Transition to Energy Efficient

Supply of Heat and Power

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In Denmark combined production of heat and power supplies almost 60% of the electricity and 80% of the demand for heat. The change to combined heat and power, from centralized and decentralized CHP has created a heat and power structure that gradually can be transitioned entirely to renewable energy.

By establishing since 1990 local consumer-owned and municipality-owned Combined Heat and Power plants (CHPs) ownership of a significant share of power production gradually shifted from conventional low-efficiency, centralized power production to local, independent, not-for-profit energy supply. This transition to decentralized CHP happened in parallel with building of 3.000 MW_{el} of new wind power with 85% owned by community power co-operatives and farmers referred to as Independent Power Producers (IPPs). *This transition represented the single most important initiative to reduce CO2 emissions in Denmark.*

Figure 1: An example of a Danish Community Owned District heating plant

By 2001 a total of 45% of the 36 TWh of power used in Denmark was being produced by IPPs. Of the 45%, wind power accounted for 20% and local CHP 25%. As a consequence the central power utilities (now owned by Vattenfall, DONG Energy and E.ON) had their share of the power market reduced to around half of the domestic demand for electricity. Thus it took only 10 years to dramatically shift almost 50% of the power production from inefficient, centralized, fossil fuel power supply to local, municipal or consumer-owned companies.

Coincidently this is the amount of time it takes to build one atomic power plant, or roughly 1200 MW_{el}. It should be mentioned that Denmark has not and is not planning to build any atomic power plants; this source of supply was ultimately withdrawn from the energy plans in 1985

In order to understand how other communities can benefit by following the lead of the Danish CHP and district heating model it is important to understand the history and framework that was developed and the subsequent advantages that they provided to the people of Denmark. This Danish model shows that a decentralized heat and power system owned by the consumers can provide a sustainable energy future.

The municipality of Thisted in Northwestern Denmark in 2007 received the European Solar Prize for its outstanding achievements with nearly 100% of the demand for collective heating and electricity now coming from wind, straw, wood, geothermal, organic waste and solar. The energy prices are some of the lowest in Denmark.

Such examples can be multiplied and reinforces the need for a European moratorium on central power production from coal. It also demonstrates that conventional fossil fuel based power production can be phased out with improved safety of supply.

History of District Heating In Denmark

During the period 1955 to 1974 fuel oil made up nearly 100% of the Danish heating supply on an individual basis, for district heating as well as the production of electricity. Typical residential homes employed fossil fuel burners to provide space heat and domestic hot water. This form of heat generation was problematic. It was expensive, dirty and required maintenance on a regular basis.

In the 1950's the idea of district heating systems started to arise which provided a cost effective, efficient solution for communities to get heat without the maintenance and at a reduced cost. The majority of district heating loops in Denmark were installed from 1960-1998 and they were predominantly owned by the members of the community which they were supplying. This gave control to the people and ensured that energy was distributed to the communities at fair prices. In addition, the savings due to the increase in efficiency could be reinvested in the community or given back to the energy consumers in the form of lower heating costs.

District heating from big CHP in Denmark started in cities such as Odense, Aarhus and Aalborg using fuel oil; after 1978 the plants gradually changed to coal and natural gas. Steam was produced for power and hot water of 80-90 degrees Celsius; from the condensers the hot water was supplied to the district heating loops thus increasing the total efficiency of the power generation dramatically.

In 1986/1987 the Danish Energy Agency and The Steering Group for Renewable Energy within the Danish Board of Technology implemented programs to encourage the use of decentralized CHP district heating distribution in decentralized community owned networks for towns and villages that were getting their heat from existing district heating boilers or individual fossil fuel heating systems.

The programs started with a few demonstration plants with sizes 100 to 3.000 kW_{el}. In 1990 the triple tariff system was introduced with tariffs for peak, medium and low load operation. The power was fed into the national grid. To encourage building of local, consumer owned CHP a premium per kWh of power production of DKK 0,10 (€0,013) was introduced.

