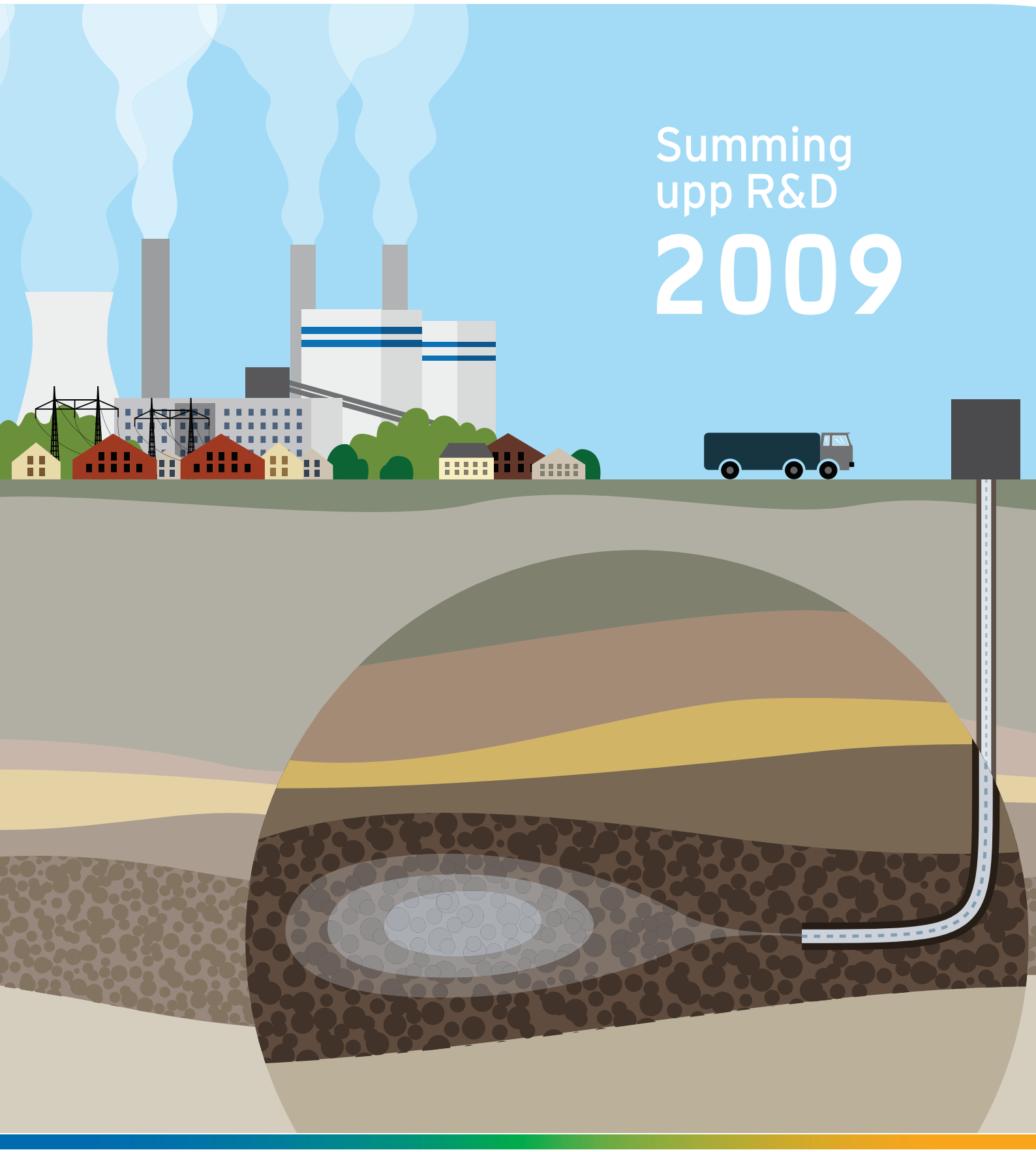
R&D Magazine

Vattenfall Research and Development Magazine • No 1, April 2010



Summing upp R&D 2009

VATTENFALL

Welcome to the

R&D Magazine

The R&D Magazine is Vattenfall's magazine about research and development within the Group. We want to give a comprehensive view of what Vattenfall is doing in the field of R&D in order to keep the readers up to date on advances in research and how they may shape the energy business of the future.

In this issue you can read about the distribution of R&D investments over different technology areas as well as the thoughts of Lars Strömberg, Vice President for Vattenfall Group R&D. We will also give you an insight into the purpose of R&D and why R&D investments in renewables are relatively limited.

Unlike previous issues of the R&D Magazine, this issue does not focus on a specific theme; instead we have interviewed all the R&D programme managers. This provides short reports on what they did during 2009, what they are up to at the moment and what the goals and visions are in their respective programmes. All the Group-wide R&D programmes will be briefly presented in this magazine. After each programme presentation, a summary of the most important projects within the programme will follow, except for the programmes Biomass and New Technologies, which are new programmes engaged in projects that cannot yet be presented to the broad range of readers this magazine is distributed to.

We hope you will find the R&D Magazine enjoyable reading!

If you have any comments or questions about the R&D Magazine or want to get in touch with any of the programme managers, please contact the editors Marcus Ericsson and Sophie Nykvist.
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no 1, April 2010

WHAT DOES VATTENFALL MEAN BY RESEARCH AND DEVELOPMENT AND WHY DO WE DO IT?

Vattenfall pursues research and development (R&D) as part of the business development of the Group. The aim is to meet the demands of customers, to reduce the environmental impact of our operations, to improve their efficiency and to contribute to our climate vision and "Making electricity clean".

Vattenfall as an energy company and a system builder and operator has little or no competence in the manufacturing or production of technical equipment; instead we define our needs to the manufacturing market. Consequently, we do not develop new hardware or software products. Our ambition is to be an excellent user of technology that is mainly developed by others, notably equipment manufacturers, to provide our customers with clean electricity. To achieve this, we often work together with different suppliers, large and small, from the laboratory stage or in demonstration or pilot projects. In these projects, we develop know-how and provide the operator's perspective on, for example, the usability and maintainability of new systems.

Vattenfall's Group R&D programmes are organized in different areas:

- **Renewables**
- **Operational efficiency**
- **Nuclear energy**
- **Energy efficiency**
- **Carbon capture and storage**
- **New technologies**

Read more about Vattenfall R&D at **www.vattenfall.com**

How R&D funding is spent and why

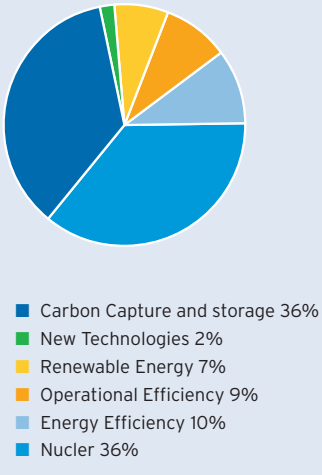
Vattenfall is actively working on research and development within a broad range of technologies, spanning from Carbon Capture and Storage (CCS) to Smart Grids, via for example wave-energy utilization and the un-destructive testing of concrete structures. Some of the technologies Vattenfall is working with are just a little more than ideas, while others are mature technologies that have been in use for decades. Our R&D activities cover the whole value chain and all the technologies that support our core businesses, electricity and heat. These activities are coordinated in different programmes divided into different areas.

R&D area	R&D program
Renewable energy	Hydro power Wind Power Ocean Energy Biomass
Operational Efficiency	Thermal Technology Smart Grids
Energy Efficiency	E-mobility Sustainable Cities Energy systems analysis
Nuclear Energy	Nuclear Power
Carbon Capture and Storage	CCS
New technologies	New technologies

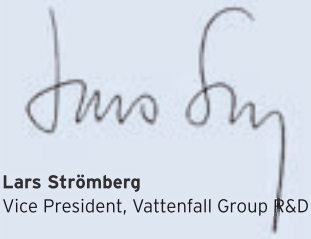
It is important to understand that there are huge differences between the two ends of the spectrum. For a new, not yet deployed technology such as CCS or Ocean energy, R&D activities play a predominant role, pushing the development and knowledge forward. For technologies in the expansion phase, for example wind-power, investment programmes are completely predominant, while R&D acts more as a support function to solve any problems that arise. For a mature technology such as hydropower, only limited amounts of money and time are spent on research and development regarding energy conversion; maintenance and the optimization of operations are in focus instead. This explains the relatively low expenditure on R&D in, for example, the field of renewables compared to the many times higher expenditure in R&D programmes on, for example, CCS.

The R&D programmes focus heavily on Vattenfall's strategy "Making electricity clean". As we are not a manufacturing company, our R&D is devoted to supporting our main products, electricity and heat, rather than to developing new products to manufacture and sell. In the 1970s, Vattenfall was heavily engaged in the development of wind power, for example we built the first MW-sized wind turbines on the Swedish island of Gotland. In the late 1980s, we developed technologies for biomass utilization, such as gasification, and we were pioneers in the development of heat pumps and solar panels, resulting in large solar panel installations in Uppsala and Linköping. All of these technologies are more or less mature today; we know how to burn biomass effectively and we can buy heat pumps and wind turbines on the market. Therefore, these technologies have left the research stage and are now in the commercial build-up stage, with large investment programmes at Vattenfall and elsewhere. This also of course influences the distribution of the R&D expenditure.

"In the 1970s, Vattenfall was heavily engaged in the development of wind power..."



Total expenditure on R&D activities distributed over the different technology areas (Total expenditure 2009: SEK 1365 million).



Lars Strömberg
Vice President, Vattenfall Group R&D

R&D PROGRAMME CCS

Carbon Capture and Storage

The goal of the programme is to develop a technology for capturing the carbon dioxide emitted from large coal-fired power plants and storing it safely underground. The R&D activities in CCS are performed in all parts of the CCS chain – capture, transport and storage – and have the objective of executing industrial-scale validation of the technology.

