Lillgrund windfarm. Photo: Vattenfall

Copenhagen: a showcase for sustainable energy production

In the Danish capital and the surrounding area, renewable energy sources are increasingly being used to generate power and heat. The city hopes to draw on its proven background in sophisticated power plant technology to put it in contention for major global energy events.

by Stefan Schroeter

The Lillgrund wind farm in the Øresund is clearly visible when flying into Copenhagen Airport. Here, where the Baltic flows between Denmark and Sweden to meet the North Sea, Sweden's first large offshore wind farm has been supplying power from a renewable energy source since December 2007. It is nine kilometres from the small marina on the edge of the Danish capital to the 48 wind turbines, each of which has a capacity to produce over 2.3 MW.

For Arne Floderus, Project Manager at Vattenfall Power Consultant AB, such a journey is part of his normal working day. Vattenfall worked for eight years to obtain the approvals necessary to build the farm, Floderus explains. No wonder: the construction of the neighbouring Øresund bridge was delayed in the 1990s due to objections from environmental campaigners who maintained that the flow of fresh water from the North Sea into the Baltic would be compromised by the bridge's supporting columns. This was also an issue in point for Lillgrund, although according to Floderus, not one of critical importance. 'We have not had any problems with the flow of fresh water into the Baltic – the base slabs of the turbine foundations have been buried in the sea floor as stipulated by the authorities.'

In the spring of 2006, Vattenfall was finally able to start constructing the wind turbines. Following extensive testing, the wind farm was finally brought online in December

2007 with a total capacity of 110 MW. In future, the farm is expected to generate 330 GWh of electricity each year. By May 2008 it had already produced 200 GWh.

There is hardly a breath of wind on this sunny May day, the sea is as smooth as glass. The powerful rotor blades on the wind turbines which stand over 100 metres tall remain still. A maintenance boat operated by Siemens has docked at one of their towers. Siemens uses the calm for maintenance work. What is not directly visible from here is the increased activity taking place in Scandinavia's electricity interconnection system. Its flexibility on days like this is particularly in demand: When there is no wind, the plentiful Swedish and Norwegian hydroelectric plants boost their output and supply electricity to Denmark, keeping the Danish national grid stable.

Further expansion

To date, it is primarily Denmark, as a pioneer in wind power generation, that has benefited from the interconnection system. The country now produces 20 percent of its power from wind. Sweden intends to follow in its footsteps. The state-run utility Vattenfall has announced its intention to invest a total of 41 billion Skr (€4.4 billion) in wind power generation by 2016. The objective is to generate 8 TWh annually.

The fact that Sweden's first major offshore wind farm is located near Denmark is symbolic, as Denmark already has extensive experience in this field and is pursuing ambitious expansion plans. The first offshore wind farm in the world was constructed in 1991 at Vindeby off the west coast of the island of Lolland, consisting of 11 turbines with a total capacity of 5 MW. In subsequent years, seven further offshore wind farms have been added. The largest of these is Horns Rev with 80 turbines of 2 MW each. At present, total capacity of Denmark's offshore wind farms amounts to over 423 MW. In the last six years however, only a small number of turbines have been added. This is a result of changes in government support which came into effect in 2002. Payment now fluctuates in line with the market price dictated by the Nord Pool exchange for electricity trading. This model has not provided strong incentives to invest.

> *'There is no other power plant as advanced as this one'*

But renewed expansion is anticipated as in February 2008 the Danish parliament agreed on a new stimulation package for renewables. 'New wind power capacity of 1,300 MW will be installed in the next four to five years', says Denmark's Minister for Climate and Energy, Connie Hedegaard. Denmark, home to 5 million people, would then have wind power capacity amounting to 4,400 MW.

The next phases of expansion have already been determined. Danish company Dong Energy is currently building Horns Rev II with a capacity of 200 MW, set to be brought online in 2009. In April 2008, Eon Sverige won the concession to construct the Rødsand II offshore wind farm, also with a capacity of 200 MW. This will be ready in 2011. In order to secure the concession, Eon has committed itself to supplying electricity from Rødsand II at a price of 62.9 øre (8.43 cents) per KWh for 50,000 peak load hours, about 14 years.

The Danish parliament has further committed itself to tender another 400 MW of offshore wind power capacity by 2012. Over and above this, 500 MW of onshore wind turbines are to be built on the mainland. Overall, the aim is to

increase the proportion of total Danish energy consumption by renewable sources from the current 16% to 20% by 2011 and 30% by 2020, primarily through wind turbines and biomass plants.

Flexibility

According to Minister Hedegaard, there will be no problems when it comes to incorporating the rapidly increasing volumes of wind power into the national grid, thanks to the extensive cooperation with Norway and Sweden in the Scandinavian interconnection system. 'If we have more wind power than we can use, we export it,' explains the conservative party politician. 'When there is no wind, we import electricity from Sweden for example, primarily hydro and nuclear.' Electricity exchange with Germany is also to be expanded. In the long term, cross-border electricity trading is not sufficient to be able to manage the growing volumes of wind power. 'There will be days when areas of Denmark will have 100 percent wind-generated electricity in the grid, on other days this will be 50 percent,' the Minister predicts. 'Our national grid must be restructured so as to allow for this.'

