DENMARK

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Current situation on CHP and biomass CHP in the national energy sector.

Energy balances in Denmark (Source: Energy Policies of IEA Countries, 2001)

	1999	**%**
Population (millions)	**5.32**	
Energy consumption/capita	**2.94**	
Total energy production (Mtoe)	**23.64**	
Coal	-	-
Oil	14.86	62.9
Gas	6.94	29.4
Biomass & Wastes	1.58	6.7
Nuclear	-	-
Hydro	0.00	0.0
Geothermal	0.00	0.0
Solar/Wind/Other	0.27	1.1
Net energy imports (Mtoe)	**-4.62**	
Coal	4.18	
Oil	-6.08	
Gas	-2.55	
Electricity	-0.20	
Total supply - TPES (Mtoe)	**20.07**	
Coal	4.64	23.1
Oil	9.33	46.5
Gas	4.42	22.0
Biomass & Wastes	1.60	8.0
Nuclear	-	-
Hydro	0.00	0.0
Geothermal	0.00	0.0
Solar/Wind/Other	0.27	1.3
Electricity Trade	-0.20	-1.0
Electricity generation	**3.34**	
Electricity generation (TWh)	38.87	

	1999	**%**
Total final consumption	**15.64**	
Coal	0.30	1.9
Oil	8.00	51.2
Gas	1.74	11.1
Biomass & Wastes	0.51	3.3
Geothermal	-	-
Solar/Wind/Other	0.01	0.1
Electricity	2.76	17.6
Heat	2.32	14.8
Total industry consumption	**3.30**	
Coal	0.28	8.5
Oil	1.12	33.9
Gas	0.81	24.5
Biomass & Wastes	0.10	3.0
Geothermal	-	-
Solar/Wind/Other	-	-
Electricity	0.85	25.8
Heat	0.14	4.2
Transport consumption	**5.01**	
Total other sectors consumption	**7.33**	
Coal	0.02	0.3
Oil	1.90	25.9
Gas	0.93	12.7
Biomass & Wastes	0.42	5.7
Geothermal	-	-
Solar/Wind/Other	0.01	0.1
Electricity	1.88	25.6
Heat	2.18	-

In Denmark, petroleum represents 46.5% of the energy supply, though coal is of some importance, representing 23.1%. Biomass as renewable energy occupies fourth place, after gas, accounting for 8% of the energy picture, some way above the European average.
Half of final consumption is accounted for by petroleum derivatives, and electricity plays a significant role, originating from thermal coal plants. It must be underlined that a significant

portion of final consumption (14.8%) comes from the use of heat generated in certain industrial processes.

More than half of the electric energy generated in Denmark comes from coal plants (57.5%), a figure which is significantly higher than the average European level (28.1%). After coal, gas and fuel oil are the most widely used combustibles for the generation of electricity. Renewable energy represents a significant 6.8%, most of which is accounted for by wind-based energy.

RTD and Demonstration projects on biomass CHP

No data available.

Legislation and support mechanisms

Denmark is one of the biggest performers in CHP, about 50% of electricity is produced through CHP units. The most important factors in this success are:

- The existence of District Heating network over the whole country. The system, which adopted in 1979, aimed at planning of large investment projects connected to the introduction of natural gas and utilisation of surplus heat. The country was divided into heat supply districts, based on available options of heat supply and individual gas supply
- The willingness of government to secure energy supply after oil crisis.
- Environmental concerns during the 1980s
- The existence of a legal framework supporting CHP

The Legal Framework for CHP in Denmark was the Electricity Supply Act (1976), the Gas Supply Act (1979), the Heat supply Act (revised in 1990), which introduced energy planning and the voluntary agreements between government and the energy sector.

The Heat Supply Act has been most important for the development of CHP in Denmark because it places an obligation on municipalities to ensure development of CHP projects in District heating areas above 1 MW of heat capacity. Also municipalities have the right to impose compulsory connection to District Heating networks and to forbid new electrical heating installations in District Heat areas.

The Ministry of Energy can issue guidelines for CHP planning and the Ministry of Industry and Trade shapes the regulation of heat and electricity prices by pricing committees.

The Electricity supply Act, which amended in 1998,ensures obligation of utilities to buy surplus power from CHP installations against a price covering both short-term as long-term marginal costs.

