

STATE OF CO₂ CAPTURE AND SUBSURFACE STORAGE ACTIVITIES IN GERMANY

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Abstract: The Federal Republic of Germany (FRG) is the greatest carbon emitter in Europe and is responsible for ~ 3.4% of the world's total fossil fuel-based carbon emissions. In the Kyoto Protocol and national climate protection programs Germany has committed to substantial reductions of CO₂ emissions. Because of the German government's priority on sustainable energies and reduction of fossil energy consumption, R&D activities on CO₂ capture and subsurface storage have so far played only a minor role. These activities are, however, increasing and several projects have been launched recently.

Key words: CO₂-emissions, CO₂ capture, subsurface storage, Germany, EU Projects, COORETEC, GEOTECHNOLOGIEN

1. INTRODUCTION

Between 1990 and 2003 worldwide annual emissions of CO₂ increased from 22,700 Megatons (Mt) to 25,700 Mt. The share of the OECD countries in these emissions increased during this period from 3,700 Mt to 4,500 Mt.

The Federal Republic of Germany (FRG) is the greatest carbon emitter in Europe with a 24.2 % share of the total European Community (EC) emissions in 2001 (993.5 Mt CO₂) which corresponds to ~3.4% of the world's total fossil fuel-based carbon emissions. Germany joined the Kyoto Protocol to the United Nations Framework Convention on Climate Change (Kyoto Protocol) on 4th March 2002 as a member of the EC, which at that time comprised 15 countries. The EC committed itself to reduce its annual

average greenhouse gas emissions by the time period 2008 – 2012 by eight percent with respect to the base 1990 level (4204 Mt). Reduction targets were allocated to the individual member countries in the “Burden Sharing Agreement” of June 1998 (Figure 1). According to this Agreement, Germany has to reduce emissions by 21% with respect to the 1990 level (1216.2 Mt CO₂ equivalent emissions). In the national FRG climate protection program of 18th October 2000 the target was set to a reduction of CO₂ emissions by 25% with respect to 1990 by 2005. By 2001 annual CO₂ in emissions Germany had decreased by 18.3 % to 993.5 Mt putting the country ahead of the reduction target and in line with the United Kingdom, Sweden and Luxembourg.

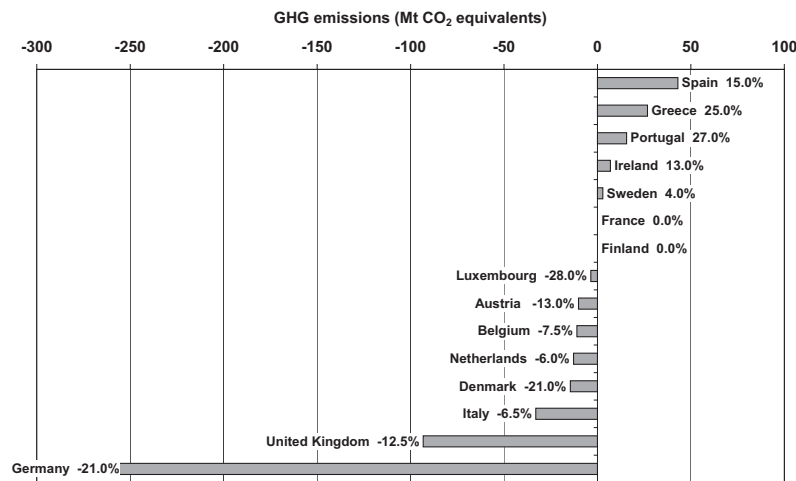


Figure 1. Greenhouse gas emission targets of EU Member States for 2008-2012 under the EU Burden-Sharing Agreement.

The decision of the German government to phase out the use of nuclear power by 2020 will have serious implications on the energy supply and requires alternative solutions. For a transition period fossil fuels will remain an indispensable source of energy.

To further reduce greenhouse gas emissions, the climate policy of the German government focuses on sustainable energies and the reduction of fossil energy consumption. R&D activities on CO₂ sequestration and subsurface storage have played a comparatively minor role. Activities have, however, increased recently both on the capture and storage fields, in view of the start of trading of CO₂ Emission certificates in 2005.