These polices paved the way for towns in the size of 500 to 40.000 people to implement CHP district heating systems using gas turbines, gas engines, solid municipal waste and biomass. Smaller towns and plants typically used CHP gas engines and small biomass combustors, while the larger towns employed gas turbines, or a combination of all of the technologies. Systems were designed based on the fuel available, the geography and the needs of the cities and towns.

Technology

The favored technology after 1990 predominantly has been natural gas powered CHP engines coming from a basket of European and North American manufactures. Stationary natural gas engines used in combined heat and power applications boast a factor four reduction in CO2 emission compared with conventionally generated thermal coal power for same produced power and individual supply of heat.

This is because:

1. The heat can be used if the system is placed in the community increasing the total efficiency of the system to over 85% compared with the best thermal coal power plant at 44% electrical efficiency.
2. Natural gas has a tenth of the SOx, half of the NOx and a third of the CO2 produced from combustion of coal. The cost of removal of these pollutants in a coal generation plant is significant.
3. The cost to install a gas engine is 30% lower per kW installed than that of a coal plant and even cheaper if removal of the emissions from coal is included. Additionally, natural gas fired engines can be installed in 6 months as opposed to 5 years for a thermal coal plant.
4. Gas engines are manufactured in big numbers and cheap while central power plants are one-of-a-kind technology. Shipping of the gas engine and the balance of plant is with trucks and trains. The gas engines can be installed in existing or new buildings without any noise impact for the neighborhood.

With these benefits it became possible for local district heating companies owned by municipalities or consumers to build their own CHPs and offer cheaper heat to the households. This became one of the driving forces which encouraged a rapid change to local CHP.

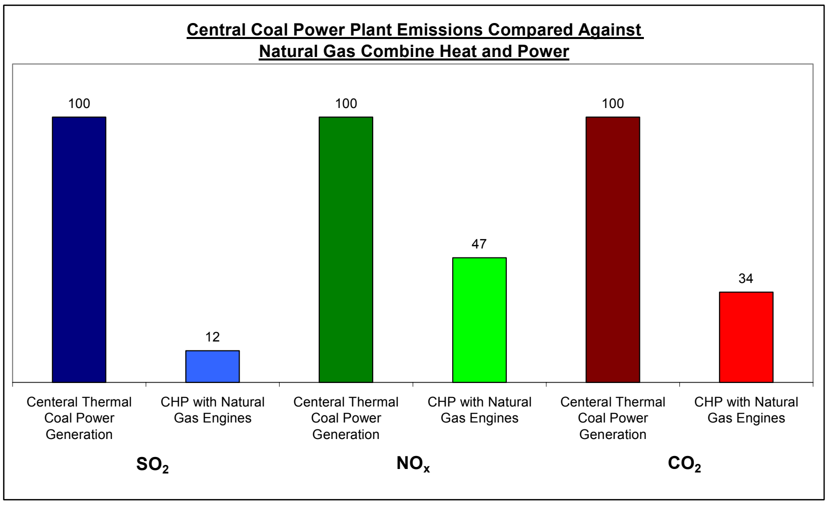

Figure 3: Comparison of emissions from central coal power production to natural gas combined heat and power for the same quantity of power produced. [1]

Is CHP renewable?

CHP using natural gas in not renewable but local CHP creates the basis for a decentralized energy structure that later can be changed to local renewable energy sources. Stationary gas engines can run on a variety of fuels which can be tailored to local fuel availability.

These fuels can include **Local**:

- Biodiesel
- Plant oil
- Biogas
- Gasified biomass
- Land fill gas

If these alternate fuel sources are not available natural gas can be used a transitional fuel while the community determines which fuel can be utilized in the future. In essence, district heating with CHP provides the initial framework towards a renewable energy power and heat system.

Figure 4: Folkecenter Biogas system.

