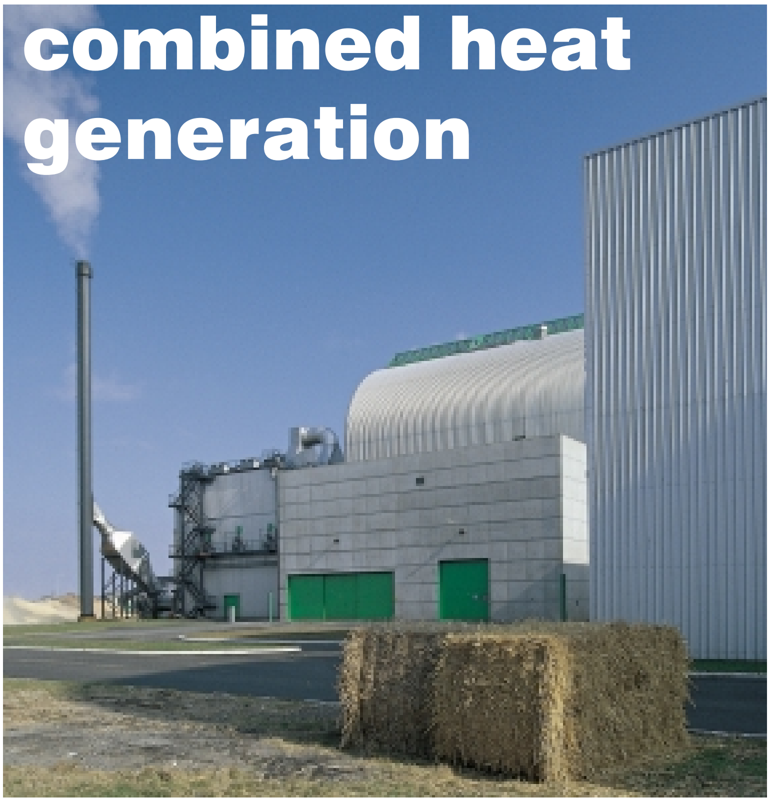
Biomass based combined heat and power generation

Biomass fueled CHP plants have now for many years been a common part of the Danish electricity and district heating supply. The Danish CHP systems are designed to handle a variety of fuels and display a very constant operation. The installation of new biomass CHP plants continues steadily and the CHP systems are constantly undergoing development towards even higher efficiency. Recently new plants have been put in operation in Assens on Funen and in Maribo-Sakskøbing on Lolland.



As the exploitation of the fuel is much better in combined heat and power.

By Morten Tony Hansen

At the beginning of this millenium Denmark had installed biomass fueled combined heat and power plants with a total power capacity of 200 MWe. Biomass CHP generation accounts for 1.5 percent of the total capacity for electricity production in Denmark. Danish energy production is to a great extend based on combined production of heat and power.

Why co-production?

There is a very good technical and environmental argument for choosing this technology. In a traditional steam based powerplant with condensing operation, only 40-45 percent of the energy input is converted into electrical power. The remaining part is lost with the cooling water into the sea and with the hot flue gas up through the stack. In a CHP plant the electrical power is generated in the same way as in a power plant, but instead of disposing of the cooling water, the steam is cooled by the return water in a district heating system and thus used for generation of heat.

As the society needs both heat and power, combined heat and power generation is environmentally and economically advantageuos. The exploitation of the fuel input is much better, which is the main reason that the development within the CHP sector has a high priority in the Danish energy policy.

The structural possibilities for utilising the heat produced by CHP plants are good in Denmark as a large part of the heat supply is covered by district heating. This means that the CHP plants and thus the electricity production in Denmark is to a large extent decentralised as opposed to a structure with large central power plants with a demand for seawater cooling.

Active political engagement

Three fundamental factors have influenced the development within biomass based CHP gen-

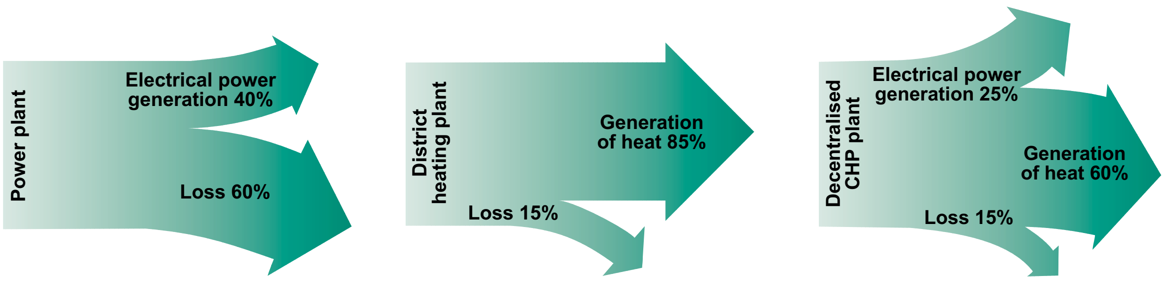


Figure 8: By separate electrical power generation and generation of heat at a power plant and at a district heating plant, total losses are much larger than by combined heat and power production at a CHP plant.