Most well-known is the Oxyfuel Pilot Plant at Schwarze Pumpe in Germany that has been in operation since 2008 for testing and verification of the carbon-dioxide capture process. During the first year, the concept has been tested mainly from a basic operability point of view. Now, the next step is to find out through tests and experiments how the technique can be scaled up in an optimal way – this means in a way that is cost effective, reliable and efficient.

In addition to our own oxyfuel pilot plant, Vattenfall is involved as a sponsor in a 40 MWh oxyfuel test rig project based on an optional supplier's technology, Doosan Power in the UK.

Recently we also joined a pilot project in order to validate an optional capture technology called Postcombustion Capture. This project, CCPilot100+, is also based on Doosan Power's technology and the project is being carried out in collaboration with Scottish and Southern Energy and co-funded by the UK Technology Strategy Board.
The capture link of the CSS chain – capture, transport and storage – is the part that has the greatest impact on the CO_2-avoidance cost. The focus is on developing capture techniques while reducing costs. This includes studies of capture technologies that are already commercially available in other applications. The initial tests will be performed over three years. The aim of the project is to have a commercial concept available by 2020.

The transport and sub-surface injection and storage of CO_2 is based on technology used mainly within oil and gas exploration and downstream technology. Ultimately, Vattenfall will not be the owner of such facilities but we are deeply engaged in adopting technology and methodology to the CO_2 application in cooperation with other utilities and the oil and gas community.

Demonstration power plant

In December 2009, it was announced that Vattenfall's planned CCS demonstration power plant at Jänschwalde in Brandenburg, Germany, is to receive up to EUR 180 million of funding from the European Commission. The money is to come from the European Energy Programme for Recovery (EEPR), the European economic programme for energy that was adopted in June 2009. A total of six innovative CCS projects in Europe are being supported with

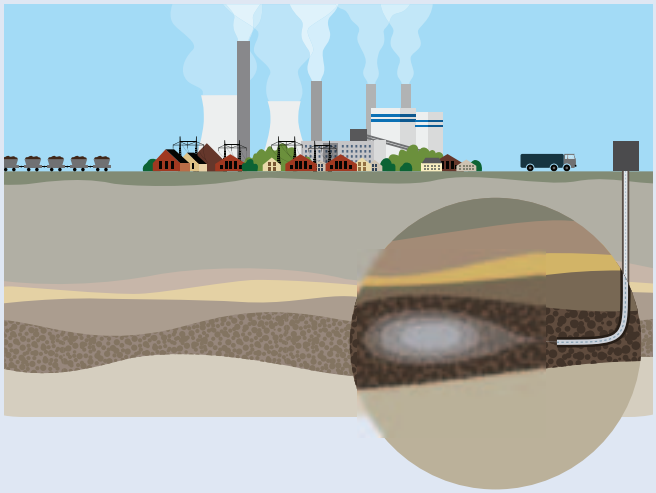
money from this source. The EU's support of the Jänschwalde demonstration plant is seen as confirmation that Vattenfall's CCS project is definitely on the right track.

"The plan is for the demonstration CCS power plant to be connected to the grid by 2015. Vattenfall estimates the investment cost at EUR 1.5 billion. The electrical power capacity of the demo plant will be around 385 megawatts (MW) of electricity. With a CO_2 capture rate of well over 90%, up to 2.7 million tonnes per year of this greenhouse gas could thus be kept out of the atmosphere," says Bjarne Korshøj, CCS Manager at Vattenfall. The Jänschwalde project comprises both oxyfuel and postcombustion technology.

Additional R&D

Since the merger with Nuon on July 1 2009, Vattenfall also has CCS activities in the Netherlands. These activities comprise additional R&D through a Precombustion CO_2 capture pilot plant at the coal-gasification plant in Buggenum and plans for the large-scale Precombustion CCS project at the Magnum plant in Eemshaven, Groningen in the Netherlands. ■

SUMMING UP R&D WITHIN CCS 2009



Environment

Monitoring of ground water and surface water

Thorough site selection and good monitoring procedures are keys to securing the successful storage of CO_2. Only storage sites with very good characteristics will be chosen for CO_2 storage, which minimises the risk of any unwanted events, such as leakage of CO_2. Nevertheless, the storage sites will be carefully monitored to make sure that everything develops according to plan. The monitoring and assessment of potential impacts on groundwater and surface water will be part of the monitoring programme for any CO_2 storage site. This includes establishing baseline conditions and performing risk assessments for potential sites. To do this we need to gather knowledge about the groundwater-surface water system. An important step in this work is to develop a groundwater model for each area, that is using a lot of data from local geophysical and geochemical investigations to develop a computerised model of the groundwater system. Vattenfall is conducting studies in Denmark and Germany in cooperation with local partners to develop such models, taking into account potential risks and measures to minimise and eliminate them. A theoretical study of the potential impacts of leakage to groundwater and surface water systems has been conducted by Uppsala University. This study indicates that impacts on surface water are expected to be very limited due to the large natural CO_2 exchange between surface water bodies and the atmosphere. For lakes in Northern Europe, there is a seasonal mixing of the water which effectively eliminates any risk of the long-term build up of CO_2 in the water body. For groundwater, local conditions at the site, such as buffering capacity, soil type and groundwater flow rate, are important to factor in when assessing potential impacts in the context of a risk assessment.

Environment, health and safety aspects of capturing CO_2

When introducing CO_2 capture technology, it is important to assess the environmental impacts of new and additional processes. The capture of CO_2 involves an energy penalty, the handling of large amounts of CO_2 and the use of chemicals and process steps that are somewhat different from those at conventional power plants. This needs to be managed with respect to environmental impacts and the health and safety aspects of the working environment. One example is the potential large-scale use of chemical solvents, which is addressed as part of our R&D work internally through international cooperation projects.

Vattenfall has reviewed state-of-the-art research on the health and safety aspects of CO_2 exposure. Due to its abundant use, CO_2 is one of the most thoroughly mapped substances there is. CO_2 can, in high concentrations, have negative impacts and be hazardous. The effects of CO_2 are believed to be mainly caused by changes in blood and cellular fluid pH, and not primarily caused by the CO_2 molecule itself or the withdrawal of oxygen. How much CO_2 workers are allowed to be exposed to during a normal working day is strictly regulated in national legislation.

Capture technologies

The first year's test phase at Schwarze Pumpe

Vattenfall's 30 MW thermal Oxyfuel pilot plant for CCS, Schwarze Pumpe, celebrated its first anniversary on


Bjarne Korshøj, CCS Manager, Head of CCS, Group Function Strategies.


Schwarze Pumpe.

September 11. The first year's test phase has provided essential knowledge about the entire Oxyfuel process chain. The Oxyfuel pilot plant will remain in operation as a test facility for research and development until 2013 and the next few years will entail intensive research on the Oxyfuel concept.

During 2009, approximately 1 400 tons of CO_2 have been liquefied in the Oxyfuel pilot plant and so far about 3 000 operating hours have been realized. A large number of tests and different measurements have been carried out during this time. One of the most important results from the first year of operation is the fact that the principle of the Oxyfuel process has been verified on an industrial scale.

A feasibility study has recently been executed in order to investigate the potential of co-firing biomass with lignite at the CCS pilot plant Schwarze Pumpe. The feasibility study has looked at what types of biomass to combust but also issues like transport, logistics and stock on site. If things turn out well and if relevant from a deployment perspective, co-combustion may start in a couple of years.

The OxyCoal UK collaboration

Vattenfall took another step forward in its committed work on CCS by joining the OxyCoal UK collaboration in 2009. The project aims to develop a competitive Oxyfuel technology suitable for full-scale plants. This involves burning hard coal in a mixture of high-purity oxygen and recycled gas to produce a gas rich in carbon dioxide that can be purified and compressed for transportation and storage.

This is one of the most advanced projects in Europe besides our own pilot plant at Schwarze Pumpe. For Vattenfall it is an important complement to our own efforts at Schwarze Pumpe.

Storage and transportation of CO_2

Exploration of CO_2 storage sites

A three-phase exploration programme for CO_2 storage sites began in 2009 and will be concluded in 2011. The first phase started with seismic studies of the Birkholz and the Neutrebbin structures. For both structures, a total area of more than 300 km^2 will be evaluated using vibration seismology. In the studies, special vehicles create vibrations in the subsoil that are reflected and returned to the surface. Geophones convert the vibrations into electrical signals and a geological profile of the subsoil can be created. The exploration drilling will then be carried out. This begins with the preparation of drilling sites. Four exploration drill holes are planned. Depending on the results, three further injection drill holes per structure may be added.

This is a continuation of the former exploration of two different sites; Birkholz-Beeskow and Neutrebbin in the German federal state of Brandenburg. These explorations were carried out together with Verbundnetz Gas and Schlumberger. The aim is to investigate the potential of these sites for the storage of carbon dioxide from Vattenfall's future CCS demonstration project in Jänschwalde.

Transportation of CO_2

Vattenfall supports R&D on transport aspects in a number of case studies and projects. We have initiated or taken part in several R&D studies with a specific interest in CO_2 transport and logistics for CCS.

The infrastructure for transporting CO_2 is a key component that connects the CO_2 delivery point at the power plants with the injection facility at the storage site. The transport part of a CCS chain is usually referred to as known technology, based on well-established operations of CO_2 pipelines for enhanced oil recovery in North America. However, there is still adoption and optimisation work to be done. The large-scale deployment of CCS has to handle CO_2 from a manifold of capture facilities, with a need to establish the corresponding transportation infrastructure that can handle these volumes. The infrastructure also has to include all the logistic aspects of the CO_2 flows, their compositions and conditions, legislation and regulations and agreements between all the actors involved. All this has to be built up step by step, each phase with certain prerequisites, while simultaneously building public acceptance and confidence in the CO_2 pipelines, ship operations and also for CCS as a concept.