2. GERMAN R&D ACTIVITIES ON CO₂ CAPTURE AND STORAGE

German research institutes have successfully participated in various international research projects at the European Union (EU) level. These comprise Joule II (1993-1995; RWE-AG), GESTCO (1999-2003; BGR), NASCENT (2000-2004; BGR, RWTH-Aachen), RECOPOL (2001-2005; DBI-GUT, RWTH-Aachen), CASTOR (2004-2006; BGR, University of Stuttgart), and CO₂GeoNet (BGR). The EU project CO₂SINK, which started in 2004, was the first major EC project of this kind initiated by a German institution (GFZ-Potsdam). A worldwide overview of former and ongoing projects on CO₂ capture and underground storage can be found at the IEG GHG website (<http://www.co2captureandstorage.info/>).

More recently three major national R&D programs have been launched to promote CO₂ capture from coal-fired power plants (COORETEC), to support research on greenhouse gas emission reduction and adaptation to climate change (Forschung für den Klimaschutz und Schutz vor Klimawirkungen), and to explore methods and facilities for underground storage of CO₂. The latter activity is embedded in the GEOTECHNOLOGIEN Program of the Federal Ministry of Education and Research (BMBF) and The German Research Foundation (DFG).

2.1 German involvement in international projects

2.1.1 Joule II

The Joule II Project “Underground Disposal of Carbon Dioxide” was the first European research project examining issues associated with underground CO₂ disposal. Its goal was to assess quality and quantity of CO₂ available from fossil fuel power plants, to examine pipeline transport of CO₂ and to examine various options for underground disposal. Furthermore it addressed safety and stability issues, investigated the geochemistry associated with underground disposal and carried out techno-economic modeling.

The Joule II consortium comprised the Geological Surveys of the UK (BGS), France (BRGM) and The Netherlands (TNO-NITG), the IKU Petroleum Research Institute of Norway and the University of Sunderland (UK). The German energy industry was represented in this project by the company RWE AG.

2.1.2 GESTCO

The GESTCO (GEological Storage of CO₂) project started in 2000. It was initiated to assess the European potential for geological storage of CO₂ from fossil fuel combustion. Participants were the Geological Surveys of eight European countries (Belgium, Denmark, France, Germany, Greece, Norway, Netherlands, UK, and the research institute ECOFYS).

