

May 2008

DENMARK

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Henrik Flyver Christiansen, Danish Energy Authority
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1.1 Danish energy policy

The Danish energy plan Energy 21 was introduced in 1996 in order to ensure a strong Danish energy supply system, with emphasis on short-term targets, and preparation of longer-term sustainable development.

The important objective is to reduce the CO₂ emission by 20% by the end of 2005 compared to the 1988 level, and 50% before 2030. The energy plan states that Denmark has to be a driving force in international development of renewable energy with ambitious environmental goals, and to support the European opening of the energy market, with strong priorities on the environment. Further the Energy 21 confirms the need for dynamic, revised energy plans.

In 1999 the Danish parliament agreed on that in 2003 20% of the electricity should be produced from renewable energy sources (10% in 1998) and the gross energy consumption should increase to 12-14 % in 2005 and 35% in 2030 (9% in 1998).

The recent elected Danish government has reduced the funding for R&D projects on the Budget from approximately 500 MDK to approx 250 MDK, with reference to that the industry has to invest in technology development.

Further the government has postponed the market for REC, until there is a well functioning European market.

So all in all the new government has removed not only the technology push but also the market pull, for innovative biomass technologies, including gasification.

The current Danish energy policy is that Denmark will use the Kyoto mechanisms and buy CO₂ reductions where they are most profitable.

Some years ago the utility companies own both the grid and the power plant. Now it have been split up in two utility companies ELSAM and Energy E2 and at the end of year 2004 the two grid companies Eltra and Elkraft System by law will be one company. The utility companies are now allowed to make profit and the Grid Company will be a part of the Civil Service with out profit.

The power production from Windmill and CHP have become so big compared to the consumption that there at different time is an overflow witch not is possible to sell. To get a better regulation of production and consumption the government has chance different Energy laws.

By law from January 2005 more or les all kind of power production will as a basis electricity price get the Nord Pool price. Nord Pool is the Nordic Power Exchange (www.nordpool.no). CHP on Natural gas will on top of the Nord Pool price be supported compared to power production and there by the income at an average level for the year 2001 to 2003. The support is monthly regulated to this level. Existing private biomass power production get 0,60 dk kr/kWh (0,072 Euro) for a period of 20 years from production start up. The utility companies use of biomass according to "The biomass

agreement” (1 mill. Tons of straw and 0,2 mill. Tons of wood yearly) get 0,30 + 0,10 (REC) + up to 0,03 = 0,43 dk. Kr/kWh (0,052 Euro) for a period of 10 years from production start up. New biomass plant get the Nord Pool price + 0,10 (REC) dk kr/kWh. New biomass plant with particular technology interest for the future get 0,60 dk kr. (0,072 Euro) for a period of 10 years and 0,40 dk kr. (0,048 Euro) for the next 10 years. New laws for CO2 quota allocation for all Energy production with fuel input higher than 20 MJ/s regulate the production from January 2005 to full fill the Kyoto protocol. Every utility companies, industry and private Energy production have to make a forward planning before the end of the year to full fill this.

1.2 National programmes

The Danish industry is very successful in attracting support to gasification projects from different European programmes i.e. JOULE, THERMIE, ENERGIE, ALTERNER and FAIR.

Support is also achieved through EUREKA and the Nordic Energy Research Program. When it comes to National programs a significant reduction in available public money for research and development has been the effect of a change in government:

- The Energy Research Program (EFP) - supporting mainly strategic energy research, has been reduced from 110 MDK to 75 MDK, further the advisory committee for Environmental Friendly Power and Heat Production in order to determine the most essential research needs has been terminated.
- The Development Program for Sustainable Energy (UVE) - supporting mainly the development and demonstration of renewable energy technology, has been reduced from 132 MDK to 0 MDK.
- Investment programme for heat and CHP from biomass technologies has been reduced from 25 MDK to 13,5 and was terminated in 2003.
- The program for supporting industrial energy conservation - supporting mainly the implementation of more efficient commercially available energy technology in industries - has been terminated.
- A Public Service Obligation provides the Utilities, Industri and others with the option to apply a part of the consumer price for electricity to ensure a continuous development of Best Available Technology for electricity production is maintained on 100 MDK annually.
- One newly introduced means for pushing research is the introduction of a tax deduction (150%) for companies buying research in another public Danish research institution.

