Annual Report 2010

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

BIGCCS Centre International CCS Research Centre

CONTENTS

Front cover photo: Thor Nielsen, SINTEF

1. MESSAGE FROM THE CHAIRMAN OF THE BOARD

2010 has been a year of fulfilling expectations for the BIGCCS. BIGCCS is an international CCS R&D centre and we have had great success in being exactly that by attracting new international partners to the Centre, expanding the scope and volume of the Centre and by international presence and interaction. The expansion has come through organic growth in the centre, we are now also covering the thermodynamics of CO_2 transport phenomena and we have made the foundation for boosting R&D within chemical looping. We are also making our presence felt globally by publications and speeches at key global conferences, journals and scientific events. BIGCCS contributed to Science Week in Washington D.C. in October and made useful contacts for further co-operation. We are also enjoying the fruitful co-operation with the US links and the true involvement of our non-Norwegian R&D partners. Investing in establishing Centres of Excellence in Environmental Friendly Energy Research has proved a vice move from our government. By having an eight year outlook these Centres can work with predictability along key R&D routes and not be subject to day-to-day shifts in policies. We have already seen this for CCS, from pure optimism to disappointment about the deployment pace to renewed optimism realizing the potential of CCS and the need for clean energy. The recent tragic events in Japan are again rewriting the agenda for energy policy makers.

Leonard Cohen sings “first we take Manhattan then we take Berlin”- I feel this is very much the spirit in the Centre and the intentions of our most valued industrial partners. Let’s keep up the good work in making BIGCCS a trademark for world class quality R&D in CCS.

Chairman of the Board
Nils A. Røkke
(Photo: Geir Otto Johansen)

2. MESSAGE FROM THE CENTRE DIRECTOR

Operating the second year of BIGCCS has been a challenging and exiting experience. The achievements are many and our contribution at GHGT-10, where BIGCCS was present with three oral presentations and seven posters, is one of many highlights. Academia, lead by NTNU, is responsible for educating 18 PhDs and eight Postdocs of which 11 has already started and another five are associated with the BIGCCS Centre. In 2010 the Scientific Committee was established, comprising world-leading experts in the main fields covered by BIGCCS.

Our efforts focus heavily on partner interaction. This is one of the main keys in fulfilling one important goal of BIGCCS, namely contribute to novel technologies and large-scale implementation of CCS. Thanks to our always engaged industry partners, we are challenged to have the end-users perspective in mind when planning and performing the research.

The Centre management group (CMG) together with the Task leaders has developed a roadmap pointing at each tasks objectives, achievements and potential innovations and spin-offs in the years to come. The CMG have developed to become a strong team and strategic discussions are taking more of our time compared to the first year were focus was directed towards developing and establishing the operation of the Centre.

The BIGCCS team is strong and a pleasure to work with. I look forward to the continuation.

Centre Director
Mona J. Mølnvik
(Photo: Gry Kari Stimo)

3. SUMMARY

The vision of BIGCCS Centre is to contribute to the ambitious targets in the Climate Agreement adopted by the Norwegian Parliament in February, 2008. The main objective is to develop knowledge and technology to enable sustainable power generation from fossil fuels based on cost-effective CO_2 capture, safe transport, and underground storage of CO_2. The research topics covered by the Centre require in-depth studies of fundamental aspects related to capture, transport, and storage. In-depth research relies on a dual research methodology for which both laboratory experiments and mathematical modelling are employed. The Centre has a special focus on enhancing exploitation of results, innovation, and value creation.

BIGCCS is set up with a General Assembly, a Board, a Scientific Committee, an Exploitation and Innovation Advisory Committee, and a Centre Management Group. Technical committees are established for the different Sub-projects. The Centre has 22 partners; 10 industrial, nine from research, and three universities. Partners come from different parts of the industry value chain, and represent both multinational and leading Norwegian companies. Cooperation takes place in specified project, tasks, and in joint meetings.

The Centre has a matrix structure with five different Sub-projects (SPs), where the two latter are horizontally oriented and integrating the first three: SP1 – CO_2 Capture, SP2 – CO_2 Transport, SP3 – CO_2 Storage, SP4 – CO_2 Value chain, and SP5 – Academia.

In terms of **research activities**, 2010 has been a year according to plans. With minor deviations, deliverables and publications have been produced. The number of scientific journal publications is somewhat delayed, and can be related to a late start of many of the PhD/postdoc candidates. **Recruitment** increased significantly in 2010, and the Centre is now ahead of schedule. BIGCCS is pleased with the experience from the technical meetings held for each Sub-project. In this way we have managed to involve industry participants deeper in both en planning and the execution of research activities. A useful tool in this respect has been the development of a technology roadmap for each of the research tasks.

On the **organizational side**, 2010 saw the establishment of the Scientific Committee. With world leading experts as members, covering all BIGCCS Sup-projects, the Scientific Committee is expected to be a useful voice in terms of strategic planning. GDF Suez, the world's largest natural gas purchaser, joined the Centre.

On the **international arena**, BIGCCS found it rewarding to be actively involved in: a *China-Norway seminar on CCS* during the EXPO2010 (Shanghai) and the *Transatlantic Science Week* (Washington DC). The Centre also has a central role in organizing the *6th Trondheim Conference on CCS Capture, Transport and Storage*.

A strategy for **innovation and centre building** was developed in 2010. This strategy points out ambitions, objectives and necessary steps of importance for BIGCCS in becoming an internationally acknowledged centre for CCS research and innovation.

BIGCCS places importance in **communication and dissemination** of results to abroad audience. The website and popular science publications are two important strategies. Furthermore, an animation movie was produced, with the aim of explaining the CCS concept and what BIGCCS is about.

One thing is more important to the host institution than the results from the Centre, namely the safety and well-being of all partner individuals. Consequently, **'health safety and environment'** is treated seriously in all aspects of the Centre. With the exception of one minor incident without injury to personnel, 2010 confirms that our systematic efforts are paying off.

4. VISION AND GOALS

VISION

The vision of the BIGCCS Centre is to contribute to the ambitious targets in the Climate Agreement adopted by the Norwegian Parliament in February, 2008.

OVERALL OBJECTIVE

The BIGCCS Centre will enable sustainable power generation from fossil fuels based on cost-effective CO_2 capture, safe transport, and underground storage of CO_2. This will be achieved by building expertise and closing critical knowledge gaps in the CO_2 chain, and developing novel technologies in an extensive collaborative research effort.

TANGIBLE OBJECTIVE

To pave the ground for fossil fuel based power generation that employ CO_2 capture, transport and storage with the potential of fulfilling the following targets:

- 90 % CO_2 capture rate
- 50 % cost reduction
- fuel-to-electricity penalty less than 6 percentage points compared to state-of-the-art fossil fuel power generation

SCIENTIFIC OBJECTIVE

To provide crucial knowledge and a basis for technology breakthroughs required to accelerate the development and deployment of large-scale CCS enhanced by comprehensive international co-operation. The fulfilment of this objective relies on long-term, targeted basic research of high scientific quality, professional management, and international user/partner involvement.

TECHNOLOGICAL OBJECTIVE

To foster future innovation and value creation within CCS technologies along the whole CO_2 value chain. To create the basis for new services and products for the user partners originating from the centre activities ranging from novel separation technologies to value creation from transport and storage on the Norwegian Continental Shelf.

RECRUITMENT OBJECTIVE

To recruit and educate personnel, of which 50% are women, with first-class competence within CCS-related topics (18 PhDs, 8 post-docs, 50 MSc graduates) to ensure recruitment both to industry and research institutions.

SPECIFIC OBJECTIVES

The following specific scientific objectives have been defined for the BIGCCS Centre:

Capture and systems: Explore novel techniques for pre-combustion, post-combustion and oxy-fuel CO_2 capture, including both new and retrofit technologies contributing to cost reductions focusing on increased efficiency in CO_2 separation by:

- Development of high-temperature membranes and sorbents, and precipitating solvent systems characterised by improved capacity, minimum degradation and a benign environmental impact.

- Continuation the development efforts in the pre-combustion and oxy-fuel combustion area for key enabling technologies. Contribute to cost reductions through increased gas turbine efficiency and thus plant efficiency.
- Assessments of advanced CO_2 capture techniques to the benefit of other energy intensive industries and offshore applications.
- Enhancement innovation and value creation by evaluating the realisation potential of novel CO_2 capture technologies and identify the main challenges to be faced when integrating these with industrial processes and point out directions for further research related to the CO_2 capture technology development.

Transport: Develop a coupled fluid-material fracture assessment model to enable safe and cost-effective design and operation of CO_2 pipelines by improving the fundamental understanding of the interaction between the mechanical and fluid dynamical behaviour.

