

# Germany

## GOVERNMENTAL PROGRAMS AND STRATEGIES

### General policy and overall situation

#### Energy and Climate

At the heart of Germany's energy policies, just as in many other European countries, is the need to create a frame for the development of a future energy sector that will meet the emerging challenges of energy security, competitiveness and climate change.

Germany, being Europe's largest emitter of greenhouse gas (GHGs) emissions<sup>108</sup> is meeting its Kyoto target within the overall European target of 8% and committed itself under the Burden Sharing Agreement to cut CO<sub>2</sub> emissions by 21% in the period 2008-2012 on the basis of 1990 levels. Germany's self imposed mid term goal is however even more ambitious, to cut CO<sub>2</sub> emissions by up to 40% of their 1990 level by 2020 whilst simultaneously phase out nuclear energy by 2022.

Just as for Europe, there is a tremendous need for re-investments in generation capacity over the next two decades. Determined by the lifecycle structure of the existing power generation system in Germany and including the projection of nuclear phase -out over the next 15 - 16 years, power stations with a capacity of around 40 GW will have to be replaced in the next 15 to 20 years in order to meet the conservatively estimated future demand of about 550 TWh per year in 2020<sup>109</sup>. Since these new power stations will then operate for a full life cycle of approximately 40 years, the investment decisions made in the next few years will strongly influence the structure of electricity generation, as well as the future GHGs path of Germany.

In Germany this poses a further challenge, since the overall capacity is characterised by the special dominance of coal and lignite. Hard coal and lignite together represented almost 50% of the fuel basis for the gross electricity production in 2007. Gas accounted for 12 %, nuclear 22%, 14% came from renewable energy sources, with the dominant renewable energy source being wind. Whilst the expansion of gas fuelled power generation is currently questionable due to high gas prices, import dependencies and supply insecurities, coal and lignite are likely to play a major role in the future energy mix of Germany, since they offer a cost effective source of secure energy due to indigenous resources and large worldwide reserves. Of the 53 power plants currently under construction or in detailed planning in Germany (with a combined capacity of 31,400 MW) due to start up in the period 2006 -2020, 27 plants are coal based technology (hard-coal or lignite). Clearly, the extensive use of coal stands in contrast to Germany's ambitious climate targets and if lignite and coal burning power stations are to have a future over the medium to long term, given the tightening of reduction targets, it will be necessary to develop power stations with high efficiencies and CCS technologies.

#### Political Framework

The political framework for the development of CCS in Germany is embedded in European energy and climate policies and since EU leaders committed in March 2007 to their "20 20" target, implying a cut in GHGs emissions by at least 20% by 2020 while increasing the use of renewables by 20% during the same period, and increasing efficiency by 20%, considerable political efforts have been and are being undertaken to construct a framework for the development of an energy sector that will meet the challenge of fulfilling environmental, competitiveness and security of supply criteria.

In 2007 CCS entered the European Commission's portfolio of climate mitigation options as part of the Energy and Climate Strategy, announced January 2007, which suggested introducing CCS as a mandatory prerequisite for new built fossil fuelled power stations from 2020. To pave the way for CCS, the EU Council further announced the development of up to 12 CCS demonstration projects across Europe and during the G8 summit in June 2007, the heads of states agreed to develop concepts for research, development and the deployment of CCS technologies as well as international cooperation and know-how transfer of the technology.

On January 23<sup>rd</sup> 2008, the Commission further proposed a Directive to enable CCS technologies in the EU as part of a major legislative package of measures to achieve the EU's ambitious climate targets. A legal framework and economic incentives for CCS as well as a network of demonstration plants are at the heart of the CCS framework directive. In October 2008, the European Parliament's Environment Committee voted in favor for the amendments proposed in the Davies report, which creates a concrete legal framework for CCS. Among others, the Committee

<sup>108</sup> with 994 million tones of CO<sub>2</sub> equivalent in 2005

<sup>109</sup> These estimates represent a conservative compromise between more extensive growth rates and energy savings potential through widespread use of efficiency gains (EWI/Prognos).

voted in favor of Emissions Performance Standard legislation which limits emissions for all new coal plants built in the EU after 2015. The limit of annual CO<sub>2</sub> emissions to a maximum of 500 g/kWh essentially rules out traditional coal plant technologies and mandates the use of CCS. The Committee also adopted an amendment to support the financing of 12 large-scale commercial CCS demonstration projects, at a cost that could exceed €10 billion. The climate package and its amendments are currently negotiated with the European Council and there is a considerable political will to pass the European climate package in the current legislative period, possibly by the end of 2008.

The German government is implementing these fundamental European policy decisions at a national level by means of the German energy and climate protection package, which was decided in Meseberg in August 2007, called the *Integrated Energy and Climate Programme*. The approach taken to the implementation of the energy and climate programme will ensure that Germany's climate targets are achieved in a continuous process by 2020 and the requisite measures are organised cost effectively. Proving the feasibility of CCS is one important pillar of the climate package.

Although some scepticism remains, CCS could become increasingly a key component of a national "Clean Fossil Fuel Strategy" and the German Government has decided to take on a "No regret" policy regarding CCS. To prove the feasibility of CCS, increased R&D efforts have been funded and initiated in 2007 and the construction of at least two or three of the 12 demonstration CCS power station that are to be built across Europe are envisaged, as well as further storage projects. Taking into consideration the results of relevant R&D projects, the German Government has in this context stated that it would consider proposals for a "capture ready" standard for future fossil fuel power plants.

## Challenges

One important prerequisite for the deployment of CCS in Germany is the availability of storage capacities. Among the different options available for geological storage of CO<sub>2</sub> in Germany, deep saline aquifers currently provide most of the storage potential. Other storage possibilities such as depleted gas fields and the storage in deep unminable coal seams, e.g. in the Ruhr district, are available but seem currently less attractive in Germany. Therefore current estimates of the BGR<sup>110</sup> (Bundesanstalt für Geowissenschaften und Rohstoffe) aggregate to a storage potential of approximately 20 ± 8 Gt for saline aquifers alone, of which one quarter is located in the northern parts of Germany, providing storage capacities for emissions for about 50 – 80 years. However, because estimates of storage capacity of saline aquifers are subject to preconditions and assumptions regarding the structural conditions, considerable uncertainty exist in this regard. Currently, efforts are being undertaken to improve the estimates of the storage capacity in Germany, however because of the North South divide of sources and sinks, onshore storage remains a complex issue for Germany.

The development of CCS demonstration plants furthermore postulates the development of a suitable legal framework for CCS in Germany. Currently, the mining and environmental law provide a basis for the conduct of CCS research projects. In 2008 the German government announced that it intends to be the first country with a national legal framework for the deployment of CCS and is currently developing a suitable legal framework for underground storage on an industrial scale (including the planned demonstration power stations), transport and capture in parallel to and on the basis of the European legal framework. German national legislation is therefore expected in 2009. It is furthermore intended to include a provision in the Federal Regional Planning Act that will secure significant locations for storage of CO<sub>2</sub> across Germany. Nevertheless, Germany is a federal republic of sixteen states with its own constitutions and political systems, providing the potential for conflicts associated with regionalisation and possibly "eco dumping". First signs are already being observed with storage pilots in Saxony Anhalt and Schleswig Holstein. Also the construction of so called climate pipelines that run through several different states might provide challenges as governments from different states are part of the negotiation process.

The great unknown in Germany however remains how an electorate with a negative view of nuclear waste storage will respond to the concept of CO<sub>2</sub> storage. Public acceptance will be decisive for the implementation of CCS in Germany. A recently published study undertaken by the Wuppertal Institute<sup>111</sup>, which covers social and acceptability issues and analyses the potentials of public risk-perception as well as the perception of CCS, finds that currently CCS is not broadly discussed in Germany and that the NIMBY Effect (not in my back yard) is likely to trigger a strong reaction, particularly regarding storage in Germany, once projects are getting started.

