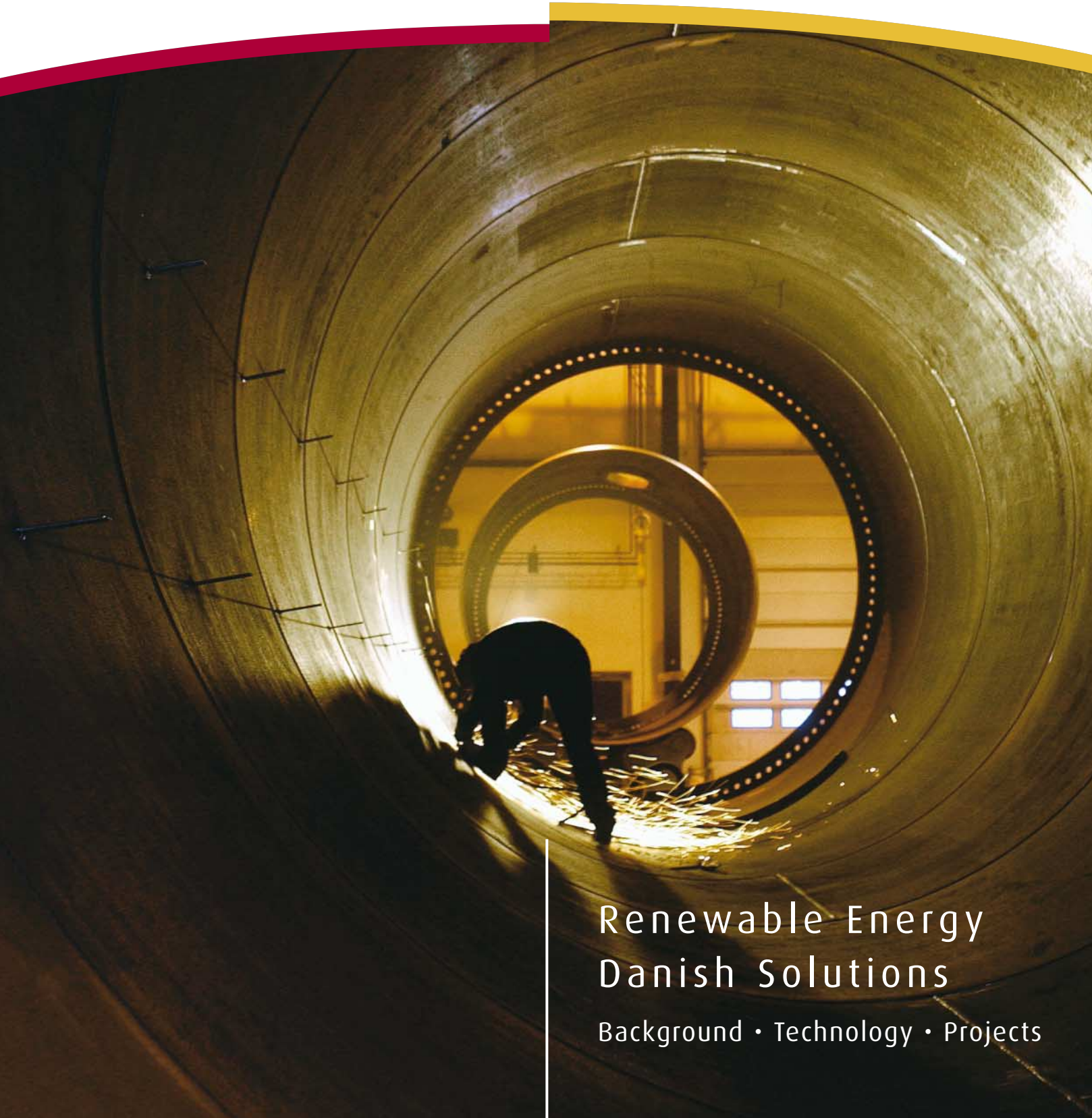




DANISH ENERGY AUTHORITY



Renewable Energy Danish Solutions

Background • Technology • Projects

PREFACE

Energy production based on renewable energy sources is an important pillar in overall Danish energy supply, as the utilisation of renewable energy contributes to security of supply and the management of environmental concerns. In the years to come, these concerns will be met most efficiently through the energy market, because an efficient and reliable energy market is a key element in a growth strategy.

The future challenges also mean new market opportunities for renewable energy technologies. Further expansion must be based on the continuous development of present technologies as well as on research efforts within new technologies.

This publication provides an updated overview of the Danish renewable energy sector. It describes a variety of Danish solutions that have been implemented to meet the challenge of utilising energy from wind, biomass and solar radiation. It also describes the results of new research and development within a range of promising future technologies.

It is my hope that the publication can provide inspiration for everyone involved in the promotion of renewable energy worldwide. I hope that it will be useful in furthering international cooperation, thus accelerating the development and economically sound deployment of the world's renewable energy sources.

Ib Larsen, Director General

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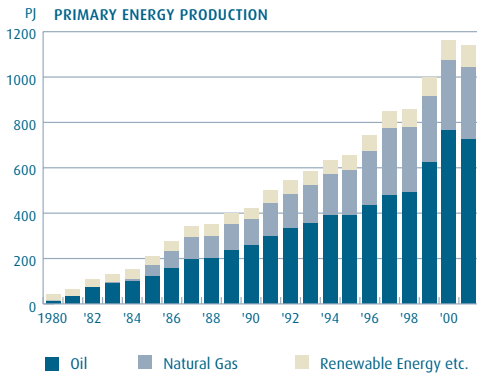
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RENEWABLE ENERGY ON THE MARKET



Source: Energy Statistics 2001 (DEA)

Danish energy production has increased rapidly since 1980, and oil, natural gas and renewable energy have contributed to this.

The utilisation of renewable energy has played an increasingly important role in Danish energy policy over the last decades, and today Danish society is using considerable resources to maintain and develop the positions of strength in Danish technology. Danish development and practical application of renewable energy technologies has contributed to enhancing security of supply, promoting economic growth by means of exports and new jobs, and reducing the environmental impact of the energy sector.

While the main objective of Danish energy policy has varied, since the energy crisis in 1973 renewable energy has been a key focus area.

SECURITY OF SUPPLY AND EMPLOYMENT

The focus of the first Danish energy plan (1976) was on security of supply, and its most impor-

tant objective was to reduce Danish dependence on imported oil. Investments were made in energy savings and the conversion of Danish power plants from oil to coal. At that time, renewable energy only had a marginal role in energy supply, mainly in the shape of waste for district heating and use of firewood in private households and agriculture.

Energy Plan 81, which focused on the socio-economic considerations in energy policy, laid the ground for rapid growth in Danish energy production, primarily by means of stepped-up development of oil and natural gas recovery the North Sea.

The plan also led to the building-up of a nation-wide natural-gas grid and subsidies were introduced for the construction and operation of

Avedøre 2, owned by Energy E2, south-west of Copenhagen, is one of the biggest, most efficient CHP plants in the world, using biomass such as wood pellets and straw.



Photo: Energy E2

wind turbines and biomass plants. New taxes on oil and coal contributed to making plants with renewable energy more competitive, and a great number of straw and wood-chip fired district heating plants were established, among other things.

ENVIRONMENTAL TARGETS

In 1990, Energy 2000 set a target to reduce Danish CO₂ emissions by 20% between 1988 and 2005. The most important instruments were renewable energy, increased utilisation of natural gas for CHP, and energy savings. The results of the Energy 2000 plan of action were that 10% of Danish electricity consumption would be covered by wind energy in 2005, and that consumption of renewable energy would be doubled in the same year. Since then, these targets have been more than met.

In 1993, there was a broad political majority in the Folketing (Danish Parliament) behind an agreement to increase the utilisation of biomass (straw and wood chips) in the centralised CHP plants. At the same time, the expansion of wind turbines, biomass-fired small-scale plants, biogas plants and solar heating was promoted by means of various subsidy schemes and planning measures.

Energy 21 from 1996 made the environmental targets more precise and put them into perspective, and greater emphasis was laid on renewable energy. The plan set the target that renewable energy should cover 12-14% of energy consumption in 2005, and the target was set of the share of renewable energy in overall Danish energy consumption gradually being increased by 1% a year up to 35% in 2030.

The 1999 energy policy agreement concerning the electricity reform set the target of electricity produced from renewable energy covering

20% of Danish electricity consumption in 2003, primarily from wind turbines but also with a contribution from biomass. The current prognosis of 25% exceeds the target.

MARKET INSTRUMENTS

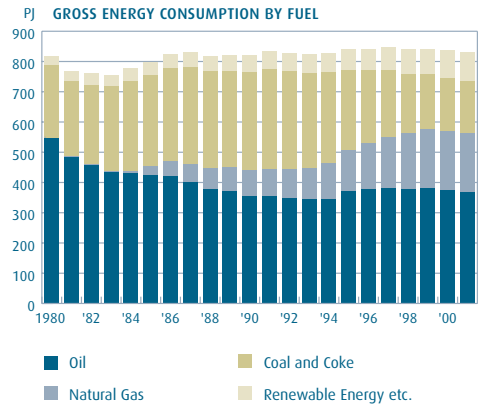
The build-up of the EU's internal energy market has achieved increasingly greater significance for energy policy in Denmark. The common, liberalised electricity market has created stronger focus on market instruments in energy policy, and the special economic support schemes for renewable energy are being converted to market-based framework conditions.

In a proposal for liberalising the energy markets, the Danish government emphasised in 2002 the need to increase competition in the energy sector, among other things to encourage greater cost efficiency in plants with renewable energy. In its 2003 climate strategy, the government prioritised the most cost efficient instruments for reducing CO₂.

In step with the development of the internal energy market in the EU and with the EU's joint Kyoto commitments, the expansion of renewable energy is to an increasingly higher degree expected to take place within the common European framework conditions that are formulated in national strategies.