Storage: Development of in-depth knowledge enabling long-term and safe storage of CO_2 by:
- Qualification and management of CO_2 storage recourses by generating fundamental knowledge through interpretation of geological data from wells, geophysical data and understanding of basin history.
- Developing the understanding and description of interactions of CO_2 with the storage volumes to give the scientific basis required for establishing safe geological CO_2storage.
- Improving CO_2 storage safety by combining geophysical monitoring methods with reservoir fluid flow simulations to reduce the uncertainties of time-lapse geophysical measurements. Improve detection and quantification of possible CO_2 leakage rates from geological storage, and describe preventive and corrective actions to handle potential leakages.

ROADMAP

During 2010, a technology roadmap has been developed. The intention with the roadmap is that each task, in a simple way, manages to visualize where the different technologies are at present (state-of-the art), and how they will develop during the course of the Centre period. The roadmap will be updated on an annual basis.

5. RESEARCH PLAN AND STRATEGIES

RESEARCH APPROACH

The research topics covered by the BIGCCS Centre require in-depth studies of fundamental aspects related to CO_2 capture, CO_2 transport, and CO_2 storage. In-depth research relies on a dual research methodology for which both laboratory experiments and mathematical modelling are employed. The modelling and experimental activities share the same theory or hypotheses, and seek answers to the same questions from different points of view. There is a two-way coupling between the modelling and experimental work: Experiments are necessary for developing and verifying models. At the same time, developing and understanding models will lead to an improved understanding of the described phenomena.

In the BIGCCS Centre, research will take place within international networks of scientists, including the participation of world-class experts. The emphasis will be on building of expertise through quality research at a high international level, both within the research tasks, the post-doctoral work, and through the education of PhDs. New knowledge will in part be gained through an integrated assessment where the realisation potential of novel CO_2 capture technologies is revealed when these are integrated with industrial processes, supporting the development of research strategies for the Centre. In CO_2 transport, the combination of theories and models describing pipeline fracture resistance and CO_2 fluid dynamics requires a coupled analysis of the problem using different numerical simulation methods that will create improved understanding of the two-way influence between the CO_2 fluid and the pipeline. In CO_2 storage, the basic knowledge of CO_2 behaviour in the reservoir and rock mechanics when influenced by CO_2 will be used in aggregated reservoir and basin models.

METHODS FOR INNOVATION

The BIGCCS Centre is developed with special focus on enhancing exploration, innovation and value creation. Since innovation has often proved to occur in the interface between disciplines, and is an area of research itself, the Centre has a separate activity lead by Studio Apertura (NTNU Social Research). The responsibility of Studio Apertura is to develop and follow up an innovation assessment process to ensure that the attention in the BIGCCS Centre research tasks is also on the potential commercial value of technology. The research tasks are organised to increase interaction between disciplines and expert groups.

Creative workshops, the Consortium Day, and the Exploration and Innovation Advisory Committee will enhance innovation. In addition, the three phases of the Centre period, of which the first two end with an evaluation and recommendation for the next phase, will direct the Centre towards fields of promising research and ideas. Overall, the research-based transfer of knowledge and technology will enhance the potential for innovation and value creation, hence this emphasis on innovative technologies with a potential for enabling CCS ensures that the concept of additionality is fulfilled.[1]

[1] Additionality as described in Kyoto's Clean Development Mechanism, i.e. the measure would not have been realised without the incentive provided for it by the mechanism

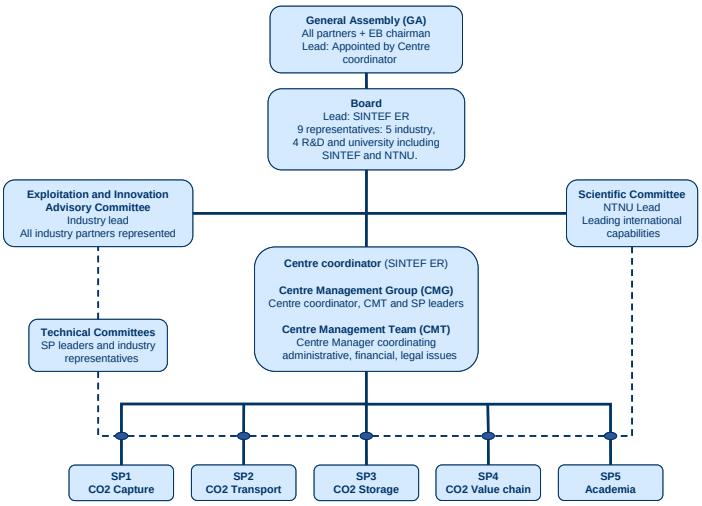
6. ORGANIZATION

The BIGCCS Consortium is made up of highly ranked research institutes and universities, and strong industry partners that include international oil and gas companies, energy companies, process industry, engineering companies, and CCS technology vendors. All the partners in the BIGCCS Centre are major players within CCS, and will have extensive CCS activity also outside of the Centre. By strengthening the competence building and technological development through industry involvement, the BIGCCS Consortium is built to secure the premises for innovation and value creation.

6.1 ORGANIZATIONAL STRUCTURE

GOVERNANCE STRUCTURE

The BIGCCS Centre is organised along topically oriented research areas. In order to manage this large interdisciplinary research centre, a management framework is set up to ensure autonomy, information exchange, governance, and clearly defined responsibilities. The governing structure is shown in the figure below.

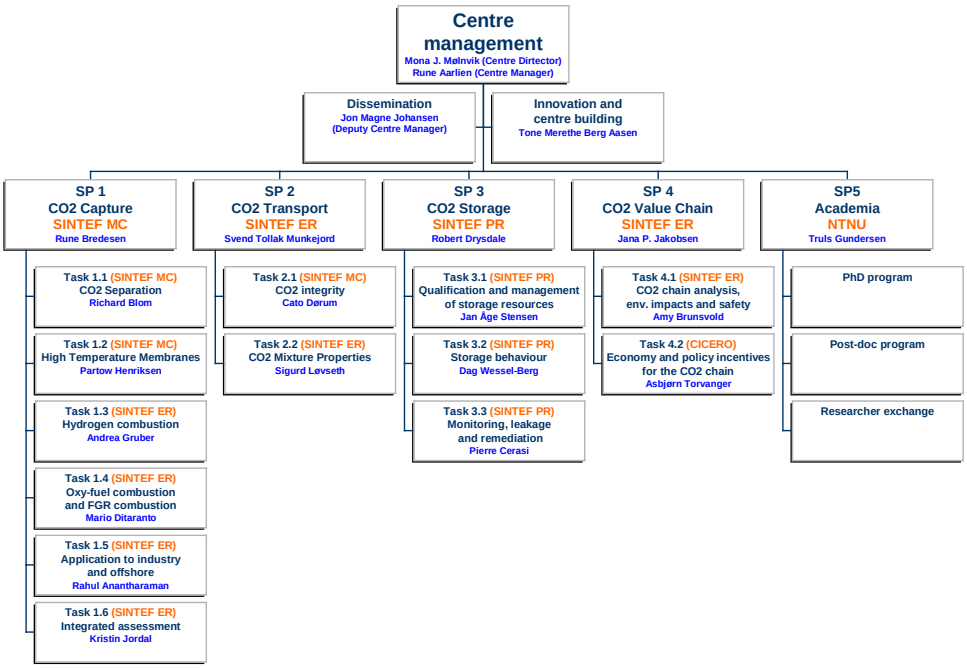


BIGCCS governance structure

- **Sub-project (SP) leaders:** coordinating the research tasks of the sub-projects.
- **Task leaders:** preparing plans and executing the research in accordance with budgets and deliverables defined in approved task plans and within the Centre contracts.
- **Scientific committee:** advisory committee with leading international academic capabilities giving guidance to the Centre towards the scientific progress.
- **Exploitation and Innovation Advisory Committee:** includes all user partners of the Centre, evaluating the commercial potentials of evolving technology and identify opportunities for spin-off projects.
- **Technical Committee(s):** advisory committees established for specific research topics to ensure knowledge transfer between Centre partners and will include representatives both from R&D providers and industry.
- **Centre Management Team (CMT):** responsible for the day-to-day operations.
- **Centre Management Group (CMG)**: includes CMT and the SP leaders, responsible for carrying out the operations of the Centre.
- **Board**: operative decision-making body of the Centre.
- **General Assembly**: ultimate decision-making body, ensuring that operations are carried out in accordance with the Consortium Agreement.

WORK BREAKDOWN STRUCTURE

The work breakdown structure is shown in the figure below.