Further acceptance problems result from a strong movement against coal which is growing in Germany. Public concern not only results from the negative climate impact associated with coal, but also from land degradation and loss of local communities resulting from lignite exploration in Germany. Public protest has inhibited several coal projects, including Ensdorf, Ingelheim, Lubmin, Dörpen, Kiel and Moorburg and projects such as the IGCC CCS in Hürth meet first negative reactions from local action groups. CCS could be seen as just another possibility for power generation companies to pursue their coal strategies. Therefore, NGOs are likely to play an important role in the public discussion. However, just as in the rest of Europe, "green groups" split over CCS. Whilst CCS is seen by some environmental groups as just another end of pipe solution ("False Hope" study by Greenpeace) with the aim to continue to invest in coal on the expenses of climate targets, others such as the WWF Deutschland, German Watch and others see CCS as a possible bridging technology that paves the way for a decarbonised energy sector.

---

<sup>110</sup> [www.bgr.bund.de](http://www.bgr.bund.de)

<sup>111</sup> Socio Economic Research on Acceptance of Carbon Capture and Storage at national and international level. Wuppertal Institut (2008)

Raising public awareness and providing sufficient information will be vital in the coming years if CCS is to be implemented in Germany.

## Private sector engagement

There is generally agreement between the political and business communities that climate protection is a central element of environmental policy and an integral part of economic and energy policy. German businesses have a self imposed objective of making a special effort, on a voluntary basis to reduce specific CO<sub>2</sub> emissions by 35% by 2012. Additionally, major players in the energy sector are signing up to the 3C – Combat Climate Change – initiative of business leaders with the commitment to draw a road map to a low emitting society and develop carbon strategies, such as Vattenfall that has the aim to reduce emissions by 50% by 2030.

German electricity producers are examining the potential of low emission power stations in the view of these commitments and due to their obligation to reduce emissions under the EU-ETS and the associated changes in the energy sector.

Especially for companies like RWE, which are heavily invested in lignite and coal fired power plants (65% in 2006), CCS could prove a viable technology under stricter climate regulation in the long-term. In the short term however utilities are asset heavy with the lion share of valuation vested in assets in the ground, making them particularly vulnerable to risk, whilst deciding on long-lived investments that exceed the current climate policy planning. Current techno – economic prerequisites, including the rise in cost of power plant construction due to high demand and rising commodity prices, render therefore the operation of CCS power plants not profitable. Clearly, CCS technologies will only be realised with the perception of long –term high price expectations, both of electricity and carbon prices and if the EU regulatory framework provides the appropriate incentives and security for these investments. The probably most challenging aspect in this context will be the high degree of uncertainty regarding future political development, also beyond 2012, for companies that are facing upcoming investment decisions. Not surprisingly several power plant projects have been put on hold until a concrete framework regarding CCS is in place in Germany and the EU.

The sentiment between German industry and government is therefore mixed. A clear governmental commitment regarding the legal framework for CCS might not only yield a more favourable investment environment but also could increase public acceptance in Germany, which today provides another decisive investment risk for power companies.

Unfavourable economics or not, seizing opportunities and pursuing innovative technologies have benefits in terms of reputation and shareholder value. CCS clearly provides a valuable opportunity for Germany's large power generators that are currently in an image crisis, to improve their reputation and three of the large power companies are embracing CCS with several pilot and demonstration projects having been announced. RWE furthermore opened an "Innovation Centre Coal" at its power plant Niederaussem and called for reliable climate policies after 2012 to ensure that power plant investments in Europe guarantee security of supply in future. In the face of the ongoing negotiations in Brussels regarding the European climate and energy package and the upcoming election of the German government in 2009, companies involved in the development of CCS projects such as Alstom Germany, Babcock Borsig, EnBW, E.ON, RWE and Vattenfall Europe furthermore produced a draft for a national CCS legislation in order to accelerate the pace of the development of a national legal framework for CCS in Germany.

R&D activities from utilities, technology companies and trading companies in Germany are not solely orientated for the European market. Power plants "made in Germany" stand for highest standards and are an internationally demanded product. Germany is the second largest exporter in the power generation plant sector. CCS technologies might become an interesting export commodity especially when considering emerging markets such as China as a possible, coal dependent trading partner. In September 2005 Chinese-European collaboration was initiated for the development of clean coal technologies. Until 2020 low emission power plants are planned in China, whereby technologies will be provided by European power plant builders.

## Public CCS funding initiatives and partnerships

R&D is the key to establish a reliable, economic and environmentally compatible energy supply. German R&D efforts in energy research are governed by the 5<sup>th</sup> energy research program "*Innovation and New Technologies*" and its amendment the "*High Tech Strategy*". Main topics include energy efficiency, renewable energies, fuel cells and hydrogen and fossil fuel power plants and CCS.

Increased national interest in CCS as a possible technology to mitigate climate change, and the ambition to demonstrate the technology in Germany, postulates an increased level of activity in research and development in this area. Currently, the BMWi and the BMBF are working in cooperation with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) on a detailed roadmap for CO<sub>2</sub> capture (BMWi/BMU) and storage (BMBF/BMU) as part of the development of an *Integrated Energy and Climate Programme* for Germany. A total sum of € 2.6 billion is available for climate policy under the federal budget for the 2008 financial year, which represents an increase of about € 1.8 billion or 200% to 2005. In April 2008, the German government announced that it would increase the funding for energy related research by €50 million compared to 2007, which translates into a total funding of € 328 million. Consequently, CCS research and development activities can expect increased funds in the coming years.

Regarding CCS, the majority of public funding to fundamental research and demonstration projects originates from two Ministries, the Federal Ministry of Economics and Technology<sup>112</sup> BMWi and the Federal Ministry for Education and Research<sup>113</sup> BMBF.

## Geotechnologien

Since 2005, the BMBF supports as part of its geo-scientific research and development program *GEOTECHNOLOGIEN* research projects on CO<sub>2</sub> storage. CO<sub>2</sub> storage in geological formations is investigated within the research theme "Investigation, Use and Protection of the Underground". The projects are undertaken in the form of collaborations from Universities and industry and in the first phase (2005-2008) nine interdisciplinary projects with the focus on technological, ecological and economic perspectives concerning CO<sub>2</sub> storage and monitoring in geological formations were funded with a financial volume of € 6.9 million. 12 Universities as well as 13 companies of the German energy sector were involved.

To quantify the CO<sub>2</sub> storage potential for Germany further, a second funding phase (2008-2011) for the national R&D programme "*Geological Storage of CO<sub>2</sub> in Germany*" was in 2007. The financial volume is € 19.6 million per year and 17 research institutions and 11 companies are involved. The main objectives are the extension of basic research on storage and surveillance technologies, complementary to the pilot projects. Basic R&D activities without site specification will be supported from 2008 with a budget of €8 million per year. Research fields include, monitoring and modelling tools, trapping mechanisms, CO<sub>2</sub> mobility, stability and integrity of reservoir and injection wells. Site specific pilot projects as public private partnerships will be funded with € 9 million per year, starting from 2008. Activities include, the "Altmark Gasfield" as a large scale demonstration site in Northern Germany, as well as the development of other pilot projects to prove saline aquifers for CO<sub>2</sub> storage.

## COORETEC

The BMWi is supporting the development of capture technologies with the research and development concept *COORETEC*, which aims to reduce the emissions of fossil fired power plants to near zero. *COORETEC* (CO<sub>2</sub> Reduction Technologies for Fossil Fuelled Power Plants) was initiated in 2002 due to the high demand for new investments in power plants in Germany. The concept rests on the two pillars of efficiency increase and avoidance of CO<sub>2</sub> emissions and intends to create the basis for satisfying at the highest possible technical level standards for new and replacement plants in the power generation sector foreseeable after the year 2010. In 2007 COORETEC launched additionally the "Lighthouse Concept". The technological objectives of the lighthouse concept are to sink costs involved in CO<sub>2</sub> capture and storage from current rates of € 50 -70 per tonne of CO<sub>2</sub> to below €20 in the future, while simultaneously reducing efficiency losses from 9 -13 percentage points today to 6 - 11 percentage points in the future. Consequently, five technology related working groups have been created in the covering natural gas combined cycle, steam cycle power plants, IGCC with carbon capture, Oxyfuel and storage. The research projects are in general collaborative projects between research institutions and industry. The level of funding varies with the projects, and whilst industry can receive coverage of up to 50 % of their costs, academia will be funded with 100 %. In 2007, CCS research projects on capture technologies were funded with approximately € 26 million, 2008 approximately € 30 million and a funding of € 35 million annually is envisaged for 2010.