The Danish Energy Authority Follow-up Programme for CPH supports the establishing of new CHP plants. The programme collects, evaluate and distribute production and performance data from commercial and semi-commercial/demonstration plants. The data are being controlled, registered and analysed by the general CPH monitoring program of the Danish Energy Authority. The program has been terminated with the end of The Development Program for Sustainable Energy (UVE). The results and draft reports have been forwarded at a seminar in 2004; final reports are expected in the end of the year.

The following institutes participate in the programme and are responsible for the validation and quality of the reported data. Danish Forrest and Landscape Research Institute (Fuel analysis), The Danish Technological Institute (Energy and environmental analysis), FORCE Technology (Ash analysis), Danish District Heating Association (Economy analysis), Danish Utilities ENERGI E2/ELSAM (Plant operation data), Technical University of Lund (Waste water analysis), RISØ National Laboratory (Tar and chemical analysis) and the Technical University of Denmark (Process analysis). Data are presented every two months in the publication Danish Bio Energy (www.biopress.dk)

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1.3 Institutes

Technical University of Denmark - The gasification group has concentrated their activities on three areas: 1. Carbon conversion 2. Modelling of gasification processes and systems, in order to improve reactor design, and system optimization. 3. Development of new gasification processes, e.g. the LT-CFB concept with Danish Fluid Bed Technology and a new fluid bed two-stage process with COWI. The verification of this process is ongoing.

Further the Department has constructed a 75 kW_{th} two-stage gasification plant mainly for long term testing of the gasifier and for testing of essential components in the CHP setup. This gasifier has now been in full automatic operation for more than 2,200 hours, and has an overall efficiency from biomass to delivered electricity of 25%.

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Technical University of Denmark - The Stirling group has developed and demonstrated the Stirling engine technology for biofuels in a 9 kW_{el}, 35 kW_{el} and a 75 kW_{el} version. Activities are related to optimization of engine performance. A field test of the 9 kW_{el} engine operating on biogas and natural gas are ongoing. The 35 kW_{el} engine is developed for direct combustion of wood chips and other biofuels. For the first 35 kW_{el} plant a commercial available grate combustion system was further developed for this application. The combustion system for the second generation was based on combustion of a producer gas from an updraft gasifier without gas cleaning, the project is reconstruct in 2004 and results are expected at the end of the year. The first production series of 10 engines for lower the cost is made in spring 2004. A larger engine with an electric power output of 75 kW have been install in Austria for direct combustion of wood chips.

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Technical University of Denmark - The CHEC, Combustion and Harmful Emission Control, group carries out research in fields related to chemical reaction engineering and combustion, with emphasis on high-temperature processes, formation and control of harmful emissions, and particle technology. In recent years activities in CHEC have included work on pyrolysis and gasification of coal and biomass in laboratory and bench scale. Cofiring of biomass and Coal has given a higher priority.

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The Danish Forrest and Landscape Research Institute are representing Denmark in the international project; standardisation and characterisation of wood based fuels. The Institute has worked on determining the critical parameters related to the use of wood chips in gasifiers, and have proposed a classification for a “large gasification wood chip”.

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Risø National Laboratory is performing research within the fields of fundamental tar formation processes, advanced chemical measuring techniques and analysis.

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Technical University of Lund, Sweden has performed thorough analysis of different techniques in order to determine the inhibition effect from all measured single tar components found in gas from up and downdraft gasifiers, and on effluents from purified tar water, following the Nordic test analysing method.

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Approved Technological Service Institutes

The Danish Technological Institute has been focused on research / development of measurement methods of energy and environmental performance for different CHP technologies. The Danish Technological Institute is representing Denmark in the work related to the EU tar protocol and the CEN tar measurement standard.

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FORCE Technology did in 2004 acquire the activities in dk-TEKNIK ENERGY & ENVIRONMENT, including the work on ash characterisation, and aspects related to PAH concentrations. FORCE Technology is in co-operation with the Danish Energy Authority performing economical and environmental analysis (LCA) for different technologies.

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FORCE Technology is in co-operation with TK Energi A/S participating in demonstrating the dry gas cleaning technology in Gjøl.

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1.4 Industries, consultants and pilot projects

Volund R/D Centre has for the last 15 years worked on commercialisation of updraft gasification based CHP of straw and wood chips. Since 1993 Volund have been working with the Harboer gasification which until 2000 produce the heat for the town and then got to engine install for CHP. For the last 8 years they have worked with commercialisation of a combined gasification / Stirling CHP solution. A long-term test of the Stirling engine is expected to be finished mid 2005. Vølund R/D centre is a owned by Babcock & Wilcox.