BIGCCS work structure breakdown

The BIGCCS Centre is built as a matrix organisation, where all activities supporting the ambition of the Centre will be coordinated, evaluated, and reported. The Centre management will conduct centre-specific strategic activities for releasing the full potential of the Centre:

- **Centre building and distributive work processes**: The objectives are to clarify expectations, to facilitate development of the overall plans for the Centre, and to facilitate distributed work processes. In particular, the tasks *Integrated assessment* and *CO_2 chain* rely on close collaboration with the other tasks. Another aim is to establish arenas for building personal relations and knowledge exchange to release the added value of the Centre, *e.g.*, annual Consortium Days, technical meetings and active use of the BIGCCS Intranet for sharing information.
- **Promoting innovation:** Actions will be to raise the consciousness of the partners pertaining to the identification of opportunities for innovation and to facilitate creative workshops where research challenges are combined with the complementary comprehensions of the Center partners in order to release the potential for overcoming scientific hurdles. Assessments of research results from the subprojects will also be presented as a basis for the expert panel of industry representatives to evaluate the commercial potential of evolving technologies.
- **Synthesis of Centre results:** The Centre management coordinates a collaborative task for synthesis of Centre results measured against the scientific and technological objectives. By the end of the proposed Centre period, this task will provide recommendations on paths for potential innovation and value creation as well as for future R&D within CCS. A public version will be made available and will serve as a major deliverable from the Centre. The task will also conduct a scientific review of all Centre activities and prepare decision basis for Board to consolidate activities and budgets before Phase II and Phase III of the BIGCCS Centre.

During 2010, one new task (2.2 – CO_2 mixture properties) was included in BIGCCS. The aim with this project is to provide accurate experimental data in selected thermo-physical properties of CO_2-rich mixtures relevant for CCS.

6.2 PARTNERS

The following organizations have been partners in the BIGCCS Centre during 2010:

INDUSTRY PARTIES:

- **Aker Solutions**: Leading global provider of engineering and construction, technology products, execution, service and integrated solutions within oil and gas and process industry.
- **ConocoPhilips Scandinavia**: Oil and gas company. Involved in several CCS R&D projects. Involved in CO_2 Capture Project (CCP2), U.S. DOE Regional Partnerships, EU programs: CO2ReMoVe, Cachet, CO2Net, and an Australian effort called CO2CRC
- **Det Norske Veritas**: Risk assessment related to CCS, involved in several R&D projects within CCS.
- **Gassco**: Operator of natural gas transport and processing systems, responsible for development of CO_2 transport concepts at Kårstø and Mongstad, CO_2 capture from industrial applications.
- **GDF Suez (joined 2010):** Europe's largest gas purchaser and the world's fifth largest power producing company. GDF Suez has four key sectors: liquefied natural gas, energy efficiency services, independent power production and environmental services, and employs 214,000 people.
- **Hydro**: Hydro is a supplier of aluminium and aluminium products. Based in Norway, the company employs 23,000 people in 40 countries and has activities on all continents.
- **Shell Technology Norway**: Oil and gas company. Involved in several R&D projects on CCS, such as Dynamis, DECARBit. Industrial partner in Test Centre Mongstad.
- **Statkraft**: Energy company. Involved in several R&D projects within CCS. A pioneer trader in 'green energy' products such as Guarantees of Origin, Renewable Energy Certificates (RECS) and CO_2 quotas.
- **Statoil**: Oil and gas company. Involved in several CCS R&D projects. Experience in CO_2 transport and storage (Sleipner, Snøhvit, In Salah), building a CO_2 capture plant at Mongstad.
- **TOTAL E&P**: Involved in several R&D projects within CCS and the Lacq CCS Regional Pilot. Partner in Snøhvit and Sleipner.

RESEARCH INSTITUTES:

- **British Geological Survey (BGS)**: World leader in science and geophysical research into the structure of underground reservoirs for CO_2. Work committed in SP3 CO_2 storage.
- **CICERO**: Global climate change, international climate policy, key policy institute for climate change.
- **Deutsche Zentrum für Luft und Raumfahrt (DLR)**: Advanced measurement techniques for combustion, large scale high-pressure combustion facilities, expertise on detailed kinetic chemistry.
- **Geological Survey of Denmark and Greenland (GEUS)**: Pioneer in CO_2 storage options, co-ordinator of the EU FP6 Geocapacity, works in opportunities for CO_2 storage in Europe, work committed in SP3 CO_2 storage.
- **Norges Geologiske Undersøkelse (NGU)**: Government agency, bedrock, mineral resources, surficial deposits and groundwater.
- **NTNU Social Research**: Organisation and management structure development. Work processes and innovation. Studio Apertura is involved in the Centre building and innovation processes.
- **SINTEF Energy Research (Host Institution)**: Thermo and fluid dynamics, combustion, modelling, modelling and integration. Project coordination and management. Major European R&D provider within CCS.

- **SINTEF Petroleum Research**: Petroleum and reservoir technology, geo sciences. Modelling of possible escape from stored CO_2, long- and short-term behaviour of CO_2 in the geological environment.
- **SINTEF - SINTEF Materials and Chemistry**: Thermo-chemical conversion, process simulation and optimization; chemistry; materials synthesis, characterization and development.

UNIVERSITIES:

- **Norwegian University of Science and Technology (NTNU)**: Thermo-chemical conversion, chemistry, unit and process modelling and integration, petroleum and reservoir technology, geo sciences.
- **TU München (TUM)**: Combustion – experiments and modelling, specialised in reactive flows, transport phenomena and thermo acoustics. Cooperation with Alstom, highest ranked "university research" university in Germany.
- **University of Oslo (UiO)**: Thermo-chemical conversion, chemistry.

6.3 COOPERATION BETWEEN PARTNERS

TASKS

Cooperation between the research and industry partners takes place at the Task-level. Task leaders coordinate activities and organize separate meetings between the relevant partners. Typically, researchers find "demanding" and active partners extremely stimulating, and therefore emphasis in 2010 has been on stimulating interaction between partners.

SUB-PROJECTS

Sub-Project leaders coordinate the efforts of the different Tasks. At least two joint meetings are held annually for all sub-project and task leaders with focus on developing research strategies and on organizational issues. In 2010, such meetings were held both with and without industrial partners. In order to stimulate the work within the different Sub-Projects, there is a possibility to establish for each SP a Technical Committee (TC) consisting of partner representatives. The aim is to challenge and advise the researchers on technical issues.

CONSORTIUM DAY

The Centre organizes one Consortium Day annually in May. At this event all Tasks, Sub-Projects, and partner institutions are invited, and the intention is to provide a snapshot of last years' activities and results. The 2010 Consortium Day was held at Ringve in Trondheim, Norway, on May 26 and attracted approximately 70 attendees.

TECHNICAL MEETINGS

In connection with the annual Consortium Day in May, a separated day was set aside for technical meetings (May 27). The different Sub-projects organized meetings open for all consortium partners with the aim of discussing progress and plans. All together, these five meetings attracted more than 50 attendees.

CENTRE MANAGEMENT GROUP

The Centre Management Group (CMG) consists of the SP leaders, leaders for the centre building and dissemination activities, the Centre Director and the Centre Manager. Representatives from SINTEF Energy Research, Petroleum Research, Materials and Chemistry, as well as NTNU Social Research are present. The CMG held 22 meetings during 2010. The focus of the CMG is to ensure that the annual work programme is carried out according to plan, and to oversee the day-to day operations.

7. RESULTS FROM RESEARCH ACTIVITIES

7.1 CO_2 CAPTURE – SP1

SP1 consists of the following six tasks:

- Task 1.1: CO_2 separation
- Task 1.2: High temperature membranes
- Task 1.3: Hydrogen combustion
- Task 1.4: Oxy-fuel combustion and flue gas recirculation combustion
- Task 1.5: Application to industry and offshore
- Task 1.6: Integrated assessment

Task 1.1 - CO_2 separation. The dynamic behaviour of a solvent based-capture process in an operating power plant is modelled to improve post combustion processes. In order for CO_2 capture by precipitation processes to give higher cyclic absorption capacities, smaller processes and less capital cost compared with non-precipitating absorbent systems, several precipitating systems have been tested that give leads towards novel solvent systems. Also, CO_2 capture at high temperature by solid sorbents which may improve efficiencies are studied along three different lines: 1) theoretical thermodynamic evaluation of possible new sorbents, 2) description and evaluation of two important but different processes that employ sorbents for CO_2 capture at 600-900°C (post-combustion carbonate looping and pre-combustion by sorbent enhanced steam methane reforming), and 3) synthesizing and testing of new materials for CO_2 capture using model gas mixtures in an automated test rig in long-term experiments.