## RWE's Coal Innovation Centre

Apart from the large German research programmes, there have been smaller, regional initiatives in Germany such as RWE's "Coal Innovation Centre" in Niederaussem. The aim is to perceptibly lower CO<sub>2</sub> emissions in coal based power generation. The intention is to invest some €90 million in the coming years in research and development for CO<sub>2</sub> reduction and conversion technologies. Besides specific projects that practically go straight from the lab to the workbench, the "Coal Innovation Centre" is designed to give international experts a platform for exchanging ideas. Starting in spring 2009 and in collaboration with the RWTH Aachen Technical University, the Juelich Research Centre and the TÜV Rheinland technical inspection agency, practice-related symposia will be held both with international experts and with students from the region. Four major projects are already up and running, such as a prototype plant, to test pre-drying lignite using the fluidised-bed method, which has the potential to increase efficiency rates in power generation using lignite by 10% to over 47%. In a joint project with BASF, Linde and RWE Power, a pilot plant for CO<sub>2</sub> scrubbing is also being constructed at Niederaussem as well as a pilot algae plant.

## International Fora

Germany has a great interest in international exchange of know-how regarding CCS. Within the EU, Germany is supporting R&D activities within the framework programs, the ZEP (Zero Emission Fossil Fuel Power Plants Technology Platform) and the ERA-NETs such as FENCO. Internationally, Germany, i.e. the BMWi became member of the Carbon Sequestration Leadership Forum (CSLF) in 2003 and has since then played an active role in the CSLF task forces and projects and is participating actively in the programs of the IEA working party fossil fuel and the IEA implementing agreements, the IEACCC and IEAGHG program.

<sup>112</sup> [www.bmwi.de/English/Navigation/root.html](http://www.bmwi.de/English/Navigation/root.html)

<sup>113</sup> [www.bmbf.de/en/index.php](http://www.bmbf.de/en/index.php)

## Current CCS projects In Germany

Although Germany has been approaching CCS cautiously at first, both R&D and pilot projects are increasingly catching up and several demonstration projects have been officially announced and are in the concrete planning process. Overall, the power sector in Germany is at a turning point and power plant operators are today already required to design their new power plants in such a way that later retrofit with a suitable CCS system is possible. Due to the growing public resentment against new coal fired power plants, several coal power plant projects in planning have announced to implement CCS as soon as the technology is available, which in some cases has been part of the concession process, such as in the case of Vattenfall's coal power plant Moorburg in Hamburg.

In order to provide proof to the public and to official bodies that the planning or erection of a new power plant has been carried out in such a way that it is possible to retrofit a carbon capture system at a later date, the German TÜV NORD, Germany's independent inspection organisation, has developed a capture ready certification and a binding catalogue of requirements for carbon capture readiness. The criteria were developed taking the current state of knowledge into consideration, and collated in the TÜV NORD Climate Change Standard TN-CC 006. The Standard TN-CC 006 contains requirements in particular regarding the technological and site-specific feasibility of retrofitting a CC system at the power plant location, the availability of the space which will be needed for the system, the possibility of transporting CO<sub>2</sub> away from the site and of CO<sub>2</sub> storage and also the possible effects on plant safety and the environment. The two first Carbon Capture Readiness Certificates have been awarded to E.ON's new coal power plants in Wilhelmshaven and Antwerp.

### Vattenfall's Oxyfuel Pilot Plant "Schwarze Pumpe"<sup>114</sup>



Figure 7: Source: Vattenfall

Vattenfall initiated the project in 2001 with a long term research and development project to develop the oxyfuel technology to a commercial application level. By May 2006 Vattenfall could start with the construction of the 30 MW (thermal) lignite oxyfuel pilot plant near its existing 1,600 MW lignite – fired power plant in the industry park "Schwarze Pumpe" near Spremberg in Brandenburg south of Berlin. The investment costs were initially estimated at € 60 million, however according to Vattennfall construction amounted to € 90 million and further € 30 million are being invested in research activities during the project. On 9 September 2008, Vattenfall officially inaugurated the plant and some 45 t CO<sub>2</sub> have successfully been separated during the first weeks of operation.

The plant is expected to be in operation for 3 years and will produce about 60,000 ton of CO<sub>2</sub> per year at full load, approximately 0.6% of the volume of the larger Schwarze Pumpe power plant (10 million ton CO<sub>2</sub> annually), currently at a cost of € 80 – 90 per tonne. From 2009, the separated and liquefied CO<sub>2</sub> produced by the pilot plant will be transferred by truck to the 350 km distant gas field in Altmark.

Linde AG provided the cryogenic air separation and air processing unit and the boiler has been developed in cooperation with Alstom. Other components, such as a new web based I&C system SPPA-T3000 and connections to the airs separation unit, the CO<sub>2</sub> liquefaction facility and the main power plant as well as the field instrumentation was provided by Siemens. The pilot plant is supported by research undertaken at the University of Cottbus (CEBra project with a 0.5 MW test facility) and the University of Dresden (ADECOS project with a 0.5 MW test facility). In September 2008 Linde Group and Vattenfall Europe Technology Research GmbH have further

<sup>114</sup> [http://www.vattenfall.com/www/vf\\_com/vf\\_com/365787ourxc/366203opera/366779resea/366811co2-f/index.jsp?WT.ac=advertise](http://www.vattenfall.com/www/vf_com/vf_com/365787ourxc/366203opera/366779resea/366811co2-f/index.jsp?WT.ac=advertise)

entered into a wide ranging technology partnership with the aim of collaborating on the testing of oxyfuel combustion processes. Linde is supporting Vattenfall with scientific and technical expertise during the first trial phase unit 2011.

The insights gained during the pilot phase will be utilised to plan a large demonstration power plant with a 250 to 300 MW electrical capacity, around 2012-2015. Then, efficiency and economic aspects will be further investigated and finally the plan is to set up a commercial power plant with the capacity of approximately 1000 MW, around 2015-2020. Progress can be monitored online<sup>115</sup>.

## Vattenfall Oxyfuel and Post combustion Demonstration Plant in Jämschwalde

In Mai 2008, Vattenfall announced its plans to build a demonstration plant for CCS technologies at one of the 500 MW blocks of the conventional lignite power plant Jämschwalde in the State of Brandenburg, Germany. The investment for the demonstration is estimated to be € 1 billion. The Jämschwalde lignite power plant consists of six 500 MW blocks. For the demonstration plant one of the blocks, consisting of two boilers, will be equipped with carbon separation technologies. One boiler will be newly built with an oxy-fuel technology; the other will be retrofitted with a post-combustion technology.

Whilst the oxyfuel technology used in the boiler is identical to the one used in the pilot plant "Schwarze Pumpe", the post combustion technology will be based on a chilled ammonia process.

To compensate the loss of efficiency of approximately ten percent in the generation process, incurred by the installation of additional components, Vattenfall is developing methods for increasing efficiency by using higher temperatures and pre drying of lignite as well as operational excellence. The demonstration plant will produce 300 MW.

Vattenfall has furthermore announced its cooperation with Gaz de France Production and Exploration GmbH for storing the captured CO<sub>2</sub> from Schwarze Pumpe and Jämschwalde in the gas field in the Altmark. Initially the separated and liquefied CO<sub>2</sub> produced will be transported by truck, however, once the processes are working in a larger scale, Vattenfall is exploring the possibilities for transport by pipeline as well.

The project has a very ambitious time schedule. In February 2008, a feasibility study was undertaken. Permits are expected to be issued 2009, ground breaking is scheduled 2010/2011 and the start of operation is planned 2015.

For both projects of Vattenfall uncertainties however exist regarding the storage of the separated CO<sub>2</sub>. Not only is the national legal framework not expected to be in place before 2009, and hence permission procedures are stalling, but in Saxony Anhalt resistance is emerging on a regional political level. The government of Saxony Anhalt is currently considering whether it will import CO<sub>2</sub> from other Bundesländer or instead binds the storage permission to a new power plant project, located in Saxony Anhalt.