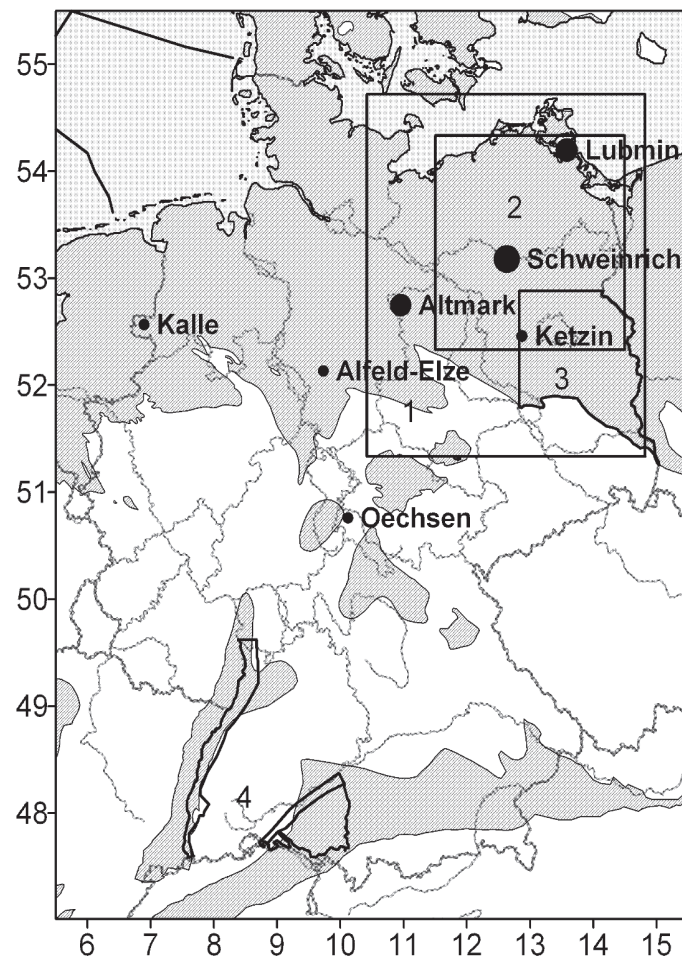


Figure 2. Sedimentary basins in Germany > 1 km depth, hosting natural gas fields and aquifer structures that could provide storage capacity. Case study sites and regional storage capacity investigations (1-4) (BGR, GESTCO).

The German Federal Institute for Geosciences and Natural Resources (BGR) calculated CO₂-emissions for large industrial point sources and mapped the extent of potential storage areas in aquifers and deep unminable coal seams. Storage capacities were estimated for the various underground storage options: aquifers, deep unminable coal fields, oil/gas fields and abandoned coal and salt mines in Germany (cf. Figure 2). Finally, a descriptive geologic overview was compiled of potential CO₂ storage formations in Northern Germany (Permian and Mesozoic) and an overview of the regional distribution of seals.

The data compiled were incorporated into a common CO₂ Storage Geographic Information System (GIS) for Europe, established within the GESTCO project and covering the territory of the participating countries and their off-shore areas as well. This GIS comprises the first systematic compilation of CO₂ point sources and potential storage facilities in Germany.

Two case studies, the abandoned natural gas field Alfeld-Elze and the Buntsandstein aquifer close to the planned power plant Lubmin have been selected for numerical simulations of CO₂ injection into the reservoirs and long-term migration, thermodynamic modeling of potential reactions between formation water, CO₂, and reservoir rocks, and for cost calculations with a decision support system developed by TNO- NITG.

BGR and the British Geological Survey (BGS) jointly prepared a report on CO₂ storage safety and conflicts of use.

2.1.3 NASCENT

Two German institutions, BGR and RWTH-Aachen University, were project partners in the EU project NASCENT (Natural Analogues for the Storage of CO₂ in the Geological Environment) from 2001 to 2004. Various locations with natural occurrences and different intensities of CO₂ emission were selected in France, Germany, Greece, Hungary and Italy and studied in great detail to analyse the conditions, effects and processes related to long-term underground storage of CO₂.

In the Vorderrhön area in central Germany natural CO₂ occurs below and locally within Permian Zechstein salts and was produced commercially until the 1980s. Here BGR conducted detailed geological studies, analyses of fluid obtained from wells and sampled in salt mines in the overburden of the CO₂ reservoir Oechsen (Fig. 2). Soil gas surveys were performed to identify potential leakage pathways of CO₂ to the surface. In addition, BGR operated automatic soil gas monitoring systems and provided expertise for surveys at the other NASCENT sites.

Within the NASCENT project, RWTH-Aachen performed fundamental experimental laboratory work to assess the sealing efficiency of cap rock sequences overlying potential CO₂ storage targets. The experiments comprised permeability tests, assessment of the capillary gas-sealing efficiency of water-saturated rocks and diffusion experiments with CO₂ in water-saturated rocks. Selected results from this project work are shown in Figure 3. The experimental data were subsequently used to develop models for the prediction of leakage rates from CO₂ reservoirs.