R&D PROGRAMME SUSTAINABLE CITIES

Expanding the role of electricity

Sustainable Cities is a relatively new research programme within R&D. The work with defining the programme is still in progress and will be developed in close cooperation with the business development program Sustainable Cities.

The idea is to link Vattenfall's R&D programs to the customer needs of sustainable energy solutions in order to ensure a market demand of our developed products and services. The existing R&D program related to Sustainable Cities focuses on the use of energy, the efficiencies in these processes and the role of electricity in end-user systems.

This involves new technologies and new system activities on the end-user side of energy systems, which fulfil our long-term strategic ambitions – Making Electricity Clean. It also includes identifying, developing and creating Vattenfall competencies. Develop partnerships with universities and companies exchanging knowledge and ideas. Facilitating knowledge sharing among the different Business Units and Group Functions. In November last year the programme had a new manager, Thomas Munch-Laursen. In connection to this, the structure of the programme became more clearly defined by being divided into four sub programmes; Metering Technologies Related Services, Product Related Customer Services, Distributed Generation Services and Cooling Systems. During 2010 two more sub programmes will be added to the programme; Geothermal Energy and Solar Energy and the work with defining the programme will continue. It will be exiting to see how the programme will develop and what the output will be!

An example of a project within Sustainable cities is the evaluation of whether small-scale wind power can become an interesting technology to be integrated into buildings for power production. This project will be carried out as a general study and overview about suppliers, an overview about technology and an economical evaluation of technology. ■

SUMMING UP R&D WITHIN SUSTAINABLE CITIES 2009

Metering technology-related services
With new technologies in the area, a variety of products and tools will become available. Our main focus is on how to support business development based on the utilisation of metering and measuring data for electricity and heat consumption. The main sector for the technical developments is private customers with services in automatic meter reading (AMR) and commercial customers that use services comprising other consumption data measurements in relation to energy services. AMR is the technology of today but we are also examining the development of future possibilities. We have also been working with energy saving in households.

Product-related customer services
We concentrate our work on technology development and the utilisation of new technology for the efficient use of electricity and heat. Key areas in 2009 were lighting and heat pumps. Vattenfall wants to increase its knowledge regarding energy-efficient lighting and heat pumps and to build competence in these fields.

Increased demands for comfort and cooling will require the development of new applications. We have been studying demands, possibilities and solutions with a focus on heat pumps and cooling machines from a system and economic perspective. Solar-heat systems are sometimes used in combination with heat pumps. We are examining how such a system could be designed most cost-effectively from calculations that show when solar panels save electric energy and how this affects the power demand of the system. We are also taking part in the Swedish Energy Agency's research and development programme on efficient lighting. The programme aims to provide knowledge that will help to promote the development of efficient lighting and to provide suggestions for energy-efficient solutions.

Distributed-generation (DG) services
This is heavily supported in some markets and will be one of the major challenges for the energy industry. Solar panels, geothermal production and engines are not feasible today, but might be in the future. Energy storage is almost non-existent today, but is the key to several other technologies, especially small-scale local generation.

The types of distributed generation that we are looking into include all types in the range lower than 5 MW, including combined heat and power production (CHP) systems and both single heat and single power generation systems close to the customer side. Small-scale CHP units will probably play an increasing role for energy supply in the future, mainly in markets with a gas supply structure. It is therefore important for Vattenfall to know the potential for such technologies and to be in a position to react. A filter to define the best available technologies for distributed generation has been developed. We have also been working on the development of an overall concept for solar heat together with district heating in a planned area in Berlin.

Cooling systems
Our focus lies on all new solutions and integration with existing cooling systems. One of our ideas is to deliver cooling based on district heating via decentralized absorption chillers, driven by hot water from CHP (combined heat and power) plants operated by Vattenfall Europe. The approach is to get cheaper, smaller and easier installations than those the technology of today can offer. The units should be easily integrated into the existing building infrastructure. The development of the absorption chillers is being conducted together with industrial partners. Prototypes of the absorption chillers for offices and households were tested during 2009 on a test rack at a university.

Forsmark

R&D PROGRAMME NUCLEAR POWER

Safety always comes first

Research and development in the field of nuclear power has a strong focus on improving the safety and efficiency of operating plants.

The primary focus when operating nuclear power plants is of course reactor safety. By conducting relevant R&D, Vattenfall supports the currently-operating nuclear reactors. At the same time, we are collecting relevant knowledge on where to focus in the event that it is decided to build new nuclear power plants in the near or far future. As a consequence, many of the R&D activities within nuclear power aim at increasing safety in the power plants and our knowledge on reactor dynamics and the ageing management of the power plants.

The secondary focus is to increase the availability and efficiency of the plants. In addition to this Vattenfall is also working, together with Universities and companies, on the third and fourth generations of nuclear power reactors. In this way Vattenfall wants to contribute to the development of future reactors, but also to make sure that we have the right competence to purchase and operate these reactors in the future. Even though Vattenfall is participating in a few specific nuclear research projects we do not favour any specific technology, we will use the technology that proves to be the best given the time of introduction.

During 2009, the programme worked on the development of new materials to replace the cobalt on the slip and wear surfaces in the valves, the separation of recyclable waste from radioactive waste in order to compress the low-level nuclear waste and a new Nordic network for material development for the fourth generation nuclear reactors. Moreover, the programme manager has supported the Nuclear Energy Agency (OECD) with his expertise concerning the opportunities and threats arising from the transformation of light-water reactors to fast reactors. For more examples of specific projects during 2009, see the next page. ■

SUMMING UP R&D WITHIN NUCLEAR POWER 2009

Current reactor systems
In 2009, Vattenfall conducted studies on availability-related and generic issues such as ageing management and environmental effects. Some of the research activities that we are involved in were carried out as part of the Elforsk Nuclear Power Programme. Elforsk is the Swedish electricity power companies' research and development organisation. Examples of work and reports produced during 2009 are:

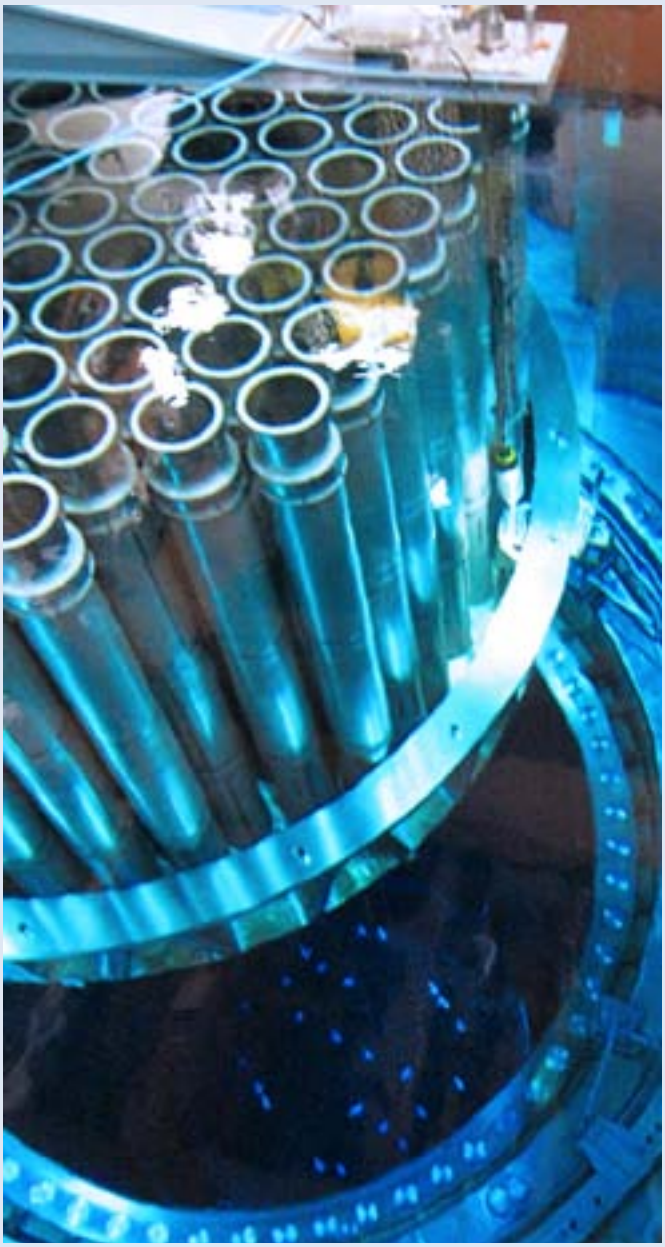
- A study of the effects of the hot water released by the nuclear power plants and the relation between the actual releases and the initial assumption at the time of construction.
- Several reports on the state of nuclear power around the world have been produced.
- Two civil structure programmes dealing with knowledge retention and build up. The focus is on both the ageing of existing reactors and issues regarding the building of new power plants and systems. These programmes are co-financed by relevant stakeholders in the Swedish nuclear business.
- Vattenfall is preparing a newsletter on the world nuclear outlook on behalf of the nuclear companies in Sweden.

Other development work involves studies on waste management and the testing of candidate materials for use in valve linings in the pressurised systems of the reactors. Vattenfall is also evaluating the third generation reactor system and is taking part in a European effort on this.

Future reactor systems
The OECD's Nuclear Energy Agency (NEA) has published a report on transition scenarios from the light-water reactor cycle to a sustainable closed nuclear fuel cycle. Vattenfall took part in the work.

A reconnaissance study on radioactive releases from future large-scale reprocessing activities has been performed. Postulating a future closed nuclear fuel cycle where the uranium resource is used much more economically and the remaining waste is far less long-lived, reprocessing may be routine. Since there are releases of radioactivity from reprocessing, concerns may be raised that a significant increase in reprocessing activities would make the closed fuel cycle impossible. The results indicate that a very large increase in reprocessing activities would probably be acceptable.

