrostatic filter. In order for the bottom-ash and slag from the boiler to be applied as fertiliser, the fly ash from the filter (that contains the major part of the heavy metals of the ash) is separated from the ash from the bottom of the boiler.

The total cost of construction of the boiler plant at the Enstedværket is approx. DKK 400 million (1995 prices). The price includes boiler, fuel storage, steam pipe to the Unit 3 turbine. Re-use of boiler house and electrostatic filter. The project was decided in January 1995, and commercial operation commenced at the beginning of 1998.

Studstrupværket

Before it was decided to establish co-firing of straw and coal at Studstrupværket (power plant), I/S Midtkraft (electricity utility) carried through experiments on two old power plant units, a pulverised-coal-fired unit of 125 MW electrical power, and a grate-fired stoker plant of 70 MW electrical power, during the period from 1992-1994. The purpose of the experiments was to investigate the generally known problematic issues in connection with straw-firing at power plants, including:

- Handling and firing of straw in a power plant boiler that is simultaneously fired with coal
- Consequences for the boiler output and flue gas emissions
- Corrosion of superheaters and slagging problems
- Mixed ash problems
- Straw influence on flue gas cleaning systems

The experiments have resulted in the carrying though of a 2-year demonstration project during 1996/97 with co-firing of straw and coal at the pulverised coal-fired the power plant (Unit 1) 150 MW electrical power of the Studstrupværket.

The plant at Studstrupværket is designed for a maximum straw input of 20% of the total input energy. A straw storage is established with space for 1,100 big bales and a total of 4 feeding lines each consisting of a shredder and a hammer mill that crushes the shredded straw stalks. The straw is together with the pulverised coal blown into the combustion chamber.

The boiler is designed for an output of 500 tonnes of steam per hour at a steam pressure of 143 bar and a superheater temperature of 540°C. The cost of construction in connection with the establishing of storage, handling equipment, and firing systems amounts to approx. DKK 90 million.


photo: sønderjyllands højspændingsværk

Straw being unloaded from a truck at the Enstedværket. The crane lifts 12 bales at a time. At the same time, the bales are being weighed, and the water content measured via microwave equipment mounted in the grip-hooks.

Avedøreværket

In connection with the construction of a new power plant unit (Unit 2) at the power plant Avedøreværket, a biomass-fired plant with an input of 150,000 tonnes of biomass per annum of which the majority will be straw. Based on experiences gained at the plant in Masnedø, a separate straw-/wood chips-fired boiler has been planned that can produce steam at 300 bar and 580°C. The steam passes to the main boiler steam turbine. If it is not possible to attain the high steam temperature without too severe corrosion problems, arrangements will be made for part of the superheating to take place in a natural gas-fired superheater. With the planned construction project and the high steam temperature, an electric power efficiency of the biomass-based unit of 43% is estimated. The plant is planned for starting up at the end of 2001.