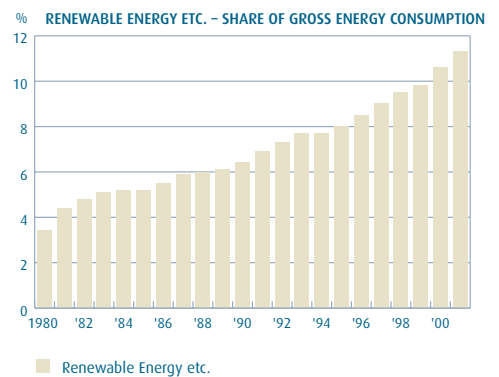
With the efforts to strengthen the utilisation of market-based instruments, it is expected that renewable energy technologies will hold their own on market terms, including with an environmental bonus or other regulation that capitalises on the benefits to society of producing energy from renewables.

The implementation of the EU Quota Directive for CO₂ emission is expected to further the impact of renewable energy at the expense of fossil fuels.



Source: Energy Statistics 2001 (DEA)

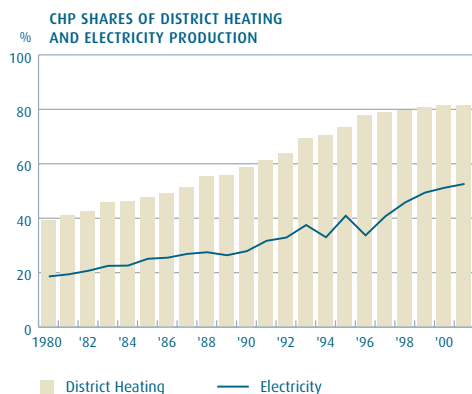
Gross Danish energy consumption has not risen during the last 20 years despite swift economic growth.



Source: Energy Statistics 2001 (DEA)

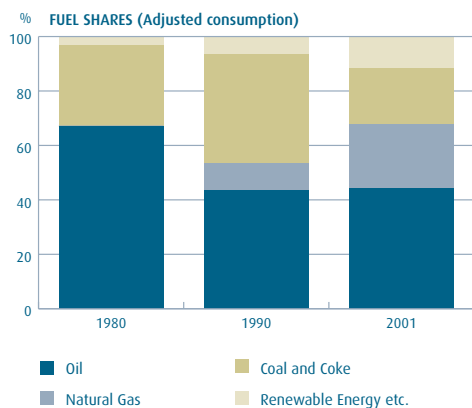
Over the last 20 years, renewable energy in the form of wind energy, biomass, biogas, solar energy, geothermal energy, heat pumps and waste has represented a steadily larger share of total energy consumption.

LONG-TERM EFFORTS BEHIND THE IMPACT OF RENEWABLE ENERGY



Source: Energy Statistics 2001 (DEA)

CHP has formed an increasing share of both power and district-heating production. The decrease in the CHP share in 1996 was due to extraordinarily large export of electricity to Norway and Sweden.



Source: Energy Statistics 2001 (DEA)

The fuel composition in Danish gross energy consumption has changed distinctively during the last 20 years. During the 1980s, the share of oil declined because of the conversion of electricity and district-heating production to coal. In the 1990s there was conversion from coal to natural gas. Renewable energy has gradually increased its share.

Danish research and development in the field of renewable energy technologies has been based on a long-term strategy with government-financed R&D programmes: the Energy (applied) Research Programme since 1976 and the Development Programme for Renewable Energy between 1981 and 2001 both managed by the Danish Energy Authority.

Through grants for specific projects and centres of expertise, strong research environments have been built up with international front-line competence, in particular in the areas of wind energy, the utilisation of biomass for energy purposes, and fuel cells.

The renewable energy development programme has also provided financing for a great number of demonstration projects and test stations that have been responsible for the quality assurance of standard plants. Support has also been granted for the market introduction of RE technologies. This innovation chain has ensured that the results of research have been applied in practice by strengthening the confidence of consumers and investors in the newly developed RE technologies.

INVESTMENT AND OPERATION SUBSIDY

To encourage the expansion of renewable energy, as a follow-up to these R&D programmes investment subsidy has also been granted to type approved RE plants, including privately-owned wind turbines, biogas plants, straw and wood-chip fired heating and CHP plants, as well as solar heating.

Private owners of power producing RE plants have been ensured sales of their electricity production to the public grid at guaranteed minimum prices. In certain periods, state electricity production subsidy has been granted to put the working economy of the plants in a position to compete with conventional electricity produc-

tion. Heat producing RE plants, for example biomass district heating plants and solar heating plants, have been exempted from energy and CO₂ taxes to safeguard an attractive working economy.

THE TASKS OF THE POWER UTILITY PLANTS

Besides these support schemes, Danish power utility plants have been obliged to promote the expansion of wind turbines and biomass-fired CHP plants. In the middle of the 1980s, the government made an agreement with the utility plants to expand with 100 MW wind turbines – later increased to 400 MW – and 450 MW small-scale CHP on the basis of domestic energy sources, among them biomass. Consumers have financed this development task over the price of electricity.

In 1990 a political agreement was entered to boost the utilisation of environmentally friendly fuels for CHP. The agreement obliged the district heating plants, among others, to convert to CHP with natural gas or biomass within certain deadlines.

In 1993, a broad political majority in the Danish Parliament adopted a biomass agreement that ordered the power plants to increase their utilisation of straw and wood chips in large-scale centralised CHP plants to 1.4 million tons per year. The additional costs of this order, which also included extensive R&D activity, have been financed by consumers over of the price of electricity.

STEPPED-UP R&D

With financing from the Development Programme for Renewable Energy, the Danish Energy Authority has implemented a number of follow-up programmes for small-scale CHP based on solid biofuels and biogas. These programmes have made a contribution to strengthening technological development in

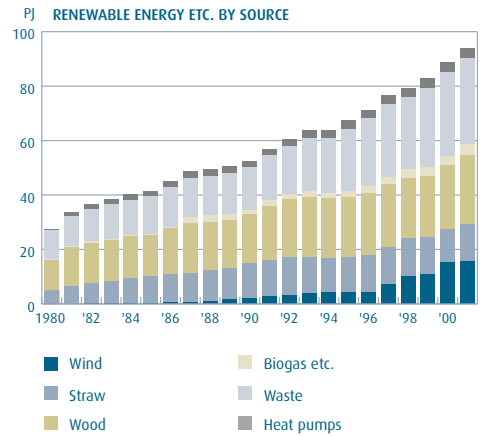
the area of biomass by the swifter collection of operational experience, the identification of new development tasks, and the dissemination of knowledge.

Between 1997 and 2001 several minor development programmes were conducted to encourage the technological development of wave power, solar electricity, hydrogen, and seasonal storage of solar heat.

In 1999 a broad parliamentary majority was behind an electricity reform implementing the EU directive on the liberalisation of the electricity market. In this connection, the task of researching and developing environmentally friendly electricity production technologies

was moved from the liberalised production companies to the two system responsible companies, Elkraft System and Eltra (east and west Denmark) – the so-called PSO R&D Programme (100 mil. DKK a year).

With its 2003 decision to provide the Ministry of Science, Technology and Innovation with the possibility of supporting research on renewable energy technologies, the government wished to strengthen basic research in the field of renewable energy. A broad energy policy agreement in 2003 increased the funds of the Energy (applied) Research Programme for the development and demonstration of renewable energy and energy efficiency in the 5-year period 2004-08.



Source: Energy Statistics 2001 (DEA)

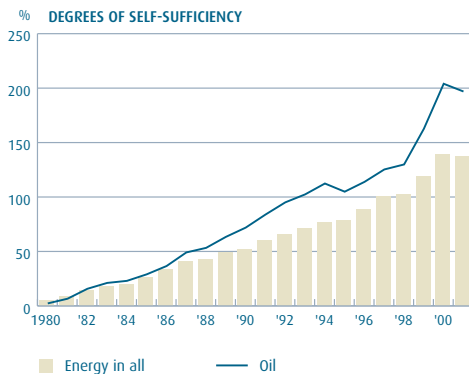
Biomass in the form of wood and straw provides the largest RE contribution, followed by waste and wind energy.



Photo: Energi E2

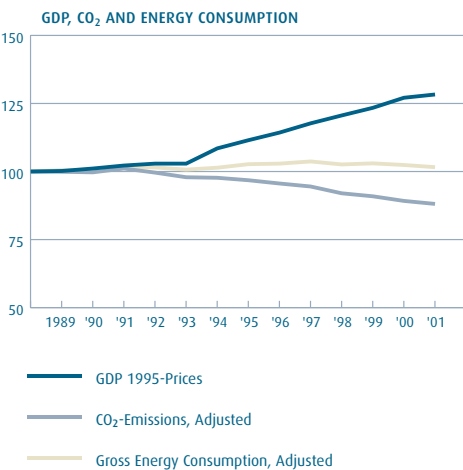
The system-responsible companies in particular have expended many R&D resources on developing efficient and operationally economical methods for the combustion of biomass such as straw and wood in large CHP units. The photo shows the large multi-fuel boiler at Avedøre 2.

RENEWABLE ENERGY LEADS TO DANISH CO₂ EMISSION REDUCTION



Source: Energy Statistics 2001 (DEA)

Since 1997 Denmark has been self-sufficient in energy, and in recent years net foreign exchange earnings from energy production has been more than 1 billion EUR per annum



Source: Energy Statistics 2001 (DEA)

Even though Danish GNP has grown by almost 30% in the last 10 years, energy consumption has been maintained at an almost constant level, and the climate-adjusted CO₂ emissions have been reduced by 13.5% due to more environmentally-friendly energy production.

Production from renewables almost doubled between 1990 and 2002, making a significant contribution to reducing Danish CO₂ emission by 13.5% over the 12 years, when adjustment is made for special Danish conditions such as electricity import and temperature. Production from wind turbines and biomass- and waste-fired plants, in particular, has grown.

IMPORTANT INSTRUMENT

In the course of the last 12 years, economic growth has reached about 30% in Denmark, while energy consumption has only risen by about 1% due to large-scale energy savings in industry and private households. Energy savings, renewable energy and increased utilisation of natural gas for energy production have been the most important instruments for realising the environmental targets.

This development has also been of great importance for Danish security of supply. The degree of self-sufficiency, only 5% in 1980 and growing to 52% in 1990, had reached 145% in 2002, mainly due to increased production of oil and natural gas.

In the area of power and district heating production, especially, renewable energy has achieved greater importance. In 2002 wind energy represented about 14% of electricity production and biomass and waste together about 5%. The share of renewable energy in electricity consumption is expected to grow to approximately 25% in 2003. In the field of district heating, biomass represents around 15% and waste more than 20%. In relation to total energy consumption, including transport, the renewable energy share is about 10%.