	Commissioned[1]	Contractor	Fuel	Technology	Steam pressure	Steam temperature	Max. steam flow	Power output, gross	Heat output	Electrical efficiency (gross)	Overall efficiency (gross)	Storage tank
	year				bar	°C	tons/h	MW	MJ/s	%	%	m^3
Assens	1999	Vølund	Wood chips, sawdust	Steam turbine	77	525	19	4.67	10.3[3]	27%	87%[3]	2 × 2,500
Avedøre 2	2001	Vølund	Straw and wood chips	Steam turbine	300	582	-	-	-	43	-	-
Ensted EV3	1998	FLS Miljø A/S	Straw and wood chips	Steam generation	200	542	120	39.7	-	-	-	-
Grenå	1992	Aalborg Boilers Ahlstrøm	Straw and coal	Steam turbine	92	505	104	18.6[2]	60	18	-	4,000
Harboøre	1993/00	Vølund	Wood chips	Updraught gasifier	-	-	-	1.3-1.5	6-8	32-35	105	1,050
Haslev	1989/99	Vølund	Straw	Steam turbine	67	450	26	5.0[2]	13	25	86	3,200
Hjordkær	1997	Sønderjyllands Maskinfabrik	Wood chips, bio waste	Steam turbine	30	396	4,4	0.6	2.7	16	86	1,000
Høgild	1994/98/00	Hollensen	Wood	Downdraught gasifier	-	-	-	0.13	0.16	22	57[3]	-
Junckers-7	1987	B&W Energi	Sawdust, chips, bark, shavings	Steam turbine	93	525	55	9.6	-	-	-	-
Junckers-8	1998	Vølund	Sawdust, chips, shavings, dust	Steam turbine	93	525	64	16.4[2]	-	-	-	-
Maribo-Sakskøbing	2000	FLS Miljø	Straw	Steam turbine	90	540	43.2	10.2	20	29	87.5	6,000
Masnedø	1996	B&W Energi	Straw, wood chips	Steam turbine	92	522	43	8.3[2]	20.8	28[2]	91	5,000
Måbjerg	1993	Vølund	Straw, wood chips, natural gas, waste	Steam turbine	65	520	123	28[2]	67	27	88	5,000
Novopan	1980	Vølund	Various wood wastes	Steam turbine	71	450	35	4.2	-	19	88	-
Rudkøbing	1990	B&W Energi	Straw	Steam turbine	60	450	12,8	2.3	7.0	22	87	2,500
Skarp Salling	1999	Reka	Wood chips	Stirling engine	-	-	-	0.03	0.09	18	87	8
Slagelse	1990	Aalborg Ciserv, BWE, Vølund	Straw	Steam turbine	67	450	40	11.7[2]	28	29	-	3,500

1. New plant or renovation of existing plant.
2. Power output, net
3. With flue gas condensation the heat output increases to 13,8 MJ/s and the overall efficiency increases to 106 %..

Table 2: Main data for the combined heat and power plants in Denmark.
Reference: Danish Follow-up Programme for Small Scale Solid Biomass CHP.

eration in Denmark during the last twenty years. Steeply rising prices on fossil fuels, the clear Danish vote against nuclear energy supply and the positive technological development supported by political incentives, requirements and agreements.

In 1986 the Danish Government made an energy policy agreement on the construction of decentralised CHP plants with a total power output of 450 MW to be completed by the year 1995. All these plants should be fueled with domestic fuels such as straw, wood, waste, biogas and natural gas. In 1990 the Government further agreed on an increased utilisation of natural gas and solid biofuels in the district heating plants. As a result of this agreement a large number of plants were converted to natural gas based CHP generation, while other district heating plants were converted to biomass based heat production.

Later, in 1993, the Danish Parliament agreed on the so-called Biomass Plan, which directs the utilities to utilize 1.4 million tonnes of biomass per year. Of this a minimum of 1 million tonnes must be straw. The utilities were supposed to honour the agreement by the year 2000, but as this has not been possible, the agreement has now been prolonged until the year 2005.

During the early nineties the utility sector constructed the first steam based CHP plants for biomass. Steam based CHP generation is a suitable technology for large plants, but it is more questionable for small plants, as the efficiency of small steam based plants will be low.

The Danish CHP plants

In order to promote the development - especially of technologies for small scale CHP generation - the Danish Energy Agency since 1995 has managed the "Danish Follow-up Programme for Small Scale Solid Biomass CHP Plants". In 1999 this programme included twelwe demonstration plants, which are divided among different fuels and different technologies:

- Two gasification plants
- Four steam turbine plants for wood fuel
- Three steam turbine plants for straw
- Two steam turbine plants for waste and a variety of biofuels
- One Stirling engine for wood chips

These plants present different levels of development. While the steam turbine part of the steam based technologies are well known and tested, the boiler parts constantly go through further development. The Stirling and the gasification technologies are still under development. The follow-up programme includes plants owned by private companies as well as utilities and district heating companies.

In addition to the twelwe plants covered by the follow-up programme, there exist a number of other biomass fueled CHP plants in Denmark. These plants use well known technology and are no longer undergoing any further development or experiments, but simply work as a reliable supply of heat and power.

All the Danish CHP plants are included in the table, which shows the main plant data.

M.sc. in Engineering Morten Tony Hansen is employed with dk-TEKNIK ENERGY & ENVIRONMENT, one of the four partners of the Danish Centre for Biomass Technology.