## RWE IGCC Plant with CO<sub>2</sub> Storage<sup>116</sup>

As early as April 2006 RWE announced its plans for the development of a CCS demonstration plant in Germany. As announced in 2008, RWE is planning to construct an IGCC lignite fuelled power plant at the Goldenbergwerk location in Hürth, nearby Cologne in North Rhine Westphalia.

Since the location is well connected to open cast mines, raw lignite will be the fuel of this power plant. To reduce the water content pre drying will be applied to bring down the moisture content to 12%. The power plant is expected to have a gross output of 450 MW, with an efficiency of 36% and integrate CO<sub>2</sub> capture. Capture rates are expected to be about 92% or 100g/Kwh<sub>net</sub>. If successfully implemented, the plant will be scaled up to produce 1000 MW.

RWE is planning to operate the plant by 2014 and was initially planning to invest some € 1 billion in this project. Today, the costs of the project have risen to € 2 billion. By choosing an IGCC technology, RWE is building up on its experience with this technology from the early 1990s. In order to cater for CO<sub>2</sub> sequestration, processing is adjusted.

The power plant development will be accompanied by the development of a storage project. RWE plans to store some 2.6 millions ton of CO<sub>2</sub> annually, amounting to a total of 104 Mt and is currently investigating different locations in the North of Germany for adequate storage capacities. Currently three different regions in Northern Germany are under investigation, which are Nordfriesland, Ostholstein and offshore storage outside the 12 mile zone of Northern Germany. In March 2008, RWE started the exploration phase with site screening, consisting of regional and feasibility studies of the reservoirs. If permission is granted, seismic studies will be undertaken in 2009.

The storage project which is coordinated by RWE Dea, is accompanied by the research project COAST, which provides the accompanying R&D for clarification and assuring of standards and methods for commercial scale CO<sub>2</sub> storage in deep saline aquifers.

<sup>115</sup> [www.vattenfall.de/co2frei](http://www.vattenfall.de/co2frei)

<sup>116</sup> [www.rwe.com/generator.aspx/konzern/fue/strom/co2-freies-kraftwerk/co2sink/language=en/id=272116/page-co2sink.html](http://www.rwe.com/generator.aspx/konzern/fue/strom/co2-freies-kraftwerk/co2sink/language=en/id=272116/page-co2sink.html)

To connect source and sink, RWE is planning to build a pipeline of about 530 km from North Rheine Westphalia to Schleswig Holstein. Currently this project is in the regional planning procedure. According to RWE end of 2009 will be an important milestone for the IGCC CCS demonstration project until which decisive internal and external project fundamentals will have to be established. However, just as Vattenfall, RWE is facing problems regarding storage sites in Schleswig Holstein and receiving the required permissions might prove to be difficult.

## RWE's Scrubbing Pilot Plant in Cooperation with BASF and Linde<sup>117</sup>



**Figure 8:** Source: RWE

In addition to the IGCC CCS demonstration plant, RWE also agreed on a cooperation with BASF and Linde Group, for the development of a CO<sub>2</sub> scrubbing pilot plant at the power plant Niederaussem. The project entails the construction and operation of a pilot plant, with operation due to commence in 2009 until 2010. The aim of the project is to reduce efficiency losses and costs associated with post combustion technologies to €30/t of CO<sub>2</sub> through energy optimised Amine scrubbing solvents supplied by BASF, and improvements in the process and plant technology. The project, including pilot and following demonstration plant, has a budget of € 90 million and is supported by the COORETEC programme.

Linde is responsible for engineering and the construction of the pilot plant and will be constructing the pilot at the 1,000-MW lignite-fired unit BoA 1. BoA 1 is with a net efficiency of over 43% the most advanced and efficient lignite-fired unit worldwide. It is equipped with optimized plant technology and is the forerunner to the two power plant units BoA 2&3 being built at the Neurath site. In Niederaussem, the carbon capture technology to be developed can thus be adapted to this type of power plant in an ideal manner.

An extensive investigation programme conducted under real operating conditions to test the new CO<sub>2</sub> solvents developed by BASF will be completed in early 2010. The height of the pilot CO<sub>2</sub> scrubbing plant (40 m) corresponds to that of the future commercial plant. The plant also comprises all individual components of large plants, but on a smaller scale. The diameter of the absorber column was limited to the size required to obtain representative results. Depending on the set test parameters, up to 300 kg CO<sub>2</sub> per hour can be separated from a flue gas bypass (corresponds to a capture rate of 90 %).

Provided that the pilot phase is completed successfully, it is planned to have a demonstration phase immediately afterwards, during which a demonstration plant is to be built. Current plans involve a 30 to 40 MW plant with capture and storage.

The project will be linked to other pilot projects undertaken at the site such as the WTA process developed by RWE in order to compensate for the efficiency losses associated with capture. The goal is to make carbon capture technology utilizable for the retrofit of existing modern plants or new power plants by 2015.

## E.ON's Post Combustion – Wilhelmshaven and Heyden

Although E.ON has been approaching CCS technologies carefully, E.ON is now planning seven smaller pilot plants, all of which are aiming to optimize post combustion methods for capturing CO<sub>2</sub>. E.ON plans to pursue the development of post combustion technologies with a budget of € 100 million until 2014. Three of the projects are planned in Germany in cooperation with Siemens, Flur, Consolv and Mitsubishi.

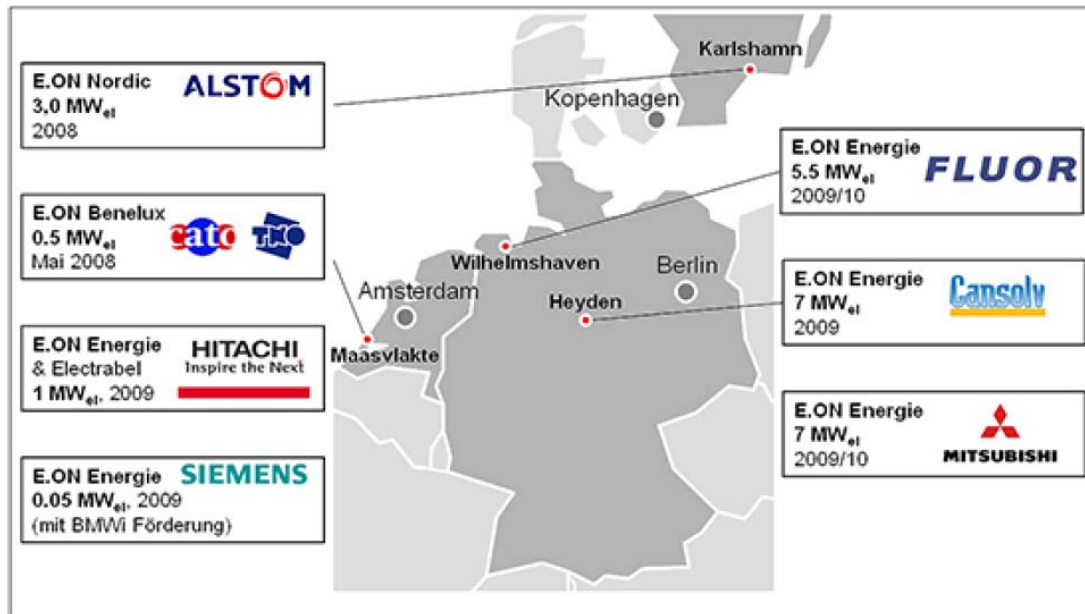
One of the projects is located at E.ON's coal fired power plant in Wilhelmshaven and is scheduled to start operation in 2010. Flor and E.ON Energy have formed a strategic partnership for the development of a retrofitted pilot plant

<sup>117</sup> [www.rwe.com/generator.aspx/konzern/fue/strom/co2-freies-kraftwerk/co2-waesche/language=en/id=272122/page-co2-waesche.html](http://www.rwe.com/generator.aspx/konzern/fue/strom/co2-freies-kraftwerk/co2-waesche/language=en/id=272122/page-co2-waesche.html)

using Flour's Econamine FG+ technology. The technology uses monoethanolamine as the solvent for efficient capture of CO<sub>2</sub>. The pilot plant will be small in scale with only 5.5 MW.