Task 1.2 - High temperature membranes. Water-based extrusion of porous supports with length 10-100 cm for tubular hydrogen transport membranes (HTMs) employing a new ram extruder is established. The procedure involves several steps: conditioning of powders, selection of rheology modifiers, milling, extrusion, drying of extrudates and annealing of tubes. Effects of temperature and additives in the pastes are currently studied to establish correlation with the processing parameters and the properties of the produced tubes. Based on this analysis, porous tubes are successfully produced with various microstructures and porosity. This task cooperates in educating two PhD candidates (from 2010). One at the University of Oslo and one candidate at NTNU in Trondheim have started their educations.

Task 1.3 - Hydrogen combustion. A very accurate and computationally expensive numerical simulation technique (Direct Numerical Simulation or DNS) is used to study the way hydrogen flames can propagate upstream of the combustion chamber into the premixer section of the burner where no flame is allowed by design. An experimental study is also conducted in parallel at TU Munich aiming to investigate the same topic. A newly observed feature consists of backflow “bubbles” that characterizes upstream flame propagation only in the region of the flow very close to the burner walls. The flame seems to create its own “survival mechanism” (backflow) that helps the flame’s creeping upstream, along the burner wall, and against the main flow direction. Experimental data obtained at TU Munich revealed first the presence of these backflow “bubbles”, and were then also observed in the DNS results that can potentially allow the formulation of a sound physical explanation for the phenomenon. This so-called “wall-flashback” never represented a problem in gas turbine burners operating with natural gas, however, when hydrogen is a main fuel component, as in pre-combustion CCS routes, this type of flashback becomes potentially a difficult design issue due to hydrogen’s high reactivity. Therefore, the new knowledge acquired here represents an important step towards enabling the pre-combustion route to power generation with CCS.

Task 1.4 - Oxy-fuel combustion and flue gas recirculation combustion. Work focuses on combustion issues and technological challenges associated with the implementation of oxy-fuel

combustion and post-combustion alternatives for CCS. In 2010 several aspects have been studied: 1) An experimental high pressure combustion facility dedicated to the study of oxy-fuel combustion has been erected and commissioned. Such an installation will help understand the change in behavior of combustion systems operated in oxy-fuel mode and develop new concepts for power plants based on gas turbine cycles. 2) To evaluate the impact of retrofitting, a testing study of an oil burner adapted to oxy-fuel operation has been performed in a 90 kW standard boiler and it was showed that emissions of NOx were reduced by 19% and CO increased by 2.4% as compared to air operation. 3) Effect of unburned CO in recirculating flue gas on combustion properties studied by high pressure shock tube experiments at DLR (Germany), showed that CO concentration up to 50% in the recirculated gas mixture had only very little impact on the ignition delay time. 4) Finally, the method of exhaust gas recirculation in post-combustion capture technologies has been evaluated by cycle simulations in collaboration with Task 1.6, and showed to what extent efficiency penalties could be reduced and how the method could be technologically implemented.

Task 1.5 - CCS applications for the offshore sector and industry. The primary goal of this project is to evaluate the potential for CCS in other industries and offshore. Four representative case studies are being evaluated in detail in collaboration with our industrial partners. The case studies are CO_2 capture from: 1) gas turbines on a Floating Production Storage and Offloading (FPSO) unit, 2) fired heaters in refineries, 3) exhaust gases from aluminium smelters, and, 4) natural gas processing facility. Each of the case studies poses specific challenges that require novel approaches to develop solutions. Work done in 2010 on characterizing the CO_2 emissions from these industries and an overview of potential CO_2 capture technologies suggests that technology developed for the case studies could be used as a basis for application to other industries.

Task 1.6 - Integrated assessment. Reduction of cost through and improved efficiency in post-combustion capture may be achieved if the exhaust gas is partly recirculated to the inlet of the gas turbine combustor. Less fresh air is needed for the combustion and if half of the exhaust gas is recirculated to the combustor, the concentration of CO_2 can be doubled from around 4% to around 8%. This will reduce the energy consumption of the capture process by around 8%, which corresponds to a 0.4% increase in the overall power plant efficiency. On the one hand, the reduced oxygen concentration in the combustion chamber may have negative effects on combustion stability and completeness, but on the other, it may result in positive effects on the reductions of NO_x emissions and amine degradation.

7.2 CO_2 TRANSPORT – SP2

SP2 has two tasks:

- Task 2.1: CO_2 integrity
- Task 2.2: CO_2 mixture properties (started in 2010)

Task 2.1 - CO_2 pipeline integrity. The main objective of this task is to develop a coupled (fluid-structure) fracture assessment model to enable safe and cost-effective design and operation of CO_2 pipelines by improving the fundamental understanding of the interaction between the pipe-material and fluid-dynamical behaviour.

The research-performing partners are SINTEF ER (thermo and fluid dynamics) and SINTEF MC (structural mechanics). The development of the coupled model will proceed in close collaboration between the two research groups, and by gradual refinement. In 2010, a first, simplified, model was implemented and tested.

Two PhD candidates and one postdoc will work in this task. The first PhD candidate was employed in September 2009, and the working title of the doctoral project is "Mathematical modelling and numerical simulation of two-phase multi-component flows of CO_2 mixtures in pipes".

In 2010, the work resulted in one journal paper, two conference articles and one conference presentation.

Task 2.2 - CO_2 mixture properties. This task was planned as a KMB project. After receiving funding in 2010, it was added to BIGCCS.

This task aims to provide accurate experimental data in selected thermo-physical properties of CO_2-rich mixtures relevant for CCS. Specifically, the objective is to measure phase state (i.e., the fractions of gas and liquid) at equilibrium, density, and speed of sound for CO_2-rich mixtures. Such data are needed to calibrate thermodynamic models, which in turn are employed for designing and operating CO_2-capture and transport systems. Several important gaps have been identified in the measurement data found in the literature.

The work is a collaboration between SINTEF ER, Ruhr-Universität Bochum (RUB), and NTNU. Two PhD candidates will be educated in this task. At RUB, a PhD candidate was hired in October 2010, and has started the work on the speed of sound and density measurement. At NTNU, a PhD candidate will be hired in January 2012. The main task of this student will be to perform phase equilibrium measurements.

The work was presented at the 2010 Climit conference.

7.3 CO_2 STORAGE – SP3

SP3 consists of the following tasks:

- Task 3.1: Qualification and management of storage resources
- Task 3.2: Storage behaviour
- Task 3.3: Monitoring, leakage and remediation

Underground storage of CO_2 is the main means of disposal considered following CO_2 capture. Pockets of CO_2 occur underground naturally, trapped by various means and CO_2 has been injected underground to enhance oil production for over 30 years, so this is not an unknown concept. For CCS it is intended to store CO_2 in underground rock or sand formations containing water (i.e. aquifers) or in depleted oil or gas reservoirs. The injected CO_2 will be trapped there for thousands of years over which time it is gradually absorbed into the water and rock.

Task 3.1 - Qualification and management of storage resources. When planning a new CO_2 underground storage site it is essential to be able to estimate the storage capacity reasonably accurately, to be sure that the CO_2 will be contained effectively and to understand what will happen to the CO_2. These aspects need more attention when an aquifer is to be used for storage than as a depleted oil or gas reservoir, since the properties of the latter will have been understood during the previous years of production.

One aspect currently under investigation is the effect of the open-ended nature of aquifers on storage capacity. At one extreme if the aquifer is fully open-ended, i.e. fully connected to large neighbouring permeable formations, then it is expected that large amounts of CO_2 can be injected without significant pressure rise in the storage aquifer. On the other hand if the aquifer is closed at its periphery e.g. due to geological barriers, then it can be expected that injection of CO_2 will result in a build-up of pressure that will limit the amount of CO_2 that can be injected.

The ultimate storage capacity in these two extremes can differ by several orders of magnitude, with serious implications for the viability of the storage site.

Storage sites depend on having a reliable seal above the aquifer, to prevent the CO_2 migrating upwards and escaping to the surface. This seal is usually in the form of another rock layer that is impermeable to CO_2, i.e. known as the caprock. However, there is a risk that even though the caprock may be impermeable initially, injection of CO_2 may cause fractures to form or open existing faults, thus generating leakage paths. Work is ongoing to develop an analytical model to predict such failure in the caprock due to changes in pressure caused by injection.

Industry and governments require guidelines for qualification of potential underground storage sites for CO_2. This is being addressed by the review of existing guidelines and developing a systematic risk-based approach to qualification, with the aim of providing a basis for verification and certification of storage sites.