Vattenfall has started to build up strategic competence to support the new irradiation facility – the Materials Test Reactor in France, the Jules Horowitz Reactor (JHR) programme. The plan is to build the JHR in 2015 in Cadarache in France. It will be a breeder reactor and considerably different from the present generation of reactors. The collaboration with the CEA and the accompanying membership of the JHR programme is an important feature in allowing Vattenfall to attract young researchers and engineers to work with nuclear-related issues at the absolute cutting edge of development.



R&D PROGRAMME E-MOBILITY

Changing our way of life

The next generation of electrical vehicles, the plug-in hybrids, will soon be on the market. Vattenfall is promoting development by initiating and participating in different projects.

Concerns about climate change and security of energy supply have made electric vehicles a very favourable alternative in the transport sector. New and better batteries have created entirely new conditions. Electricity requires a significantly lower input of energy compared to conventional combustion engines. It also expands the diversity of energy sources for road transport, making it possible to use low-emitting and domestic energy sources. The impact on the climate as well as local emissions will be significantly reduced. Today, car manufacturers and battery producers are investing in the development of electric vehicles and we can expect to see a range of models and technical solutions on the market in the near future.

In June 2009, Volvo and Vattenfall joined forces in a unique cooperation with the goal of having a plug-in hybrid electric vehicle (PHEV) on the market by 2012.Vattenfall and Volvo see the PHEV as an opportunity to reduce CO_2 emissions and as a means of controlling these emissions. By joining forces with Volvo, Vattenfall will speed up the introduction of PHEV on the market.

There are a number of of challenges to overcome before electric vehicles can take a substantial part of the market. The challenges include customer acceptance, the infrastructure for battery charging and reduced battery costs. Vattenfall is working with all these issues. In 2009, we started to test two plug-in hybrid vehicles under real-life conditions together with Volvo. The test drivers charge their cars through ordinary wall sockets and can also use a small number of public charging posts. In Germany, a demonstration project involving 50 battery-driven BMW Mini Coopers is being carried out together with BMW in Berlin.

Vattenfall is involved in developing different charging solutions for electric cars. This involves developing home charging services and acquiring more knowledge and competence about the possibilities for fast charging and inductive charging. Standardization is important for the progress of the charging market. Vattenfall is therefore working together with the energy industry and automotive industry to develop different standards, for example for the communication between vehicles and charging points. ■

SUMMING UP R&D WITHIN E-MOBILITY 2009

Charging technologies

Home charging optimization
In this area we deal with charging car batteries (PHEV) from private homes. Our intention is to find the most cost-effective and straightforward solutions for the customer and to describe these in guidelines. Our work has focused on how to better understand the operation of chargers including how the charger affects the grid, different designs of low-voltage systems, pricing models and relevant safety regulations and their eventual impact on the possible solutions for various battery-charging solutions.

Retrofitting engine pre-heater systems
We have been investigating the potential for charging electric vehicles in parking places already equipped with engine pre-heater poles. Today, a number of engine pre-heating system designs and different suppliers can be found in various locations. This must be taken into consideration when retrofitting the engine pre-heater system to handle the charging of electric vehicles.

Fast charging and inductive charging
The fast charging of electric vehicles as well as inductive charging has the potential to make it easier for users to charge their cars. We have therefore been looking into the design and operation of fast charging units, the different developers, other companies' experiences of fast charging of lithium ion batteries and the market situation. We have also analysed what technical constraints to use when developing the financial models for fast charging. In the field of Inductive charging, we have described the state-of-the-art and the technical specification for an inductive charging system.

Standardisation and vehicle movement in the Swedish car fleet
Vattenfall takes part in the standardisation work for vehicle charging in order to be able to influence coming standards and to enable a large-scale introduction of electric vehicles in society by making it easy to charge and also to cross borders in or between countries. We are also involved in a project that aims to put together a representative database of the movement patterns of private cars in Sweden. This database will provide a framework regarding charging needs, system load and design of charging systems and available battery capacity in terms of space and time, applied to the normal use of vehicles today.

Industrial cooperation to develop system solutions

Vattenfall, Volvo Cars and ETC Battery and FuelCells Sweden AB, are since 2007 working together with the intention to develop and demonstrate PHEVs and charging-infrastructure solutions. Volvo is developing a PHEV prototype with 30 km driving distance with electricity and a maximum speed with electricity of approximately 90 km/h. ETC is developing a lithium-ion battery system. Vattenfall is developing and demonstrating charging solutions for use at home, at workplaces and at public places with both slow (230V/10-16A) and semi-fast charging (230V/32A). Five charging poles have been installed and are in operation at Lindholmen (2), Volvo Torslanda (2) and Råcksta (1). A payment solution with company card or credit card access is demonstrated. The public charging technology and payment solutions have been demonstrated at Lindholmen in Gothenburg.

Battery technology
Lithium-ion batteries may become an important product in the future to support networks at peak load stability and for use in connection with power shortfalls, load management, electrical power quality and resourcing balance. The vehicle industry also has a need for such batteries with different properties suitable for various kinds of electric vehicles. In 2009, we increased the cooperation with ETC and started to look into the opportunities to create a battery R&D department, a test laboratory and a pilot production line. We are doing this in order to become a highly competent battery hub for customers interested in developing energy-storage systems.

System studies – vehicle to grid

We have been working on analysing vehicle to grid systems (V2G), the concept in which battery-driven vehicles may act as control-power resources. Each vehicle has a limited battery capacity so it is necessary to have a control system that would aggregate a large number of electric vehicles and give the appropriate control signals to the vehicles regarding when to activate them as control-power resources. A visionary outlook on V2G in terms of opportunities, threats and limitations has been included in the work, along with a mathematical-optimisation model for testing the design in a limited scenario.

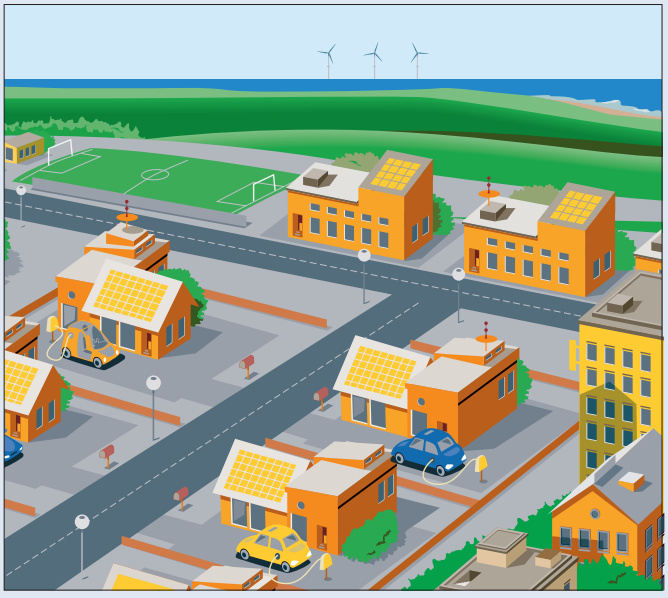


Illustration: Kjell Ericsson.

R&D PROGRAMME BIOMASS

Enabling more renewables

Biomass will play an increasing role in Vattenfall's energy mix of the future. Its goal is to find and implement solutions to substantially increase Vattenfall's use of biomass in electricity generation and heat production.

In line with its strategic ambition "Making Electricity Clean", Vattenfall has decided to substantially increase the co-firing of biomass in hard-coal power plants. It is planned to replace about 10 per cent of the hard coal used in our plants with biomass by 2014.

In 2009, the short to mid-term goal in Vattenfall was stretched higher than this 10 per cent. This has resulted in a sourcing strategy for biomass with the aim of using 4 million tonnes of biomass for co-firing in 2015, giving a CO_2 reduction of about 5 million tonnes.

"The volumes we will need in the future are not available in the market today. Therefore, we have to take a broader view and get involved in the supply chain. We have decided to increase biomass use by 4-5 million tonnes by 2015 and target is to use at least 10 million tonnes in 2020," says Göran Lundgren, who is responsible for the biomass expansion programme at Vattenfall.

In addition to the ramp-up of biomass sourcing, the Biomass R&D Programme is driving and promoting a number of projects in order to develop the most efficient and environmentally-friendly techniques for the use of biomass. For example, the potential for so-called black pellets is being investigated in a benchmark study. Different technologies exist on the market to "roast" different types of biomass. This results in a coal-like product that potentially can be more easily handled on site at the power plant and will also improve storage capabilities.

Another project is being run in cooperation with Heat Nordic concerning the technical and economic aspects of a process to convert agricultural waste into a bio-oil, which would replace fossil oil at the respective power plants.

"We have decided to increase biomass use by 4-5 million tons by 2015..."

Further studies will be initiated during the year in order to find new biomass fuel types suitable for increasing the share of biomass in the fuel supply for the Vattenfall Group. ■

Uppsala Combined Heat and Power plant.

R&D PROGRAMME NEW TECHNOLOGIES

With a feeling for what's valuable

Working in the New Technologies programme is like Forrest Gump's mother used to say; "Life is like a box of chocolates, you never know what you're gonna get". A considerable number and wide variety of ideas are collected and evaluated in this programme each year.

Every year many ideas and innovations are presented to Vattenfall by professors, venture capitalists, companies and individuals. Many of these ideas are either not suitable for use on a large scale, more expensive to build than the value they would generate or simply outside the business scope of Vattenfall. Some of them, however, have potential and should be picked up. It is the responsibility of the programme manager for New Technologies to single out any ideas that may be of value to Vattenfall and make sure that they are taken care of in the organization.