Advantages

Advantages of community based CHP units are vast, the main benefits being:

1. *Reliability:* Natural Gas engines are extremely reliable as they are used in the harshest of conditions where reliability is of the utmost importance. Typically these gas engines are installed in transcontinental gas compressor stations, drilling rigs, offshore oil platforms, and villages not served by the national power grid.
2. *Community Autonomy:* Having a local power and heat producer in the community provides the local community with autonomy giving the, "power to the people". This gives the community the ability to ensure that the power is developed in an appropriate manner.

3. *The Ability to incorporate Renewable Energy in the Future:* Having CHP with district heating opens opportunities to incorporate large fractions of renewable energy in the form of biogas, solar thermal heating, wind for heat, biomass gasification, plant oil based fuels and combustion of locally based biomass.

4. *Scalability and Flexibility:* Local CHP are scaleable and flexile to operate. This makes it easy to increase capacity in the future and matches well with the incorporation of wind and solar power in the supply system.

5. *High Efficiency:* Stationary Natural Gas CHP units boast an electrical efficiency of 42% and with heat recovery of the jacket water, exhaust, lube oil and turbo charger can achieve and overall efficiency of over 85% (power 42% plus heat 43%).

6. *Cost Effective Heat and Power:* With high total efficiencies cost of power and heat can be reduced. As an example in 2001 Denmark according to Eurostat had the third lowest power prices (without taxes) in Europe with Sweden and Finland being lower due to high contributions from hydro. In contrast France, with 80% of its power coming from atomic energy, had a higher power price than Denmark with its thousands of independent power producers.