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Hollensen Engineering and Boilers Co has in co-operation with the Community of Herning worked on commercialisation of a down draft gasification technology. The Høgild project was initiated in 1994 and terminated in 2003.

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ENERGI E2 A/S has participated in the development of co-firing technology based on CFB gasification of straw for gasifiers coupled to boilers in co-operation with Finish companies and institutes. The aim was to produce an ash and K, Na and Cl free gas, which can be co-fired in modern high efficiency steam boilers. The results were promising and it was only because of locally unfavourable prices and lack of long term experiences of warm gas cleaning that a 100 MWth was not realised. The activities are continued with various waste fractions as fuel, with emphasis on the development and verification of reliable warm gas cleaning in order to minimise the environmental impact from efficient conversion of waste to electricity and heat. ENERGI E2 was a partner in the Biocycle project, the Finish Lahti project (40–70 MWth, RDF and biomass) and in the EPZ (now Essent)/Amargaz project (85 MWth, waste wood).

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ELSAM A/S is operating the larges co-fired CHP plant, using up to 150.000 ton of straw annually. Further ELSAM has participated in the EU APAS and the Biocycle project.

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BioSynergi Proces ApS continues the development of an air-staged open core pilot gasifier. Previously has process design and erection of a test plant together with a combustion engine been carried out. Measurement results from more than 300 hours of test operation that includes 110 hours of gas engine operation at the test plant has proved that the gasifier was capable to produce a sufficiently clean gas for continuous operation of an engine. A continuous wood chip dryer was developed as well in the project and operated with a satisfying result. A 80 kWel demonstrations plant in Graested are in operation since 2003.

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Weiss A/S is a well known manufacturer of straw and wood boilers in Denmark. Weiss is now upscaling the two-stage gasification process in corporation with DTU and COWI A/S. The aim is plants of 1MWe and up, with an electrical efficiency of 35%. A pilot plant with design data of 600kWth and 200kWe (35% electrical efficiency) will be established during 2004/2005.

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TK Energi A/S has developed and tested a three-staged open-core gasifier, with dry gas cleaning technology. The testing has proved process stability in the pilot plant with a capacity of 300 kWth fired with wood-chips. TK Energi has in co-operation with Hedeselskabet received national funding for a study aiming at implementation of an up-scaled version of the gasifier, where the producer gas is used in an existing engine now fired with landfill gas. A third generation test plant, partly funded by PSO, will be tested at 500 kWth during 2002.

TK Energi has participated in a European Project aiming at developing a three staged, slagging entrained flow gasifier mainly for straw. A 300 kWth pilot has been tested. TK Energi has high expertise in handling, preparation and feeding of straw.

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KN Industries has developed an updraft gasifier for straw, using CO₂ as gasification agent. The plant with an installed capacity of 250 kWth has with success been tested in pilot scale and proved process stability, including no ash agglomeration. KN Industries has in co-operation with the community of Løgstør received national funding for a study aiming at implementation of an up-scaled version of the gasifier. The 500 kWth unit has now been built, and is being tested with a 100 kWel dual fuel diesel genset.

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Danish Fluid Bed Technology Aps are testing and developing the “Low Temperature Circulating Fluid bed” (LT-CFB) gasifier within a cooperation between Danish Fluid Bed

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Technology Aps (DFBT), the Technical University of Denmark, FORCE Technology, Rica-Tech A/S and Tech-wise A/S.

The LT-CFB gasifier is designed in a way that allows the use of not only woody fuels, but also very difficult agricultural and waste fuels. The main idea is to convert such biomass and waste into a hot fuel gas with low content of ash, K and Cl, and to burn the gas in e.g. highly efficient power plant boilers.

Tests conducted with a 50 kW plant at DTU has given a number of encouraging results, such as no deposition or agglomeration problems in spite of gasifying difficult Danish wheat straws, > 6 % ash, > 1.8 % K and 0.8 % Cl (d.s.), and using ordinary silica sand with no additives as the bed material.

By re-using the bed material from earlier tests and by avoiding the addition of fresh sand a steady concentration of 5.3 % K in the bed material was reached. Moreover, retentions of particles and K beyond 90 % has been achieved using only an ordinary secondary cyclone operating at 600-650 C, and as a positive surprise the PAH concentration in the ash was only around 2 mg/kg. According to Danish regulations, this low PAH content allows the straw ash to be "returned" to the fields without further processing.