Task 3.2 - Storage behaviour. Although the occurrence of CO_2 underground is not new, the success of CO_2 storage is dependent on having a good understanding of small-scale mechanisms such as mobility, trapping and dissolution of CO_2, as well as any possible effects on the aquifer rock or caprock.

One area of work is aimed at improving the understanding of the basic chemical reactions between the CO_2-water solution and the minerals of the rocks. Several series of laboratory experiments are underway, some of them up to seven years long, which investigate dissolution of the rocks, any deterioration of the mechanical strength of the caprock, the release of trace elements and the effect on the flow properties of the aquifer rock. The results of this fundamental work may have impact on the evaluation of the sealing and storage potential of prospective underground storage sites.

Another interesting subject is the development of a predictive model for convection of CO_2-rich water within the aquifer. The results so far suggest that when CO_2 dissolves in saline water it will mix convectively with virgin water, thus increasing the rate of CO_2 absorption considerably. The net effect would be that a much higher rate of CO_2 injection would be possible than previously believed.

Task 3.3 - Monitoring, leakage and detection. Besides simulation, the complementary approach to managing CO_2 stored underground is by utilizing effective monitoring methods. These would be used to verify that the CO_2 is where it is expected to be, i.e. to confirm the simulation forecasts and also to warn of leakage, in time to allow contingency measures to be activated.

Several established techniques for monitoring of underground water, oil, gas reservoirs are suitable candidates for application to CO_2 storage. The ongoing work in the area has concentrated on developing several specific techniques for processing seismic data in order to track the underground movement of CO_2 and to increase the imaging resolution of very thin CO_2 layers.

Laboratory work has also begun to investigate how the seismic properties of the caprock vary with changing stress (pressure) and CO_2 content. The goal of this work is to enhance monitoring of CO_2 movement and possibly to give an indication of changing caprock integrity with respect to leakage.

7.4 CO_2 VALUE CHAIN – SP4

SP4 has two tasks:

- Task 4.1: CO_2 chain analysis, environmental impacts and safety
- Task 4.2: Economy and policy incentives for the CO_2 chain

Task 4.1 - CO_2 chain analysis, environmental impacts and safety. The aim is to use the common framework for CCS chain assessment including analysis of techno-economic criteria, risk, and environmental impacts associated with CCS chains. In 2010, the structure of the common framework (for Tasks 4.1 and 4.2) was further developed in the second SP4 workshop and led to a paper, "Comprehensive Assessment of CCS Chains – Consistent and Transparent Methodology" presented at GHGT-10.

Important achievements on the level of the particular working package activities were:

- Workshop held within SP4 to established common understanding of interrelationship between the research tasks in SP4.
- Qualitative study of how implementation of CCS affects operational flexibility of fossil fuelled power generation was performed.
- Components and systems in the value chain were mapped and an LCA-model was developed to aid in determining the global warming potential (GWP) of CCS chains and components.
- Mapped state-of-the-art in risk management models, ongoing projects, etc.
- Developed the main principles of the conceptual model for rational acceptance criteria settings for CO_2 chains.

Task 4.2 - Economy and policy incentives for the CO_2 chain. The aim is to develop scenarios for CCS development and deployment and to develop a stochastic model for investment decisions. This work will improve stakeholders' understanding of possible future value of CCS technologies and therefore also provide a better knowledge basis for spending money on R&D on CCS and investments in such technologies.

Single companies typically invest too little in new technologies because they only consider the value for the company, whereas improved technologies have a value for other companies and the whole society. Therefore, sufficient investments require governments support. Learning effects, whereby the cost per unit produced by the new technology falls over time as more investments in the technology are made, implies support for one or a few technologies to save costs. On the other hand uncertain future payback from investing in a specific technology points to support for many technologies to hedge against the risks involved. Taken together these factors and various national circumstances lead to a recommendation that a government should support a focused portfolio of emerging technologies.

If a government introduces a strict CO_2 emissions rate performance standard for electricity generation, this will require installation of CCS on fossil-fired plants and thus affect investment choices. In this setting, three policy options can be compared: 1) a strict standard, 2) a flexible standard that imposes a surcharge for emissions in excess of standard, and 3) an even more flexible standard that allows the surcharge revenue to fund later CCS retrofits. Results indicate that increasing flexibility leads to the earlier introduction of CCS, lower aggregate emissions, and higher profits for the electricity generation plants.

In 2010, the major results were summarized in three deliverables:

- Technical report on flexible mandates for investment in carbon capture and Storage
- Journal article on the political economy of technology support
- Technical report on policy measures to support CCS invention, innovation and dissemination

7.5 ACADEMIA – SP5

The delay in recruitment of PhDs and Post-docs in 2009 (only one PhD student was recruited) has been more than compensated for during 2010. A total of 10 PhD students and two postdocs were recruited. One PhD student resigned after a few months, but has (in 2011) been replaced by a new candidate. This means that we have recruited a total of 12 researchers by the end of 2010, two are females. This will improve during 2011 since one female PhD student started in January 2011, and one female postdoc has signed a contract. In addition, UiO is funding one PhD student (female) as an "in kind" contribution. We also have two "associated" PhD students at University of California, Berkeley (UCB), and one "associated" PhD student at Ruhr University, Bochum (RUB). The total work force by the end of 2010 is therefore 16, where 14 are PhD students.

The volume of publications in 2010 is modest due to the fact that most of the candidates started around mid 2010 and are involved in compulsory courses that are part of the PhD program at NTNU. For the PhD students and postdocs in BIGCCS, not counting the "associated" PhDs from UCB and RUB, a total of tree journal publications and four conference papers were published in 2010. These numbers are expected to increase considerably during 2011 and 2012.

Regarding highlights from the research activities that the PhD students and postdocs are involved in, these are more appropriately reported under the headings of the relevant Sub-Projects (SP1-SP4).

8. INTERNATIONAL COOPERATION

International cooperation is a central and integrated part of the BIGCCS Centre activities. Through the participation of strong European industry partners and highly ranked international R&D providers in the Consortium, the BIGCCS Centre has a high international profile. Seven nations are currently represented, including the industrial international participation of *ConocoPhillips* (USA/Norway), GDF Suez (France/Norway), *TOTAL* (France/Norway), *Shell* (Netherlands/Norway), and the active collaborative contributions of the research institutes DLR (Germany), TUM (Germany), GEUS (Denmark), and BGS (UK). In addition, several research groups work in close collaboration with researchers from other international research institutes and universities. The partners play active roles within the various research tasks, and as members of the Committees. Below are listed some of the 2010 activities.

COOPERATION WITH INTERNATIONAL RESEARCH GROUPS OUTSIDE BIGCCS

SINTEF Energy Research has established a contract with University of Berkley (California, USA) where SINTEF ER will provide partial funding for two PhD candidates. Headed by Professor Robert Dibble, University of Berkley is one of the world leading research groups on combustion. The intention is that this cooperation will be included in the BIGCCS Centre. Studying turbulent combustion, the PhD candidates have already started their projects.

SINTEF ER has also established a close collaboration with the Combustion Research Facility at Sandia National Laboratory, USA, which is the U.S. Department of Energy's premier site for broad-based research in combustion technology. Of great value to researchers and students is the commitment and guidance of the world-class experts Drs. Jackie Chen and Alan R. Kerstein. A formal collaboration agreement between SINTEF ER and Sandia NL is established, and the aim is that also this partnership will be included in the BIGCCS Centre.

COOPERATION WITH INTERNATIONAL ORGANIZATIONS

No formal cooperation is yet established, however, BIGCCS personnel are actively participating in activities spearheaded by the following international organizations: International Energy Agency, The European Energy Research Alliance, Global CCS Institute Australia), National Institute of Advanced Industrial Science and Technology (Japan), CORIA-Université de Rouen (France), Corning S.A. (France), Air Liquide (France), SGU (Sweden), TNO (the Netherlands), IFP (France), Colorado School of Mines (USA), and Freie Universität Berlin (Germany).

ORGANIZATION OF CONFERENCES, WORKSHOPS AND SEMINARS

BIGCCS personnel have participated in the organization of the following events:

- China-Norway seminar on CCS at the World Expo 2010 in Shanghai (May). Aiming at establishing cooperation in education and R&D between the two countries, the seminar was organized by the Norwegian Research Council in cooperation with the CEERs BIGCCS and SUCCESS.
- Science Week in Washington D.C. (October). BIGCCS shared the responsibility of organizing one of the parallel sessions.
- IEA Summer School at Svalbard (August). BIGCCS contributed with organizational efforts.
- South African CCS delegation visited SINTEF and NTNU. BIGCCS organized the visit. In the aftermath, at least two South African corporations are considering BIGCCS membership.