NEW NEED FOR POWER REGULATION

This development has led to a radical change in electricity production. At the beginning of the 1980s, all Danish production of electricity took



Photo: Elsam

Rapid growth in Danish wind-energy capacity, among other things from the world's biggest offshore wind farm at Horns Rev, has presented the electricity system-responsible companies with new challenges.

place at a few oil and coal fired power plants. Since around 1990, the decentralisation of electricity production has increased in pace, and in 2002 about 40% of Danish electricity consumption was produced at wind turbines and other small-scale plants.

Along with the liberalisation of the Danish electricity market, this has presented new challenges to the two Danish electricity system-responsible companies that must safeguard the quality of electricity and security of supply. They now have to manage production from about 5,500 wind turbines, about 800 local CHP plants, and 12-15 centralised CHP plants in such a way that total production together with electricity exchange with other countries always corresponds to current market demand. Using IT, the system responsible companies expect to be able to optimise production from the small-scale CHP plants in relation to the needs of the market, so that local producers to a higher degree supply the regulating power of the system.

Such development of the power systems will make it technically possible to incorporate greater volumes of fluctuating electricity production from wind turbines for example, and in the longer term PV cells and wave energy, and thus increase the share of CO₂ free electricity production.

TECHNOLOGY ON THE MARKET

Over the last 20 years, Denmark has constantly increased its production from renewables. This has taken place because of the favourable economic conditions for the investment in and operation of RE plants and by means of targeted investment in R&D in the areas of wind energy, biomass and solar energy. On the next pages some of the most important results of these efforts are presented.



Photo: Torben Skott, BioPress

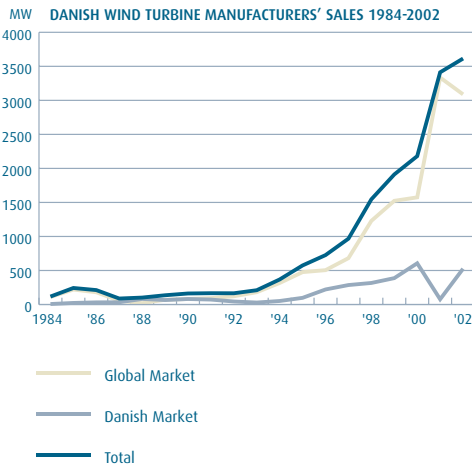


Photo: Samsø Energiselskab Smba



Photo: Elsam

MORE ELECTRICITY FROM FEWER WIND TURBINES



Source: Danish Wind Industry Association

With rapidly increasing turnover and exports, Danish wind turbine manufacturers have experienced a true industrial adventure. In recent years Danish manufacturers have been successful in maintaining a 50% global market share.

Danish development in the area of wind energy has been an energy policy and commercial success story. Since the first wind turbines were industrially constructed around 1980, there has been tremendous growth in technological development and turnover. This development has been particularly rapid since 1990. Modern Danish wind turbines produce about 100 times as much electricity as the first industrial wind turbines from 1980, and over the last decade the global sales of Danish wind turbine manufacturers have grown from about 200 MW a year to 3,600 MW. The global market share of the Danish wind turbine industry has stabilised at around 50%.

LEADING RESEARCH ENVIRONMENT

This technological development has been driven forward by a favourable combination of market conditions and research efforts. Risø National Laboratory is the centre of Danish technological development. Already in 1978, a Test Station was established here for (small) wind turbines, which was responsible for the type approvals that were a precondition for obtaining plant and production subsidy from the state.

At Risø, this know-how was combined with the Laboratory's traditional front-line competencies in the fields of meteorology and materials technology and with the expertise of the Technical University of Denmark and other universities in the area of fluid mechanics. Risø began to function as a technological service facility for the nascent Danish wind turbine industry, whose individual companies did not at that point have the resources to themselves undertake technological development.

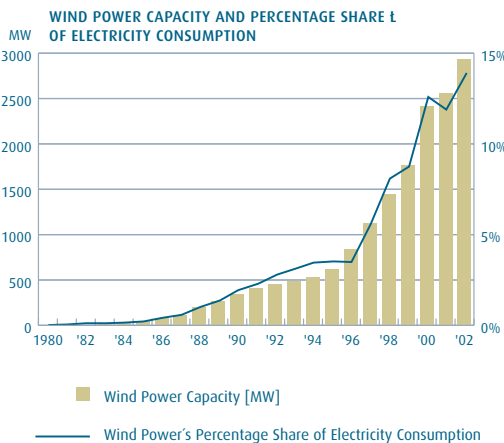
Risø National Laboratory and Danish producers of wind turbines have cooperated on a great number of R&D projects co-financed by the Energy Research Programme of the Danish Energy Authority. To maintain this position of

strength, with the active support of the Danish wind turbine industry in 2002 a research consortium was set up consisting of Risø National Laboratory, the Technical University of Denmark, Aalborg University and DHI – Water and Environment. The aim of the consortium is to enhance the interaction between government-financed research and the R&D activity of the wind turbine industry itself, and to create synergy between the Danish centres of competence in order to strengthen the current technological lift in the area of wind energy. Another important task for the consortium is to ensure the training and further education of the researchers and technicians that the wind turbine industry needs.

FEWER AND LARGER WIND TURBINES

The technological development of Danish wind turbines meant that throughout the 1990s demand increased explosively in both Denmark and on the export markets. In Denmark the development was propelled by framework conditions that have ensured investors guaranteed sales of production at favourable settlement prices. In the first years, the Danish state financed the additional costs involved in the development of wind turbines. Following the liberalisation of the electricity market this economic commitment was taken over by Danish electricity consumers thus emphasizing the market maturity of modern wind turbine technology.

Danish wind turbines, with favourable wind conditions and attractive financing conditions, can today compete with newly established, conventional electricity production plants. Therefore the special Danish support scheme is undergoing reorganisation so that, following a transition scheme, the wind turbines will have to produce on market terms with an environmental bonus that capitalises on the societal benefits of wind energy.



Source: Energy Statistics 2001 (DEA)

With total installed capacity of about 3000 MW, wind energy supplies 15% of Danish energy consumption (2002).



CASE

TRIPLING OF ELECTRICITY PRODUCTION WITH NEW, LARGER WIND TURBINES

Elsam A/S, the energy producer that operates and owns a large number of power and CHP plants inside and outside of Denmark, is Denmark's biggest owner of wind turbines with about 400 wind turbines ashore that have an overall capacity of around 215 MW, and 94 off-shore wind turbines with an overall output of a total of 176 MW. This is in addition to 15 wind turbines in Poland with a total output of 30 MW.

In order to achieve greater production of CO₂ free wind turbine electricity and limit the visual nuisance of the wind turbines, ELSAM has decided to replace some of the older, wind turbines ashore.

By the end of 2002, a total of 57 of Elsam's old wind turbines at two locations with an overall output of 10 MW had been replaced by 21 new wind turbines with an overall output of 31.5 MW. The new wind turbines each has an output of 1.5 MW.

In an average wind year, the installation of the 21 new wind turbines will mean an increase in CO₂ free electricity production of over 50,000 MWh, corresponding to an increase of about 300 per cent in comparison to the 57 old wind turbines.

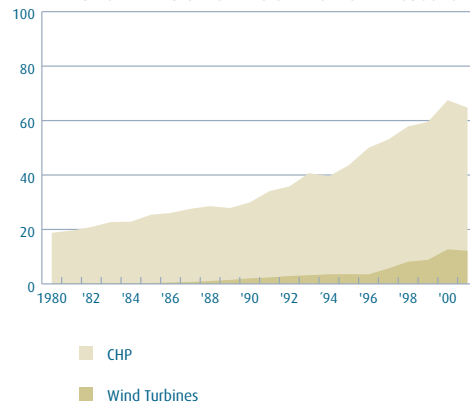
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Elsam was successful in tripling production by replacing older, badly located wind turbines with fewer and bigger turbines.

In 2001 the total installed capacity of wind turbines in Denmark amounted to more than 6,000 units with an overall installed capacity of approximately 2,500 MW. However, many of these wind turbines were small and inappropriately located. This led to the introduction of a scheme that made it possible to replace the smallest wind turbines. Under this scheme, in 2002 alone about 1,300 wind turbines with an overall capacity of about 100 MW were replaced by about 300 new wind turbines with an overall capacity of around 300 MW. Today overall capacity has reached more than 3,000 MW distributed over significantly fewer units.

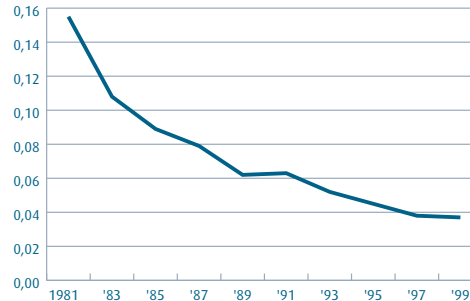
WIND POWER AND CHP SHARES OF ELECTRICITY PRODUCTION



Source: Energy Statistics 2001 (DEA)

Wind turbines and CHP represent a swiftly rising share of total Danish electricity production.

ELECTRICITY PRODUCTION COST WINDPOWER



Production cost EUR/kWh
 • 20 years depreciation
 • 5% interest rates
 • Siting in roughness class 1 (6-7 m/s)

Source: Danish Energy Authority

The price of electricity production from newly developed Danish wind turbines has fallen to under a quarter during the last 20 years, and efficiency continues to grow in step with the turbines increasing in size.

GREAT PERSPECTIVES IN OFFSHORE WIND



- 1 VINDEBY
- 2 TUNØ KNOB
- 3 MIDDELGRUNDEN
- 4 HORNS REV
- 5 SAMSOE
- 6 RØNLAND
- 7 FREDERIKSHAVN
- 8 NYSTED/ROEDSAND
- 9 GRENA

Danish wind turbine expansion has developed rapidly in recent years. Future offshore wind farms will be established on market-based conditions following calls for tender.

With a couple of pilot projects in the 1990s and a number of large demonstration projects in recent years, Denmark has taken the lead in exploiting the specially favourable wind conditions at sea for CO₂ free electricity production from large MW wind turbines. Danish experience encompasses the special production conditions with stronger wind and less turbulence at sea, the technical conditions for grid connection, and the environmental impacts. There is great interest in Danish experience at international level and several other European countries are running offshore wind turbine projects.