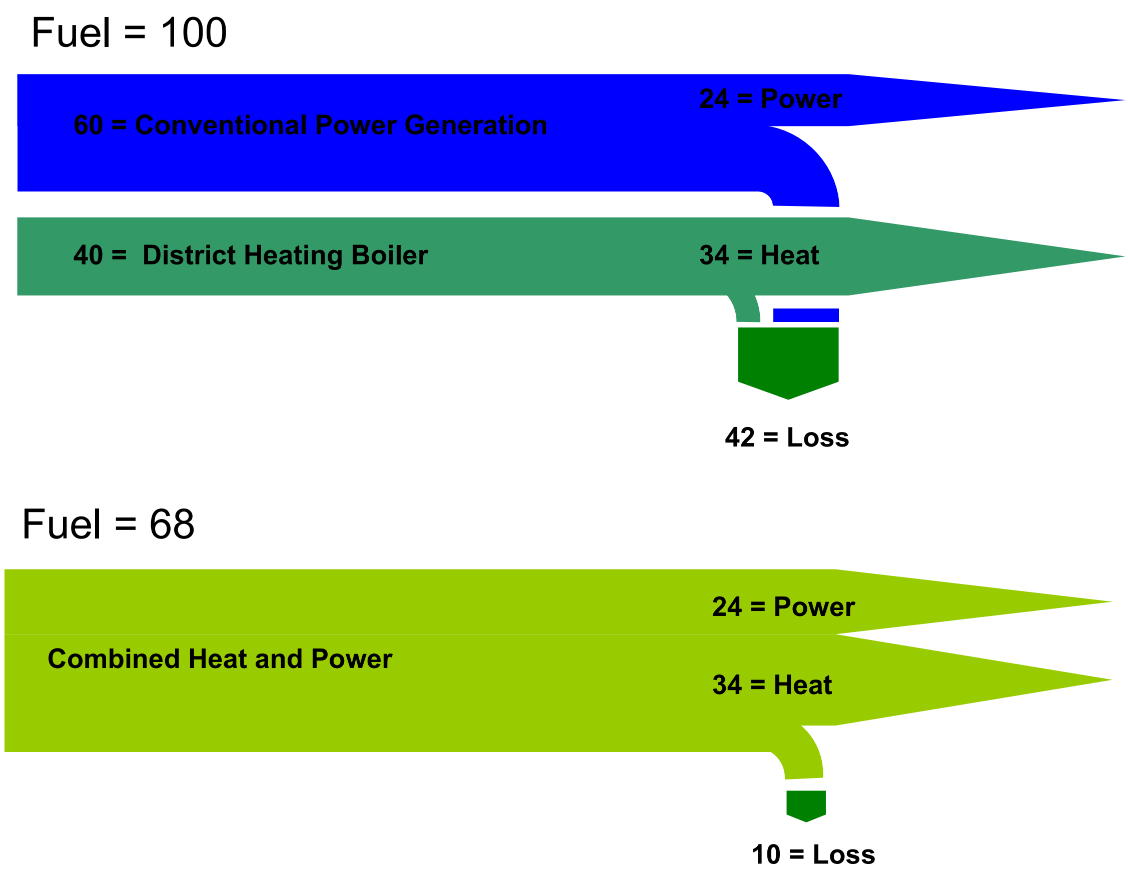

Figure 5: Energy flow diagram comparing separate heat and power plants versus 1 combine heat and power plant to accomplish both. It is evident that using combined heat and power saves 30% of the energy regardless of the energy source.[1]

Individual Use of CHP

Single users of CHP can include apartment buildings, super markets, railway stations, hospitals, hotels, schools, commercial buildings, and industrial businesses.

In addition to community power systems, single users could also benefit from the use of CHP like the Reichstag (German parliament building) that is using its plant oil CHP unit as the main power and heat supply for the building and using the grid as the power back up.

If the infrastructure is already in place then there is little to no capital cost to switch the operating philosophy; it is simply a management decision.

Small individual CHP up to 10 kw_{el} is an energy box that makes the family house autonomous with its own supply of heat and electricity. The energy box can be combined with solar energy and other renewable energy. Fuel for the energy box may be biogas, other biomass gases, plant oil, ethanol or solid biomass for external combustion in stirling-type engines.

If mass produced like automobiles, such energy box could become very cheap compared to conventional power plants and CHP. A 100 kW car costs around 100 € per kW, 90 – 95% less than a conventional power plant. Besides the drive train, included in the price of a car are five wheels, sofas, entertainment, windows and many accessories that in principle makes it much costlier to manufacture than an energy box of similar capacity. Therefore an energy revolution based on mass produced CHP solutions has tremendous environmental, resource and cost perspectives. The solution may be a derivative of hybrid car technology and pulse-operation.

Coal moratorium in Denmark, 1990 and 1997

Parallel to the implementation of CHP in Denmark, in 1990 the first moratorium for building new coal fired power plants was decided. The moratorium for coal did not require special legislation as building of new power capacity must have the permission of the energy minister. And it was not given with reference to the need for improved efficiency in the production of power and environmental concerns. Only CHP could meet such requirement.

It was also decided by the minister of energy as part of the *Energy 2000* plan that permission would not be given to build conventional power plants without utilization of the heat production. However, a dispensation was issued to two 450 MW el CHP units on the condition that similar coal-based, conventional power capacity was decommissioned and scrapped.

In 1997 the government presented the ***Energy 21*** plan with even more focus on energy efficiency and renewable energy. The moratorium from 1990 for coal in new power plants was maintained. As a consequence even new central CHP were built with straw and wood as the primary fuels in addition to 10-20% natural for superheating in order to obtain sufficient power generation efficiencies.

Liberalization and discontinuation of the renewable energy programs by the government in 2001 did not lead to building of new coal-fired CHP or conventional power plants. The central power producers have requested to change the fuel mix on some of the coal-free power stations, however without a substantial increase in the use of coal for which permission cannot be expected as part of a political compromise. Thus the coal stop has been maintained.