SCIENTIFIC COMMITTEE

The BIGCCS Scientific Committee (SC) was established in 2010, and held its first meeting in August in conjunction with the GHGT-10 in Amsterdam. Chair of the Committee is Professor May-Britt Hägg (Chemical Process Technology, NTNU, Norway). Committee members are:

- Sally M. Benson Stanford University, USA
- Susan D. Hovorka University of Texas at Austin, USA
- Alan Kerstein Sandia National Laboratories, USA
- Gary T. Rochelle University of Texas at Austin, USA
- Per Morten Schiefloe NTNU, Social Research, Norway
- Mathias Wessling University of Twente, Netherlands
- Forman A. Williams University of California at San Diego, USA

The SC will report back to the BIGCCS Board in 2011.

9. RECRUITMENT

The aim is for BIGCCS to produce 18 PhDs and 8 Postdoc candidates. A total of 10 PhD students and two postdocs were recruited in 2010.

One PhD student resigned after a few months, but has (in 2011) been replaced by a new candidate. This means that we have recruited a total of 12 researchers by the end of 2010, two are females.

The gender imbalance in recruitment will be somewhat rectified during 2011 since one female PhD student started in January 2011, and one female postdoc has signed a contract. In addition, UiO is funding one PhD student (female) as an “in kind” contribution.

BIGCCS also has two “associated” PhD students at University of California, Berkeley (UCB), and one “associated” PhD student at Ruhr University, Bochum (RUB). The total work force by the end of 2010 is therefore 16, where 14 are PhD students.

10. COMMUNICATION AND DISSEMINATION

BIGCCS seeks to be a source for objective information on status and potentials of CCS at several levels, i.e. for the research community, for decision makers, and for the public. Different instruments and communication channels are used for the different target groups. Below is highlighted some of the work carried out in 2010.

CONFERENCES

The BIGCCS Centre receives a high public profile by organising bi-annually *The Trondheim Conference on CO_2 Capture Transport and Storage*, which has become a major scientific CCS conference. BIGCCS has a central role in organizing the next conference in 2011. It is also the ambition of the BIGCCS Centre to take an active role in the organization one of the next *GHGT*-conference. A joint NTNU-SINTEF expression of interest was submitted in 2010 to host the GHGT-13 in 2016. BIGCCS was among the single most visible entities at the GHGT-10 in Amsterdam in August. With three oral papers, and seven posters presented in a common format, BIGCCS stood out and received attention.

WEB

An Internet homepage has been established for the Centre, see: www.bigccs.no. The page includes sub-pages titled: partners, sub-projects, events, news, publications, links, recruitment, and contacts. The intention is that this web-page will contain information relevant to all BIGCCS target groups.

POPULAR SCIENCE

Aiming at disseminating information also to the broad public, the popular science format is important. Based on a visit and interviews conducted in 2009, a feature article appeared in *Illustrated Science* (*Illustrert Vitenskap)* in July, 2010. This magazine has a circulation of 600,000. Furthermore, articles appeared in *IEAGHG Newsletter*, *Climit Newsletter* and *Teknisk Ukeblad*. For a comprehensive overview of articles see the Attachment section.

ROADMAP

For the purpose of communicating goals, strategies, and technology developments in the BIGCCS Centre, a technology roadmap has been developed. The intention with the roadmap is that each task, in a simple way, manages to visualize where the different technologies are at present, and how they will develop during the course of the centre period. The roadmap will be updated on an annual basis.

CCS Animation Movie

A CCS animation movie has been produced. Aiming at a broader audience the movie seeks to explain the concept of CCS, and what BIGCCS is about. The movie was officially launched in 2011, and can be found on the BIGCCS web (www.bigccs.no).

BOARD MEETINGS

BIGCCS held three Board meetings in 2010:

- January 26, Trondheim
- May 27, Trondheim
- November 23, Trondheim

PRESENTATIONS

Information on the BIGCCS Centre has also been given at a series of meetings and seminars, both nationally and internationally. Some of them are:

- EXPO2010, Shanghai, May 21-22
- GHGT-10, Amsterdam, August 19-23
- ONS2010, Stavanger, August 24-27
- NEEREC pre-Conference, Oslo, September 27
- COMBI2010, Finland, October 7-10
- Climit Days, Oslo, October 12-13
- The Transatlantic Science Week, Washington DC, October 18-21

A complete listing of all 2010 publications is found on page 30 in this report.

11. INNOVATION AND CENTRE BUILDING

The ambitious targets in the Norwegian Climate Agreement imply a need not only for extensive research, but also for turning the research results into widespread practices. Implicitly, research must be innovation-oriented, meaning that focus must be on the potentialities of research results in BIGCCS tasks, as well as purposeful cooperation between research communities and industrial partners. For this reason, a *Strategy for centre development*, including innovation, was completed by the BIGCCs Centre Management Group in May, 2010. The strategy document points out ambitions and objectives that are of importance to move towards the realization of BIGCCS Centre as an internationally acknowledged centre for CCS research, and outlines necessary steps towards reaching this target:

- *Internationalization*. The BIGCCS Centre has an ambition to become an internationally recognized hub for outstanding CCS research.
- *Dissemination*. The ambition is to extensively communicate results from the Centre on various arenas. BIGCCS will be a public source for objective information on status and potentials of CCS, and will follow up on questions concerning public awareness and acceptance.
- *Innovation*. The BIGCCS ambition is to facilitate future innovation and value creation within key technologies along the CCS value chain, increasing the competitive edge of partner companies.
- *Academic education*. The ambition is to recruit and educate the planned number of candidates, and to integrate BIGCCS research activities within Academia as part of the centre activities.
- *BIGCCS Centre work processes*. The ambition for the BIGCCS Centre Management Group is to develop work processes and routines which encourage active cooperation between innovative industry, public administrative bodies, and prominent research institutions. A particular focus will be on the quality of research, the promotion of research-based innovation, and on new opportunities emerging within and in the interfaces between current fields of R&D.

The five strategic areas should be seen as interdependent activities, which complement the technical objectives set for the centre. Together, the scientific and innovation-oriented activities form important means to approach the target of substantially reduced CO_2 emission.

In BIGCCS, NTNU Samfunnsforskning, Studio Apertura, assumes a particular responsibility for the continued focus on innovation processes. The task includes the exploration of BIGCCS experiences as basis for academic and popular science contributions within the fields of research and innovation management. In 2010, this activity resulted in one conference paper, and a feature article:

- Aasen, T.M.B.; Amundsen, O.; Mølnvik, M. & Tangen, G. (2010) *Innovation in Transdisciplinary and Heterogeneous Collaborations: Exploring new ways of Organizing Environment-friendly Energy Research*. Paper presented at the Helsinki Combi 2010 conference
- Olsen, M.S; Aasen, T.M.B & Røyrvik, J.: *Måneformørket klimadebatt* ('Climate debate eclipsed by the moon'). Feature article published in Norwegian in Klima, februar 2011

12. HEALTH, SAFETY AND ENVIRONMENT

As the overall objective of the BIGCCS Centre is to enable sustainable power generation from fossil fuels based on cost-effective and safe CO_2 capture, transport and storage, the environmental impacts are imbedded in the objective since the main focus is in-depth knowledge and technologies for GHG avoidance. For the Centre, a 90% CO_2 capture rate is targeted. Although this emission is far less than conventional gas power generation, a 10% emission rate may have some environmental impact. In SP4, *CO_2 value chain*, application is used of Life Cycle Assessment (LCA) methodology for analysing environmental impacts throughout the CO_2 chain associated with alternative scenarios for CCS deployment.

The project involves no experiments with persons, no personal data, and no risk for humans, animals or nature. There is nothing about the means or methods in the project that violates the values of society.

As Host Institution, SINTEF Energy Research conducts all its projects in line with NORSOK Standard S-006, "HSE Evaluation of Contractors", and the Consortium Agreement commits the partners to use HSE regulations in line with the NORSOK Standard. This includes a stringent evaluation of criteria and guidelines of environmental impacts of activities.

FIRST THINGS FIRST

All BIGCCS meetings have HSE as the first agenda item. As a minimum, fire escape routes are explained. Also, the Consortium Agreement requires all Partners to report immediately and without undue delay to the Host Institution any accidents, incidents or near misses in connection with BIGCCS activities. This issue is dealt with at each Board meeting.

CONTINUOUS REPORTING OF ACCIDENTS, INCIDENTS AND UNDESIRED CONDITIONS

SINTEF has implemented *Synergi* as an integral part of its systematic HSE work. This is a web-based system where all employees can report on a continuous basis any kind of accidents, near misses, observations, dangerous conditions, non-conformance and improvement proposals. Each BIGCCS meeting starts with a discussion of such reports and conditions that should have been reported

HES ANNUAL REPORT

Based on a suggestion for the Board, a separate HSE annual report will be produced. The first one will be issued for 2010.