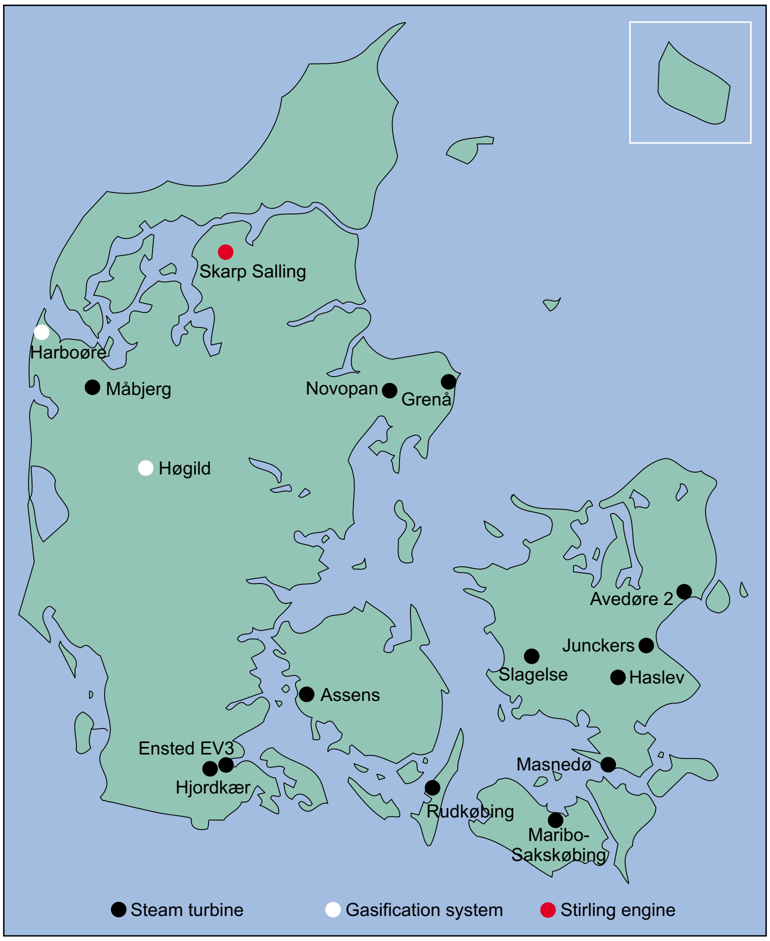


Figure 9: The location of the Danish CHP plants. The plants are owned by private companies as well as utilities and district heating companies. Both the steam based systems, the gasification systems and the Stirling engine system are constantly subjected to development towards a higher efficiency.

Biomass - Waste - Energy Consultancy

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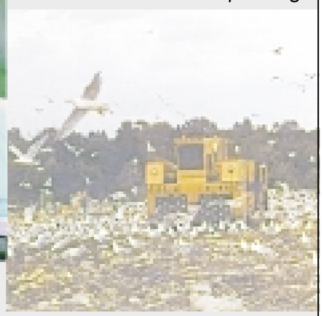
Cogeneration based on MSW

Haslev CHP
Straw pyrolysis
for more efficient
electricity generation

Low cost biogas plants with soft-top
and integrated process tank

Landfills and composting



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Wood-fired CHP plant covers local energy demand

Denmark's largest privately owned biomass-fired combined heat and power plant is situated at the small town of Assens on the island of Funen. The plant, which has cost DKK 127m, covers almost the entire electrical power and heating demand of the town and its 10,000 inhabitants. In the winter, when the plant is operating at full load, 150 tonnes of wood is converted per day.

By Torben Skøtt

On 29 May 1999 Denmark's largest privately owned biomass-fired combined heat and power (CHP) plant was inaugurated at the small town of Assens on the island of Funen.

The plant was erected by district heating operator Assens Fjernvarme, which has long been known for its ability to supply district heating to the town's 10,000 inhabitants at very favourable prices.

The operator expect to be able to maintain this position when the new DKK 127m CHP plant has been put into operation. The plant constitutes the largest investment ever in the local area, and it meets the entire electricity and heating demand of the town through "eco-friendly energy". 26,000 MWh of electrical power and 50,000 MWh of heat is generated each year.

The original district heating plant was coal-fired, but by the end of the 1980's the board agreed that this was not a viable path, considering the increase in energy and environmental taxes. Consequently, the coals were replaced by wood pellets, and later on other types of wood fuel were introduced.

The decision to build the new CHP plant was made almost four years ago, when the Danish Energy Agency ordered the plant to produce electrical power as well as heat in the future.

The two alternatives at the time were natural gas and biomass. A natural gas-fired plant would cost DKK 55m plus an additional DKK 17m to deliver the gas to the plant. As mentioned above, the biomass-fired plant was more expensive, but as the state was willing to provide a DKK 25m grant to help cover construction costs and an additional subsidy amounting to DKK 0.27 per kWh generated, the biomass plant was the most attractive solution.

150 tonnes of wood per day

The new CHP plant uses wood only, and there is a good reason for this: At Assens they are quite experienced in buying wood at the right price. Apart from using Danish wood chips and pellets they import tree-trunks from the Baltic countries, and they know where to buy sawdust, wood shavings and other sorts of waste wood from the industry.

"The most expensive fuels are wood pellets and Danish wood chips", says plant manager John Jessen. Sawdust is our cheapest fuel, but the boiler doesn't allow us to use more than 30 per cent sawdust.

The plant has an indoor storage capacity that covers approx. 10 days' consumption at full load. Approx. 150 tonnes of wood products are used per day, and the plant generates 4.68 MW of electrical power and 10.3 MW of heat.

Several innovative features

A large part of the plant, such as the boiler and the steam turbine, is based on proven technology, but it also includes several innovative features. The handling of the different sorts of wood fuels has required a good deal of innovation, and the boiler has been equipped with an entirely new feeding system.