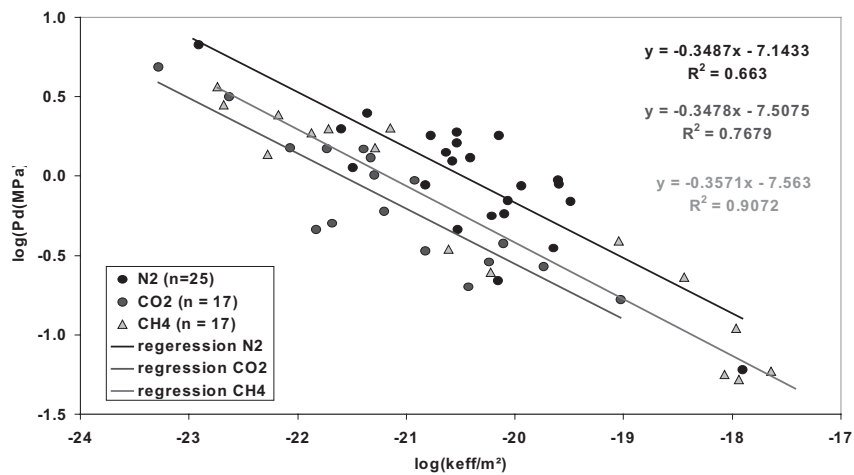


Figure 3. Capillary gas sealing efficiency (breakthrough pressure) vs. gas permeability of cap rocks (RWTH-Aachen, NASCENT).

2.1.4 RECOPOL

RWTH-Aachen University and DBI-GUT, a company specialized in underground storage of natural gas, were the two German partners in the EU RECOPOL project (Reduction of CO₂ emission by means of CO₂ storage in coal seams in the Silesian Coal Basin of Poland) that started in November 2001 and will finish in 2005. RECOPOL was initiated and co-ordinated by the Netherlands Institute of Applied Geoscience -National Geological Survey (TNO-NITG) in co-operation with the Polish Central Mining Institute (GIG) to investigate the feasibility of CO₂ underground storage in unminable coal seams in combination with the production of coal bed methane (CBM). The project comprised extensive laboratory studies on high-pressure sorption and transport processes of methane and CO₂ in coals,

performed mainly at the Technical Universities of Delft (The Netherlands) and RWTH-Aachen, in close co-operation with the Institut Français du Pétrole (IFP). The main achievement of RECOPOL was the first European field test on CO₂ storage in deep coal seams in the Silesian Coal Basin of Poland near the city of Katowice.

RWTH-Aachen contributed extensive experimental data sets on single gas and mixed gas sorption capacity, selectivity and kinetics which were incorporated into reservoir simulation software in close collaboration with the Australian partner CSIRO Petroleum.

DBI-GUT was in charge of planning, preparation and supervision of the engineering activities at the RECOPOL CO₂ injection site.

Figure 4 shows the scheme of the RECOPOL field test with CBM production from an existing well (MS-4) and CO₂ injection into the newly drilled MS-3 well. Liquid CO₂ is delivered by trucks and stored on-site in two 30 t storage tanks.

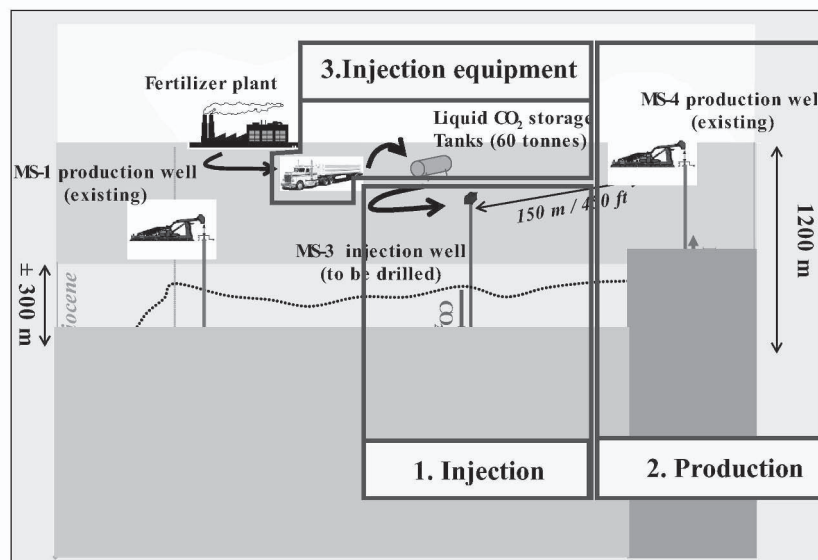


Figure 4. The RECOPOL field test.