ATTACHMENTS

ATTACHMENT 1: PERSONNEL

ATTACHMENT 2: ACCOUNTING REPORT

ATTACHMENT 3: PUBLICATIONS

A1. PERSONNEL

KEY RESEARCHERS

Name	Institution	SP	Main Research Area
Bredesen, Rune	SINTEF MK	1	Membrane technology
Blom, Richard	SINTEF MK	1	Process chemistry, physical chemistry
Henriksen, Partow	SINTEF MK	1	Sequestration, gas sorption
Gruber, Andrea	SINTEF ER	1	Combustion
Ditaranto, Mario	SINTEF ER	1	Combustion, measurements in fluid flow
Anantharam, Rahul.	SINTEF ER	1	Combustion
Jordal, Kristin	SINTEF ER	1	CO_2 capture technology, process simulation
Munkejord, Svend T.	SINTEF ER	2	Modeling of fluid flow
Dørum, Cato	SINTEF MK	2	Structural engineering, experimental mech's
Løvseth, Sigurd	SINTEF ER	2	Phase equilibrium meassurements
Drysdale, Robert	SINTEF PR	3	Reservoir engineering
Stensen, Jan Åge	SINTEF PR	3	Reservoir engineering
Wessel-Berg, Dag	SINTEF PR	3	Reservoir engineering
Cerasi, Pierre	SINTEF PR	3	Storage, monitoring and leakage of CO_2
Jakobsen, Jana P.	SINTEF ER	4	CO_2 chain analysis
Brunsvold, Amy	SINTEF ER	4	CO_2 chain analysis
Torvanger, Asbjørn	CICERO	4	Environmental effects of CO_2
Gundersen, Truls	NTNU	5	Process technology, pinch point analysis

PH.D. STUDENTS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

Name	Nationality	Period	Sex	Topic
Morin, Alexandre	France	2009-2013	M	Mathematical modeling and numerical simulation of two-phase multi-component flows of CO_2 mixtures in pipes
North, Andrew	USA	2010-2013	M	Numerical modeling of lifted H_2/N_2 jet flames at pressurized conditions
Frederick, Don	USA	2010-2013	M	Experimental investigation of lifted H_2/N_2 jet flames at pressurized conditions
Baumgartner, Georg	Germany	2010-2013	M	Experimental Investigation of Hydrogen Flashback Behaviour in Turbulent Boundary Layers
Sánchez, Rafael Antonio	Argentina	2010-2013	M	Modeling and simulation of Sorption-Enhanced Steam Metane Reforming (SE-SMR) operated in circulating Fluidized Bed Reactors

Bhuiyan, Anwar	Bangladesh	2010-2013	M	Time-lapse CSEM sensitivity analysis for CO_2 sequestration
Karimaie, Hassan	Iran	2010-2013	M	Optimal design of CO_2 injection operation
Taheri, Amir	Iran	2010-2014	M	Experimental Study of CO_2 Dissolution in Brine Aquifers
Soroush, Mansour	Iran	2010-2014	M	Modeling and simulation of different phenomena in CO_2 storage
Ystad, Paul	Norway	2010-2014	M	Process dynamics related to post-combustion CO_2 capture
Nafisi, Vajiheh	Iran	2010-2014	F	Nano-Structured Low Temperature Membranes
Chen, Xinzhi	China	2010-2014	M	Dense ceramic membranes for separation-high temperature mechanical performance and chemical/mechanical stability
Grude, Sissel	Norway	2010-2014	F	Seismic monitoring of $C0_2$ Injection
Vøllestad, Einar	Norway	2010-2014	M	Characteristics of mixed proton cond. materials
Ma, Xiaoguang	China	2010-2014	M	Absorption in precipitating systems

PH.D. STUDENTS WORKING IN CENTRE PROJECTS WITH FINANCIAL SUPPORT FROM OTHER SOURCES

Name	Funding	Nationality	Period	Sex	Topic
Vigen, Camilla	UiO	Norwegian	2009-2013	F	Novel mixed proton electron conductors for hydrogen gas separation membranes

BOARD MEMBERS 2010

Name	Company	Country
Chadwick, Andy	British Geological Survey	UK
Eriksson, Kjell	Det Norske Veritas	Norway
Morin, Pascale	TOTAL E&P	France
Myhr, May Britt	SINTEF Petroleum Research	Norway
Solgaard Andersen, Henrik	Statoil	Norway
Steinskog, Tom	GDF Sues	Norway
Svendsen, Hallvard	NTNU	Norway
Viksund, Randi Isaksen	Gassco AS	Norway
Aam, Sverre (Chairman)	SINTEF Energy Research	NORWAY

GENERAL ASSEMBLY MEMBERS 2010

Name	Company	Country
Berg Aasen, Tone Merethe	NTNU Samfunnsforskning AS	Norway
Britze, Peter	GEUS	Denmark
Bøe, Reidulv	NGU	Norway
Chadwick, Andy	British Geological Survey	UK
Deshpande, Deepak	Shell Technology Norway	Norway
Eriksson, Kjell	Det Norske Veritas	Norway
Haarberg, Torstein	SINTEF	Norway
Kutne, Peter	DLR	Germany
Lindefjeld, Ole	ConocoPhillips	Norway
Lundegaard, Valborg	Aker Solutions ASA	Norway
Myhr, May Britt	SINTEF Petroleum Research	Norway
Morin, Pascale	TOTAL E&P	France
Nordby, Truls	University of Oslo	Norway
Sattelmayer, Thomas	Technische Universität München	Germany
Ringrose, Philip	Statoil	Norway
Svendsen, Hallvard	NTNU	Norway
Svendsen, Pål Tore	Hydro	Norway
Torvanger, Asbjørn	Cicero	Norway
Vaggen Malvik, Håvard	Statkraft	Norway
Viksund, Randi Isaksen	Gassco	Norway
Steinskog, Tom	GDF SUEZ	Norway
Aam, Sverre	SINTEF Energy Research	Norway
Riis, Trygve (observer)	Research Council of Norway	Norway

SCIENTIFIC COMMITTEE MEMBERS 2010

Name	Company	Country
May-Britt Hägg	NTNU	Norway
Sally M. Benson	Stanford University	USA
Susan D. Hovorka	University of Texas at Austin	USA
Alan Kerstein	Sandia National Laboratories	USA
Gary T. Rochelle	University of Texas at Austin	USA
Per Morten Schiefloe	NTNU	Norway
Mathias Wessling	University of Twente	Netherlands
Forman A. Williams	Univ. of California at San Diego	USA

A2. ACCOUNTING REPORT

Costs are composed of cash and in-kind contributions. All figures in NOK.

Actual costs	
Personell and indirect costs	16.428.038
Purchases of R&D services	35.427.210
Equipment	100.050
Other costs	2.693.566
Total costs	**54.648.864**
Funding	
Host institution	13.048.444
Private funding	21.600.420
Research Council of Norway	20.000.000
Total funding	**54.648.864**

A3. PUBLICATIONS

JOURNAL PAPERS (WITH REFEREE)

Title	Author(s)	Magazine
Blir CCS viktig?	Asbjørn Torvanger	2010, Montel kraftjournalen, Nr. 1, p. 72.
Wave propagation in multicomponent flow models	Tore Flåtten, Alexandre Morin and Svend Tollak Munkejord	*SIAM Jl. Appl. Math.*, vol. 70, no. 8, pp. 2861-2882, 2010.
Controlled source electromagnetic three-dimensional grid-modelling based on a complex resistivity structure of the seafloor: effects of acquisiition parameters and geometry of multi-layered resistors.	Anwar H. Bhuiyan, Bård P. Thrane, Martin Landrø and Ståle E. Johansen	*Geophysical Prospecting*, vol. 58, no. 3, pp. 505-553, May 2010.
Low IFT gas-oil gravity drainage in fractured carbonate porous media	Hassan Karimaie and Ole Torsæter	Jl. of Petroleum Science and Engineering, vol. 70, no. 1-2, pp. 67-73, Jan. 2010.