When a promising idea has been identified, the New Technologies programme may conduct smaller studies in order to evaluate the business case for Vattenfall, i.e. to answer the question "What's in it for Vattenfall?" If the idea still looks promising after this evaluation it may be adopted by one of the business units within Vattenfall, or - if the idea does not fit any of the existing business units - a new R&D programme may be created for the idea to be further developed. Even joint ventures with an innovative company may arise from such collaboration. If the idea does not fall into any of these categories it is abandoned. Vattenfall is not interested in developing technology to manufacture and sell, only technology that can improve Vattenfall's core businesses, that is to generate and sell electricity, heat and gas, is of interest.

In 2009 many different ideas were investigated, from new turbine technologies to electricity generation from algae and the utilization of waste heat from cooling water. As to what will happen in 2010 - no one knows. It depends entirely on the ideas that are encountered during the year. ■

R&D PROGRAMME OCEAN ENERGY

How to become one of the leaders

The purpose of the Ocean Energy Programme is to build up in-house expertise in order to evaluate technologies as well as environmental and business issues. When ocean energy reaches its commercial phase in 10–15 years time, Vattenfall aims to be a world-leading wavepower operator.

Several techniques for Ocean Energy are available and Vattenfall is currently focusing on wave power. Ocean Energy supports Vattenfall's strategic ambition "Making Electricity Clean" as it is a renewable energy source and does not emit carbon dioxide or other substances harmful to nature.

Last summer, Vattenfall launched a pilot project off the west coast of Norway. The test site consists of two wave-energy converters, underground switchgears and a cable that connects the converters to the distribution grid on shore. The project involves an environmental monitoring programme to observe the potential impact of the installation on the environment and to get experience from different monitoring methods.

In 2009, we concentrated our efforts to favourable markets concerning wave climate conditions and governmental supporting schemes. We also participated in tests of prototypes and have been deeply involved in design work and gained a lot of knowledge. A total of 56 R&D projects were run under the Ocean Energy Programme in 2009. Following the evaluation of more than 20 different technologies, we decided to actively support two of them; Pelamis and Wavebob.

The agreement between the European Commission and the Consortium composed by six partners under the leadership of Wavebob was signed in the middle of November. The goal is to design and manufacture a full scale model in three years. Vattenfall has a central role in the Consortium with main focus on Site Operation and Maintenance management and in the Risk Assessment of the entire system.

Today wave power techniques still are in their innovation and testing phase; in this phase Vattenfall focuses on building competence, get permits for wave power sites and participate in pilot tests. To do this Vattenfall cooperates with different universities and has also founded one company on Ireland, Tonn, and a company in Scotland, Aegir, together with local technology development companies, with the purpose to establish wave power sites. In the second phase Vattenfall will focus on developing and operating demonstration wave power farms and the third phase is when wave power becomes commercial. ■

SUMMING UP R&D WITHIN OCEAN ENERGY

Technology and grid
Vattenfall has been working to strengthen its competence and develop its knowledge of technology issues and the technical design of ocean energy systems over the past year. This has given us of the basic knowledge we need to be a good buyer and operator of ocean energy technologies.

We have started the build up of a database for wave energy concepts, where we look at various concepts for the open sea. We have also been looking at the operational prerequisites for wave converters, such as distance from the shore and water depths, to determine the potential. Studies of the design of a sub-sea grid and an inventory of available components started in 2009.

Environment
In the environmental field, we have focused on issues such as the investigation and monitoring of noise and electromagnetic fields from sub-sea cables and artificial reef effects from wave power installations. We have studied earlier experience of underwater noise relating to the construction and operation of wave power farms. Monitoring methodologies for dealing with underwater noise and the usefulness of them were also part of the study. We accomplished an up-to-date information study about electromagnetic fields from cables under water and the potential effects on marine organisms. The investigations have provided us with increased knowledge, which enables us to suggest how to proceed with further investigations and what methodologies to use in various situations.

An environmental monitoring programme (EMP) was planned and set up at the site for the pilot project off the coast of Norway. The purpose is to investigate the environmental impact of the test site in accordance with legal requirements and to build up Vattenfall's knowledge and experience regarding environmental-monitoring programmes for wave power. We will of course use the experience gained from the environmental-monitoring programme in future wave power projects. The aspects included are fish, benthos, birds, noise and overall management. A field baseline study concerning fish has been undertaken.

Site development
We need to secure sites for demonstration projects and to acquire permits for commercial sites until 2011. Vattenfall has selected Ireland and Scotland to develop commercial ocean energy electricity generation. Due to especially favourable market conditions and the wave resources in the area, the Irish and UK markets are our main areas for site development. Important steps were taken when we established the two joint venture (JV) companies together with the Irish wave power development firm Wavebob and the Scottish wave power development firm Pelamis.

Much of our work in 2009 has focused on the collaboration with our partners in the JV companies Tonn (meaning "wave" in Irish) and Aegir (meaning "king of the sea" in Norse mythology). In Ireland, we focus our development on a test site off the coast of Mayo County. The development work in Aegir is concentrated to a site outside the Shetland Islands with Pelamis wave power technology. The site is planned for up to 20 MW installed wave power. The work with application processes is ongoing, as is the strategic work on environmental assessments, in parallel with the work on the localisation of new sites.

We have also worked with the regular coverage of grid issues, tidal power and wave power as well as surveys of universities and institutes associated with Ocean Energy research and development.

Linear generator. Copyright O Danielson.

R&D PROGRAMME SMART GRIDS

A necessity for realizing our goals

Vattenfall is facing a number of major challenges for Making Electricity Clean. So far, the main focus of R&D activities and investments has been on generation. However, it is now recognised around the world that the grid will play a crucial role in the effort to get both renewable generation and conventional generation into the system.

Smart Grids is not a technology that is implemented in the grid. The Smart Grid concept is rather one that cuts across the entire value chain of Vattenfall. In an unbundled value chain, on a deregulated market, the benefits of Smart Grid investments will not arise in the grid where they are made. For example, providing for the connection of distributed energy resources to the grid will create profits for the generation unit owner or for an aggregator of such units.

Given this reasoning, it is not possible to find one definition of Smart Grid that fits all of Vattenfall's markets. As a result, the Smart Grids R&D Programme develops common local solutions as well as local variations of the Smart Grid concept within Vattenfall.

An important part of the Smart Grid technology is the integration of Smart Meters. Vattenfall already has a leading position in Smart Metering for its customers. In the Nordic region, Vattenfall has a market penetration level of 100 per cent for smart meters. There are also several pilots throughout Vattenfall in which consumption information is being fed back to the customers. This is the first step in a development towards more direct customer participation on the electricity market. In addition, the smart meter data is being used to improve the operation of the distribution networks.

At the customer end of the grid, the Smart Grids Programme is also studying the concept of prosumers, this means customers that have a generation level that sometimes exceeds the local demand. This is a situation that has both technical as well as market impacts on Vattenfall.

At the other end of the value chain, the R&D programme is looking at solutions to connect new intermittent power sources to the distribution grid. Novel technical solutions have been explored and documented in a vision for the Substation 2030 having a large portion of new functionality. Some of these novel solutions are now under discussion with the main suppliers and full-scale demonstrations are planned.

On the technology side, the combination of new power technology and recent advances in information and communications technology means that the possibilities for monitoring and controlling the grid can be greatly increased. One of the benefits is that the reliability and quality of supply can be greatly improved. ■

SUMMING UP R&D WITHIN SMART GRIDS 2009

Smart metering

Customer Information Pilot

A project called Customer Information Pilot (CIP) was operated successfully during 2009. About 2 500 end-customers have been using a web application that gives them access to data on their hourly electricity consumption as well as a number of other services. The project has been very valuable for all parties. Many lessons have been learned, ranging from direct feedback from end-customers to solving technical problems when setting-up functions for hourly data from the meters. The results from the project have been used in the implementation of a real system for all network customers in Finland.

Business model for small-scale generation

We have looked at the expectations concerning a business model for small-scale electricity generation. One conclusion is that end-customers who invest in small-scale solar power will have a negative business case under the current market situation. The investment cost is high and the market situation is likely to remain static for the next 5–10 years. The time for considerable market growth will be highly dependent on governmental support systems. One result of the study is that we now have a much better understanding of development in this area and of the potential for and limitations of small-scale generation.

Network planning and design

Wind-cooled overhead lines

We have studied the correlation between high electricity generation from off-shore wind power plants and the cooling effects on the overhead lines (OH) from the weather conditions. If the wind speed can be assimilated in dimensioning criteria, we could avoid reinforcement work or the construction of new power lines. The first results show that there is a fairly high correlation, but at some hot spots on the lines the cooling effects may be insufficient. The cooling effects of wind speed in overhead line calculations have not yet been fully utilised.

Active electricity demand

Consumers' electricity consumption varies throughout the day in a pattern specific for each consumer. If a large number of consumers are aggregated, their combined consumption elasticity may be utilised on the market, for instance for load reduction in certain areas. The consumers' own generation may be utilised in a similar manner. By aggregating demand and generation relating to electrical appliances, distributed generation equipment and energy storage systems installed at consumers' premises, it is possible to study, develop and validate solutions to enable active demand. Vattenfall is taking part in this EU project together with, all in all, 25 participants.

Substation technology

New types of distribution transformer

In this project, we have investigated the potential for lowering the losses in the distribution networks within Vattenfall. By using new types of amorphous distribution transformer, the losses can be substantially reduced, resulting in lower costs and reduced CO_2 emissions. Research has found that new types of transformer made from amorphous sheet material can reduce the no-load losses by up to 60–80 % compared to conventional transformers. By replacing existing transformers situated in a grid chosen with expected low-load conditions, we will validate the performance in different situations in a pilot during 2010.