2.1.5 CASTOR

The CASTOR (CO₂ from Capture to Storage) project started in 2004 and aims at the development of new technologies for the separation of CO₂ from flue gases and its geological storage. The development of tools and methods to quantify and minimize the uncertainties and risks linked to the storage of

CO₂ is another aim of this project. Thirty parties from industry, research organisations and universities participate in this integrated project. Three off-shore and one on-shore hydrocarbon reservoirs have been selected as case study sites. On the CO₂ storage side, BGR is the only German project partner but has subcontracted experimental work on the characterisation of seal efficiency to RWTH-Aachen University. At the Atzbach-Schwanenstadt natural gas field in Austria, BGR conducts soil gas investigations, including flux measurements, monitoring and isotopic and geochemical analyses of gases. Furthermore, BGR coordinates the studies on preventive and corrective action technologies for leaking wells and faults. RWTH-Aachen investigates CO₂ transport processes in core samples from the cap rock sequences above the gas reservoirs. In the context of the demonstration of subsurface storage of CO₂ in a nearly depleted gas reservoir and enhanced gas recovery, RWTH will perform further experiments on cap rock sequences of an offshore hydrocarbon reservoir in the Netherlands (K12-B).

On the capture side, the University of Stuttgart provides a mini power plant for the development of efficient methods for CO₂ extraction from flue gas. German companies involved in the project are Siemens AG and RWE Power, participating in the evaluation, optimisation and integration of post-combustion capture processes in power plants and the process validation of a pilot capture plant. BASF contributes to the developing and improving of solvents for CO₂ separation.

2.1.6 CO₂SINK

CO₂SINK is the first EU project on CO₂ emission reduction initiated and co-ordinated by a German research institute. It was proposed by GeoForschungsZentrum (GFZ, National Research Centre for Geosciences) Potsdam as an *in-situ* R&D laboratory for geological storage of CO₂.

The target reservoir is located near the town of Ketzin (Fig. 2) west of Berlin and Potsdam at a depth of ~700m and represents a sandstone aquifer of several tens of metres of thickness. The scope of the project comprises a baseline geologic survey with a detailed risk assessment to ensure safe injection and storage of CO₂. Detection and monitoring of the injected CO₂ is another focus in this project.

A total of 14 organisations from 8 European countries, including universities, research institutes and industrial companies are presently participating in this project. Its aim is to integrate CO₂ injection into a framework of CO₂ capture facilities including a biomass power plant.

2.1.7 CO2STORE

CO2STORE is a European integrated project with the aim of transferring the experience gained in the scientific projects SACS I+II from Statoil's offshore CO₂ injection to other potential storage sites with different geological conditions. One of the four additional cases proposed is the lignite fired power plant Schwarze Pumpe in East Germany. For this power plant BGR had to find potential storage sites capable of taking in 400 Mt of CO₂. The only gas field with a storage capacity of this magnitude is located in the Altmark (Fig. 2). Numerical modelling to simulate CO₂ injection and enhanced gas recovery have been performed for this reservoir. One of the identified aquifer structures, Schweinrich (Fig. 2), has been selected for further characterisation of the reservoir structure and caprock properties. Risk assessments are carried out together with BRGM (the simulation of geochemical reactions), NITG-TNO (long-term CO₂ migration simulation) and Vattenfall/NITG-TNO.

2.1.8 CO2GeoNet

The EU has initiated a Network of Excellence for CO₂ capture and storage, intending to facilitate a better co-ordination of research activities in this field. The network comprises 12 institutes from 8 European Countries was formed in 2004. BGR is the sole German participant. After initial activities to create inventories of relevant research infrastructure and to identify gaps in knowledge and future research needs, longer term joint research begins in 2005.

2.2 National research programmes and initiatives

Germany has recently initiated national research activities for the reduction of CO₂ emissions from fossil fuel utilization. One of these, the COORETEC initiative, is aiming at improved power-plant technologies while the GEOTECHNOLOGIEN program investigates underground storage options for CO₂. Other individual research and development activities of universities, industry and research institutes exist. Their description is, however, beyond the scope of this paper.