HIGHER PRODUCTION

Interest in the potential of the development of offshore wind energy has grown more or less in step with the upscaling of wind turbines. The overall maximum height of the tower and rotor of the wind turbine of about 150 meters, meant that the MW wind turbines would dominate the landscape and that the precondition for continued large-scale development of wind energy in Denmark would be the exploitation of the offshore potential.

The mapping of potential major sites for offshore wind farms in 1997 identified an immediate potential of approximately 4,000 MW in Danish waters. However, there are many indications that in step with the development of more cost-efficient foundations more sites can be found because the wind turbines can be located at greater depths than foreseen in 1997.

The increased costs of foundations, grid connection etc. and for service inspections for offshore wind farms will to a steadily increasing extent be balanced by higher production and longer lifetimes. The additional costs of electricity production from offshore wind farms for the large-scale demonstration projects in Horn Rev and Nysted have been estimated as 20% in relation to good locations ashore. But when the experi-

ence from these projects can be incorporated in coming projects, the additional costs are expected to be significantly reduced.

ON MARKET TERMS

During the 1990s Denmark implemented two pilot projects that provided crucially new knowledge about the economic and environmental conditions for developing offshore wind farms. Since 2001 these projects have been followed up by three large-sale demonstration projects at Copenhagen (Middelgrunden), Horns Rev at Esbjerg and Nysted at Rødsand, respectively, with a total installed output of approximately 200 MW and wind turbines of 2-2.3 MW. Wind turbines of up to 3 MW are to be tested in some near-shore areas in the coming years.

The two large demonstration projects at Horns Rev and Nysted were constructed following orders from the government to the power plants. The original plan was that five demonstration plants with a total output of approximately 750 MW should be established on similar terms. But following the liberalisation of the electricity market, the Danish government has decided that open invitations to submit tenders should be issued for further offshore wind farm projects and that production should be on market terms.

The Danish Energy Authority has analysed where and on what economic and environmental terms future offshore wind farms can be established. The government is expected to call for tenders for the next project so that the first commercial offshore wind farm can start production for the Nordic electricity market from 2007.

The economic framework conditions will depend to a high degree on the way in which CO₂ free electricity production is integrated in the European electricity market. But under all

circumstances the Danish government wishes to call for tenders for projects internationally so that increased competition can lead to the cheapest possible CO₂ reduction from future large-scale offshore wind farms.

CASE

150,000 HOUSEHOLDS SUPPLIED BY 80 WIND TURBINES

The largest offshore wind farm in the world to date, at Horns Rev about 40 km west of Esbjerg, began producing electricity for the Danish grid in autumn 2002. This followed a lengthy preparatory phase with economic feasibility studies, environmental monitoring programmes, analyses of cost-efficient foundations, testing of prototype wind turbines on land etc. The project was carried out with Elsam, the electricity production company, as developer, on the basis of an order issued by the then government.

The project consists of 80 2 MW Vestas V80 wind turbines erected on foundations of drilled monopiles. The wind turbines are connected to a transformer substation erected by the electricity system-responsible utility company, Eltra, which has also laid the submarine cable that transports the electricity produced to the Danish electricity system.

The wind turbines are located in an area covering about 20 km² at a distance of 14-20 km from land. Water depths vary between 6 and 14 meters. The turbines, each of which weighs about 450 tons, have been erected with the help of specially constructed jackup vessels. The hubheight of the turbines is 70 meters, with a rotor diameter of 80 meters. Total con-

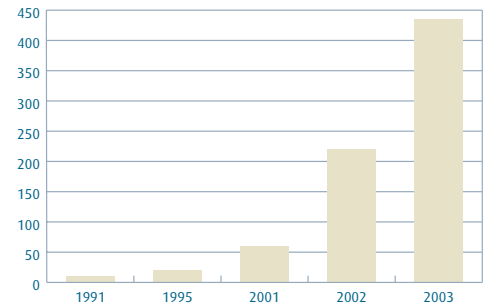
struction costs amount to approximately DKK 2 billion (about 265 million euros).

Under average wind conditions the offshore wind farm will produce approximately 600 GWh a year, corresponding to electricity consumption in 150,000 households. As a warning of the market-based operating conditions for Danish offshore wind farms, the production does not form part of the electricity production from environmentally friendly production plants that is subject to a purchase obligation. Elsam has, however, obtained a guaranteed price of DKK 0.33/kWh for production that approximately corresponds to the first ten years of operation of an expected lifetime of a minimum of 25 years.

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MW EXISTING AND APPROVED OFF-SHORE CAPACITY (MW)



■ Existing and approved off-shore capacity (MW)

The offshore wind farm at Horns Rev is the biggest in the world to date, and further development in the area is possible.



CENTRALISED CHP PLANTS INCREASE UTILISATION OF BIOMASS

Photo: Energi E2

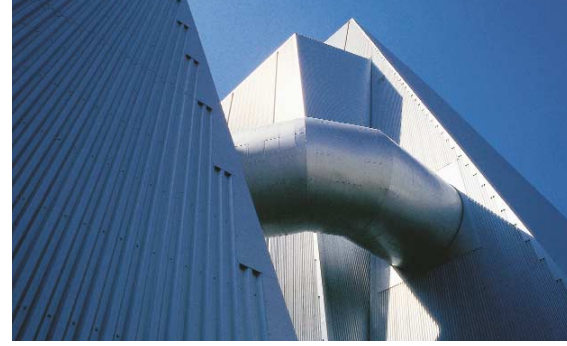


Photo: Torben Skott/Biopress

Wood chips and pellets have become an important fuel in the large, centralised CHP plants.

Over the last 20 years, a steadily increasing share of Danish electricity has been produced at environmentally friendly CHP plants and by means of renewable energy. In years with Danish electricity exports, production from the least environmentally friendly condensation plants is increased.

Source: Energy Statistics 2001 (DEA)

The utilisation of biomass for the co-production of power and district heating grew rapidly in Denmark when the electricity utility companies were ordered by the government to use 1.4 million tons of biomass – straw and to a lesser extent wood – per year in the centralised CHP (combined heat and power) plants.

In 1989 the burning by farmers of the formerly large amounts of surplus straw in the fields was prohibited. The wood utilised for energy purposes comes from sustainable forestry and wood production in Denmark, and in recent years this has been increasingly supplemented by imported wood pellets and wood chips.

Biomass, straw in particular, is a more difficult fuel than coal, oil and natural gas, among other things because the calorific value is lower and because of the content of chlorine and alkalis that react aggressively and corrosively under the operating conditions characteristic of steam turbine plants in general, with high steam pressure and temperatures.

Therefore the Danish electricity production companies have conducted a comprehensive

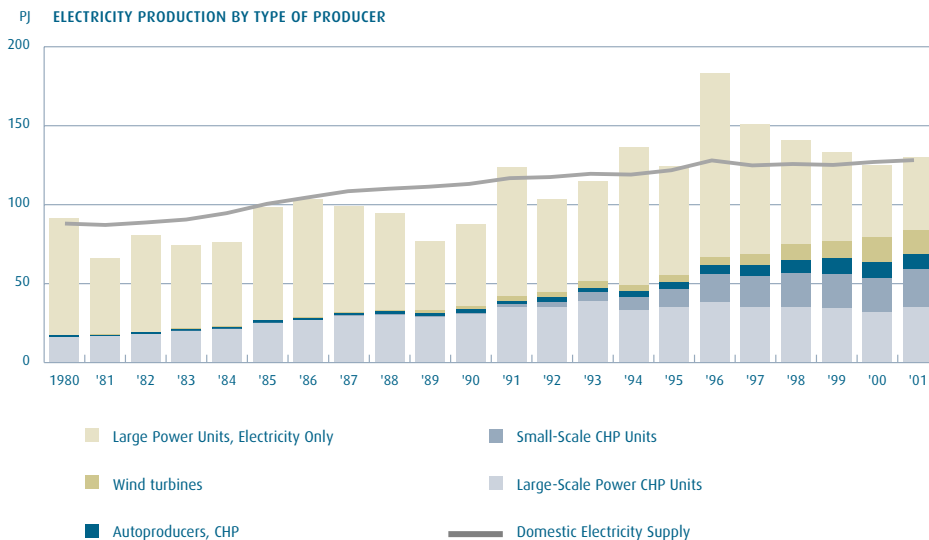
research and development programme for combustion technologies that is capable of dealing with the challenge.

The two big Danish electricity producers – Energi E2 in east Denmark and Elsam in west Denmark – take care of the practical implementation. Elsam has experimented with supplementary firing with straw in existing coal-fired boilers, while Energi E2 has preferred pure biomass plants. To date, in the course of a decade the average efficiency in straw-fired steam turbine plants has been raised from 20-25% to 25-32% in small plants, while the more modern, large boiler plants can reach efficiencies of 42-50%.

MORE FLEXIBLE PLANTS

Danish technological development using straw and wood for CHP purposes can also be applied to other difficult types of biowaste. Although there have been significant additional costs in utilising biomass instead of coal for CHP up to the present, increasing international demand is expected for the efficient Danish combustion technology for biomass. The EU has set ambitious targets for the increased utilisation of biomass and CHP, and many developing countries are facing swiftly growing waste problems and growing demand for electricity where the use of biowaste from, for example, the food industry could fulfil many societal needs at one stroke. Future Danish development activity will to a rising degree focus on the development of plants that are more flexible with respect to changing biofuels.

Avedøre 2, commissioned in 2001, is one of the most efficient and environmentally friendly CHP plants in the world. The plant has a capacity of 570 MW electricity and 570 MW heat, with total efficiency of 94%. Situated in Greater Copenhagen, this is a multi-fuel plant that can use natural gas, oil, straw and wood pellets.



BIOMASS GASIFICATION – AN OPTION

Gasification of biomass (wood and straw) is regarded as one of the lines of technology that in the longer term can pave the way for the commercial application of CO₂ free biomass for local CHP production in small-scale plants.

Research has been conducted on various gasification technologies in Denmark for several years, with the economic support of the Energy Research Programme and the R&D programmes of the electricity system-responsible companies.