The Risø National Laboratory at the Technical University of Denmark in Roskilde near Copenhagen is focussing on these restructuring efforts. Hans Larson, head of Systems Analysis Development, clearly remembers the initial scepticism expressed by the established industry towards wind power. 'Ten years ago, Dong Energy and other people didn't believe it would be possible to exceed five percent', Larson reports. 'There have been a lot of systems changes.' Denmark has as a back-up a well-developed system of decentralised combined heat and power stations, with which fluctuations can be evened out.

Distributed power

Henrik Bindner, senior scientist at Risø's Wind Energy Department, believes that the energy mix will be much wider in the future than today. 'You will have wind farms, individual wind turbines, photovoltaic power plants, hydropower plants, household fuel cells.' He anticipates that larger volumes will be consumed at those times when prices are low. New technologies will be needed to link production to consumption. On a small scale, Risø set up such an electricity system using computer-aided measuring and control equipment three years ago in their own laboratory. In this 'Syslab', two wind turbines, one photovoltaic plant and one diesel generator produce electricity. The end user is the scientists' office building with computer controlled lighting, heating and cooling. Surplus electricity is used to charge a special vanadium battery and the battery of a hybrid Toyota Prius. At the same time, the shared system is connected to the national electricity grid, which can both supply and be supplied with electricity.

In future, a fuel cell, a hydrogen filling station and an ethanol refinery are to be integrated into the system. 'Our system could be a model for a larger facility', Bindner reports. 'But it can also be viewed as a single entity connected to a larger system. We can have areas that are autonomous, that can survive a transmission system malfunction.'

At the same time, the Risø researchers are working on new technologies for energy generation from wind, sun and biomass. They have developed a new laser-based measurement system, which can be

Combined heat and power plant Avedore. Photo: Stefan Schroeter

operated from the ground to measure wind speeds at numerous points around a 150 metre tall wind turbine. Using a test rig, the tensile strength of 35 m long rotor blades from wind turbines is tested under extreme conditions. Risø research into solid oxide fuel cells (SOFCs) is currently in the initial stages of industrial manufacture. The industrial partner Topsoe Fuel Cell is building a pilot plant in Lyngby near Copenhagen. In the first phase, fuel cells will be produced for demonstration projects, which will be used as the foundations to develop the technology further. As Soren Linderoth, head of the Risø Chemistry Department, explains, SOFCs have the potential for high electrical efficiency of above 50% in stand-alone units and above 70% when combined with a gas turbine. They can also use a wide range of fuels, including natural gas, biogas, diesel, methanol and ethanol. According to Linderoth, some of the obvious uses are emergency power plants, electricity for lorries and ships, micro power plants for individual family homes and large combined heat and power plants.

Linderoth believes that one of the most important aims of the research is to reduce the manufacturing costs associated with fuel cells and to improve their durability. To this end, he is working with his colleagues on the so-called third generation of fuel cells. More cost-effective materials can be used here, the current working temperature of up to 850 degrees Celsius will be lowered to 600-650 degrees.

Solar hats

In Risø's Biosystems Department, program manager Erik Steen Jensen is clutching a bundle of straw in his hand. 'This is stored solar energy,' he explains. Energy stored in the form of sugar, which is in turn bound in cellulose and hemicellulose. Jensen and his colleagues have been working for 20 years on ways of releasing the sugar from the straw and using bacteria to turn it into ethanol. Together with Dong, they have developed a pilot plant near a conventional power plant. From one ton of straw, 250 litres of ethanol per hour can be produced. 'The potential, when we can use both cellulose and hemicellulose, is about 400 to 500 litres of ethanol per ton of straw,' Jensen says. 'Right now we are only able to use the cellulose.' The next step for Dong is to build a demonstration plant which can process four tons of straw per hour.

Whilst Jensen is concentrating on extracting the solar energy stored in straw, his colleague, Peter Sommer-Larsen, is working on directly converting sunlight into electric power. The solar plastic cells he is developing with his colleagues at Risø have the potential to be simple to produce and cost-effective. An extremely thin photoelectric plastic material is printed onto plastic film or textiles. 'Using a typical printing process, similar to that used in the newspaper industry, you can print a solar cell', Sommer-Larsen explains. 'As many square metres of polymer solar cells can be produced in one hour as silicon solar cells can be produced by a standard factory in one year. The second major advantage is that no scarce materials are needed. 'It is simple chemistry,' Sommer-Larsen reports. It is the manufacturing of the photoelectric polymer that still presents the biggest challenge. At the moment, the solar plastic cells are achieving electrical efficiency of 2% and durability of a few months. The long-term goal is to achieve efficiency of 10% - equal to thin-layer silicon cells, and a durability of over five years. In the short term, the cells can be used in applications where lower efficiency and durability are acceptable. In the medium term, the cells may be used as rechargers for mobile phones and laptops.