2.2.1 COORETEC

The COORETEC initiative was launched in 2002 by the Federal Ministry of Economics and Labour (BMWA) to promote CO₂-reduction-technologies for fossil fuel-fired power plants. Four working groups (WG) were

established to address technical, scientific, socio-economic and legal aspects of CO₂ capture and storage:

- WG1: Boundary conditions (legal framework, economic conditions)
- WG2: CO₂-capture, utilisation and storage
- WG3: Short and mid term power plant technologies
- WG4: Future technologies

In 2004 the report of these four COORETEC working groups was published under the title: “Research and Development Concept for Zero-Emission Fossil-Fuelled Power Plants”. This report can be downloaded from the COORETEC website (<http://www.cooretec.de>).

As shown in Figure 6, the short-term priority target of the COORETEC project is to increase the efficiency of steam (DKW) and gas & steam (GuD) electric power stations and thus decrease the CO₂ emissions per unit of electric energy produced from fossil fuel combustion. Thus, R&D activities of COORETEC projects focus on:

- Measures to improve efficiency of combined cycles
- Measures to improve efficiency of conventional steam power plants
- Integrated Gasification Gas Combined Cycle (IGCC) power plant development with and without CO₂ capture
- Novel technology developments with CO₂ capture, especially oxyfuel concepts

With the OXYCOAL-AC project, funded in the context of COORETEC, the Institute of Heat and Mass Transfer (www.wuek.rwth-aachen.de) of RWTH-Aachen is conducting front-end R&D work in this field.

CO₂ capture and storage technologies are also in the scope of the COORETEC program, but with lower priority and on an intermediate and long-term R&D horizon. The compilation of a national storage inventory is considered a prerequisite for near-zero-emission power generation.

2.2.2 GEOTECHNOLOGIEN

In November 2003 a call for project applications was launched by the GEOTECHNOLOGIEN Programme with the research focus: “Exploration, Usage and Protection of the Subsurface”. GEOTECHNOLOGIEN is a geoscientific research and development programme funded jointly by the Federal Ministry of Education and Research (BMBF) and the Deutsche Forschungsgemeinschaft (DFG — German Research Council).

The call solicited project applications related to “Utilisation of the Subsurface for Global Climate Protection Purposes” with a specific focus on the “appraisal of procedures for subsurface storage of the greenhouse gas CO₂ and the development of corresponding exploration and monitoring technologies”.

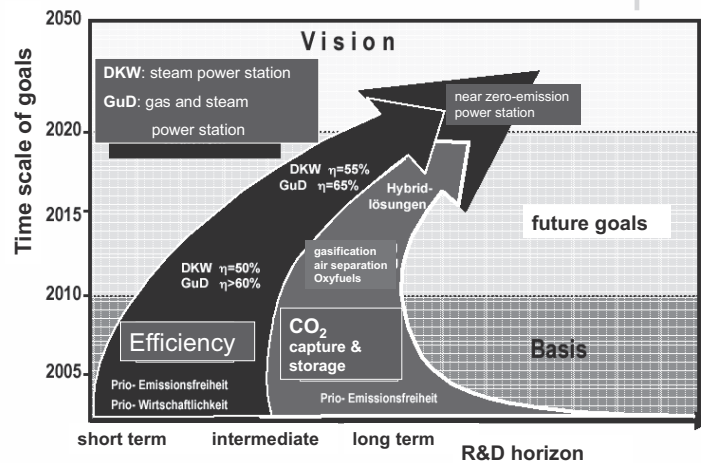


Figure 5. The COORETEC program.

The scope of R&D activities envisaged by this programme comprised the evaluation of appropriate rock formations, such as deep saline aquifers, depleted oil and natural gas reservoirs and deep, unminable coal seams for underground storage of CO₂ with special consideration of long-term integrity and safety. Specifically, applications were requested related to the investigation of reactive transport of CO₂, the reaction kinetics of this gas with reservoir rocks and seals and potential effects on their petrological and mechanical properties. Furthermore, this programme aimed at promoting research into new injection procedures and geophysical and geochemical monitoring techniques ensuring a safe long-term deposition and precise survey of CO₂ migration in the subsurface during and after injection. Project applications were also requested for the development and application of numerical models for the prediction of CO₂ transport and the assessment of potential risks of groundwater contamination.