The environmental and economic perspectives in biomass gasification are, among other things, that a product gas of sufficient quality can be utilised in gas engine plants and small gas turbine plants, and thereby utilised in small plants covering a local heat demand. Biomass does not have to be transported so far and the local heat markets are better exploited.

Gasification is based on the chemical conversion of biomass at temperatures that normally are above 700°C. The process is divided into initial pyrolysis followed by gasification.

Danish R&D has involved various types of gasification design: inverse gasification, co-current gasification and fluidised bed plants (both circulating and bubbling). Promising results have been achieved within several of these designs.

Gas purification before the gas is used in an engine is one of the core problems for which a satisfactory solution must be found. The aim is to develop a process that can manage an operationally reliable and environmentally friendly gasification of difficult biofuels with sufficient plant and working economy.

Therefore further expansion of local biomass CHP plants is awaiting the results of current pilot and demonstration projects before later upscaling to plants that operate commercially.

CASE

NEW GASIFICATION METHOD FOR DIFFICULT BIOFUELS

A new method developed by project partners Danish Fluid Bed Technology, the Technical University of Denmark, dk-TEKNIK, Rica-Tec and Tech-wise makes it possible to gasify straw and other difficult biofuels so that, with high energy use, they can be used at conventional coal-fired power plants without the risk of costly corrosion damage.

The new Low Temperature Circulating Fluidised Bed (LT-CFB) gasifier is able to gasify the fuel at an operating temperature that is 100-200°C lower than in a normal gasifier. This means reduced melting and evaporation of, for example, potassium and chlorine, which can then be simply separated together with the ash before the product gas is burned in the boiler.

A number of successful tests have already taken place with a 50 kW test plant. These tests have in part included two types of straw with an especially high content of ash, potassium and chlorine, and in part wood and domestic animal manure. But it is expected that other organic fuels such as domestic waste and sewage sludge can be gasified in this gasifier.

A 500 kW test gasifier will be tested from autumn 2003. The next step will probably be a gasifier of 5-10 MW. The work of development in this phase is receiving economic support from Eltra's PSO financed R&D programme.

In a global perspective, the new gasification technique can also be applied to more efficient electricity production based on a large number of difficult biofuels such as rice straw and waste streams from the production of olives, cotton and sugar.



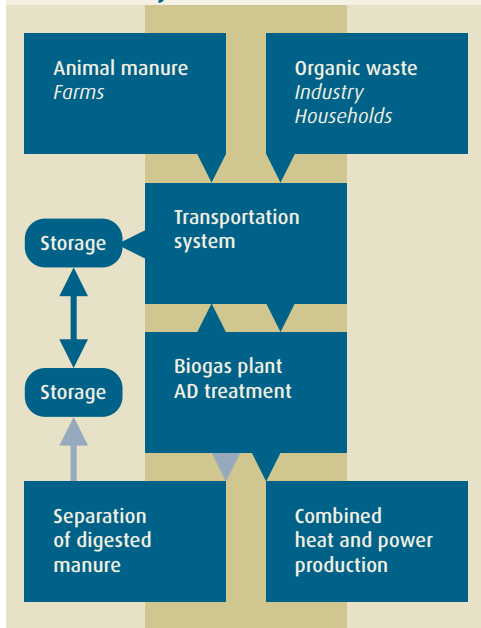
On the basis of promising results from test operations, the electricity system-responsible company Eltra is now financing the upscaling of the LT-CFB plant to commercial size via its R&D programme.

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JOINT BIOGAS PLANTS HAVE BECOME AN ENVIRONMENTAL PROBLEM CRUNCHER

PRINCIPLE DRAWING FOR THE CONSTRUCTION OF A DANISH JOINT BIOGAS PLANT



Large-scale joint biogas plants, which convert animal manure and organic industrial waste to CO₂ free biogas and fertiliser, have been undergoing swift technological development since the middle of the 1980s, and today are a well-developed concept capable of solving a number of urgent environmental problems.

THE FOLLOW-UP PROGRAMME

At present Denmark has 20 joint biogas plants that were built with 20-40% investment subsidy between 1984 and 98. A coordinated follow-up programme has collected experience, analysed working economy, harmonised research activities, launched demonstration programmes and disseminated knowledge among actors and manufacturers, resulting in marked improvement of the biogas process and the working economy. These activities were financed by the Energy Research Programme and the Development Programme for Renewable Energy.

Analysis of these societal benefits has shown that large-scale joint biogas plants can be erected and operated in such a way that the costs to society of the accompanying CO₂ reduction are small or at best negative. For this reason, the Danish government regards joint biogas plants as an attractive instrument, within the given resource limitations, for realising the Danish Kyoto commitments to CO₂ reduction towards 2008-12.

The uncertainty concerning the corporate economic framework conditions in the liberalised electricity market can prevent potential actors among farmers and other investors from starting to exploit the large potential. The challenge is, therefore, to establish market-based framework conditions that create the necessary cohesion between the advantages to society and the corporate economic operating conditions. In 2003 the government introduced a fixed price system for electricity sold to the public grid from biogas plants.

There are more than 60 small farm biogas plants in addition to the large-scale biogas plants.

BETTER UTILISATION

The 20 Danish joint biogas plants treat 1.1 million tons of animal manure and about 400,000 tons of industrial waste a year. This concept has proved well suited to solving the special environmental problems that follow with intensive animal husbandry in a densely built-up community. Animal manure and organic industrial waste are converted in a way that contributes to less emission to the aquatic environment, ensures the hygienisation of slurry and waste, and provides better utilisation of the total fertiliser value of the waste. At the same time biogas is produced that is utilised for the CO₂ free production of power and heat for the local community.

LINTRUP BIOGAS PLANT

Lintrup Biogas Plant in Southern Jutland was erected in 1989-90 and rebuilt and expanded in 1999. Today it converts 410 tons of animal manure and 137 tons of organic industrial waste every 24 hours, and produces 5.7 million Nm³ biogas a year in a thermophilic process at 53 °C. The biogas is utilised in a CHP plant 7.5 km from the plant with an capacity of about 2 MW and heat capacity of 2.6 MW.

The plant is owned by the cooperative society LinkoGas A.m.b.a. with the 66 local farmers who supply animal manure as investors. Lintrup Biogas Plant, with ten years of operational experience, has proved to be technically and economically well-functioning.

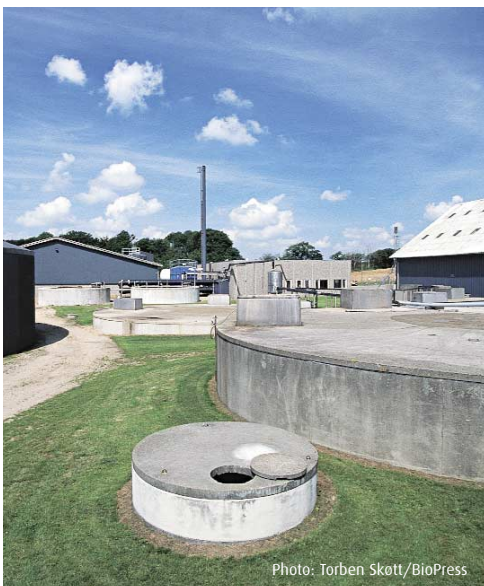


Photo: Torben Skott/BioPress

Lintrup Biogas Plant

SUSTAINABLE USE OF BIOMASS FOR SPACE HEATING

Energy consumption for space heating in dwellings accounts for one quarter of overall Danish energy consumption. It has thus been very important for the development in Danish energy consumption and the reduced CO₂ emission that energy application for space heating has been successfully made more efficient since the 1973 oil crisis. This has primarily taken place through energy savings and by converting from oil-firing to natural gas and biomass and district heating.

BIOMASS FOR DISTRICT HEATING

Very large energy savings had already been achieved before 1990, by means of subsidy schemes for more efficient use of energy in private households among other things, and the low energy consumption has been maintained ever since even though the heated area has grown steadily. At the same time there has been a radical switchover to more environmentally correct forms of heating. Oil consumption has fallen by about 50%, while the use of natural gas has grown by 44%, district heating by 25% and renewables by 25% between 1990 and 2002.

Alongside this, energy consumption in district heating plants has become more environmentally correct. More than 100 biomass-fired district heating plants have been established, many of them in small villages, and large-scale CHP plants have been converted from coal and oil-firing to natural-gas based heat and power. About 30% of Danish district heating production comes from sustainable use of biomass, including waste. This achievement has formed the basis for vibrant technological development in Denmark, where manufacturers of wood stoves, biomass-fired boilers, wood-chip boilers and peripheral equipment for the handling and storage of biomass have developed equipment with very high degrees of efficiency and operational stability and low emissions.

CASE

FLEXIBLE BIOMOILER IN LOCAL DISTRICT HEATING PLANT

The Sydlangeland district-heating plant was built in 1993 and produces approximately 30,000 MWh heat a year for the plant's about 760 consumers.

From the outset the district heating plant was equipped with a 5 MW straw boiler and a 6 MW oil boiler. Owing to rising oil prices the Board of the district heating utility company decided to obtain another biomass boiler so that the original oil boiler is only used as a backup.

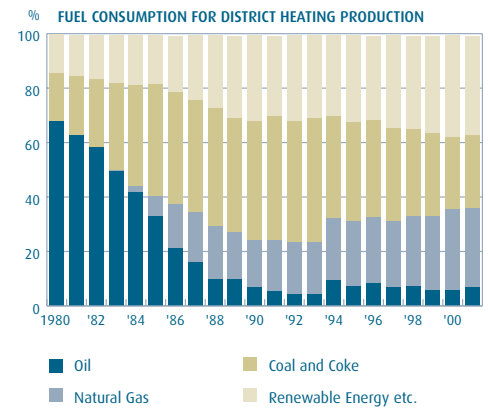
The new 6.3 MW biomass boiler was supplied by the Danish firm of Weiss A/S and it is very flexible with respect to fuel, as it can burn different types of straw, wood chips, wood pellets etc. The boiler design is quite new and consists in part of a combustion chamber that is reduced in size in relation to traditional boilers, a new grate design and a new turbo nozzle through which the flue gas passes and is then burnt with an efficiency of as much as 92%.