The vast majority of the functions are automatic, so a

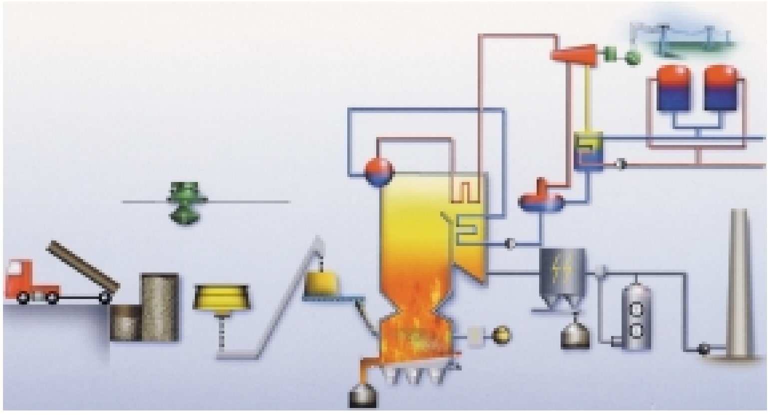

Figure 10: Flow diagram showing the new wood- fired CHP plant at Assens.

mere four employees manage to operate the plant.

Two fully automatic cranes and a conveyor transport the fuel from the storage area to the feeder silo in front of the boiler. From here it is led to the so-called “air spouts” that throw the fuel onto an oscillating grate in the boiler. Much of the fuel is combusted while flying through the chamber, and the large parts burn on the grate.

The heat from the boiler is used to produce steam at a temperature of 525°C and a 75 bar pressure. This output is similar to that achieved at far larger plants, and it has made it possible to reach an electrical power efficiency of 27 per cent.

The smoke is cleaned in a 70,000 volt DC electrostatic precipitator and led to the chimney at a temperature of approx. 110°C. The fly ash, approx. 90 per cent of the ash, is kept in a container and subsequently disposed of at a controlled refuse dump.

The steam leaves the turbine at a temperature of 85°C and a 0.6 bar pressure. This allows the steam to heat the district heating system return water from approx. 37°C to 75°C.

In the winter, when the use of wet fuels such as wood chips typically increases, it is possible to incorporate a flue gas condenser capable of generating a further 3.5 MW of heat. Naturally, the condenser is not introduced until the heat demand exceeds the 10.3 MW that the plant can produce without the condenser.

Three-period rate

The plant charges the electrical power produced by a so-called three-period rate. This means that the highest price is obtained during the peak load periods in the morning and in the evening, while the lowest price is obtained during the low load periods at night.

In the summer months, when the heat demand is low, the plant only operates 6-8 hours a day. It is normally started up early in the morning to be ready for the first peak load period, when the price is high. Surplus heat is stored in two accumulation tanks, each of which holds 2,500 m^3 of hot water.

“The problem is that it takes a couple of hours to start up the plant, and during that period we only produce heat”, says John Jessen.

“We therefore look forward to the replacement of the three-period rate with a standard rate, which hopefully will be introduced soon. This will be a clear advantage, as it will allow us to run the plant for longer continuous periods. Consequently, we can produce more electrical power and avoid the many start-up processes, which wear on the plant.

The new CHP plant was supplied by Vølund with COWI Consulting Engineers acting as consultant.

Torben Skøtt is a journalist and editor of the magazine Dansk BioEnergi (Danish Bioenergy).

Bio-gasification breakthrough

Thanks to ten years of research in biofuel gasification, Denmark is today one of the leading countries in the area of small-scale combined heat and power plants based on bio-gasification. The oldest plant has been operating since 1993 and produces electricity as well as heating to approx. 600 consumers.

By Henrik Flyver Christiansen

On the international arena Denmark takes a prominent position in the area of straw gasification. One of the centres of expertise is this combined heat and power plant at Haslev, where a pyrolysis plant capable of converting straw into gas was in operation for several years.

It all started in the late 1980's with research at the Technical University of Denmark, the Danish Technological Institute, in industry and within the utility sector. In 1993, as a result of this work, subsidies were granted for the setting up of an actual demonstration project at the Harboøre Fjernvarme district heating plant. Since then, the Danish Energy Agency and the utility company Elkraft have provided grants for a total of six different demonstration projects.

The background to these initiatives was very simple. The engineers were convinced that the technology of converting biofuel into gas was the ideal solution for combined heat and power generation purposes. Especially at relatively small plants, where the proven steam turbine technique appeared to be costly as well as inefficient.

As regards environmental impact, there are also advantages in converting solid fuels into gas. The gas mainly consists of hydrogen and carbon monoxide, which after conversion turn into flue gases that only contain water, carbon dioxide and nitrogen compounds.

Harboøre running steady

After several years of development, the first gasification plant was put into commercial use at the Harboøre Fjernvarme district heating plant by the end of 1993. Supplied by Vølund, the plant is based on a so-called updraft gasifier capable of firing fuel with a water content of up to 50 per cent.

Until 1996 the plant was converted and optimised several times. In this connection a number of tests were carried out, which showed that the plant output was twice as high as estimated. In addition, the load could quickly be changed from 10 to 100 per cent, which is not possible in a conventional wood chip boiler.

At the time when the plant was built, no efficient gas cleaning techniques were available. Therefore, the gas was combusted in a boiler for many years, but today an efficient gas cleaning technique has been found, so now the gas is used in two engine/generator plants supplied by Jenbacher. The overall electrical output is 1.5 MW, and the cogenerated amount of heat meets the demand of the 600 households connected to the plant.