Insulation medium

New environmentally-friendly insulation mediums and techniques in high- and medium-voltage pro ducts were evaluated in 2009. The purpose was to evaluate the possibilities of using alterna tive mediums as insulation material ins tead of conventional oil and SF6* gas. The state of the art in R&D was mapped and possible future appliances identified. The results show that esters can be developed to become a substi tute for PCB oil. Work on using a vacuum as an insulation medium for circuit breakers is in progress in app lications with higher-rated voltages and switching currents. Other innovative solutions that can be used as the main insula tion medium in circuit breakers will appear in the future.

Optimal operation and Asset Management

Asset Strategy Planning (ASP)

To bring Asset Management to a higher level, we have tested and evaluated a software programme called the Asset Strategy Planning Tool in Distribution Sweden by running a pilot project. This tool is used by Distribution Germany and has the ability to simulate the ageing of large infrastructure asset groups, maintenance costs, reinvestment costs and the effect on network indices (customer interruptions, energy not supplied) of choosing different strategies. Strategies may be to reduce or increase the maintenance of different assets, or to replace assets before or at the end of their lifetime. This makes it possible to invest money in the most effective way, in other words with reduced investment costs and an increased service level. One result of the project was that bringing more automation equipment into the grid is the best way of reducing customer interruption. Since the pilot project demonstrated the great potential of the software, Distribution Nordic has decided to implement the tool into its ordinary business.

On-line cable sheath test

Since cables are one of the common components in all of Vattenfall's networks, we have run several projects to study various aspects of cables. One example of this is the online cable sheath testing. Cable sheaths may be damaged due to frost in the ground or bad laying. To discover sheath damage, off-line methods are used, which requires customers to be disconnected. As this is costly, bad for the customers and worsens the network quality indices there is a need for an on-line method. The project has studied this and come up with an innovative on-line method that needs to be evaluated. This method will significantly reduce the costs for the sheath tests and at the same time increase the reliability of the grid.

* SF6 is sulphur hexafluoride and is used as an insulation medium in circuitbreakers in high-voltage networks.

R&D PROGRAMME WIND POWER

R&D supports wind power growth

The Wind R&D Programme is working to develop key tools and competences that support the ongoing rapid growth in wind power generation capacity.

Iced Measurement instruments. Beginning of February at Stor-Rotliden wind farm site.

Vattenfall is currently constructing eight new wind farms in six different countries, which will double our generation from wind power by 2011. The recent award of rights to develop up to 7.2 GW offshore wind power in the UK East Anglia zone (starting year 2015) ensures that the vast expansion will continue.

Objectives

The objective of the Wind R&D Programme is to identify and work to remove technical, financial and environmental obstacles to viable growth in wind power. This is done through long-term strategic R&D aimed at developing key tools and competences. In order to secure business relevance and to anchor results, research goals are defined in close collaboration between Group Strategies and BU Wind.

Due to the multi-faceted range of activities, the programme is organized into five technology platforms, including Wind Resource & Micro-siting, Turbine & Foundation Technology, System Integration & Grid Connection, Energy Storage for Renewables and Acceptance & Governance. Each technology platform has a reference group of experts in different fields to ensure coordination of the R&D efforts and the widespread use of the results. The programme currently supports more than sixty R&D projects.

Icing measurements

One example of a current R&D project is icing measurements. There is increased interest in building wind farms that will operate in extremely cold climate conditions in Northern Sweden. It is important to understand the risk of icing on wind turbines, and how this will impact operation. In the event of severe ice formation, there is a risk that turbines must be halted for extended periods, which could significantly affect annual production.

For this reason, the Wind R&D Programme has initiated multiple projects to better understand where and how often icing occurs. An example is instrumentation with ice sensors in a metering mast situated at Stor-Rotliden, where Vattenfall Windpower is building a wind farm with 40 Vestas wind turbines. ■

SUMMING UP R&D WITHIN WIND POWER 2009

Modelling of local icing potential
Vattenfall is building wind farms in harsh conditions in frosty parts of northern Sweden. To support these investments we are working with a research project to develop a methodology for estimating the local icing potential. Icing may lead to costly periods of wind turbine unavailability and associated loss of production. We are investigating the use of mesoscale weather models to simulate conditions at sites with available icing measurement data in an attempt to find relations between measurements and the corresponding model simulations. The models are based on sound physical reasoning. Once determined, these relations will be further studied and modified for independency of location and period. In order to be able to present climatologically representative local icing characteristics, procedures for long-term corrections will be studied. Icing characteristics at the Vattenfall site Stor-Rotliden will be investigated at a later stage, when icing measurement data at this location is available.

Common SCADA for wind power
Today, Vattenfall operates several different vendor-specific SCADA* systems for the control and monitoring of wind power plants. We are working to integrate the SCADA system into another system, the PI system which is used as a base in our wind power data centre. The PI system is interfaced to these vendor-specific SCADA systems for data exchange. It also performs functions such as the logging and storing of on-line and historical data and operates as the front end for control, reporting, monitoring and alarm handling. By integrating SCADA functionality into the PI system the need for future SCADA systems can be minimized when procuring new wind power plants and therefore also the cost. We will identify and document the functions in the SCADA systems that Vattenfall operates today, as well as the requirements regarding future systems, and suggest how to arrange the functions to better support the operation and maintenance performed today.

Lillgrund power quality and transients
Vattenfall needs to collect and develop the know-how required to perform the electrical design of new wind farms. The focus is on power quality issues during normal operation and faults in the collection grid or upper export transmission grid. An insulation coordination simulation study has been performed at the Lillgrund wind farm and has detected overvoltage conditions during faults in E.ON's 130 kV grid. Based on these unknown design criteria, the insulation levels of the main circuit components were increased and, in addition, surge arresters were installed at each wind generator to mitigate overvoltages. The idea is to simulate the electrical transients as well as the power-quality parameters of the Lillgrund wind farm and to compare the results of the simulations with electrical measurements from the wind farm.

Acceptance of new wind power establishments
Although public acceptance of wind power in general is high, local opposition and conflicting interests can hinder projects from being realised. Knowing what factors influence acceptance will enable the formation of early strategies for a successful and smooth permit process. It has been seen that even a small negative minority may be enough to stop local projects. It is therefore difficult to define when acceptance has been achieved. In order to learn more about acceptance, a project has been initiated to evaluate what acceptance is and to draw experience from case studies of wind power developments of varying characteristics. Understanding how to gain and measure acceptance, taking into account regional and site-specific issues, will help Vattenfall to decide what strategies have to be used for specific wind power development projects.

There are several different methods and ways to define and measure acceptance. In this study, social acceptance at the local level regarding specific projects is considered as most relevant for Vattenfall, since the level of acceptance in society as a whole is generally considered to be high. Local acceptance can be measured through interviews, surveys, opinion polls and also by using economic methodologies of stated preference.

* SCADA – Supervisory Control and Data Aquisition

R&D PROGRAMME ENERGY SYSTEM ANALYSIS

Together all the pieces form the whole picture

Today's society meets ever-increasing demands relating to environmental protection, supporting renewable energy, securing supply, promoting energy efficiency and further liberalizing markets. These challenges will change electricity generation and its use in society, influence technology choices and the functioning of the energy markets, influence price formation on power and CO_2-markets and ultimately affect Vattenfall's business opportunities.

The magnitude of these challenges is hard to measure, but the effect on Vattenfall's bottom line could be profound. The competence to assess and analyze each separate issue could in most cases be found in different parts of the Group. However, the competence available within the business units is being complemented by CESAR (Climate and Energy System and Market Analysis), a common pool of energy-system competence developed at Vattenfall R&D. CESAR works with strategic issues for a system point of view, integrating the aspects of policies, technological development, markets and society to map the overall effect on Vattenfall. In 2009, the CESAR-team performed in-depth analyses of different energy system challenges, for example in relation to the European transmission grid, energy end use and renewables.

One of the main external partners in the R&D area of Energy System Analysis is Chalmers University of Technology in Gothenburg, Sweden. Within the Vattenfall-sponsored Pathways programme, Chalmers has developed an in-depth database of the European

electricity system. With this database and models, the researchers at Chalmers have been able to estimate system costs and the development of the so-called "Bridging measures", the path towards a CO_2-neutral energy system in 2050. Vattenfall has conducted joint research projects with Pathways, for example assessing the consequences of energy-performance standards on future electricity generation. The intention is to further leverage the market and policy knowledge at CESAR with the in-depth energy-system analysis competence at Chalmers. ■

SUMMING UP R&D WITHIN ENERGY SYSTEM ANALYSIS 2009

The road to Copenhagen and beyond
Over the year, we have analysed key issues and their possible impacts on Vattenfall on the road to and after the Copenhagen climate negotiations in December 2009. More specifically, this has meant looking into the effects of larger commitments for the European Union (EU), sector agreements and the linking of trading schemes, with a special focus on the USA and the effects on the EU's energy trading system (ETS) of the different policy proposals that are in the pipeline.

Energy market development
We have worked with several analyses of the development of energy markets and systems in relation to transmission related issues. If the EU attains the target of increasing renewables by 20 per cent by 2020, this will have some effects on the Nordic market. We have analysed the implications for the transmission grid and the generation mix in Europe of the economic effects of capacity limitations in the Nordic market, and of how tariffs could be divided between generators and end-users, to see what the effects may be. We have also looked into forecasted electricity balances in northern Europe and their possible implications and what this will mean to Vattenfall.

EU energy and climate policy
The European Union's climate and energy targets call for a 20 per cent reduction in carbon dioxide emissions, 20 per cent renewables and a 20 per cent increase in energy efficiency by 2020. Based on these climate targets, a climate and energy policy package has been adopted by the European Council. Several of the adopted directives have now entered a commitology process. Much attention has been paid to the development of the EU ETS, where we have analysed auctioning, emission performance standards, benchmarks for free allocation in the heat sector and domestic offsets. The possible impacts of energy efficiency policy proposals and the development in the end-use of energy have been studied. It is of great importance for Vattenfall to have knowledge of how energy and climate policies, and the design of the EU ETS, may influence our operations.