In 1990 the CHP Conversion Programme was established. The basic issue of this Programme was the conversion of all small- and medium sized district heating plants to CHP or to biomass before 1998. The programme consists of three phases starting with the largest coal- and gas-fired DH plants up to small-scale DH schemes. The financial incentives was :

- Investment subsidy for conversion of DH into small-scale CHP and biomass if conversion would lead to higher heat prices
- Investment grants for new DH networks and rehabilitation of existing networks in cases of compulsory connection to the grid
- Subsidy for electricity production sold to the grid from small-scale CHP and industrial CHP based on natural gas or renewables (100 DKK/MWh, later reduced to 70 DKK/MWh).
- Investment subsidies for installation of central heating in pre 1995 houses in areas with DH supplied from CHP plants.
- Introduction of green taxes on trade and industry. The tax yield is returned as investment grants.

The barriers to further increase of CHP are:

- The uncertainty of liberalisation. Government is discussing new legislation, which is not certain what will establish.

- The most of the CHP potential in Denmark has actually been developed and the remaining potential lies in the industrial sector
- Decrease in subsidy to industrial CHP has increased payback time, which is unacceptable to most industries
- Gas is relatively expensive and the price is not likely to decrease. The electricity price is quite low. Possibility exists that electricity prices will raise after liberalisation
- There is large overcapacity of electricity in Denmark.

Existing CHP plants

- **Vejen CHP plant**

The CHP plant in Vejen is a special combined fuel system, because the steam producing boiler can be fired with either waste, straw, wood chips, or pulverized coal .The output of the system is 3.1 MWe and 9 MJ/s heat at a steam production of 15.7 t/h at 50 bar and 425^{o}C.

Wood chips and waste are fed to a waste grate. Straw can be fired as whole big bales in a single “cigar burner”. The plant’s annual consumption of wood was originally estimated at approximately 1,200 t/y. The idea was to use wood as a supplementary fuel in periods with too low calorific value of the waste. However, the annual consumption of wood chips is estimated to be reduced significantly, since the waste input has been of sufficiently high calorific value and at the same time, sufficient quantities of waste are available. As a consequence, it is the intention in the future only to use wood during the starting up and closing down of the system. Environmental considerations prohibit the use of waste during those periods, because the temperature in the combustion chamber is too low for complete combustion to take place.

- **Masnedøværket**

Masnedø CHP plant was put into operation in 1995. It is a biomass-fired backpressure system for electrical power and district heating supply to Vordingbord, in Eastern Denmark. It uses only indigenous and CO_2–neutral fuels, straw and wood chips. The consumption of biomass is about 43 kt/y. The boiler is designed for straw with 20% of the energy supplied by supplementary firing with wood chips. Masnedø is the only CHP plant in Denmark burning both straw and wood chips in the same boiler. In 1997, the fuel comprised 38 kt of straw and 5 kt wood chips. For short periods sugar canes, olive stones, branches from prunings and waste from parks and gardens have replaced the wood chips.
The steam data of the plan are 92 bar and a steam temperature of 522 ^{o}C. The electrical power capacity is 9.5 MW, while the heat output that can be supplied to the district heating system is 20.8 MJ/s. The input is 33.2 MW. The boiler is a shell boiler with natural circulation. It is a retrofit system, where the steam data have been boldly set close to standard coal-fired plants of the same size, despite the fact that the primary fuel here is straw. Experiences acquired from operating the system in practice suggest that the system concept is successful. The boiler has two feeding systems one consisting of a straw shredder followed by a screw feeder. The chip feeding system consists of transport and screw feeders in the bottom of the silo to the straw- fired unit. The wood chips are mixed with the straw and fired together on to a water-cooled oscillating grate.

- **Hjordkær CHP Plant**

The CHP plant is the smallest steam turbine system installed at a district heating plant in Denmark. One of the ideas behind the plant is to demonstrate whether steam turbines this size are remunerative which is also the reason why the Danish Energy Agency has subsidized the construction of it. It was constructed in 1997, in order to obtain guarantee data on the use of forest chips with a moisture content of up to 50%. In addition to that, the fuel spectrum is a wide range of combustible materials, including a number of residual products from industries.
The system steam data are 30 bar and 396 ^{0}C steam temperature. The electrical power efficiency is 9.6 MW with a heat output of 2.7 MJ/s for the district heating system. The input is 3.8 MW. The relatively low steam data were not selected due to it being a biofuel system,

but due to the fact that for systems that size, it is rather expensive to produce boilers with higher steam data.
The boiler design is a pre-combustor coupled as a vaporizer, containing a step grate, refractory reflection surfaces, and a super heater divided into two sections of fire tube section as a convective vaporizer and an economizer in a steel plate casing, standing apart. The grate that is hydraulically operated consists of a bottom frame of steel, which to some extent is water-cooled. The grate itself consists of elements in special cast iron.