In recent years the gasification plant has been reliable enough to be left unmanned for periods of two to three weeks. It has covered approx. 95 per cent of the heat demand, and for the last two years there have been practically no production interruptions due to the gasifier.

Høgild is too small

In 1994 a small-scale gasification plant was set up in the village of Høgild just south of Herning to supply heat and electricity to the approx. 100 households of the village. The plant was built by the public utility company in Herning, who bought a gasification plant from the French company Martezo. The gasifier was based on the so-called downdraft principle, which was used on many vehicles during the Second World War.

The principle of the plant was viable, but the technical design was so poor that it was not safe to continue operating the plant. Consequently, in 1997 it was decided to have Danish engineers Hollensen ApS carry out comprehensive refurbishing and reconstruction of the plant.

This work was completed by the end of January 1998, and from mid-April it has been possible to monitor the plant from a home-based PC outside normal working hours.

The plant is now undergoing reconstruction to allow it to use ordinary wood chips as fuel. So far it has only been operational if the fuel consisted of dried wooden blocks of a certain size - a fuel source that has often been hard to provide in sufficient quantities.

The experience from the Høgild plant shows that it is difficult to make plants economically viable with only about 100 consumers connected. It seems that at least 2-300 consumers are required in order for such a project to be economically viable.

The gasification plant at Høgild, which has been running since 1994. The plant is currently being converted to use ordinary wood chips as fuel.

Other projects

The other demonstration projects have not yet come this far, but they have all been developed over the past years.

In the village of Blære near Aars the machinery manufacturer REKA has co-operated with the Technical University of Denmark to set up a two-stage gasifier with a gas cleaning and engine/generator system. Having dealt with most of the initial teething troubles, the operators succeeded in running the engine for 100 hours. After this, certain problems occurred causing the plant to stand idle for 18 months so far. However, further development has taken place at the Technical University of Denmark, and now the technology is considered to be fully developed.

The company dk-TEKNIK ENERGY & ENVIRONMENT has co-operated with the machine manufacturer Butina to further develop the so-called "open core" principle. The principle has proven to be viable for ordinary

A glance into one of the first versions of the "Open Core" gasifier from dk-TEKNIK.

wood chips, provided that the water content is below 25 per cent before gasification. In particular, the dust and tar levels measured in the cleaned gas justify optimistic expectations for the future of the plant. It has been operating for approx. 400 hours, including 100 hours of continuous operation with a 20 kW_e engine/generator system connected. Now the aim is to achieve at least 3,000 hours of fully automatic operation of the pilot plant. The natural next step is a demonstration plant supplying a major institution or a small-scale heating plant.

In 1988, TK-Energi in Roskilde and its French partners obtained grants from the EU-programme Joule and the Danish Energy Agency. Based on multi-stage straw gasification, the project was launched in the autumn of 1998.

Straw gasification

In recent years the main effort has been concentrated on gasification of wood, as experience shows that gasification of straw is much more problematic.

At international level, however, Denmark takes a prominent position in this area, as we are one of the few countries that have worked seriously with straw gasification. In this context the research department at Elkraft has made a particularly fine long-term effort in the area, which now appears to bear fruit.

For instance, the Kyndby plant has carried out several straw gasification tests, the Technical University of Denmark has had a straw gasification plant, and at the straw-fired combined heat and power plant in Haslev they have a so-called pyrolysis plant at which some of the straw can be converted into gas and coke. The gas can be combusted in the super-heater at the plant, whereas the coke can be exploited in the straw-fired boiler. This means that the electricity efficiency is increased, while the risk of corrosion is reduced.

Follow-up programme

The various gasification technologies form part of the Danish Energy Agency's follow-up programme for decentralised combined heat and power generation from solid biomass fuel. In addition, work is being carried out on various steam technologies and stirling-engines.

The purpose of the follow-up programme is to make an assessment of the economic aspects as well as the energy and environmental aspects of plants with an output of up to 10 MW.

Thanks to the positive experience, especially from the plants at Høgild and Harboøre, Denmark has managed to place itself at the forefront of international development. We have come particularly far in the development of small-scale plants, e.g. minor district heating plants.

Things are now moving so fast that the Danish Energy Agency has already received requests for support for the first second-generation plants. And we expect that there will be more in the years to come, as 6 - 8 pilot projects concerning the installation of new plants or conversion into combined heat and power plants are ready.

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Table 3: Outline of gasification plants in Denmark.

Plant	Built	Plant owner	Supplier	Principle	Output	Status
Harboøre	1993	Harboøre Fjernvarme	Vølund	Updraught gasifier for wood	4 MW	Steady operation. In March 2000 an engine/generator system was installed at the plant, which now produces both electricity and heat for 600 consumers.
Høgild	1994	Herning Kommunale Værker	Martezo/ Hollesen ApS	Downdraught gasifier for dried wood	700 kW	Steady operation, but the plant is too small to make it economically viable. Converted to wood chip-firing in the spring of 2000.
Blære	1994	Ove Olsen	Maskinfabriken Reka/DTU	Two-stage gasifier for wood	400 kW	The plant has been running for 100 hours. Technology fully developed.
Haslev	1996-1999	Elkraft	COWI/Elkraft/ Vølund	Pyrolysis gasification of straw	3 MW	This project proved that it is possible to gasify straw. The plant has now been dismantled.
Holbæk	1996	dk-TEKNIK	dk-TEKNIK/ Maskinfabrikken Butina	"Open Core" principle	200 kW	400 operating hours, including 100 hours of continuous operation for electricity production. The construction of a larger pilot plant is being considered.