In North Rhine Westphalia E.ON Energy will work together with Canadian Cansolv Technologies at its location in Heyden. The objective of this project is again to improve efficiency of post combustion by testing different solvents. The pilot plant which is expected to commence its operation in 2009 is planned to produce 7 MW.

Other projects are in the planning with Siemens and Mitsubishi.



Quelle: E.ON

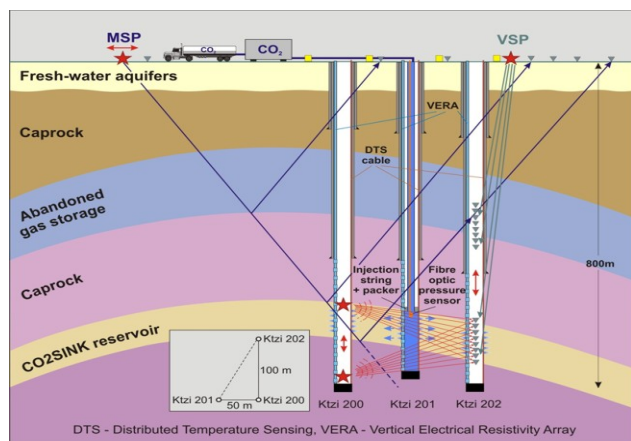
## CO<sub>2</sub> SINK<sup>118</sup>

The CO<sub>2</sub>SINK integrated project, which is the first European Showcase for Onshore CO<sub>2</sub> storage, is supported under the FP6 framework by the EU commission with a budget of € 14 million. 18 institutions from 9 European countries are involved. The project started in April 2004 and aims to develop the basis for onshore storage techniques by injecting CO<sub>2</sub> into a saline aquifer near the town of Ketzin, west of Berlin. The project's aim is to demonstrate long-term geological storage of CO<sub>2</sub> in a saline aquifer. The project will develop an *in situ* laboratory for CO<sub>2</sub> storage to fill the gap between the numerous conceptual engineering and scientific studies on geological storage and a fully-fledged onshore demonstration. To characterize the underground and understand the processes that happen there, detailed analysis will be made of samples of rocks, fluids and micro-organisms from the underground. The project involves intensive monitoring of the injected CO<sub>2</sub> using a broad range of geophysical and geo-chemical techniques, the development and benchmarking of numerical models, and the definition of risk-assessment strategies.

The test storage system is a sandstone reservoir at depths below 600 meters. This will facilitate geophysical monitoring, since part of the CO<sub>2</sub> will be in a gaseous state. Within a two year period, 60.000 t of highly pure (> 99%) CO<sub>2</sub> is being injected to depth of 700m. Linde AG supplies the necessary CO<sub>2</sub>.

Whilst the first phase of the project was mainly occupied with attaining the necessary approval for injections, drilling started February 2007 and an injection well and two observation wells have been lowered to depth of 800m. Injections of CO<sub>2</sub> started in June 2008 and some 420 ton have been successfully injected since then. First results, concerning the feasibility of CO<sub>2</sub> storage in saline aquifers are expected no later than 2009.

<sup>118</sup> [www.co2sink.org](http://www.co2sink.org)



**Figure 9:** Source: CO2 Sink

Being close to a metropolitan area, the site provides a good opportunity to raise public awareness and accelerate acceptance. The site is therefore equipped with an information centre which is open to the public.

## Enhanced Gas Recovery in the Altmark gas field

From 2008, the Erdgas Erdöl GmbH, Gaz de France's wholly owned exploration and production affiliate, will be in cooperation with Vattenfall explore the possibilities of Enhanced Gas Recovery (EGR) in the nearly exhausted gas field in the Altmark.

The Altmark gas field has a long tradition of exploitation, which started in 1969 and became Europe's second largest onshore gas field with a yield of over 9 billion m<sup>3</sup> of natural gas. In 1994, Gaz de France bought the gas reservoir of the size of about 1000 km and in 2007 Gaz de France announced its plans to engage in a CO<sub>2</sub> storage project.

With a storage potential of 508 MMt, the reservoir currently has the largest storage volume available in depleted gas fields in Europe and is the only nearly exhausted gas field capable of storing the CO<sub>2</sub> from a power plant over its entire lifespan. Being already investigated, explored and developed, this gas field therefore provides very favourable conditions to explore the possibilities of the entire CO<sub>2</sub> value chain.

The project will be accompanied by the research project CLEAN (Geotechnologien), which will provide support for the development of technologies and methods for CO<sub>2</sub> storage and EGR. 17 research institutions and companies are involved. During a three year period (2008 -2010) the technologies for injection, the characterisation of the geological system and process monitoring are being investigated. CO<sub>2</sub> from Vattenfall's test facilities is transported by truck to the Altmark field and injected into one compartment of the Altmark field.

## Other Projects

The Danish company Dong Energy<sup>119</sup> has announced plans to construct a 1.500 MW coal plant with CCS in Lubmin close to the city of Greifswald. CO<sub>2</sub> will be retained via post combustion, based on the experiences gained during the CASTOR project at the coal plant in Esbjerg, Denmark.

## CCS TECHNOLOGY COMPANIES IN GERMANY

| Company/association                  | Web site                                                       | Relevant business/technology                                                                                                                                                                                                                                                                                                                                    |
|--------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ALSTOM Power Boilers                 | <a href="http://www.power.alstom.com">www.power.alstom.com</a> | Extensive knowledge of steam generation, combustion, fuel technology and heat recovery systems. ALSTOM, the Electric Power Research Institute (EPRI) and We Energies are combining forces to build a pilot plant to demonstrate a unique CO <sub>2</sub> capture process in US. ALSTOM carbon capture process uses chilled ammonia to capture CO <sub>2</sub> . |
| BASF AG                              | <a href="http://www.basf.com">www.basf.com</a>                 | BASF Operating Division Intermediates is taking part in EU research projects on CO <sub>2</sub> capture. BASF has extensive expertise amine scrubbing technology.                                                                                                                                                                                               |
| DBI GAS and Environmental Techniques | <a href="http://www.dbi-gut.de">www.dbi-gut.de</a>             | DBI participated in the RECOPOL project with drilling and completion of CO <sub>2</sub> injection well, as well as engineering and monitoring of CO <sub>2</sub> injections.                                                                                                                                                                                    |
| Deutsche Shell                       | <a href="http://www.shell.de">www.shell.de</a>                 | Active in employing CCS technologies for their refineries                                                                                                                                                                                                                                                                                                       |

<sup>119</sup> [www.dongenergy.com](http://www.dongenergy.com)