- **Grenaa**

Grenaa CHP plant is a local energy center built in 1992 producing electricity, district heating and process steam using a flexible fuel mixture of surplus straw with coal. The plant is highly automated and operated from a control room continuously manned by an engineer and an operator. Newly- developed equipment automatically controls and optimizes the acceptance, internal transport and processing of the substantial volume of straw.
The plant is equipped with a Circulating Fluidized Bed (CFB) boiler where crushed coal and shredded straw are burned in a fluidized bed of sand and limestone. CFB boilers are known for high efficiency combined with a relatively low environmental impact. They are used world–wide but a boiler burning a mixture of coal and straw is new.
CHP Grenna includes a two-stage back–pressure steam turbine plant of 17 MW net electric and 60 MW thermal capacities. Electricity is delivered to the local 10 kV grid. The plant is flexible in design allowing both electricity and heat production to be varied according to demand. Thermal demand is dominated by Danisco A/S which operates a 250 kt/y wastepaper recycling plant. The frequent variation in process steam demand is automatically balanced by a 3700 m^3 hot water accumulation serving the district heating system. The plant covers 60% of the heat demand in Grenaa. At full operation, the annual fuel consumption (1998) amounts to 69000 tones of straw and other biomass. The total investment was DKK 415 million.

- **Haslev**

The Haslev CHP plant in Denmark is the first in the world to use straw for heating and power generation with no overall greenhouse effect. The total net efficiency is about 86% of the calorific value of the straw, giving an energy loss of only 14%. Flue gases pass through a bag filter removing 99% of the fly ash which is subsequently sent to an environmentally – controlled landfill. The residual slag is used as fertilizer in agriculture.
The Haslev CHP boiler was first fired in April 1989 and went into a commercial operation later that year. Since then the plant has supplied electricity to the grid and has provided heat to about 2,000 customers of the Haslev regional district-heating network. The Haslev CHP plant uses about 26 kt/y of straw. It has nominal production capacity of 5 MW_e and 13 MJ/s heat. The annual electricity production is around 17 GWh, corresponding to the consumption of around 3,000 households. Heating output in 1998 was around 228 TJ.

- **Rudkøbing**

The Rudkøbing CHP plant is situated on the island of Langeland, which is predominantly farmland and is a good source of straw. The water content in straw varies from 10-25%. The Danish straw- fired combined heat and power (CHP) plant Rudkøbing was one of the first CHP plants to use locally produced straw as its sole feedstock. It has become a model plant, as it was previously believed to be difficult to produce both heat and electricity from an inhomogeneous fuel such as straw, when efficient cleaning of fuel gas was also a requirement. Built as a model plant to produce environmentally friendly electricity and heat from an inhomogeneous fuel such as straw, the plant became operational in 1990. The Rudkøbing, CHP plant has a capacity of 2.3 MW electricity (net) and 7.5 MJ/s heat (net). At full load 3 t of straw are burned per hour. In 1998 the fuel consumption was 14950 t of straw, the electricity productions was 11866 MWh (gross) and the heat production was 151490 GJ. The total investment of Rudkøbing CHP plant was DKK 64 million (where DKK is the Danish Krone).

- **Hoglid**

In 1994 a small-scale gasification plant was installed in the village of Hoglid near the city of Herning in Denmark. The purpose of this plant was to supply heat and electricity to about 110 households in the village of Hoglid. This plant fuelled by dry wooden blocks of a certain size, a waste product of the furniture and flooring, industries, became operational in January 1998. However, from time to time it has been difficult to supply dry wooden blocks of this particular size from the industry and therefore the operational hours of the gasifier were limited.

- **Logstor**

In June 1998 a woodchip fired CHP unit with a Stirling engine was installed at a farm in a small village close to Logstor, Denmark. The Stirling engine is designed for an electrical power output of 35 kW_e and a heat output of about 100 kW.

- **Herning**

Herning is situated in the middle of the Danish peninsula Jutland. The number of inhabitants is approximately 58,000, making it the largest city in the county of Ringkøbing. Already in 1988, Herning Kommunale erected a biogas plant utilizing mostly manure. The co-generation unit, burning biogas, has a net electrical output of 620 kW and net heat production of 1.7 MW. Based on the experiences gained in erecting this first biogas plant, it was decided to build a new and considerably bigger plant at Studsgard, which was finished in 1996. The produced biogas is also utilized in a co-generation unit. The heat is distributed via existing district heating system in Herning and the power is fed into the national grid. The biomass fuel for this plant consists of animal, industrial and household waste. The capacity of the plant is 160kW electricity and 180kW of district heating.