The district heating plant uses about 8,000 tons of straw a year. About 4,000 tons are bought on the field after the harvest at a price of approximately DKK 290 per ton and is transported directly to the district heating plant's own storage facilities. The remaining 4,000 tons are bought over the course of the year from the farmers' storage facilities and at a slightly higher price of DKK 370 per ton.

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Source: Energy Statistics 2001 (DEA)

Renewable energy together with natural gas now covers about two-thirds of Danish district-heating production.

Photo: Torben Skott/Biopress



Even though straw is a difficult fuel to work with, the board of the Sydlangeland district heating utility company preferred this fuel due to very favourable local straw prices.

SOLAR ENERGY FOR HEAT AND POWER PRODUCTION



Photo: EnergiMidt

With a subsidy of 40% for the Sol 1000 Project (see page 17), the price per kWp installed capacity is DKK 28,000 (about 3,725 EUR), giving private users an annual return of 3-4%. With long-term mortgage-credit financing, this can ensure a working economy that is neutral or even a little positive.

For a great number of years, Danish research institutes and companies have been working to optimise the utilisation of solar energy for both heat and power production.

The utilisation of the energy of the sun for heat production is based on a simple principle. In principle, the solar heating panel consists of a black plate – the absorber – that collects the sun's energy. A fluid that passes the solar energy to the hot water tank cools the absorber. To increase efficiency, the absorber is placed in an insulated box with a cover plate of glass or plastic.

There are about 30,000 solar heating plants in Denmark that are utilised for heating domestic water, and about one-third are used for co-production of space heating and hot water. A number of large-scale solar heating plants have also been installed as a supplement to collective plants and district heating systems that in this connection are often based on biomass such as wood pellets, wood chips or straw.

PV PLANTS

Based on the photovoltaic (PV) process, the sun's electromagnetic rays can be converted to electricity through absorption of the photons of

sunlight. In principle, PV plants are a battery that only works when illuminated. PVs can be roughly divided into three types: traditional semiconductor PVs made of silicium, photo-electrochemical (PEC PVs) and plastic PVs – also called organic PVs. Today only semiconductor PVs are commercially produced. These are divided into crystalline and amorphous PVs – also called thin film. The crystalline PVs have an efficiency of 13 - 14% while the efficiency of the amorphous PVs is 8 - 9%.

The costs of producing silicium PVs remain relatively high, to which may be added costs for assembly and installations etc., which constitute between 1/3 and 2/3 of total expenditures. Semiconductor PVs are therefore mainly utilised as stand-alone systems, for example light buoys or street lighting in areas without access to an overall electricity supply grid.

The greatest R&D effort in Denmark has taken place within the practical utilisation of PVs, for example technical and architectonic integration in various buildings and plants. In Denmark, as demonstration plants, a number of large grid-connected PV plants have been erected in connection with the retrofitting of collective housing complexes.

Photo: Marstal District Heating Company



The solar heating plant in Marstal is one of the biggest in the world.

CASE

MARSTAL SOLAR HEATING PLANT

One of the world's largest solar heating plants connected to a district heating grid is on the Danish island of Ærø. Marstal district heating plant consists of about 18,300 m² of solar heating panels that together cover around 30% of the district heating demand in the town of Marstal, corresponding to annual production of 7,500 MWh. The remainder of the heat supply comes from burning waste oil.

To be able to exploit and save the surplus heat production, in connection with the solar heating plant a 10,000 m³ sand pit storage facility with floating top cover, an pipe storage facility in the ground and a traditional steel storage tank have been established. This brings the total storage capacity to about 750 MWh, which means that the summer's heat production can be utilised far into the autumn.

A total of DKK 49 million has been invested in the plant. To put the plant in a position to compete with more traditional district heating production, the Danish state and the EU have provided support of a total of DKK 19 million.

The solar heating plant saves the environment approximately 2,135 tons of CO₂ per year.

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CASE

PV-SOLGÅRDEN IN KOLDING

One of the largest photovoltaic (PV) projects in Denmark was carried out in the Solgård residential property in the town of Kolding. The plant was established in connection with thorough retrofitting of the property in 1998. The building was constructed in 1939-40.

During the process, glass-covered balconies were constructed with PVs integrated in the breast walls. In addition, a large number of solar panels were mounted on the roof. The overall area of the PV plant is 932 m², of which 757 m² on the roof. The total installed capacity is 106 kW_{peak} (90 kW_p on the roof and 16 kW_p in the balcony breast walls) and annual production is around 72 MWh.

The plant supplies electricity to the local electricity grid via 104 current inverters, thus in principle functioning as several independent units, making it more resistant to operating problems. Any surplus production is sold to the public electricity grid.

Five years of operating experience show that the plant functions satisfactorily and requires almost no maintenance.

The costs of the PV plant have been calculated at about DKK 42,450 per kW_p for the plant on the roof, and about DKK 18,450 per kW_p for the PVs in the balcony breast walls.

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Sol 1000 is one of Denmark's most ambitious demonstration projects to date, organised by EnergiMidt and the Danish electricity grid utility companies with EnergiMidt leading the project. The aim is to install about 600 plants in private households on the basis of standard solutions at guaranteed prices and with the assistance of architects for aesthetic and functional integration in the house. Following an international call for tender, two consortiums of suppliers have been selected, who have offered PV cells at a price about 15% under that of earlier projects one of the cheapest photovoltaic installations worldwide for private households. The consortiums include Danish sub-contractors in the areas of e.g. inverters and silicium.

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RENEWABLE ENERGY ISLAND - SAMSO



Photo: Samsø Energiselskab

An offshore wind farm of 23 MW will compensate for diesel consumption for transport and ferry operation.



Photo: Samsø Energiselskab

About 100 buildings have had solar heating plants installed during the first 5 years of the project.

Following a competition between five island communities, in 1997 the Danish Energy Agency selected Samsø as the island that in the course of one decade is to convert to energy supply 100% based on local RE. This is primarily an organisational and financing demonstration project, the aim of which is to show that by establishing strong, broad local involvement it is possible to achieve a very high degree of self-sufficiency based on renewable energy sources, and that benefits the local economy and growth. This is not a technical demonstration project but is based on known and well-tested RE technologies. Almost all renewable energy sources are available on Samsø.

DISTINCTIVE INTERNATIONAL DEMONSTRATION PROJECT

The project is being carried out in close cooperation with all local actors, i.e. the local authority, the utility companies and the most important organisations on the island. Samsø Energiselskab Smba (Samsø Energy Company) has been set up as the joint organisation that coordinates the planning and the practical implementation of the project. Samsø covers 114 km² and has 4,400 permanent inhabitants as well as a very large number of Danish and foreign tourists. Already halfway into the project period, the project has received the status of a distinctive international demonstration project.

At the start of the project in 1998, renewables covered 6-7% of the island's total energy consumption of approximately 900 TJ. This means that converting to 100% supply with renewables in the course of ten years presents a great challenge.

POWER FROM WIND AND BIOGAS

Already in 2000 Samsø became self-sufficient in electricity from eleven new wind turbines in three clusters with an overall output of 11 MW. Wind turbine companies own two of the wind

turbines with 450 inhabitants as investors, and individual farmers own the other nine. The plan is later to produce more electricity from a joint biogas plant, small farm-based biogas plants and, to a lesser extent, from PV plants and small domestic wind turbines.

VILLAGE DISTRICT HEATING

Heat consumption in the villages is to be covered by 4-5 district heating plants that are supplied with straw, wood chips and solar heating, perhaps in addition to surplus heat from ferry operations. The three first plants have been constructed and are in operation. Outside of the villages, solar heating plants, biomass-fired central heating plants and heat pump plants are utilised. 15% of the 1200 year-round dwellings in open country had been completely supplied with renewable energy.

OFFSHORE WIND FARMS

In 2003 a wind farm was established at Samsø with ten wind turbines, each of which has an output of 2.3 MW. Half of the turbines are owned by the municipality of Samsø and four by large industrial investors. The last is a cooperative turbine sold to the wind turbine company, Paludan Flak I/S, with local citizens as investors. Annual power production from the offshore wind farm corresponds approximately to the consumption of fossil fuel in Samsø's transport sector, and in that sense makes the island "self-sufficient" in renewable energy for transport. The electricity grid on Samsø is linked to the mainland and all surplus is today sold to the public grid on market terms, just as the grid acts as a "storage facility" when the wind turbines do not produce sufficient electricity.

In the longer term Samsø is hoping to be a leading island for the utilisation of hydrogen produced from RE sources in transport. The size of the island is suitable for this type of demonstration project.

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FUTURE ENERGY TECHNOLOGY

With expectations of increasingly focus on security of supply and more far-reaching international commitments concerning CO₂ reduction, Danish research centres and innovative enterprises are targeting investment at developing the energy plants of the future. Some examples of promising energy technologies are presented on the next pages.