The two most recent test with the 50 kW plant has been on pig and hen manure. As expected also this type of fuel can be gasified without problems, whilst retaining most of the valuable nutrients (K, P, Ca, Mg) in the ash stream.

Furthermore a 10 times up-scaled (500 kW) LT-CFB test plant has also been build at DTU and commissioning this plant is planned for autumn 2004.

The LT-CFB gasifier is based on fast pyrolysis, and plans for optimising it for the production of bio-oil is intended. The ELTRA PSO R&D program, supports most of the efforts described.

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Elsam Engineering A/S is a consulting engineering company specialised in all kind of services related to energy and power plants and systems based on the utilisation of fossil fuels and renewable energy.

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COWI A/S is an independent consultant operating worldwide within all principal fields of engineering and related sciences. COWI works with several different gasification projects together with many partners. Examples of COWI's participation are upscaling of the two-stage Viking gasifier to a 500 kW demo, consultant on mechanical and electrical work for the 18 MW CARBONA gasifier at Skive, demonstration of 3 MW pyrolyser for superheating of steam cycles, development and demonstration of fluid-bed version of the low tar two stage gasification process LT-BIG. Participation in the EU supported BIOCELLUS project, where use of producer gas in fuel-cells is being tested in order to optimise design of FC's and gascleaning. Analysis of several waste gasification and thermal treatment concepts in connection with WTE projects in Ireland, UK, Ukraine and Malaysia. COWI has further developed methods for HAZOP and safety analysis, which

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has been performed for various gasification plant. COWI carries out design, tender and supervision of complete biomass, WTE and gasification plants.

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ReAddit Aps. is a company focused towards production and utilisation of additives and research -within the fields of additive utilisation in combustion and gasification of coal, biomass and waste. The basis of ReAddit is a professionally developed knowledge concerning, reactivity, kinetics, catalysis, ash chemistry, gas cleaning, reactor design and model evaluation of data.

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ReaTech is a consulting research company, specialised in experimental scientific fuel characterisation and preparation. The work is focused towards research within the fields of combustion and gasification of coal, biomass and waste. The basis of ReAddit is a professionally developed knowledge concerning, reactivity, kinetics, catalysis, ash chemistry, gas cleaning, and model evaluation of data.

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1.5 Implementation

Harboøre CHP plant

In 2000 a complete biomass gasification process system fitted with two gas-engines of total 1,4 MWe was set in operation at Harboøre district heating plant. This was the final step in a development process, which started in 1988.

Based on a traditional German updraft moving bed gasifier Volund in 1988-1992 experimented with a pilot unit for gasification of straw. Next step was construction of a wood-chip fired version of this gasifier, which since 1993 has been supplying gas to the boiler at Harboøre district heating plant, and since 1996 the gasification plant has produced all district heating for Harboøre, with minimal operating staff. The final conversion to a CHP plant was completed in the summer of 2000. The gasifier has been operating 74.000 hours (8.100 hours / year since 1996)

Since July 2000 the engines has been operating 9.100 hours and 6.400 hours, the CHP power to the grid has been 7.700 MWh and the CHP district heating 65.000 MWh in total. Since December 2003 the engines has been full available. The operational data for the period until today (July 2004) are, woodchip fuel with a moisture content varying between 39 and 50%, 3691 MWh of power to the grid, corresponding to mean power efficiency (woodchips to power) of 27.2%.

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Ansager Stirling

In 1999 the Technological University of Denmark received national funding for the development of a 2nd generation Stirling unit. In connection to this project Volund received national funding for implementation of a combined Stirling/gasifier unit. The project in Ansager includes an updraft Volund gasifier, fired with wood chips up to 50% moisture. The gas is lead directly to a burner on top of the Stirling engine combustion chamber without any gas cleaning.

The plant has been operated for approximately 400 hours, and several improvements have been made. An electric power output of up to 37 kW has been measured, which is well above the predicted 35 kW. The results of a one-hour test showed that a net electric efficiency of 16,7% (woodchips to power) was obtained and the total energy conversion efficiency was 88 %. The project is reconstruct in 2004 and results are expected at the end of the year. The Danish company FLADDER International will operate the plant in the field test, which will soon be initiated.