|                                               |                                                                                            |                                                                                                                                                                                                                                                                                                                                              |
|-----------------------------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                               |                                                                                            | and process plants. Working with Coal Gasification Technologies.                                                                                                                                                                                                                                                                             |
| Deutsche Steinkohle AG                        | <a href="http://www.deutsche-steinkohle.de">www.deutsche-steinkohle.de</a>                 | The Deutsche Steinkohle Aktiengesellschaft has been participating in the European CO <sub>2</sub> ECBM (Investigation into the Basic Scientific Phenomena of CO <sub>2</sub> Injection and Retention in Coal for CO <sub>2</sub> Storage and Enhanced Coal Bed Methane Recovery).                                                            |
| E.ON Germany                                  | <a href="http://www.eon.com">www.eon.com</a>                                               | E.ON has been deeply involved in climate protection for many years and is engaged in numerous German and EU projects on CCS.                                                                                                                                                                                                                 |
| EEG- Erdgas Erdöl GmbH                        | <a href="http://www.gasdefrance.de">www.gasdefrance.de</a>                                 | Expertise in the upstream sector, exploration and production. Involved in the Altmark EGR project. Affiliate of Gaz de France.                                                                                                                                                                                                               |
| Fichtner GmbH & CO Kg                         | <a href="http://www.fichtner.de">www.fichtner.de</a>                                       | Fichtner offers a comprehensive range of technical and economic expertise in the energy sector, ranging from power generation engineering to all inclusive solutions for power supply. Fichtner is administering the Post combustion technology screening of Karstø.                                                                         |
| G.E.O.S. Freiberg Ingenieurgesellschaft mbH   | <a href="http://www.geosfreiberg.de">www.geosfreiberg.de</a>                               | The GEOS Freiberg is participating in a variety of R&D projects within CCS in Germany, such as the CO <sub>2</sub> Sink project. It is a Consulting and Monitoring company.                                                                                                                                                                  |
| Krupp Uhde GmbH                               | <a href="http://www.uhde.biz">www.uhde.biz</a>                                             | Turbines/ICGG involved in COORETEC projects                                                                                                                                                                                                                                                                                                  |
| Linde AG                                      | <a href="http://www.linde.com">www.linde.com</a>                                           | Is supplying CO <sub>2</sub> for CO <sub>2</sub> Sink, operates with CO <sub>2</sub> transport in the Netherlands via pipelines, supplies air separation units and is actively engaged in the construction of the Hammerfest LNG plant. Linde is furthermore involved in the development of solvents and membranes for separation processes. |
| Lurgi AG                                      | <a href="http://www.lurgi.com">www.lurgi.com</a>                                           | Lurgi is participating in the R&D program such as ENCAP (FP6) and COORIVA, sponsored by the German Ministry of Economics and Technology and is working on both Zero Emission Syngas Technology and Zero emission IGCC.                                                                                                                       |
| Mannesmann Anlagebau AG                       | <a href="http://www.mannesmann.com">www.mannesmann.com</a>                                 | Engineering and technologies.                                                                                                                                                                                                                                                                                                                |
| Doosan Babcock Energy (former Mitsui Babcock) | <a href="http://www.doosanbabcock.com">www.doosanbabcock.com</a>                           | Major Power Plant constructor. Oxyfuel Boiler Technologies.                                                                                                                                                                                                                                                                                  |
| RWE Power AG<br>RWE DEA                       | <a href="http://www.rwe.com/en">www.rwe.com/en</a>                                         | CO <sub>2</sub> free power plants – mainly coal based. Engaged in, and forerunner of several CCS projects including storage.                                                                                                                                                                                                                 |
| Siemens AG Power Generation                   | <a href="http://www.powergeneration.siemens.com/en">www.powergeneration.siemens.com/en</a> | Siemens power is one of the leading specialists for power plant construction and equipment and offers a wide range of technologies, ranging from gasification technologies with multifuel capability and gas turbines, to post combustion technologies and options for retrofit as well as transport and storage equipment.                  |
| TÜV Nord                                      | <a href="http://www.tuev-nord.de">www.tuev-nord.de</a>                                     | Inspection Organisation - Carbon Readiness Certification                                                                                                                                                                                                                                                                                     |
| Vattenfall Europe                             | <a href="http://www.vattenfall.de">www.vattenfall.de</a>                                   | Forerunner with several CCS projects. Post combustion and Oxyfuel                                                                                                                                                                                                                                                                            |
| Vattenfall Europe Technology Research GmbH    | <a href="http://www.wintershall.com">www.wintershall.com</a>                               | Subsidiary of Vattenfall Europe providing research consulting services.                                                                                                                                                                                                                                                                      |
| VDI – Technology Center                       | <a href="http://www.vvdi.de">www.vvdi.de</a>                                               | Handles and conceptualises R&D activities and funding                                                                                                                                                                                                                                                                                        |
| Wintershall Holding                           | <a href="http://www.wintershall.com">www.wintershall.com</a>                               | Expertise in the upstream sector, drilling and pipelines.                                                                                                                                                                                                                                                                                    |

## CCS RESEARCH AND DEVELOPMENT

### COORETEC<sup>120</sup>

One of the main technological objectives of the new COORETEC Lighthouse Concept of the Ministry of Economics and Technology BMWi is to sink the costs of CO<sub>2</sub> capture and storage, while simultaneously reducing efficiency losses. Research will focus on oxyfuel technologies, IGCC processes, post combustion processes, membrane technology and geological storage. Examples of major research programmes in this context are:

| Program | Description                                                                                                                                                                                                                                                                                                                                                                                                                            |
|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| COORIVA | CO <sub>2</sub> reduction by integrated gasification and separation. This research and development program with a budget of €4.6 million (2005-2008) is working with the development of a state of the art CO <sub>2</sub> free IGCC process. Special attention is being paid to the optimisation of lignite gasification and overall construction, potential and overall concept of an IGCC CO <sub>2</sub> free power plant. Program |

<sup>120</sup> <http://www.fz-juelich.de/ptj/projekte/index.php?index=1368>

|                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                         | partners are, RWE, Vattenfall, EON, Siemens, Linde, IEC, Uhde, and Lurgi. Coordinator of the project is TU Freiberg.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| ADECOS                                                                  | The ADECOS program (Advanced Development of the Coal-fired Oxyfuel Process with CO <sub>2</sub> separation) with a budget of €3.1 million (2004-2008) brings together 9 partners from the industrial and university sector for bringing forward oxyfuel processes with CO <sub>2</sub> separation. The ADECOS concept is based on contemporary power plant technology. Aim of this program is to proof the technical and economical feasibility of the oxyfuel technology with CO <sub>2</sub> separation for coal. This includes experiments in laboratory and technical scale as well as theoretical investigation, modelling work and component design. As part of the program a first oxyfuel pulverised combustion test rig for lignite is operated at the University of Dresden. Special technological focus is the oxyfuel burner for pulverized coal. Many suggestions from the ADECOS consortium concerning the process layout have already and are being considered in the planning process of Vattenfall's pilot plant. Partners are Vattenfall, RWE, EON, ALSTOM, BHI, Siemens, TU HH, and FH Zittau/Görlitz. Coordinator of the program is TU Dresden. |
| OXYCOAL                                                                 | The OXYCOAL program with a budget of €5.9 million is also working with the oxyfuel technology. The research team consists of 6 Institutes of the RWTH Aachen and is predominantly working with the combustion of coal in an O <sub>2</sub> /CO <sub>2</sub> atmosphere and the development of high temperature membranes in order to bring down the cost of oxygen in the process. As part of the program component tests and test operations of an oxyfuel research plant are conducted. Project partners are RWE, EON, Siemens, and Linde and WS. Coordinator of the program is RWTH Aachen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| HotVeGas                                                                | This COORETEC project is a basic investigation for the development of future high temperature gasification and gas cleaning processes for IGCC power plants with CO <sub>2</sub> capture and for the production of synthetic energy carriers. The project with a budget of €8.8 million in the period 2007-2011 has the goal to develop high efficient high temperature gasification processes with integrated hot gas cleaning and CO <sub>2</sub> capture for IGCC power plants and processes for the production of synthetic fuels, the extension of the basics of gasification kinetics and trace element behaviour and the development of integrated concepts as well as a general extension of the gasification competence in Germany. Project partners are EnBW, RWE, EON, Vattenfall, Siemens, Uhde, TUB Freiberg, Forschungszentrum Jülich, GTT Technologies. Coordinator of the program is the University of Munich.                                                                                                                                                                                                                                      |
| POSEIDON                                                                | This post combustion project is occupied with the modelling and simulation of CO <sub>2</sub> capture by wet chemical absorption, CO <sub>2</sub> compression as well as with the analysis of the overall process under realistic boundary conditions. The project is coordinated by the TU Hamburg Harburg in cooperation with E.ON, RWE, Vattenfall, EnBW                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Chemical absorption processes for CO <sub>2</sub> capture from flue gas | Aim of the project is the development and optimisation of scrubbing columns, the analysis of earth alkali solvents and adaptation of corresponding processes. Coordinator of the project are the Universities of Stuttgart and Duisburg-Essen in cooperation with RWE, E.ON, Vattenfall, EnBW, Evonic and Hitachi                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Carbonate Looping                                                       | The project will be coordinated by the University of Darmstadt and is currently in the definition phase.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| CLock                                                                   | The project investigates chemical looping combustion for coal. The project is expected to start Q3 2008                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| COORAL                                                                  | The German Federal Institute for Materials Research and Testing (BAM). The German Federal Institute for Geosciences and Natural Resources (BGR), the German Fuel Institute (DBI) and the Universities of Halle Wittenberg and the Hamburg University of Technology are undertaking this project which covers the entire CO <sub>2</sub> chain from generation, transport, injection to storage. Goals of the project are the estimation of expected flue gas composition from CO <sub>2</sub> capture, the impact assessment of components in the transportation chain, especially corrosion, the assessment of the influence of pollutants on geochemical reactions underground and the techno economic optimisation of the complete chain from capture to storage. The project is currently in planning.                                                                                                                                                                                                                                                                                                                                                          |