Mapping of carbon dioxide reduction
Some years ago, Vattenfall mapped the global potential for carbon dioxide reduction. The methodology used has now been reshaped and developed into a mapping method that can be used as a tool for reducing carbon dioxide emissions in cities. We will adapt and use the method in a real case in a municipality in Sweden. We have also analysed drivers, policies and measures that could influence Vattenfall's ambitions in the concept Sustainable Cities.

Cooperation with universities
Throughout the year, we have worked in close cooperation with the Pathways project at Chalmers University of Technology. We have jointly analysed the effects of energy performance standards on the European energy system and the effects of attained renewables targets on the European transmission network and generation portfolio. Another interesting area of cooperation is where we coupled the macro economic models developed by Vattenfall with the more detailed energy system models at Pathways. We also cooperate with MIT (Massachusetts Institute of Technology) in the USA on model development and analyses of policy issues.

R&D PROGRAMME HYDRO POWER

Looking 50 years into the future

The hydropower programme focuses on increasing efficiency and safety in the long term. But it also aims to minimise the impact on the environment in some short-term projects.

Since hydropower is a mature technology, the research and development activities within this area do not aim to develop any new technologies. The focus is rather on improving the existing sites and increasing the efficiency of the systems by renewing waterways and improving the machinery, the daily operations and the maintenance procedures. This work mostly results in small changes that allow the existing facilities to generate electricity with fewer disturbances and ensure a long life span.

Another focus area is safety; dam safety is of course most important because of the dramatic consequences in the event of a dam breakage, but also measures to reduce flooding risks and human-machine interfaces are being improved all the time. Considerable work is also devoted to the environmental aspects of hydropower. This work is important to ensure that Vattenfall meets all the ever-increasing demands and requirements from the authorities, but also to strengthen public acceptance and trust.

The chosen direction may sound elementary, but it is harder than it first appears; since major renovations of the facilities are made only once every 50 years it is important to try to foresee hydrological changes due to climate change. On top of this, the R&D programme is trying to combine the research and development activities with activities to secure the future supply of skilled and competent personnel. Lack of competence might be one of the biggest challenges for the hydropower business in the future since many of the most experienced experts are about to retire.

No matter how careful one is, as long as oils are used in this type of system there is a risk it will leak out into the water in the event of an accident. Vattenfall is working towards eliminating all use of oils in the hydraulic systems. In the first phase, the fossil oils will be replaced by more environmentally-friendly oils, in the second phase they will be replaced with water-based hydraulics and, in a third phase, some systems will use a completely alternative technology. This strategy was initiated in 2006. In the summer of 2010, all the tests, experiments and pilot projects will be reviewed and summarized to start a long perspective implementation plan. An interesting year lies ahead of us within hydropower. ■

Suorva water reservoir.

SUMMING UP R&D WITHIN HYDRO POWER 2009

The worlds largest stationary Li-Ion batteries
At the Älvkarleby power plant, in central Sweden, the world's largest stationary lithium-ion battery has been installed, replacing around 20 conventional batteries that had acted as a source of reserve power for the plant's control facility. The new battery takes up less space and is safer than the older ones it replaced, although the technology is more expensive. Several years' of operation are necessary before we can evaluate how to put the battery technology to the most effective use and assess areas for additional application.

Better fish ladders
A new and improved fish passage was built at Stornorrfors in the summer of 2009. The new ladder will improve both the upstream and downstream migration of fish past the power plant. A large development project is currently studying the possibilities to further improve the conditions for fish populations as well as for recreational fishing in the area.

Improved environmental conditions
A research programme aimed at proposing socially- and economically-viable measures for improving environmental conditions for hydro power is currently being conducted by Vattenfall in co-operation with Swedish government agencies for energy, fishing and environmental protection and Elforsk, the Swedish electrical utilities' R&D company.

PhDs improve our efficiency
Several of Vattenfall's employees working in the hydropower field gained a PhD or licentiate degree during 2009. One of the dissertations was about how to generate more electricity in old hydro power plants by using computer calculations instead of expensive real-life experiments. When reinvesting in and maintaining old hydropower plants it has proven difficult and expensive to adjust modern equipment to old power stations. By using calculations instead of expensive experiments in the real power stations, it has been possible to test various technical solutions regarding the adjustment of new equipment. Even small improvements have a large impact on electricity generation.

Midskogs Power Station Indalsalven.

The falls at Älvkarleby, Sweden.

R&D PROGRAMME THERMAL TECHNOLOGY

Introducing flexi-fuel power plants

This programme focuses on improving existing and new conventional combustion plants that use fossil and renewable fuels. The overall objective is to achieve more cost-effective heat and power plants with less environmental impact. One important part of this is to facilitate an increased use of renewable fuels.

Vattenfall has very large assets in its various thermal power plants. The focus of the Thermal Technology Programme (TTP) is to further develop these plants by providing tools and solutions for:

- Cost-efficient use of fuels and optimal fuel blends in Vattenfall plants
- Reduced operation & maintenance costs
- Increased efficiency and availability
- Reduced emissions

TTP supports Vattenfall's strategic goals. For example, reduced CO_2 emissions are achieved by providing solutions for the efficient and increased use of renewable fuels, as well as increased efficiency in fossil fuel-fired power plants. TTP focuses on short- and medium-term R&D and the results should be ready to be implemented within 5–7 years.

One of the main areas within TTP is Renewable Fuels Utilisation, which focuses on fuel flexibility and the increased use of renewable fuels. The plans for 2010 include looking at concepts for the more efficient use of renewable fuels. For example, raising the steam temperature to 600 °C can increase electrical efficiency, but this also places new demands on material and boiler design. Another area is fuel characterisation. During 2010, new and improved methods for key fuel parameters will be implemented at one of Vattenfall's fuel laboratories. This will support the use of new biomass fuels and blends of different fuels. The latter is one of many examples of R&D projects within the Thermal Technology Programme that support co-combustion in Vattenfall plants.

The other main area is Plant and Process Optimization which focuses on operational efficiency for larger plants. This includes condition-based maintenance, combustion & boiler optimization, flue gas cleaning, control strategies, improved efficiency and availability as well as operation and maintenance of the heat distribution systems. An example of a project within this area is a system using a neuron net and advanced cameras that has been developed and implemented in one Vattenfall plant. The result is reduced emissions and improved efficiency. The aim is to find applications for this system in other plants during 2010. ■

SUMMING UP R&D WITHIN THERMAL TECHNOLOGY

Renewable fuel utilisation

Co-combustion

Much of our research and development work focuses on how to use a larger share of biomass in co-combustion applications in a cost-effective manner. We have also started to use co-combustion in hard coal-fired plants and not only in lignite-fired power plants, something that has not been done to a large extent in Vattenfall before. Unit 1 at the Amager power plant in Copenhagen has been extensively refurbished and now has a new 350 MWth suspension-fired boiler with burners capable of firing biomass like straw and wood as well as coal and oil, together with a new fuel handling system. The new boiler was commissioned in 2009. Initially, the plan was that bio pellets would account for 40 per cent of the annual input but the plan now is to instead run almost entirely on biomass.

Existing and future biomass plants

New types of fuel and financial drivers for reaching higher efficiency put new demands on the materials used in boilers. The materials should extend the lifetime of heat exchangers, allow higher steam temperatures and support the realisation of fuel flexibility. Work in the area is focused on trying to quantify corrosion caused by the combustion of waste wood and compare it to other fuel mixtures. This has meant we can suggest more corrosion-resistant and economically-viable material. We have estimated the corrosion resistance of protective coatings on furnace wall panels in laboratory tests and field tests. The right material and measures to limit corrosion are also important when looking at new concepts for future plants where higher steam temperatures and pressure will be applied.

Plant and process optimisation

Optimisation of maintenance and availability

Planning maintenance may be difficult since there are a number of factors that affect the optimal time for doing maintenance. This partly relates to the decision whether to wait with maintenance until electricity and heat prices are low, taking into account that the performance of the component may be reduced due to degradation, also causing financial losses. A method has been developed to optimise the time intervals between maintenance actions. An on-line method and a set of standardized software tools are used to predict the optimal time for maintenance from a financial point of view. The method is based on the present and future condition of specific plant components. The idea is to provide a graphical presentation that shows the predicted performance of different components and the resulting accumulated cost. The graphical interface has an on-line connection to the power plant allowing operating staff to see the actual information about the performance of each component. This also makes it easier to plan maintenance stops. We are demonstrating the methodology at the Wedel plant in Hamburg.

Control of combustion air to improve boiler efficiency

Other types of process optimisation that we are focusing on include the level and distribution of the combustion air. A low level is desired for efficiency reasons. On the other hand, too low a level locally in the boiler may cause problems like a high degree of unburnt fuel, corrosion, slagging and fouling. Low local oxygen levels may be due to an uneven distribution of fuel or to undesired flow conditions within the boiler. Many methods can be used to decrease or compensate for this. One is something called the "self-optimising strategy for control of the combustion process". This is a new control system which has been developed based on more advanced camera information and new algorithms for signal processing and control. The adaptive control strategy uses sensor information like camera information and other process measurements and experiences from the actual control. This in turn generates new control actions to distribute the combustion air in an optimal way. We also use CFD (computational fluid dynamics) to visualise the oxygen, carbon monoxide and temperature distribution at different loads and can optimise plant processes from the model.

Fuel characterisation

Traditional methods for the characterisation of fuels do not describe the actual conditions in modern power plants very well. Therefore, new laboratory instruments are being developed for characterising solid fuels. The benefit for Vattenfall's plants of new fuel characterisation methods is that we can avoid fuels with unwanted properties. We can also gain knowledge about the optimization of operational parameters and fuel mixtures, reduced emissions and support for the introduction of co-combustion.