Gasification prepares the heating plant for the future

When setting up new heating plants or replacing existing boilers, operators should seriously consider investing in a gasification plant instead. The costs are approximately the same, and the gasification plant is prepared for the future.

photo: torben skøtt/biopress

On the basis of seven years of experience with the Harboøre gasification plant, Vølund now offers the same guarantees for this type of plant as for conventional boiler plants.

By Martin W. Fock and Henrik Flyver Christiansen

At the latest seminar of the Danish Energy Agency on decentralised combined heat and power generation, the company Vølund stated that today they can offer gasification plants for wood under the same guarantees as conventional grate-fired heating plants. Vølund base their guarantees on the experience gained from the district heating plant at Harboøre, which has been operating a gasification plant since 1992/93. For quite some time the plant has only been producing heat, but in March 2000 it was fitted with two gas engines, so that it now produces electricity as well as heat.

The seminar also revealed that Vølund is no longer the only Danish supplier of gasification plants operating according to the updraft principle. Today, both Danish Shell and FLS Miljø have embraced the technology.

As this is a considerable technological breakthrough, the Danish Energy Agency has assessed the possibility of existing and future district heating plants making use of the technology.

In many of the oldest straw- and wood-fired heating plants the boilers are now worn out and in need of replacement. In this connection many of the plant operators have to look at the possibilities of converting the plant into a combined heat and power plant.

This is where the gasification technology should be considered. Instead of investing in a new boiler, which normally cannot be converted to CHP generation, the operators now have the possibility of investing in a gasification plant that can subsequently be extended to include CHP generation.

Two solutions

Figure 11 shows the two alternatives that heating plant operators can choose from today. The upper one is the conventional heating plant with a wood chip-fired boiler, and the lower one is the gasification system, where the chip-fired boiler has been replaced by a combination of a gasifier and a gas/oil boiler converted from the existing oil boiler. The fuel handling and flue gas cleaning installations are maintained. Later on, the gasification plant can be converted to CHP generation by adding a gas cleaning system and a gas engine, as shown in the box.

Table 4 shows a relative comparison of the initial investments for the gasification plant and the conventional boiler plant, respectively. The costs relating to the district heating network have been excluded, as they are the same in the two cases.

The boiler plant figures are based on experience from a number of established chip-fired heating plants. As regards the gasification plant, the prices are based on the costs at Harboøre and various pilot projects as well as an estimate of the technical measures required.

Higher output

As you can see from the table, the gasification plant is more costly than the conventional boiler plant, but this is largely due to the fact that the output from the gasification plant is 30-40 per cent higher, as it is prepared to produce electricity as well. Thus, it is not only the gasifier itself that is more expensive. The costs in connection with fuel handling, flue gas condenser, oil/gas boiler and the building are also higher due to the higher output.

In the case of two plants of the same size, the gasification plant is currently deemed to be slightly more expensive, but as soon as gasification plant number five is set up it is expected that investments are at the same level

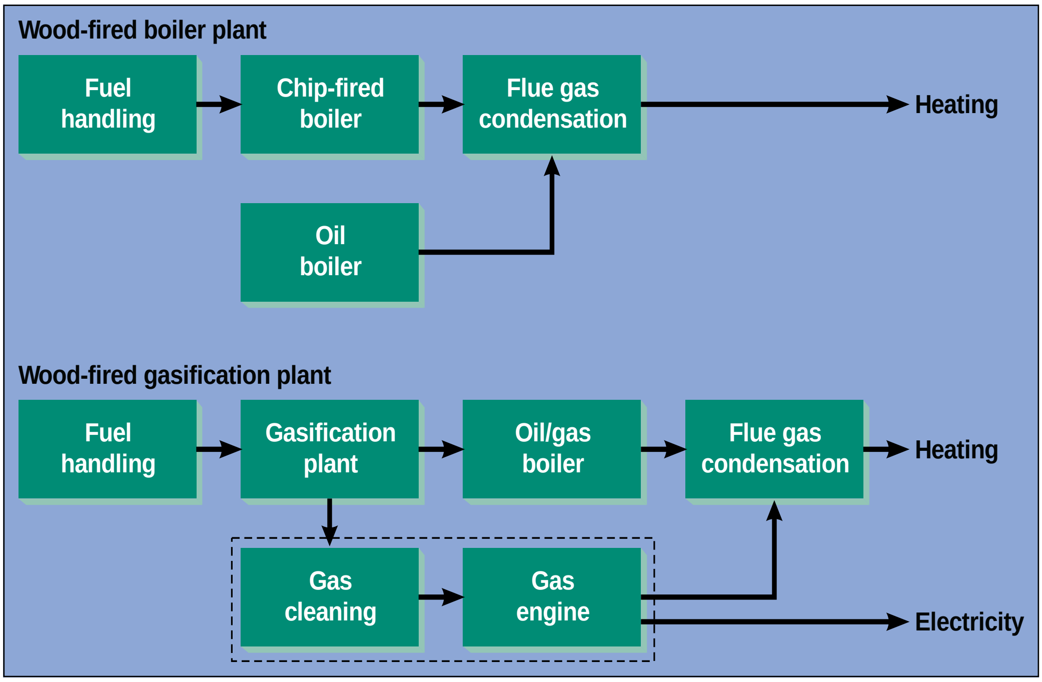

Figure 11: The operating principle of a conventional chip-fired heating plant and a gasification plant, where the boiler has been replaced by a combination of a gasifier and a converted oil boiler. The gasification plant can subsequently be converted into a combined heat and power plant by adding a gas cleaning system and a gas engine, as shown in the box.

as or lower than those for a boiler.