## GEOTECHNOLOGIEN<sup>121</sup>

Since 2005, the BMBF has been supporting research projects concerning the development of new storage options and CO<sub>2</sub> monitoring within the Geotechnologien programme. Whilst the 9 interdisciplinary research projects of the first funding phase are almost completed, 12 new projects have been suggested. The following projects are currently and will be supported under the "CO<sub>2</sub> Storage in Geological Formations" program:

| Program              | Description                                                                                                                                                                                                                                                                                                                                                                      |
|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CO <sub>2</sub> TRAP | The project is concerned with the development and evaluation of innovative strategies for the sequestration and permanent immobilisation of CO <sub>2</sub> in geological formations. Partners are the RWTH Aachen, University of Bayreuth, University of Stuttgart, RWE DEA AG, RWE Power AG, SARR Energie GmbH, Deutsche Steinkohle AG, Herne, and Deutsche Montan Technology. |
| CSEGR                | The project is a feasibility study on the potential of CO <sub>2</sub> storage for enhancing the recovery factor in mature gas reservoirs. Partners are TU Clausthal Zellerfeld, BGR Hannover, Vattenfall Europe, EEG Gommern, E.ON – Ruhrgas, and Wintershall.                                                                                                                  |
| COSMOS               | The project is assessing CO <sub>2</sub> storage, monitoring and safety technologies. Research partners are                                                                                                                                                                                                                                                                      |

<sup>121</sup> [www.geotechnologien.de](http://www.geotechnologien.de)

|                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                               | GEOForschungsZentrum Potsdam, Deutsches Brennstoff Institut, Vattenfall Europe Mining AG, University of Karlsruhe and RWE Power AG.                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| RECOBIO                       | The project investigates the recycling of sequestered CO <sub>2</sub> by microbial-biogeochemical transformation in the deep subsurface. Partners are GEOS Freiberg Ingenieurgesellschaft mbH and Dresdner Grundwasserforschungszentrum.                                                                                                                                                                                                                                                                                                                                                               |
| CDEAL                         | The project investigates the possibility of CO <sub>2</sub> elimination by using acid mine lakes and calcium oxide suspensions. Coordinator is the Technical University of Freiberg.                                                                                                                                                                                                                                                                                                                                                                                                                   |
| CDEAL                         | The project investigates the possibility of CO <sub>2</sub> elimination by using acid mine lakes and calcium oxide suspensions. Coordinator is the Technical University of Freiberg.                                                                                                                                                                                                                                                                                                                                                                                                                   |
| CO <sub>2</sub> CRS           | The project is developing high resolution images of subsurface CO <sub>2</sub> storage sites in time and depth by the CRS methodology. Partners are Trappe Erdöl Erdgas Consultant, the University of Karlsruhe and University of Berlin.                                                                                                                                                                                                                                                                                                                                                              |
| CHEMKIN                       | The project is monitoring the real time observation of chemical and kinetic behaviour of CO <sub>2</sub> during geological sequestration. Partners are GEOForschungsZentrum Potsdam, Environment and Engineering Technology GmbH, University Potsdam, Technological University of Clausthal, and Optimare GmbH.                                                                                                                                                                                                                                                                                        |
| PROBLEM ORIENTATED BENCHMARKS | The project numerically investigates CO <sub>2</sub> sequestration in geological formations. Partners are the University of Stuttgart and Deutsche Montan Technologie.                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| CO <sub>2</sub> - UGS - RISKS | The project assesses the long-term risk and sustainability of underground storage of CO <sub>2</sub> in Germany. It investigates current practices, future R&D needs and development of methodologies. Coordinator is the Gesellschaft für Anlagen und Reaktorsicherheit (GRS)                                                                                                                                                                                                                                                                                                                         |
| CO <sub>2</sub> MoPa          | The project is working with the modelling and parameterisation of CO <sub>2</sub> storage in deep saline formations for dimension and risk analyses. The project has a budget of € 4.8 million during the period 2008-2010. Project manager is the Christian Albrecht University Kiel, partners are University of Stuttgart, Helmholtz UFZ, LANU (Kiel), University of Freiberg, ENBW, E.ON, Vattenfall, Wintershall, Stadtwerke Kiel, RWE DEA.                                                                                                                                                        |
| COAST                         | This project is connected the IGCC CCS project of RWE and provides the accompanying R&D for clarification and assuring of standards and methods for commercial scale CO <sub>2</sub> storage in deep saline aquifers. The project also contains a pilot site in North Friesland and currently 32 research institutions and companies are involved. The project is scheduled to start 01.01.2009 and projected injections in the second phase are 2.6 million t CO <sub>2</sub> per year. It a funding of € 15 million from the BMBF and € 69 million from industry in the period 2008-2011.            |
| CLEAN                         | This project is connected to the Altmark Gas field pilot site and has the objective to develop technologies and methods for CO <sub>2</sub> storage and ERG. 17 research institutions and companies are involved. During a three year period (2008 -2010) the technologies for injection, the characterisation of the geological system and process monitoring are being investigated. CO <sub>2</sub> from Vattenfall's test facility is transported by truck to the Altmark field and injected into one compartment of the Altmark field. Total injection volume is 100,000 ton of CO <sub>2</sub> . |
| CO <sub>2</sub> Sinus         | CO <sub>2</sub> storage in in -situ converted coal seams. RWTH Aachen, DMT GmbH & Co KG, Essen                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| ALCATRAP                      | Optimising CO <sub>2</sub> storage through reactions with alkaline residues by the Alkaline Carbon Trapping process. University Bayreuth, RWTH Aachen,                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| RECOBIO2                      | Investigation of the biogeochemical transformation of injected CCO <sub>2</sub> in the deep surface. TU Bergakademie Freiberg, DGFZ, BGR Hannover                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| CO <sub>2</sub> SEALS         | Integrity of cap rock formations for CO <sub>2</sub> storage. RWTH Aachen, University of Karlsruhe, Shell international Exploration                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| COMICOR                       | Fault related CO <sub>2</sub> fluid migration and its impact on the wall rock alteration and integrity of CO <sub>2</sub> reservoir rocks. Investigation on the Buntsandstein of the Hessian Depression as a natural analogue for industrial CO <sub>2</sub> sequestration. Coordinator University of Jena                                                                                                                                                                                                                                                                                             |
| COSONOSTRA                    | CO <sub>2</sub> -SO <sub>2</sub> -NO <sub>x</sub> stimulated rock alteration. Coordinator GFZ Potsdam                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| CO <sub>2</sub> - SUGAR-A     | Submarine Gashydrates as storage option for CO <sub>2</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| CO <sub>2</sub> DEPTH         | Software for accurate depth focussing, resolution and localization of CO <sub>2</sub> storage and migration processes from 3 D seismic data. Coordinator University of Karlsruhe                                                                                                                                                                                                                                                                                                                                                                                                                       |
| COBOHR                        | Development and testing of CO <sub>2</sub> resistant borehole cements and natural materials for the long term sealing of CO <sub>2</sub> injection wells. DBI Gas und Umwelttechnik GmbH, University of Karlsruhe                                                                                                                                                                                                                                                                                                                                                                                      |

## EU projects

Germany and German companies and research institutions are participating in a variety of European research projects and platforms within the FP5 and FP6, which funded CCS research projects with over € 100 million. For the seventh research program, that covers the period 2007 - 2013, the EU announced a funding for CCS research and demonstration projects of € 500 million.