- **Aabenraa**

The Aabernaa plant has been operating since January 1998. A straw boiler equipped with a super heater fired with wood chips has been fitted parallel to an existing conventional coal-fired boiler. The new biomass-fuelled boiler, which contains two boilers, one for straw and one for wood chips, will reduce the station's coal consumption and CO_2 emissions. The size of the new boiler has been based on annual consumption of 120,000 tones of straw and 30,000 tones of wood chips. The electricity generated from straw and wood chips is 40 MWe (100% load). Electricity is led to the grid. Heat is supplied to the local district heating system.

- **Filskov**

In the Danish village of Filskov a CHP facility incorporates a biogas plant and a woodchip-fired system. The Filskov Biogas plant receives manure from 11 local farms and organic waste from local abattoirs and industries as well as woodchips from a neighboring sawmill. The manure consists of 95% cattle manure and 5% pig manure. It is collected by a 20 m^3 vacuum tanker from storage tanks at the farms or directly from the animal pens. Digested biomass is returned to the farms in proportion to their area. Surplus manure is sold to three plant breeders. The biogas fuels a gas engine. The nominal electrical power output is 380 kW and the heat output is 680 kW. The heat produced is supplied through a district heating network to about 170 customers in the village of Filskov and the Electricity is sold to the public grid. The biogas engine, designed to meet heat demand during the summer, supplies about 45% of the annual heat consumption. The remaining 55% is supplied by a 1 MW woodchip-fired boiler using about 3500 m^3/year of woodchips and is normally in operation from October to April. In the year 1999 the biogas production was 1,200,000m^3, the electricity production was 2.5 GWh and the heat production was 4.7 GWh.

- **Avedore**

The Danish energy Agency approved the SK power Co plans for a new 570 MW plant at Averdore Holme and Koge Bay, south of Copenhagen in September 1994. The plant was to be located adjacent to an existing coal fired 250 MW CHP plant, Avedore-1. The new plant design was required to make a minima impact on the environment. As a condition of the project approval SK Power had to decommission three older power plants to reduce net emissions by 10% CO_2, 20% NO_x and 30% SO_2.

The Avedore -2 plant has been designed for multifuel operation and its, so far, unique combination of gas turbines, a fossil fuel boiler and a biomass boiler offering a high operational flexibility and plant availability.

Electric power output from the new plant will meet 20% of power demand in eastern Denmark. The plant will additionally supply 570MJ/s of heat to Greater Copenhagen's district heating system. The unit is able to supply district heat to about 180,000 homes and cover the electricity consumption of 800,000 households. To achieve even greater power availability, SK Power has an agreement with Vattenfall of Sweden whereby the Swedish company can take up to 200 MW of Avedore-2 power and in return SK Power can call on 200 MW of hydropower from the Indalseiven plant in the north of Sweden.
Natural gas is expected to contribute 86% of Avedore – 2's total fuel consumption. The plant will burn about 600 million cubic meters per year. Biomass will contribute 10% of the total requirement. The biomass fuel input will initially be 150 kt/y of straw, but future plans are for a mixture of straw and wood chips. The biomass consumption replaces effectively 90 kt/y of coal consumption. Natural gas or coal fuels the main fossil fuel steam generator. The steam generator can be powered with fuel oil, but this is used only as a back up. The Avedore 2 plant will help Denmark meet its energy policy goal of using biomass to meet 10% of its total fuel energy requirement.

- **Odense Fjord**

The largest landfill gas plant in Denmark is situated in Denmark on reclaimed land from Odesne Fjord. More than 6 Mtons of waste is deposited at an area of about 540,000 m^2 (54 ha). At some places the depth of waste is more than 30 meters. The plant became operational in February 1997.
The gas is extracted from 160 vertical wells with total length more than 2000 m. A network of buried suction lines (more than 25 km) connects the 160 wells with four pump modules each capable of pumping up to 720 m^3 landfill gas per hour. After being compressed to 1 bar the gas is transmitted 4 kilometers in a buried plastic gas transmission pipeline for utilization in a new CHP plant. The utilization system consists of 4 gas engines, each with 16 cylinders. Each gas engine runs an electric generator. Waste heat from the engines is used for district heating. Each generator set produces 736 kW electricity and 1000 kW heat. The electricity is sold to the public power supply network via two transformers and the heat is sold to the local district heating network.