As is the case with the initial investments, it is possible to compare the operating costs for the two plant types.

As appears from table 5, the overall operating costs are identical for the two plants. The difference is that in the case of the gasifier the electricity and lye consumption is higher, while the oil consumption is lower, as the heat production of the gasifier can more easily be adjusted to the consumption.

Advantages and disadvantages

At a conventional boiler plant the output can normally be controlled between 30 and 100 per cent. If the boiler is forced to produce a higher output, the amount of unburned particles in the ash increases, which may necessitate landfilling of the ash. At the Harboøre plant it is possible to control the output from the gasifier between 10 and 200 per cent, and a further advantage of this technology is that there are practically no unburned particles in the ash - the ash is all white.

Normally, the wood chip-fired boiler can convert all sorts of wood chips, wood pellets and in several cases also sawdust.

The gasification plant, on the other hand, is not expected to be capable of converting wood pellets and sawdust.

In conventional boiler plants the grate must constantly be repaired, whereas the costs incurred by gasification plants particularly concern maintenance of the gas burner.

The future

When setting up new plants or replacing existing boilers, it is highly recommendable to check the possibility of installing a gasification system instead. The gasification plant may be slightly more expensive, but it provides a much more flexible solution that can quickly be adapted to the heat consumption and converted into a combined heat and power plant.

The Danish Energy Agency is currently processing applications from all three plant suppliers who have opted for the same gasification technology but apply different gas cleaning methods and use the gas for different purposes.

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M.sc. in Engineering Henrik Flyver Christiansen is employed with the Biomass section of the Danish Energy Agency.

	New plant		Replacement	
	Boiler	**Gasifier**	**Boiler**	**Gasifier**
Fuel handling	13	15		
Boiler/gasifier	30	38	30	38
Flue gas condenser	10	12		
Flue gas cleaning	3	0		
Ash and slag system	4	3		
Oil/gas boiler	5	8		3
Building	35	39		
Total	**100**	**115**	**30**	**41**

Table 4: Relative comparison of the initial investments in a conventional boiler plant and a gasification plant.

	Boiler	Gasifier
Revenue from sale of heat	**100**	**100**
Costs:		
Operation and maintenance	10	15
Fuel, wood chips	45	48
Fuel, oil	10	2
Loan instalment and interest	20	20
Labour, administration	15	15
Total costs	**100**	**100**

Table 5: Relative comparison of the operating costs of a conventional boiler plant and a gasification plant.

Smedemester Biogas Plant

Danish Biogas Technology A/S, a sister company of Bio-Energy Lab, undertakes planning, installation, operation and marketing of Smedemester farm and industrial biogas plants. The Smedemester biogas plant is a unique type of biogas plant that uses animal manure together with small amounts of organic waste, resulting in the production of 2 - 4 times more biogas compared to traditional plants and concepts. The produced biogas is used in a CHP unit to produce "green" electricity and heat. The Smedemester biogas plant is profitable and has several environmental benefits such as reduction in the emissions of greenhouse gases, reduction of the smell inconvenience from animal manure, reduction in water and air pollution.

Smedemester farm biogas plant at Hemmet. The plant has a reactor of 800 m^3 and a 400 kW dual-fuel engine.

400 kW dual-fuel engine.

Smedemester farm biogas plant at Hadsund. The plant has a reactor of 600 m^3 and a 400 kW dual-fuel engine.

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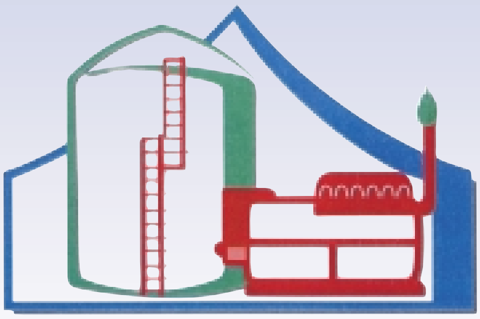

Stirling engine breakthrough

A major Danish effort in the development of Stirling engines for decentralised combined heat and power (CHP) production now appears to bear fruit. The Stirling engine has now been operating on wood chips for just over 1,000 hours, and all major problems finally appear to have been solved.

By Henrik Carlsen

So far, CHP production based on biomass-fuels has been problematic at minor plants. The large plants owned by the electrical power corporations apply the proven technique involving steam turbines, but this solution is too costly for small plants, and the electrical efficiency is far too low.

By using a Stirling engine that powers an electrical generator it is possible to achieve a relatively high electrical efficiency, and as the technology is fairly simple, capital costs can be kept at a reasonable level. The engine is particularly suitable for fuels that are hard to process, as combustion does not take place inside the cylinders of the engine but in an external boiler.

The development of wood chip-fired Stirling engines started back in 1990. The utility company ELKRAFT saw the possibilities of the technology and accepted to participate in the project and bear a significant part of the financing burden. Since then, the Danish Energy Agency has actively contributed to the project by providing subsidies to the plant now being developed.

The first test results show that it is possible to operate a wood chip-fired Stirling engine for more than a few hours. Previous results from abroad have not been promising, because the tests had to be interrupted after a few hours due to clogging in the boiler section of the engine.