Sommer-Larsen intends to showcase one of the first widely-used applications of the polymer solar cells at the Roskilde Rock Festival in early July 2008. 'We have integrated a solar cell into a hat,' he reports. 'It is just a gimmick. But we have been able to implement our technology in the printing industry and they can deliver a few thousand solar cells.'

> *The port district in Copenhagen has become a veritable power plant park*

Whilst Sommer-Larsen and his colleagues have many more years of research ahead of them, renewable energy sources are already being used in a large-scale power plant south of Copenhagen to generate power and heat. In the Avedore combined heat and power plant (CHPP), managed by Dong, a coal-fired unit with a capacity of 215 MW and 330 MJ/s heat has been in operation since 1990. In 2001, the power plant was expanded to incorporate a so-called multi-fuel fired unit with 495 MW and 575 MJ/s heat. The majority of the energy here is generated from pulverised wood pellets which can be burned together with natural gas and oil in a steam boiler. In a second steam boiler, steam is generated from straw. Both boilers drive a steam turbine which ultimately produces power and heat. 'The fuel mix is determined primarily by price,' explains Bent O. Petri, senior director of the Avedore power station. 'Normally we start with natural gas and then switch to wood pellets.'

The wood pellets are primarily imported from the Baltic states. The straw comes from 500 farms operating in Denmark's provinces to the south of Copenhagen – transport would otherwise be too expensive. This year there has been a lack of straw as the farmers were not able to collect sufficient quantities during the last wet autumn. 'We are trying to use more wood pellets', reports Petri. In the meantime, Avedore has overcome the technical problems known to be associated with straw-fired units. According to the director, the power plant is the only one of its kind. 'There is no other power plant as advanced as this one.' This is in terms of not only the fuel mix used and the size of the plant but also the efficiency. In CHP operation, the efficiency achieved is extremely high at 93%.

The construction of the Lillgrund wind farm. Photo: Vattenfall

Political discussion

In the east of the city, at the Amagerforbraending (AF) waste-to-energy plant, traditional power plant technology has been in use for 37 years. Here, 420,000 tons of rubbish from Copenhagen and other cities is disposed of each year. Through the sale of district heating, power and recycled materials, as well as revenues from disposal charges, AF turned over €57 million in 2007, posting a profit of €10 million. Although waste is increasingly being recycled, the volume of residual materials which must be disposed of is steadily rising. The capacity of the plant is no longer sufficient. 'We have to put 30,000 tons of waste into interim storage each year', reports technical director Fredskov. In addition, the plant is having difficulty complying with Denmark's environmental standards. At present there is also much debate as to whether waste-to-energy should continue to be categorised as CO_2-free, as it has been to date. AF is therefore keen to build a new waste-to-energy plant. 'We would like to start tomorrow, but our owners cannot decide,' says managing director Ulla Röttger. 'There is a lot of political discussion.'

World Energy Showcase

The port district in eastern Copenhagen, where AF operates its waste-to-energy plant, has become a veritable power plant park as Röttger puts it. Vattenfall operates a CHPP fired with coal, biomass and oil in the vicinity. Right next door, a geothermal plant extracts heat from the bedrock two kilometres beneath the surface and feeds it into the district heating system. Not far away there is a municipal sewage treatment plant where biogas is extracted from the sewage waste and used to produce heat. There are also treatment facilities for hazardous waste and soil. 'In the middle of Copenhagen we can showcase solutions to energy and waste problems which are extremely environmentally friendly,' says Röttger.

> *If little wind power is being generated in Scandinavia, the Norwegian and Swedish hydroelectric plants boost their output*

AF wants to draw on the concentration of energy technology in the area to create a 'World Energy Showcase' (WES) with the help of the city. An exhibition is to be opened next year before the United Nations Climate Change Conference in Copenhagen (Cop15) from 30 November to 11 December 2009. When the delegates from across the world are discussing a new agreement to reduce greenhouse gases, WES will be able to provide them with all the information they need about the relevant technology.

At a later stage, the site will also be used to build demonstration projects for new energy technologies. Possible projects mentioned by Röttger include a Vattenfall power plant which uses carbon capture and storage and a plant for producing ethanol from waste which Dong wants to build. Dong has also announced that it will erect three of the largest available wind turbines in the vicinity before Cop15. With Copenhagen's background in sophisticated power plant technology and its highly developed use of renewable energy sources, the city's administration and the Danish World Energy Council (DWEC) are also hoping to secure another major energy industry event for the city – the next but one World Energy Congress in 2013. As DWEC Secretary Peter Hinstrup explains, 'We can showcase the solutions.' ■