Change of the tariff structure and market prices for power had as a consequence that most of the decentralized CHP owned by IPPs since 2004 produce less power but obtain same revenue as earlier. These CHP have a function as reserve capacity within the overall power supply and will in general not be in operation when wind power or central coal power CHP cause low prices of electricity. In general government policies in favor of the central utilities and liberalization has increased the use of coal power and reduced overall efficiency in the energy system as more of the demand of heat for district heating now comes from boilers and not local CHP. Also sale of electricity to neighboring countries have resulted in increased use of coal and in 2006 the first increase in CO_2 emission for two decades was registered.

As another consequence of the present government policies no new wind power has been installed in Denmark since 2003. The state owned DONG Energy has become an international operator that builds big offshore wind farms in UK and a 1.600 MW coal power plant in Lubmin, Germany. DONG informs that investments in new power production in Germany and UK are much more profitable than in Denmark. This has caused heavy protests from the Danish renewable energy community that insists that best Danish practice within consumer owner CHP should rather be transferred to Germany.

The Coal-Stop in 1997 resulted in concrete political initiatives:

In order to live up to the CO_2 targets the following initiatives have been accepted and implemented by the energy sector:

- The biomass agreement of the parliament from 1993, with a supplementary agreement from 1997 secures that at least 1.4 million tons of biomass (straw, wood chips and willow) will be used in Danish CHPs. In addition an increased used of biogas and land-fill gas was planned.
- The energy minister instructed in 1998 the Danish power stations to build offshore wind turbines with a capacity of 750 MW by the year 2008.

- Central and decentralized CHP plants were changed from using coal to natural gas, household waste and biomass.
- The Danish parliament passed in March 1997 a coal-stop which implies that permission for building power stations that use coal will no longer be issued. Basically all of the more than 400 district heating stations have changed from using coal and oil to environmental friendly CHP production based on natural gas and waste – or to using biomass and waste. This reorganisation was launched in 1990 according to the heat supply law and was finally implemented in 1998.
- The development of industrial CHP based on natural gas was subsidized.
- With the passing of the green taxes law in 1995 came a tax on sulphur at 20 DKK (€2.8) per kilo emission of sulphur (10 DKK pr. kilo sulphur dioxide). Till January 1st 2000 fuel for the production of electricity was exempt from the tax that was replaced by a tax on consumption of electricity at 0.013 DKK pr. kWh.
- Maximum annual quotas for sulphur dioxide and nitrogen dioxides that are allowed to be released from the big power stations.
- The trades and industries were imposed a CO2 tax. The revenue from the tax is sent back to the sector to subsidy investments in energy efficiency.
- The building code was tightened to secure a lower consume of energy for heating new buildings.

- Information campaigns were carried out and counselling given for house holds and companies in order to urge them to reduce the energy consumption.
- Denmark should work persistently to pass common and coordinated initiatives in the EU to reduce the energy consumption and the greenhouse gas emission.

DANISH POWER SECTOR RESTRUCTURED IN 2004

In 2004 the organizational structure of the Danish supply of power was dramatically restructured. The consumer owned power companies were commercialized as part of a politically compromise. Distribution, transmission and production became independent sectors with each their sort of framework.

1. Distribution is the responsibility of local not-for-profit cooperatives, municipal, or companies with a concession.
2. Power transmission (over 60 kV) is the responsibility of energinet.dk, a new, wholly state-owned company.
3. Production of power comes from
    - central power plants owned by DONG Energy (owned by the Danish state), Vattenfall (owned by the Swedish state and E.ON (German)
    - local consumer owned CHP, and
    - wind power with 85% owned by IPPs and the rest of the central power companies.

Appendix

The collective supply of heat (cities, towns, villages, 2004) is coming from:

16	Central CHP
285	Decentralized CHP
130	Decentralized district heating plants

The private supply of heat (companies and institutions):

380	CHP
100	District heating plants

The fuels used for the supply (2002):

Natural gas	30%
Coal	24%
Waste	23%
Biomass	15%
Oil	7%

The heat is distributed by 50.000 km of district heating network.