| Program                  | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| GESTCO <sup>122</sup>    | The project was an early investigation of the geological storage of CO <sub>2</sub> from fossil fuel combustion for the enhanced recovery of oil in the North Sea. Germany's federal Institute for Geo science and Natural Resources (BGR) participated in this project.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| RECOPOL <sup>123</sup>   | The project investigated the reduction of CO <sub>2</sub> emissions by means of CO <sub>2</sub> storage in coal seams in the Silesian Coal Basin of Poland. The RWTH Aachen participated in this project.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| CO2 STORE <sup>124</sup> | Aim of this project is to continue the development of geophysical monitoring methods. It is the continuation of the SACS project and the monitoring site is the SLEIPNER storage. As part of the project there are four case studies for CO <sub>2</sub> onshore storage in saline aquifers in Wales, Norway, Denmark and Germany. The federal institute for Geoscience and Natural Resources (BGR) investigated in this context the storage capacity in the case study "Schwarze Pumpe" in Brandenburg.                                                                                                                                                                                                                                                                                                                                                                                                         |
| CASTOR <sup>125</sup>    | From capture to storage. The work on capture is aimed at developing new CO <sub>2</sub> post combustion separation processes suited to the problems of capture of CO <sub>2</sub> at low concentrations in large volumes of gases at low pressure. The processes will be tested in a pilot unit in Denmark, capable of treating one to two tones of CO <sub>2</sub> per hour from real fumes. Germany research institutions and companies in this project are, BGR, University of Stuttgart, RWE Power AG, Siemens AG and BASF AG.                                                                                                                                                                                                                                                                                                                                                                               |
| ISCC <sup>126</sup>      | Innovative <i>in-situ</i> CO <sub>2</sub> capture technology for solid fuel gasification. The project aims to develop new processes for upgrading high moisture low rank lignite, i.e. development of high temperature sorbents. The University of Stuttgart is participating in this project.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| ENCAP <sup>127</sup>     | The ENCAP (enhanced capture of CO <sub>2</sub> ) is a 5 year integrated project in the period 2004 – 2009 with a total budget of € 22.2 million and an EC support of 10.7 € million. The research project is working on the development of pre-combustion technologies for enhanced capture of CO <sub>2</sub> in large power plants. It aims at technologies which meet a target of at least a 90% CO <sub>2</sub> capture rate and a reduction in the cost of capture of 50% compared to present. The ENCAP consortium consist of 5 large energy companies, including RWE Power, 11 leading technology provider and 12 high ranked research providers including the German University of Stuttgart.                                                                                                                                                                                                            |
| GEO NET <sup>128</sup>   | Germany, with the Federal Institute for Geosciences and Natural Resources (BGR) is also part of the CO <sub>2</sub> GeoNet, which was funded within the FP6 with € 6 million. The main objective is the formation of a partnership consisting of key European research centres and other expert collaborators in the area of geological storage of CO <sub>2</sub> , and the identification of knowledge gaps in the long-term geologic storage of CO <sub>2</sub> as well as the formulation of new research projects and tools to eliminate these gaps. The CO <sub>2</sub> GeoNet project will result in re-alignment of European national research programs and prevent duplication of research efforts. It will also contribute to the knowledge base for CO <sub>2</sub> storage site selection, injection operations, monitoring, verification, safety, environmental protection, and training standards. |
| GEO NET <sup>129</sup>   | Germany, with the Federal Institute for Geosciences and Natural Resources (BGR) is also part of the CO <sub>2</sub> GeoNet, which was funded within the FP6 with € 6 million. The main objective is the formation of a partnership consisting of key European research centres and other expert collaborators in the area of geological storage of CO <sub>2</sub> , and the identification of knowledge gaps in the long-term geologic storage of CO <sub>2</sub> as well as the formulation of new research projects and tools to eliminate these gaps. The CO <sub>2</sub> GeoNet project will result in re-alignment of European national research programs and prevent duplication of research efforts. It will also contribute to the knowledge base for CO <sub>2</sub> storage site selection, injection operations, monitoring, verification, safety, environmental protection, and training standards. |

## Institutes

Apart from several German Universities, there exists a growing number of institutes that are working with CCS technologies.

Federal Institute for Geosciences and Natural Resources (BGR)<sup>130</sup>

The BGR, is the dominant research institute concerning geological storage of CO<sub>2</sub> and is part of the BMWi. It is participating in both European research projects as well as in a variety of national research and development programs.

<sup>122</sup> [www.nitg.tno.nl/projects/eurogeosurveys/projects/GestcoWeb](http://www.nitg.tno.nl/projects/eurogeosurveys/projects/GestcoWeb)

<sup>123</sup> [recopol.nitg.tno.nl/index.shtml](http://recopol.nitg.tno.nl/index.shtml)

<sup>124</sup> [www.co2store.org](http://www.co2store.org)

<sup>125</sup> [www.co2castor.com](http://www.co2castor.com)

<sup>126</sup> [www.eu-projects.de/ISCC](http://www.eu-projects.de/ISCC)

<sup>127</sup> [www.encapco2.org](http://www.encapco2.org)

<sup>128</sup> [www.co2geonet.com](http://www.co2geonet.com)

<sup>129</sup> [www.co2geonet.com](http://www.co2geonet.com)

<sup>130</sup> [http://www.bgr.bund.de/clin\\_030/nn\\_462770/EN/Home/homepage\\_node.html](http://www.bgr.bund.de/clin_030/nn_462770/EN/Home/homepage_node.html)

### **Wuppertal Institute for Climate, Environment and Energy**<sup>131</sup>

The Wuppertal Institute is working on a variety of issues concerning CCS technology, including socio and economic aspects. It is participating in workshops and conferences and is cooperating with the BMU.

### **Potsdam Institute for Climate Impact Research (PIK)**<sup>132</sup>

The PIK is also following actively the discussion of CCS in Germany. Interestingly the head of PIK, one of Germany's leading climate change experts, is the advisor for Climate Change of the current government.

### **GeoForschungsZentrum Potsdam**<sup>133</sup>

The GFZ Potsdam is part of the Helmholtz Association and the BMBF. The scientific projects are part of the major research fields "Earth and the Environment" and "Energy", and the Institute is coordinating the storage project "CO<sub>2</sub>" Sink in Ketzin.

### **Frauenhofer Institut ISI**<sup>134</sup>

The Frauenhofer Institute for System and Innovation Research ISI complements the techno – scientific spectrum of the Frauenhofer Society by economic and social aspects. Frauenhofer produces analysis of technological developments, their market potential and their impact on the economy. The Frauenhofer Institute has been producing reports covering CCS for the BMU.

### **Projektträger Jülich**<sup>135</sup>

The Jülich institute is also part of the Helmholtz Association. It contains a research centre as well as project management. The project management Jülich (PTJ) undertakes project management of research projects of the different German Ministries. The PTJ is also a national contact for EU support research programmes and it coordinates activities for the International Energy Agency (IEA).

### **IZ Klima – Informationszentrum Klimafreundliches Kohlekraftwerk**<sup>136</sup>

Since public acceptance is decisive for the implementation of CCS in Germany, German utilities and manufacturers have established the association IZ Klima, in Berlin. Members of the association are among others Alstom Germany, Babcock Borsig Services EnBW, E.ON, Hitachi Power Europe, RWE Power, Siemens Energy Sector and Vattenfall Europe. The IZ Klima is an information platform and works towards raising public awareness and acceptance for CCS technologies. The association is actively involved in the public debate and organises Seminars and information brochures about CCS.

---

<sup>131</sup> [www.wupperinst.org](http://www.wupperinst.org)

<sup>132</sup> [www.pik-potsdam.de](http://www.pik-potsdam.de)

<sup>133</sup> [www.gfz-potsdam.de](http://www.gfz-potsdam.de)

<sup>134</sup> [www.isi.frauenhofer.de](http://www.isi.frauenhofer.de)

<sup>135</sup> [www.fz-juelich.de](http://www.fz-juelich.de)

<sup>136</sup> [www.iz-klima.de](http://www.iz-klima.de)