Among the applications filed in response to this call, approximately 10 have been selected for funding over a period of three years. Details on the selected project and the total funding will be released by April 2005.

2.2.3 Research for Climate Protection and Protection from Effects of Climate Changes

This programme, launched by the Federal Ministry of Education and Research in 2004, has two focal points: (i) Reduction of CO₂ emissions,

especially in industrial applications (power generation is a focus of the COORETEC Programme) and (ii) Adaptation to climate change and extreme weather events. Projects probably will not commence before 2006.

3. CONCLUSION

Although the climate policy of the Federal Republic of Germany is aiming at an increased use of renewable energy and reduction of energy consumption, fossil fuels will remain an important energy source in the foreseeable future, even more so because the production of nuclear energy within Germany will be phased out over the next 20 years. In this context one strategy, namely the reduction of CO₂ emissions from fossil fuel power plants is reflected in the COORETEC programme. Here the first priority is the development of modern, highly efficient power plant technology. New procedures for CO₂ separation and zero-emission fossil power plants are also considered within COORETEC but will invariably reduce power generation efficiency and increase energy costs. Provided that this approach continues to find public acceptance, the issue of long-term geological storage of large quantities of CO₂ arises as an immediate consequence of CO₂ separation. Experience gathered by several German research groups in European projects is now integrated into the national GEOTECHNOLOGIEN R&D programme which takes into account the specific geological, infrastructural, socio-economic and legal situation in Germany. Involvement of German research groups in previous (GESTCO, NASCENT, RECOPO) and ongoing EU projects (CASTOR, CO2SINK, CO2STORE, CO2GeoNet) will ensure the continuity of exchange of expertise on the international level. Additionally, according to the second call in the EU 6th Framework Programme, joint research projects on CCS with the participation of German research institutes involved in current EU projects are in preparation.

ACRONYMS AND PROJECT LINKS

- CASTOR: CO₂ from capture to storage
- COORETEC: CO₂ Reduction Technologies (<http://www.cooretec.de>)
- CO2SINK: In-situ R&D laboratory for geological storage of CO₂ (<http://www.co2sink.org/>)
- GEOTECHNOLOGIEN: (<http://www.geotechnologien.de/>)
- GESTCO: GEological STORAGE of CO₂ (<http://www.nitg.tno.nl/projects/eurogeosurveys/projects/GestcoWeb/>)

- JOULE II: Underground Disposal of Carbon Dioxide (http://www.dti.gov.uk/energy/environment/eerp/reports/ps_001.pdf)
- NASCENT: Natural Analogues for the Storage of CO₂ in the Geological Environment (<http://www.bgs.ac.uk/nascent/home.html>)
- RECOPOL: Reduction of CO₂ emission by means of CO₂ storage in coal seams in the Silesian Coal Basin of Poland (<http://recopol.nitg.tno.nl/>)

INSTITUTION NAMES AND CONTACT INFORMATION

- BGR: Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources); (<http://www.bgr.de/>)
- BMBF Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research); (<http://www.bmbf.de/>)
- BMWA Bundesministerium für Wirtschaft und Arbeit (Federal Ministry of Economics and Labour); (<http://www.bmwa.bund.de/>)
- CSIRO Petroleum: Commonwealth Scientific and Industrial Research Organisation – Petroleum Resources (<http://www.dpr.csiro.au/>)
- DBI-GUT: DBI Gas- und Umwelttechnik GmbH (<http://www.dbi-gut.de>)
- GFZ-Potsdam: GeoForschungsZentrum Potsdam (National Research Centre for Geosciences); (<http://www.gfz-potsdam.de/>)
- GIG: Główny Instytut Górnictwa (Central Mining Institute), Katowice, Poland (<http://www.gig.katowice.pl/>)
- RWTH-Aachen University (<http://www.rwth-aachen.de/>)
- TNO-NITG: Netherlands Institute of Applied Geoscience - National Geological Survey (TNO-NITG) (<http://www.nitg.tno.nl/eng/>)
- Universität Stuttgart (<http://www.uni-stuttgart.de/>)