Photo: Gaia Solar

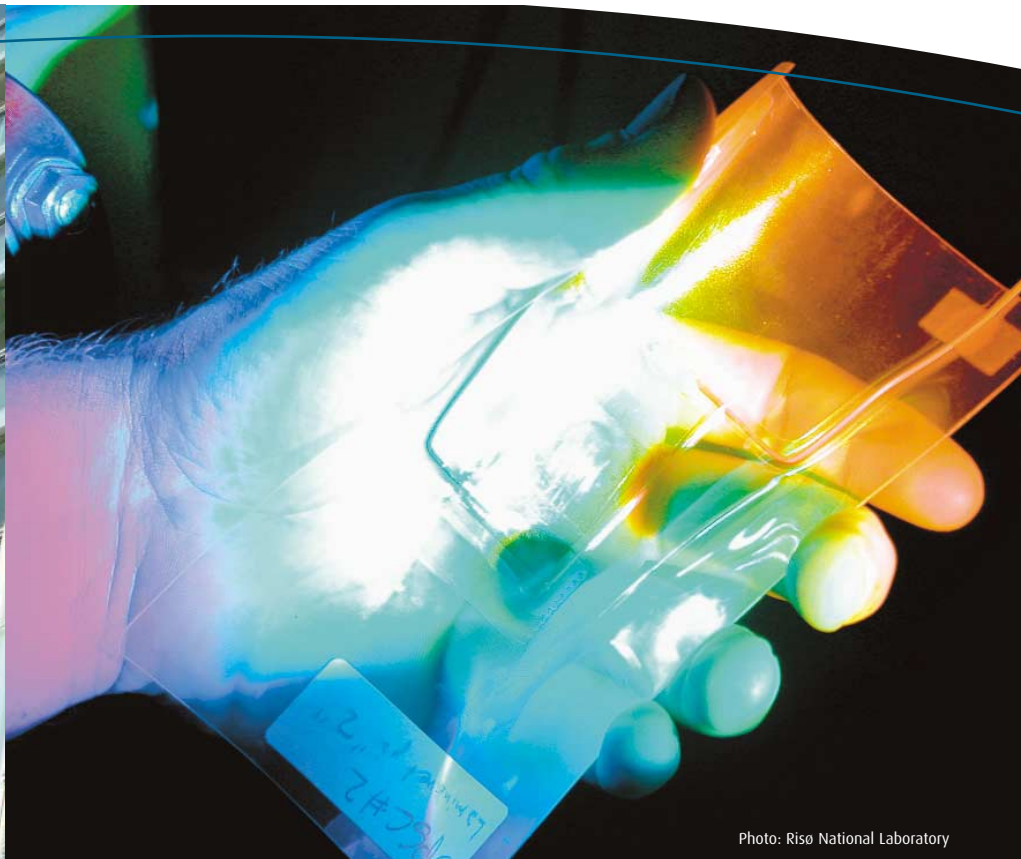
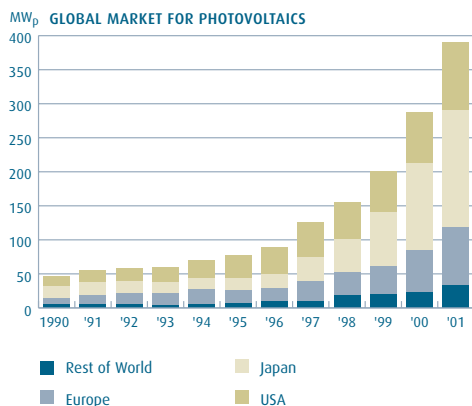


Photo: Riso National Laboratory



Photo: Wave Dragon & Earth-vision

FUTURE ENERGY TECHNOLOGIES ON ITS WAY



Source: PV News

Next to wind energy, PV cells have developed as the fastest growing energy source, and even though the price of electricity production is still unable to compete with traditional production based on fossil fuels — or with windpower — this is a market with great global potential — not least if the development of new, more efficient technologies can force the competitive power of PV cells. During the 5-year period between 1997 and 2001, the annual growth in installed PV cell plants more than tripled.

Danish enterprises, research institutions and authorities are targeting investments in maintaining the Danish positions of strength in the field of renewable energy technologies. Therefore extensive state-supported research is being conducted in energy technologies with particularly great perspectives for a future energy system, which in a way that is cost efficient can contribute to security of supply and significant reductions in CO₂ emissions in the longer term.

FUEL CELLS

Fuel cells can for example produce power and heat for a single household, but can also be utilised in large CHP plants, for transport, in emergency generators, in computers and mobile phones — even in toys.

Fuel cell technology has many advantages compared to traditional electricity production. Among other things, the cells have a high efficiency and low pollution and they can utilise many different types of gases for electricity production — fuels that again can be produced on the basis of renewable energy.

There are many different types of fuel cells. In Denmark development efforts are concentrated on two types of the size of 1 – 500 kW: the high temperature type called SOFC (Solid Oxide Fuel Cells) for large plants and a low temperature type called PEM (Polymer Electrolyte Membrane) for small plants — both types primarily for stationary purposes. All kinds of fuel can be considered — natural gas, methanol, methane, hydrogen etc.

SOFC AND PEM FUEL CELLS

Fuel cells can convert the chemical energy in natural gas to electricity with an efficiency of 55% including all losses. If the fuel cells is linked to a gas turbine the electrical efficiency can be raised to 70-75%.

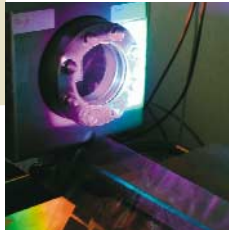
Fuel cells are flexible with respect to fuels and can convert a number of different hydrocarbons — such as diesel oil — when subjected to light preformation. Fuel cells can convert hydrogen directly to electricity or carry out the opposite process — electrolysis, where hydrogen is produced from electricity.

This flexibility makes the ceramic fuel cells well suited for creating the transition between the known centralised energy supply system based on fossil fuels and a future more decentralised energy supply dominated by renewables and with hydrogen, for example, as the system's energy carrier.

The relation between power and heat production can be constantly adjusted in a fuel cell. In a future decentralised energy supply, fuel cells will thus contribute to greater regulating capacity. As SOFC fuel cells are operative at relatively high temperatures of about 700°C, a certain amount of preheating is necessary. The preheating period must be reduced or other solutions found if SOFC is to be interesting in relation to the transport sector.

SOFC fuel cells for the professional market are tipped as breaking through commercially within 5 to 10 years. SOFC for the consumer market has probably a slightly longer time horizon because the requirements as to reliability etc. are far greater in this market.

The low operating temperature of normally approximately 80°C is an advantage for PEM fuel cells, but there can also be operating advantages in increasing the temperature to 150 – 200°C. The Danish research environments and enterprises are investing in further developing and commercialising both types of PEM cells, where the low temperature type has come furthest today.



PLASTIC PV CELLS ON THE WAY

With today's technology, the utilisation of solar energy for electricity production is based on silicon semiconductors. Sunlight contains all the colours of the rainbow and consists of photons with different wavelengths and thus amounts of energy. In order to extract electricity from a semiconductor cell, it must be hit by a photon with a certain amount of energy. All photons with lower energy are wasted, while photons with higher energy are only partially utilised.

Therefore research is now being conducted on two new types of PV cells that can exploit more of the colour spectrum of the sun and thus energy.

At the Danish Polymer Centre at Risø National Laboratory, a team of researchers are working on developing a new type of PV cells made of plastic.

Plastic PV cells can be composed of several different types of molecules, each of which can absorb specific photon energy and wavelengths, so that a higher efficiency can be achieved.

The plastic PV cells that have been developed to date have, however, a short lifetime and a low efficiency. The short lifetime is due to the decomposition of the plastic because of sunlight and the presence of oxygen. This is why work is being done on screening the PV cells from oxygen.

Plastic PV cells are cheap to produce and easy to work with. The physical properties of plastic, for example hardness and colour, can easily be changed chemically, making them easy to adapt to an application.

Together with a Danish company, experiments have already been conducted with methods of

production for the first plastic PV cells. This is being done among other things to increase the speed of development. For the moment the first plastic PV cells are expected to be introduced in pocket calculators, mobile phones etc. within 3 years. PV cells for energy production proper will take longer and will only be ready for commercial production in 15-20 years, if they are not outstripped by technologies that are better suited.

The project receives support over three years by Danish research funds.

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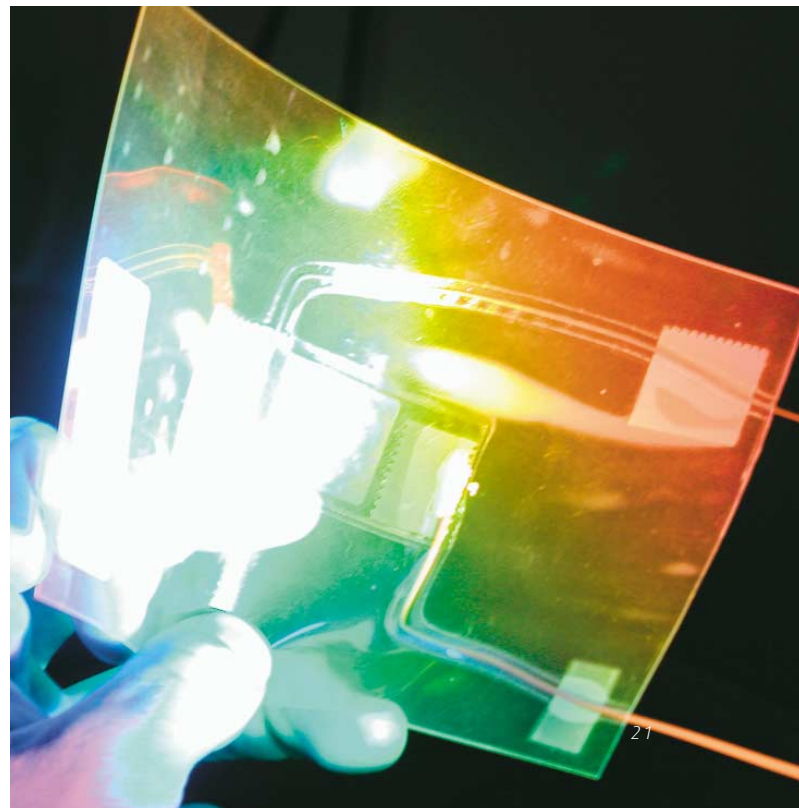
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The Danish development of plastic PV cells is taking place at the Danish Polymer Centre at Risø National Laboratory, where the combination of energy technology and materials technology will create PV cells with a longer lifetime and a higher degree of efficiency. The time horizon for the commercial application of this high-technology research is 15-20 years.

Photos: Risø National Laboratory





WAVE ENERGY

When the wind blows across the oceans, waves are started up that can travel hundreds of kilometres without any great loss of energy. In this way the ocean becomes a natural storage place for the energy of the wind. A wave energy plant can convert this energy to power.

In Denmark a number of research institutions and inventors have worked with this challenge, not least to develop constructions that can withstand the violent impacts of the oceans and which have sufficient efficiency and cost-efficiency that point to a possible commercial breakthrough in the longer term.

In 2003 the first grid connected wave power plant, Wave Dragon, on the scale of 1:4 commissioned. Wave Dragon was invented by Erik Friis-Madsen and developed in cooperation with a great number of firms and institutions from most of Europe.

The principle in Wave Dragon is that two "tentacles" lead the waves towards a curved ramp. When the waves wash over the ramp, a large reservoir fills with water. The reservoir is higher than the ocean and this difference in height is used to flow the water through turbines that run the electricity producing generator.

When Wave Dragon is fully developed it can be located at water depths of more than 20 meters, for example in the North Sea, the Atlantic or the Pacific. The size of Wave Dragon is adapted to the water depth and the size of the waves. A plant in the North Sea will weigh about 22,000 tons, be 260 meters broad and have a generator efficiency of about 4 MW.