- **Blaabjerg**

Blaabjerg Biomass Plant is thermophilic (53.5 ^oC). The concept includes a number of new developments making the plant more adaptable to various input materials and viable for the surrounding environment. After mixing animal manure, organic waste sewage sludge, the biomass is heated and pumped into the fermentors. After fermentation biomass is separated into a fibre and nutritious liquid fraction. The fibre fraction is used in combination with wood chips for heat production and the liquid fraction is returned to farmers and used as fertilizer. The biogas produced is utilized in two gas engines at the new CHP plant in the nearby town of Norre Nebel. The electricity produced is sold to the grid and the heat is distributed to 550 heat consumers in the town.
The undigested fibre is utilized as a fuel additive in a wood chip boiler at the CHP plant. The fibre contributes to the heat production with up to 3 GWh/y, thus increasing total energy efficiency by 15%. Part of the liquid is utilised in an H_2S process.

- **Ribe Centralised Biogas Plant**

The Ribe Centrilised Biogas Plant project was initiated in 1987 and production started in July 1990. The plant is owned by a limited company. Shares are held by, among others, local farers supplying manure, a group of slaughterhouses, the regional electricity supply company and a public pension fund. The objectives of the company were to establish and operate a biogas undertaking and to develop and disseminate biogas technology. Manure as slurry, primarily from dairy cattle, is supplied by 80 farms. The slurry is transported to the plant by their own lorries and fed into digesters where the gas is generated. The slurry is co-digested with slaughterhouse waste and other organic wastes. The balance between manure, waste and other organic wastes varies depending on season and year. In total about 450 tonnes are digested daily producing 13000 m^3 of biogas. The plant is thermophilic in operation, the biomass being degassed at approximately 53^oC, which offers two advantages: the process takes only 11-12 days and the high temperature ensures a satisfactorily sanitary output.

- **Aarhus Nord**

Aarhus Nord centrilised biogas plant was initially built in 1995 and modified in 2001 with the aim of producing a biogas to fuel a CHP unit. The biogas plant is owned by Aarhus Municipality and operated by Aarhus Municipal Utilities. The biomass supplied consists of slurry (85% pig, 15% cattle) from 70 farms, source-separated organic household waste, intestinal content from abattoirs, flotation and protein sludge, medicinal industrial waste, vegetable waste from argo-industries, and tannery waste. The slurry from the pigs and cattle makes up the bulk of the raw material. The plant has a digester capacity of 9800 m^3 and receives about 350 tonnes/day of slurry and 75 tonnes/day of other biomass. The slurry is transported to the biogas plant by tankers. These tankers also return the degassed biomass to the slurry suppliers where it is used as fertilizer. The slurry suppliers association is responsible for the transportation of the slurry and fertilizer. About 10% of the digested biomass is sold to 15 crop farmers in the area. The transportation of the biomass is free of charge for crop farmers located within a 10 km radius and a fee of 7DKK/km is paid (where DKK is the Danish krone) outside this radius. Aarhus biogas plant is one of four Danish biogas plants that are capable of treating source-separated household waste.

- **Mabjergvaerket**

The Mabjergvaerket CHP plant started up in 1993. The plant is based on local available fuel: waste, wood chips and natural gas. An interesting point of this plant is that natural gas is used in super heaters located behind the two waste boilers and the biomass boiler to raise the steam temperatures from 410 to 522 ^oC.

The waste is fired in two identical three-stage movable stepped grate boilers. Basically, it is possible to replace the waste up to 25% (by weight) with straw and up to 100% by wood chips. Each of the two furnace/boiler systems has the same nominal waste feed rate. Particle separation takes place in an electrostatic separator, where the content of fly ash is brought down to less than 30 mg/Nm^3. A two stage scrubber, using water in the washing process, takes care of further cleaning. The water is finally cleaned by a five step waste treatment.

Like the waste boilers, the straw/wood chips boiler is an all-welded water-tube boiler with natural water circulation. The straw/wood chips boiler is built up as a combined unit and can handle 100% straw or 100% wood chips or any combination of the two. Straw is fired on the "cigar burning" principle in which whole, uncut Hesston bales are fed to six burners. Wood chips are fed by three pneumatic feeders that blast the wood chips into the combustion chamber. The bottom of the combustion chamber consist of a water cooled vibrating grate on which any straw falling from the straw burners can be completely burnt together with the wood chips.