The Department of Energy Engineering at the Technical University of Denmark has been in charge of the development of the engine in co-operation with Vølund and Danstoker. The machinery manufacturer REKA has developed the wood chip-firing system. The company PlanEnergi has co-ordinated the project and handled the contact with the Danish Energy Agency. Tests are carried out at farmer Poul Munk's farm at Salling in North Jutland.

The new Stirling engine

The Stirling engine is designed as a hermetically sealed unit like the compressor in a refrigerator. All mechanical parts of the engine are enclosed in a housing together with the generator, and the only connection to the surrounding environment is the cable connecting it to the electrical power grid.

The engine is based on the principle that gas expands when heated and contracts when cooled down. The Danish Stirling engine uses helium, which is heated to 650-700°C by means of a chip-fired boiler. The pressure in the cylinder increases, and the piston is forced downwards. In the next phase the gas is cooled down, and the piston returns to its initial position.

Due to the high temperatures on the engine's boiler surfaces the flue gas is very hot, and if led directly to the chimney the efficiency drops significantly. Therefore, the flue gases are used to pre-heat the combustion air.

The use of wood chips and straw involves the risk of high temperatures making the ash melt and stick to the heat conducting surfaces. Consequently, an important part of the Danish activities has been concentrated on developing an efficient combustion system.

The other components of the engine have been adapted to the strong tubes in the boiler and the large internal volume. This means that the four cylinders of the engine have a large cylinder volume and a low mean pressure of only 40 bar.

The development of the Stirling engine makes it possible to generate electricity and heat from biomass, even at very small plants. The electrical power output of the engine is 28 kW, and the entire plant is automated, eliminating the need for manual operation monitoring.

The piston rings and seals are made of non-lubricated materials. An entirely new crank mechanism ensures low piston ring wear. Oil in the engine is avoided completely by using grease-lubricated bearings. The bearings have been designed for a service life of 50,000 hours. No oil or spark plug change is required, and consequently the need for service has been reduced to a minimum.

The engine's combustion system is designed for operation with ordinary wood chips. A considerable effort has been put into developing a control system to ensure that the temperature in the engine boiler can be maintained at the required level. This is vital in order to achieve sufficient electrical power output.

The entire plant is fully automated, eliminating the need for monitoring of operations. Even day-to-day production start-up and stop is carried out automatically. However, manual firing is required if the plant has been out of operation for several days.

Promising results

After several rounds of plant reconstruction, testing was finally started in the beginning of July 1998. Since then, the plant has been operating for just over 1,000 hours.

The host, farmer Poul Munk, has put the plant back into operation whenever an alarm from the monitoring system stopped it, but apart from this the plant has been in unmanned operation.

In the laboratory, where the engine has been tested with natural gas, the generator has yielded a 35 kW output. When firing with wood chips, however, it has been necessary to lower the temperature in the Stirling engine boiler by approx. 50 degrees and increase the inlet temperature of the cooling water from 50°C to 80°C. Consequently, the electrical power output is only approx. 28 kW at max. operating pressure in the engine. The electrical power efficiency has been measured at 19 per cent for wood chips with a 40 per cent water content.

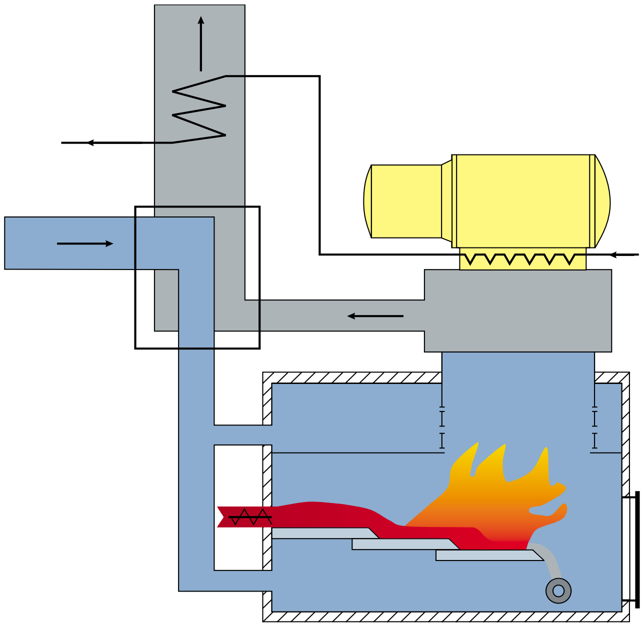

Figure 12: The Stirling engine is placed on top of a boiler, which is automatically fuelled with wood chips. The electrical power generator at the top of the picture yields a 28 kW output.

The boiler tubes of the Stirling engine were cleaned after 500 hours' operation. Deposits on the tubes and fins could easily be removed by means of a brush and compressed air. The fact that the boiler is not clogged in slag in a matter of hours and that the deposits can easily be removed is one of the major results of the project. Tube cleaning at 500 hour intervals, i.e. approximately once a month, is fully acceptable. The inspection of the tubes did not reveal any signs of corrosion.

Backed by the Danish Energy Agency, the team behind the Stirling engine is now fully engaged in exploiting the experience from the first engine with a view to building a new version incorporating a number of improvements in the construction. One of the main concerns has been to ensure that, as originally required, the new engine yields 35 kW of electrical power output, also when running on wood chips.

The new plant will have an updraft gasifier developed by Vølund. The possibility of setting up yet another plant with a wood chip-fired boiler from REKA is being considered.

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