With the present concept, such a plant will produce as much as 12 GWh per year. To reduce the costs when connecting to the electricity grid and for maintenance, the plants can be placed in groups with up to 200 plants in each.

Up to now, Wave Dragon can utilise up to 16% of the energy of the waves, but the project group is expecting to improve the operating results by further development of the construction.

In 2005-06 the project group expects to test a full-scale plant off the coasts of Europe. Calculations suggest that a commercially developed plant can produce electricity for about 0.04 Euro/kWh.

Since the beginning, Wave Dragon has received 7.6 million Euro from the Danish Energy Authority, EU Energie and a great number of other sponsors.

Wave Dragon is one of the most promising wave power concepts developed with support from a targeted R&D programme 1997-2001. The photo shows a prototype, which was the first Danish grid-connected wave power plant, being prepared for installation under relatively protected conditions in Ringkoebing Fjord — an inlet at the westcoast of Denmark. The target is later to establish a full-scale plant off the coast.

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Photo: Wave Dragon & Earth-vision

PEM FUEL CELLS

In Denmark we are close to commercial production of PEM fuel cells at low temperature – Polymer Electrolyte Membrane.

IRD Fuel Cells A/S, together with Danish universities and public research institutions, have developed PEM fuel cells which, in contrast to SOFC fuel cells, can operate at room temperature and therefore can start immediately without preheating. For example, this is an advantage if fuel cells are to be used in cars or a UPS plant. On the other hand, PEM fuel cells can only use hydrogen as fuel, for example hydrogen-rich reformed natural gas.

IRD Fuel Cells have developed the first Danish prototypes of PEM mini-CHP units which, when hydrogen, coolant, aeration and electricity have been added, are started by pressing a button. The plants run automatically and produce 2.5 kW electricity and 2-3 kW heat at an operating temperature of about 70°C. This demonstration has among other things led to IRD Fuel Cells selling several PEM fuel cell stacks to German households' mini power plants.

The electricity efficiency is about 50% and the total efficiency of the small power plant is about 80%.

The company is aiming at starting up commercial mass production in 2-3 years. This presupposes further efficiencies in the production process to reduce the construction price to DKK 10,000–12,000 (EUR 1,300–1,600)/kW electricity.

The development of fuel cell systems for Denmark's first PEM car and mini-CHP plants has been carried out with support from the Danish hydrogen programme of a total of DKK 6 million.

FURTHER INFORMATION AND CONTACT:

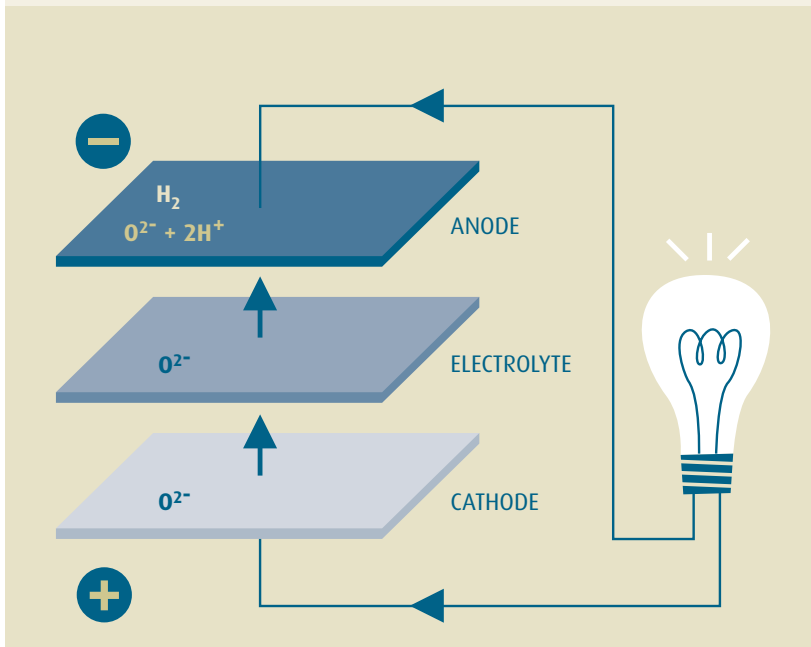
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SOFC - PRINCIPLE DRAWING



CASE

FUEL CELLS WITH HIGH OPERATING TEMPERATURE

Risø National Laboratory and Haldor Topsøe A/S have joined forces in a research project that will further develop ceramic fuel cells, also called Solid Oxide Fuel Cells (SOFC).

Researchers at Risø are in charge of cell production while Haldor Topsøe is building stacks and developing fuel cell systems which also contain the other auxiliary components such as heat exchangers and pre-reformers.

Haldor Topsøe is financing the work of Risø in this phase of the project, after the Energy Research Programme of the Danish Energy Authority granted considerable support to the research for a number of years. The

researchers at Risø have made sure that they have the freedom to also work with their own ideas in the field of SOFC, and to publish research results. Haldor Topsøe owns the exclusive rights to utilise the results in the commercial production of fuel cells.

Between 1989 and today, Danish companies and research institutions have invested up to DKK 200 million in developing SOFC fuel cells.

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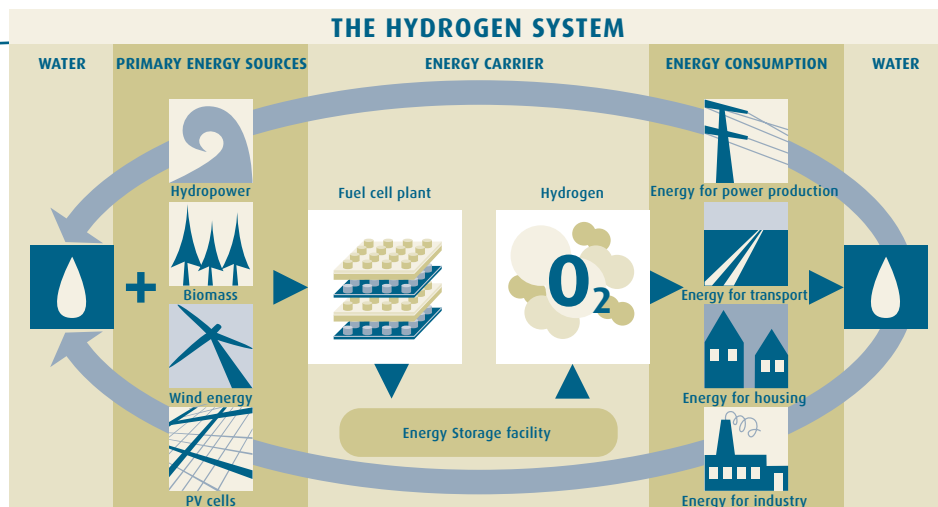
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HYDROGEN- A POSSIBLE ENERGY CARRIER OF THE FUTURE

In an energy system based on hydrogen, fossil fuels like coal and oil are to be replaced by renewable energy that is used to produce hydrogen. Hydrogen as an energy carrier can contribute to solving some of the present environmental problems, in the transport sector for instance, but at the same time contains a number of technological, economical, and infrastructural challenges.



There are untold amounts of hydrogen in the water and no CO₂ is developed during combustion. By introducing hydrogen as an energy carrier in energy supply, it is possible to store electricity relatively simply and efficiently.

In addition, a greater part of energy supply can be based on renewable energy sources, both because fluctuating electricity production can be stored and because it can be utilised in the transport sector in either electric or hydrogen cars.

Hydrogen can be produced from both fossil fuels and renewable energy. The greatest environmental benefit is achieved by energy production based on CO₂-neutral forms of energy such as wind turbines, PV cells and hydropower, or by using hydrogen recovered from biomass.

TECHNOLOGICAL DEVELOPMENT

The realisation of the hydrogen society presupposes comprehensive development of technology and infrastructure in the whole chain from production to application. Electrolysis is a key process for hydrogen production and is today implemented with an efficiency of 75-85%. New methods are expected to raise the efficiency to over 90%.

Hydrogen can also be produced by the conversion of organic materials to methanol or directly to hydrogen, for example by means of hydrogenases – and work is also being performed

here on developing and optimising the biochemical processes.

The distribution of hydrogen will be based on already known technologies. Studies are in progress among other things on the extent to which hydrogen in the form of gas can be transported in the established gas grid. One possibility could be to mix a small amount of hydrogen in natural gas.

HYDROGEN STORAGE

Storage is one of the big challenges, and work is being performed especially on optimising the three main methods for storage. Hydrogen can be stored as high-pressure gas, requiring special tanks. For the transport sector, experiments are being conducted inter alia with aluminium and plastic tanks that can keep the weight down.

Another possibility is metal hydrides, a solid that changes its nature when hydrogen is added. The problem with metal hydrides is that they are still very heavy in relation to their storage capacity. Finally, hydrogen can be cooled to minus 253 degrees as liquid hydrogen. This process is also problematic as it leads to great losses.

With regard to applications, fuel cells will play a key role because they can convert hydrogen to power and heat efficiently and without pollution. The only residual product is steam.

RESEARCH PROJECTS IN DENMARK

The Technical University of Denmark, Aarhus University, Risø National Laboratory and Haldor Topsøe A/S and Danfoss A/S have received subsidies for a four-year basic research project that is to identify the technical and economic possibilities of realising a hydrogen system.

A Nordic initiative has been taken towards joint research efforts – read more on the home page www.h2foresight.info

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The Danish Energy Authority was established in 1976, and as of 27 November 2001 is an Authority under the Ministry of Economic and Business Affairs.

The Danish Energy Authority carries out tasks, nationally and internationally, in relation to the production, supply and consumption of energy. This means that the Authority is responsible for the whole chain of tasks linked to the production of energy and its transportation through pipelines to the stage where oil, natural gas, heat, electricity etc. are utilised for energy services by the consumer.

By establishing the correct framework and instruments in the field of energy, it is the task of the Danish Energy Authority to ensure security of supply and the responsible development of energy in Denmark from the perspectives of the economy, the environment and security.

It is the task of the Danish Energy Authority to advise the minister, to assist other authorities, to administer Danish energy legislation and to conduct analyses and assessments of the development in the field of energy, nationally and internationally.