SELECTION OF REPORTS PRODUCED IN 2009

Below you can find a brief description of work from various R&D programmes from some selected reports. This will give you glimpse of a wide range of research and development issues. All the contacts can be found at Vattenfall.

Hydropower
"Vibration analysis – force and vibration relationship"

During test runs after the upgrading of Forsmo U4 in 2005, the hydropower unit underwent two emergency stops due to excessive vibrations in the shaft train. Measurements of the bearing loads were then made to study the loads on the ra-dial bearing during different operational conditions. The results of the measure-ments show that the bearing loads are relatively small, despite the large amount of axle wobble due to large bearing clearances.

For more information contact Mattias Nässelqvist or Niklas Dahlbäck.

Ocean Energy
"Review of the wave hub of environmental impact assessment"

The goal of this project was to assimilate the knowledge from the EIA (Envi-ron-mental Impact Assessment) process for Wave Hub - a renewable-energy project to create the UK's first offshore facility to demonstrate the operation of arrays of wave-energy generation devices. The study was based on a litera-ture review of the Environmental Statement and relevant material related to the EIA process, such as websites, newspaper articles and letters of consent.

For more information contact Kristin Andersen

Wind Power
Reports from the Lillgrund pilot project

Experience from the building of Lillgrund wind farm, a Swedish pilot proj-ect within off-shore wind power, is summarized in a number of reports. The reports comprise areas like technology, project realization, environmental and permit issues, accep-tance and communication, operation and maintenance and production evaluation.

Find the reports on www.vattenfall.se

E-mobility
"Styrmedel för introduktion av eldrivna fordon och utbyggnad av laddinfrastruktur"

In order to know what measures might be appropriate to promote the market for electric vehicles, it is important to analyze the needs and barriers that characterize the different stages of development. The report describes, based on five different stages of market development, which customer groups and which barriers can be expected and how this may effect the design of a strat-egy for means of control.

Find the report on www.elforsk.se

Energy system analysis

Vattenfall has analysed how external stakeholders as IEA, Greenpeace, Eurelectric and the European Commission view the future development of the European en-ergy system. In all the external views climate change targets will be met, but different ways and solutions to reach the targets are shown. All four views are important as these influence public opinion, planners and policy makers in Europe.

Find the report on www.vattenfall.com

Smart Grids
"Expectations on a business model for small-scale generation"

The market for small-scale generation units is expected to increase. This will put new requirements on the distribution grid and its business model. The focus in the report was to identify what requirements such a business model should fulfil in or-der to benefit both grid owners and customers. Some factors indicate that the market could gain momentum sometime between 2015 and 2020.

For more infor-mation contact Johan Söderbom

Thermal Technology

The NextGenBioWaste project is a four-year integrated project within the EU'd sixth framework programme. The overall objective is to improve the electrical effici→ency, reliability, performance and environmental compli→ance of waste and biomass combustion plants, which produce heat and electricity, and to reduce costs at a competitive level. Several companies within the Vattenfall Group are working together in the project.

Read more about project presentations at www.nextgenbiowaste.com

Nuclear Power
"Strategic and Policy Issues Raised by the Transition from Thermal to fast Nuclear Systems"

The NEA Nuclear Development Committee (NDC) has hosted an expert group car-rying out a study. A team of 17 experts from 11 countries and two interna-tional organizations (IAEA, EU) assessed various scenarios in the deployment of fast re-actors on a large scale as an integral part of the nuclear energy system.

Find the report at the OECD's bookshop: www.oecdbookshop.org

Carbon Capture and Storage (CCS)
Life cycle assessment

Vattenfall has performed a Life Cycle Assessment (LCA) of the total CCS chain – capture, transport and storage. The results show that all CCS technologies achieve a high reduction of greenhouse gas emissions also from a life-cycle perspective. The predominant effects come, as expected, from the increased use of fuel and other resources when introducing CO_2 capture.

For more information contact Magnus Pettersson.

LIST OF OPEN REPORTS PRODUCED 2009

All in all we produced about 250 reports from the R&D Programmes 2009. Most of them are internal reports or reports bounded to secrecy agreements, the open reports are listed in the table below. If you are interested to know more please contact the author, some of the reports are also available via www.elforsk.se.

Programme	Title	Author
Hydropower	Utredning och provtagning av förankringsstag i Hotagens regleringsdamm	Christer Larsson, exarbete
	Non-dispersible underwater concrete and maintaining technologies of erosion damage	Huang Guoxing exjobb (James Yang)
Ocean Energy	Mapping of Universities and Institution	Magnus Andersson
	Evaluation of the potential of different ocean energy technologies	Magnus Andersson
	OEP Components and design	Lovisa Stenberg, Daniel Salomonsson, Jonas Persson, Magnus Andersson
	OEP Analysis of the electric grid of ocean-energy farms	Lovisa Stenberg, Emil Eriksson, Jonas Persson, Daniel Salomonsson – U-NE
Wind power	Lillgrund Windfarm modelling and reactive power control	Isabelle Boulanger Exarbete på UNI
	Platform feasibility	Emil Eriksson, Lovisa Stenberg
E-mobility	Laddning av eldrivna fordon. State-of-the-art 2008	P. Herbert, Vattenfall Research and Development.
	Standardisering av laddningsteknik för eldrivna fordon. Lägesrapport 2009-04-06	P. Herbert, Vattenfall Research and Development.
	Studie avseende dagens och morgondagens elmätnings- & avräkningsinfrastruktur för PHEV/EV-laddning	L. Spante, Vattenfall Reseach and Development & M. Moilanen, Vattenfall Services Nordic
	Styrmedel för introduktion av eldrivna fordon och utbyggnad av laddinfrastruktur	E. Grundfelt, Vattenfall Power Consultant & E. Filipsson, Vattenfall Research and Development
	Kostnadsanalys för utbyggnad av laddsystem samt inledande analys av några affärsmodeller	E. Grundfelt, S Lundberg Fredriksson, Vattenfall Power Consultant
	Standardisering av laddningsteknik för eldrivna fordon. Lägesrapport 2009-12-09	P. Herbert, Vattenfall Research and Development.
	Inspiration till vision om en transportsektor oberoende av fossila bränslen år 2030. En litteraturstudie	E. Grundfelt, S Lundberg Fredriksson, Vattenfall Power Consultant
Energy system analysis	The EU roadmap for Energy End-use	F Pettersson, G Larsson, V Otto
	World Energy Outlook 2008 assessment from a Vattenfall perspective	Gunnar Larsson, Fredrik Petersson, Bo Nelson,
	Renewable energy support schemes – market design of cluster markets	Fredrik Pettersson

Smart grids	Smart metering - next generation	Roberth Hamrén, Robert Thelander
	Market trends and regulations affecting smart metering	Henrik Engdahl, Per Petersson, Robert Thelander
	AMR to measure reactive energy and network losses in low voltage network	Pernilla Owe
	Utvärdering av den aktiva skärmslinga Miloten utanför huset "Ställverket" i Trollhättan	Anette Larsson
	Asset Strategy Planning – Pilot project for Nordic Distribution to evaluate a strategic planning tool	Christoffer Börefelt, Mattias Androls
Thermal technology	Air-borne thermography of district heating networks	Jürgen Helmig, Linn Saarinen
	Mineralogical and environmental assessment of ash-stabilized TASP	Holger Ecke m fl
	Total cost analysis of solid biofuels – creating av preliminary model	Martin Petersen, Monika bBubholz, Nader Padban, Matts Almark, Daniel Nordgren
	Total cost analysis of solid biofuels – summary report phase 1	Martin Petersen, Monika bBubholz, Nader Padban, Matts Almark, Daniel Nordgren
	Biomass losses durin gshort-term storage of bark and recovered wood	Martin Anheller, exjobb
	Improved Coal Mill Control at Nordjyllandsværket – Phase I	Jonas Funkquist , Linn Saarinen, Erik Ramström
	Removal of Technical Constratints	Olle Jidinger
	Status report on renewable fuels within Vattenfall 2009	Monika Bubholz, Martin Petersen, Hauke Beeck, Klaus Friborg, Jan Grundmann, Hans Nordström, Juha Puolakka, Michał Roliński
	SOFCOM final report	Jonas Funkquist, voker Stephan, Power Intelligent Technologies, Erik Schaffernicht, Ilmenau University of Technology
	Corrosion probe testing at Idbäcken simulating superheaters	Annika Stålenheim, Stig-Björn Westberg, Pamela Henderson
	ESP capacity and efficiency improvements	Tetyana Bogdanova, André Handke, Olle Jidinger, Jan Eriksson
	Boiler optimisation performed in Vattenfall biomass and waste fired plants	Raziyeh Khodayari, Matts Almark
	Using CFD simulations to reduce deposit build-up at Amager 1 – full report	Karin Eriksson, Jan Eriksson
	SCR in Lignite-fired Power plants	Raziyeh Khodayari
	Using CFD simulations to reduce deposit build-up at Amager 1-short report	Karin Eriksson, Jan Eriksson
	Reduction of fuel side costs due to co-combustion	Andrea Wils (exjobb)
Nuclear power	Stratification issues in the primary system. Review of available validation experiments and State-of-the-Art in modelling capabilities	Johan Westin m fl
	Prerequisites for a future implementation of a closed nuclear fuel cycle in Sweden	Cheuk Wah Lau
	Strategic and policy issues raised by the transition from thermal to fast Nuclear systems- OECD/NEA,	
	Miljöeffekter av stora kylvattenutsläpp	
	Provning av borrkärnor från Forsmark	Manouchehr Hassanzadeh
CCS	Postcombustion Dynamics, Phase 1	Richard Faber, Benjamin Faulhaber
New technologies	Electricity from waste heat - PCM engine	Linn Saarinen
	Evaluation of Powerbox	Andreas Lennartsson, Gerth Karlsson