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Løgstør CHP plant

The community of Løgstør are producing heat from straw fired boiler, and have together with KN Industries received national funding for the two first stages of a project including building of a first generation small scale demonstration plant, and a 2000 h test run of the gasifier located at the supplier. The straw fired gasifier, using CO₂ as gasification agent, has been developed by KN Industries. Before the final stage, implementation at Løgstør, is funded and initiated a successful outcome of the test run is required.

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Kibæk CHP plant

In 1996 the community of Kibæk received national funding for implementation of a steam based CHP plant. In 1998 a review of the plant design and implementation showed an advantage in choosing a 2. generation of the Volund Harboøre gasifier, fired with wood chips (50% moisture) instead of the steam cycle. The gasifier is designed to have an installed capacity of 3 MW_{el} (31%) and 6 MJ/sheat. The total efficiency is expected to reach 92%. Contractual negotiations with two diffret company are still ongoing.

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Skive CHP plant

I/S Skive Fjernvarme (District heating company in Skive town) has received European, US and national funding for a project aiming at the installation of a new biomass fired

gasification plant producing gas for 3 biofuel modified gas engines, build in connection with an existing biomass boiler plant. The plant is a fluidized bed gasification plant (Carbona) utilizing palletised biofuels, the plant will have an installed capacity of around 20 MW base load and 28 MW extended load.

The local authority and the City Council of Skive has both approved the project and adopted the main part of the necessary permits, allowing the project to move into the construction phase.

Engineering work on the plant building and the district heating system is nearly completed.

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Gjøøl

Gjøøl Private Kraftvarmeværk (District heating company in Gjøøl) has received National and European funding for the establishment of a wood chip fired gasification unit, in order to be able to produce gasification gas for two existing natural gas fired Jänbacher engines, which will be modified to accommodate the gasification gas. The plant delivers heat for 300 housings, the annual heat sale is 5500 MWh and the electrical sale is 5,900 MWh. TK Energi A/S will deliver the gasifier, based on an open core gasifier and a patented wood chip dryer and dry gas cleaning technology. All necessary approval has been obtained from the local authorities for the project to move into the construction phase. The construction of the building and the installation of the grab crane system and the biomass boiler will commence shortly. The consortium consists of Gjøøl, TK Energi, FORCE Technology and European partners.

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Græsted

Græsted Fjernvarme (Græsted district heating) is hosting the BioSynergi demonstration CHP pilot plant. . The activities are performed in the ongoing project: Optimizing and automatically operation of an Open Core gasifier pilot plant for combined heat and power with wood chips as fuel, funded by the Danish Energy Authority

The aim is to demonstrate and optimize a staged Open Core gasifier fuelled with forest wood chips (45-50 % moisture on wet basis), as a part of a CHP plant.

The electrical output from the pilot plant is designed to 90 kWel and the thermal heat output to 200 kJ/s. The plant includes all components from wood chip storage and drying to output of energy in the manner of electricity for the electric distribution network and heat for delivery to the private district heating plant in the town of Græsted.

The completion of the plant and supply lines to the heat and electricity networks was finished in 2003. First half of 2004 was dedicated tests of the individual components and minor improvements of the plant design, leading to the ongoing long-term test period.

Unmanned operation will be implemented as soon the safety procedures are tested with satisfying result. The long-term test period is settled to 3000 operation hours.

The future goal is to up-scale the CHP plant to 250-1.000 kW electrical output.

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Weiss A/S

A 200 kWe pilot plant of the two-stage gasification process is being established at the factory of Weiss A/S. In the two-stage gasification process, the pyrolysis and the gasification process are separated into two different zones. In between the pyrolysis and the gasification zones, the volatiles from the pyrolysis are partially oxidised. Hereby, most of the tars are decomposed into gas. To enable high energy efficiency, the thermal energy in the gasification gas and the exhaust gas is being used for drying, air preheating and for pyrolysis.

The two stage gasification process has successfully demonstrated that the process offers

- Low tar content in gas (<5 mg/Nm³)
- Stable unmanned operation
- High coldgas efficiency (>95%)
- Low environmental impact (clean condensate, high carbon conversion)

The process verification and documentation has been performed in small scale, and in order to manufacture economical attractive plants the process is now being upscaled. The two-stage gasification process is modified, so the drying is separated from the pyrolysis unit. The drying agent is steam and produced steam from the dryer is lead to the pyrolysis-gasification reactor, and hereby soot production is reduced and char reactivity is increased. scale

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