PUBLISHED CONFERENCE PAPERS

Title	Author(s)	Magazine
"The impact on boundary conditions on CO_2 static capacity estimation in aquifers"	Smith, D.J. Bentham, M.S., Holloway, S., Noy, D.J. & Chadwick, R.A.	Proceedings of 9th Annual Conference on Carbon Capture and Sequestration, 2010 Pittsburgh, USA
"The impact of boundary conditions on CO_2 storage capacity in aquifers"	Smith, D.J., Noy, D.J., Holloway, S. & Chadwick R.A.	2010. Energy Procedia. Elsevier

PRESENTATIONS, INCL. POSTERS

Title	Author(s)	Magazine
"FME – BIGCCS – Internasjonalt CCS Senter"	Mona J. Mølnvik	CLIMIT dagene, 12-13 October, 2010
Exploring new ways of Organizing Environment-friendly Energy Research	Tone Merethe Berg Aasen, Oscar Amundsen, Mona Mølnvik and Grethe Tangen	Combi2010, Vantaa, 7-10 October 2010, Finland
BIGCCS Visions value potential and results	Rune Aarlien	NEREC Preconference, Oslo, 27 September 2010
BIGCCS Centre	Rune Aarlien	Rumanian CCS Delegation, 23 September 2010 Trondheim
Modeling Fracturing in Rock using a Modified Discrete Element Method with Plasticity	Haitham Alassi, Rune Holt	9th International Conference on Fracture and Damage Mechanics, 21 September 2010 Nagasaki, Japan

Towards a formally path-consistent Roe scheme for the six-equation, two-fluid model, International Conference on Numerical Analysis and Applied Mathematics	A., Flåtten, T. and Munkejord, S.T	ICNAAM 2010: International Confere of Numerical Analysis and Applied Mathematics 2010. AIP Conference Proceedings, Volume 1281, pp. 71-74, 2010.
Impacts of exhaust gas recirculation (EGR) on the natural gas combined cycle integrated with chemical absorption CO_2 capture technology	Hailong Li, Geir Haugen, Mario Ditaranto, David Berstad, Kristin Jordal	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
CO_2 pipeline integrity: A new evaluation methodology	T. Berstad, C. Dørum J.P. Jakobsen, S. Kragset, H. Lib, H. Lund, A. Morin, S.T. Munkejord, M.J. Mølnvik, H.O. Nordhagen, E. Østby	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
The impact of boundary conditions on CO_2 storage capacity estimation in aquifers	D. J. Smith D. J. Noy, S. Holloway, R. A. Chadwick	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
Up scaling studies of diffusion induced convection in homogeneous and heterogeneous aquifers	Erik Lindeberg, Dag Wessel-Berg	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
Techno-economic Assessment of Flexible Solvent Regeneration & Storage for Base Load Coal-Fired Power Generation with Post Combustion CO_2 Capture	Jo Husebye, Rahul Anantharaman, Stein-Erik Fleten	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
BIGCCS Centre -Boosting CCS research and innovation	Mona J. Mølnvik, Grethe Tangen, Rune Aarlien and Nils Røkke	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
The effect of CO_2 on the mechanical properties of reservoir and cap rock	Ira O. Ojala	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
Technologies for increasing CO_2 concentration in exhaust gas from natural gas-fired power production with post-combustion, amine-based CO_2 capture	Hailong Li, Mario Ditaranto, David Berstad	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
Controlled source electromagnetic modeling and sensitivity analysis for monitoring subsurface CO_2 storage	Anwar H. Bhuiyan, Martin Landrø, Amir Ghaderi	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
Comprehensive Assessment of CCS Chains – Consistent and Transparent Methodology	J.P. Jakobsen, A. Brunsvold, J. Husebye, E.S. Hognes, T. Myhrvold, P. Friis-Hansen, E.A. Hektor, A.Torvanger	10th International Conference on Greenhouse Gas Control, 19-23 September 2010, Amsterdam.
Validation of a dynamic absorber model for CO_2 capture	Hanne M. Kvamsdal, Actor Chikukwa & Magne Hillestad	WCCM/APCOM, June 19 2010, Sydney Australia

Hydrogen transport membranes for pre-combustion gas separation	Yngve Larring, Camilla Haavik, Thijs Peters, Paul Inge Dahl, Marie-Laure Fontaine, Partow P. Henriksen, Rune Bredesen	Electroceramics XII – 14-16 June 2010, Trondheim, Norway
"The impact of boundary conditions on CO_2 capacity estimation in aquifers",	D. J. Smith, M. S. Bentham, S. Holloway, D. J. Noy, R. A. Chadwick	Ninth Annual Carbon Capture & Sequestration Conference, May 2010 Pittsburgh Pa, USA
What should be Norway's role in CCS development?	Asbjørn Torvanger	CICERO lunch seminar, CICERO, Oslo, Norway.
"BIGCCS"	Mona J. Mølnvik	Official South African CCS Delegation trip to Norway, BIGCCS organized and presented BIGCCS, Trondheim, Norway.
BIGCCS contributed with several presentations in CCS workshop arranged by the Research Council of Norway	Mona J. Mølnvik, Rune Aarlien	EXPO 2010, May 21 Shanghai, China
"Comparing estimation methods in two North Sea aquifers"	D. J. Smith	UK-US CCS R&D Workshop, May 2010, Pittsburgh PA, USA.
Bør staten støtte utviklinga av få eller mange klimavennlege teknologiar	Asbjørn Torvanger	CICERO Klimaforum, Litteraturhuset, 20 April 2010 , Oslo, Norway.
BIGCCS Presentation	Mona J. Mølnvik	Norsk Petroleumsforening Ung, vårmøte trøndelag, April 29 2010, Trondheim, Norway
BIGCCS Presentation	Mona J. Mølnvik	GASSNOVA, NORCEM/HEIDELBERG CEMENT AND ECRA in cooperation with Tel-Tek - Workshop in Langesund on CCS in industry, Langesund, Norway
Experimental simulation of 4D overburden effects associated with depletion of or injection into a subsurface reservoir	R.M. Holt & J.F. Stenebråten,	EAGE Shale Workshop, 26-28 April 2010, Nice, France
BIGCCS Presentation	Mona J. Mølnvik	German – Norwegian Commerce Ministry delegation, visit SINTEF and BIGCCS, Trondheim, Norway.
Time-lapse seismic monitoring at Sleipner provides insights into the performance of reservoir seals	Andy Chadwick.	Invited Lecture at 'Caprocks and Seals for Geologic Carbon Sequestration'. January 12-15, 2010, Stanford University – USGS Special Workshop, Monterey CA.
"Performance of Ca-based sorbents during sorption-enhanced steam methane reforming (SESMR) in a CFB reactor"	B. Arstad J. Prostak, C. Sprung, U. Olsbye and R. Blom	2nd Network meeting on High Temperature Solid Looping Cycle, 15-17 September 2010, Alkmaar, The Netherlands.
"Direct Numerical Simulations of Flame Propagation in Turbulent Boundary Layers"	Andrea Gruber	Invited lecture for "Kolloquiums Thermo- und Fluiddynamik" at the Faculty of Mechanical Engineering, 17 November 2010 ETH Zurich, Switzerland

Oxy-Fuel CO_2 Capture	M. Ditaranto	IEAGHG Interdisciplinary CCS Summer School 2010, 24 August 2010, Longyearbyen, Norway.
CO_2 seismic quantification at Sleipner	Ravaut C., Alerini M., Buddensiek M., Ghaderi A. and Dillen M	Presented at the Biennial Geophysical Seminar - March 2010, Kristiansand, Norway.
"CO_2 lagring - utfordringer og muligheter"		11 mars 2010, Norskehavskonferansen 2010.
Application of full waveform inversion to the Sleipner field data, invited talk given at the DGG/SEG Workshop: Geophysical Aspect of CO_2 storage –Challenge and Strategies	Ravaut C.	2010, Germany.
Sleipner: a monitoring research laboratory	Andy Chadwick.	UKCCSC Academic Research Strategy Meeting for UK Geological Storage and Monitoring of CO_2, 2010, University of Edinburgh.
Er norsk CCS-satsing avhengig av ein global klimaavtale?	Asbjørn Torvanger	16 November 2010, CICERO Klimaforum, Litteraturhuset, Oslo
CO2 and C1 Gas Injection for Enhanced Oil Recovery in Fractured Reservoirs. SPE International Conference on CO2 Capture, Storage, and Utilization	Hassan Karimaie and Ole Torsæter	New Orleans, Louisiana, USA, 10-12 November 2010.

REPORTS

37 Confidential reports.

POPULAR SCIENCE ARTICLES

Title	Author(s)	Magazine
“BIGCCS Centre Kick-off”	Mona J. Mølnvik, Nils Røkke, Grethe Tangen	IEAGHG Greenhouse Issues, Issue 96, 2010
”BIGCCS Synlig Internasjonalt”		CLIMIT Nyhetsbrev, September 2010
Sikker og effektiv CO2-transport	Cato Dørum, Svend Tollak Munkejord, Mona J. Mølnvik	Teknisk Ukeblad, 2010

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