BIGCCS Centre
International CCS Research Centre

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Annual Report 2009

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CONTENTS

1. MESSAGE FROM THE CHAIRMAN OF THE BOARD

BIGCCS- Targeting international relevance and excellence

A first hectic year of the CEER[1] BIGCCS- "International CCS R&D Centre" has passed. The centre has managed the start-up process very well and transformed plans into action and scientific frontier research. Does the centre live up to it's ambitions of being a true international CCS R&D Centre? My answer is "we are getting there". Building trust and relations with the international R&D community within this area takes time but in the BIGCCS we have the unique possibility to build upon the network our international R&D and industrial partners cover. Within storage the partners are well positioned along the North Sea basin and can develop and utilize common knowledge and tools to release the potential of storage in this area. The centre is also building upon the strong links across the Atlantic. Within combustion modeling and tools development we enjoy the co-operation with SANDIA and Berkeley. To make the next step in our internationalization effort we need to build even more strategic partnerships – an endeavor that will take effort and time to achieve. But CCS will need to be deployed at a global scale and this is one of the features that distinguishes a centre from a project, we have a long term mission to achieve. It is increasingly important that we get the right support to make this possible within the operational time of the centre. Being a centre means that we are also able to adjust the course of R&D and if needed redirect work to areas which become more urgent to address. Emerging areas are carbon negative solutions, co-production of CO_2 and other materials and capture from industrial sources and off-shore operations. Having such a competence pool at hand as in the BIGCCS makes us well prepared to address these new possibilities.

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

[1] CEER = Centre for Environmental friendly Energy Research"

2. MESSAGE FROM THE CENTRE DIRECTOR

BIGCCS arranged its Kick-off seminar in Trondheim 22-23 June, 2009, with the Research Council and all partners represented. Rector of NTNU, Torbjørn Digernes, president of SINTEF Energy, Sverre Aam, and director of Department for Energy and Petroleum Research at the Research Council of Norway, Fridtjof Unander gave opening speeches. It was a great surprise among the participants as the Centre director Nils Røkke received a phone call from the Prime Minister Jens Stoltenberg who appeared on video and officially opened BIGCCS. The contract with the Research Council was signed during the NEREC conference October 6th by the Director of the Research Council, Arvid Hallén and Sverre Aam.

Prime Minister Jens Stoltenberg opens the BIGCCS Centre at its Kick-off meeting on June 22
(Photo: SMK)

Arvid Hallén congratulates Sverre Aam with the establishment of the BIGCCS Centre on October 6
(Photo: Claude Olsen)

BIGCCS is up and running! Already during the first year the research teams organized activities between the partner institutions and showed ability to respond to challenges by completing most of the planned deliverables. The industry partners, nine in all, are taking active part in BIGCCS. They contribute to relevance and quality in research through involvement in the activities and participation in consortium days and the technical meetings, as well as in the Board and the General Assembly meetings. Academia, lead by NTNU, is responsible for educating 18 PhDs and 8 Postdocs. BIGCCS is a great team to work with and I look forward to the continuation.

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

3. SUMMARY

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. The main objective is to develop new knowledge and technology in order 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 BIGCCS Centre require in-depth studies of fundamental aspects related to CO_2 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 exploration, innovation, and value creation.

BIGCCS is set up with a General Assembly, a Board (nine members), a Scientific Committee, an Exploitation and Innovation Advisory Committee, a Centre Management group, a Director, and a Centre Manager. Technical committees will be established for the different Sub-projects. The Centre has 21 partners; nine industrial partners, nine research partners, and three university partners. Partners come from different parts of the business 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 (SP), where the two latter are horizontally oriented and integrating the first three:

1. SP1: CO_2 Capture
2. SP2: CO_2 Transport
3. SP3: CO_2 Storage
4. SP4: CO_2 Value Chain
5. SP5: Academia

Main activities in 2009 have been to develop proper plans for the research activities, establish state-of the-art reports for the different sub-projects and tasks, and to commence the research activities. Despite a “short” first year, since the kick-off seminar was held in June, the Centre managed to complete close to a full years production.

In 2009, one PhD candidate started. In total, the Centre will produce 18 PhDs and eight Postdocs. By and large, this is the only activity the Centre is behind schedule, owing to the later than expected signing of the Contract with the Research Council of Norway.

Heavy emphasis is put on communication and dissemination of results. Already during this first year of operation, BIGCCS was involved in organizing the Trondheim Conference on CO_2 Capture Transport and Storage. Furthermore, a web-site has been set up and popular science articles have been produced.

Other important aspects for the Centre is innovation and centre building. This cross-cutting activity is headed by NTNU Social Research, and work in 2009 centred on developing a strategic plan.

Finally, Health Safety and Environment is of prime concern. All meetings in BIGCCS start with HSE as the first agenda item. Special measures are taken to ensure the lowest possible risk in connection with laboratory activities. No accidents, incidents or near-misses were registered in 2009.

The accumulated cost in 2009 was NOK 38.7 million. This includes cash and in-kind contributions.

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.

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.[2]

[2] 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

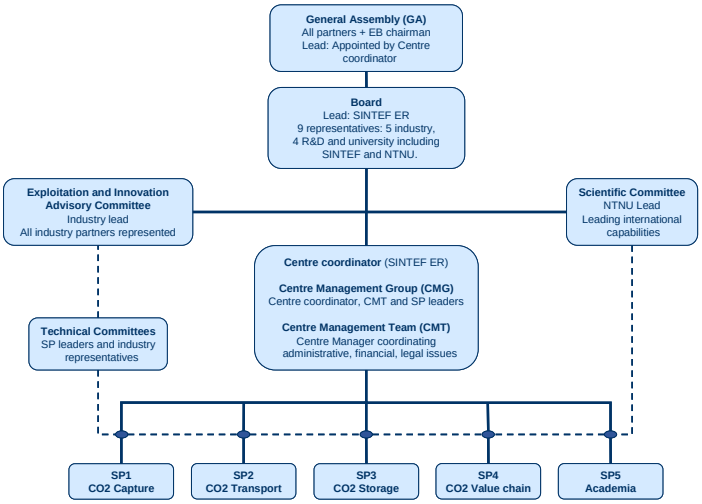
6. ORGANIZATION

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.

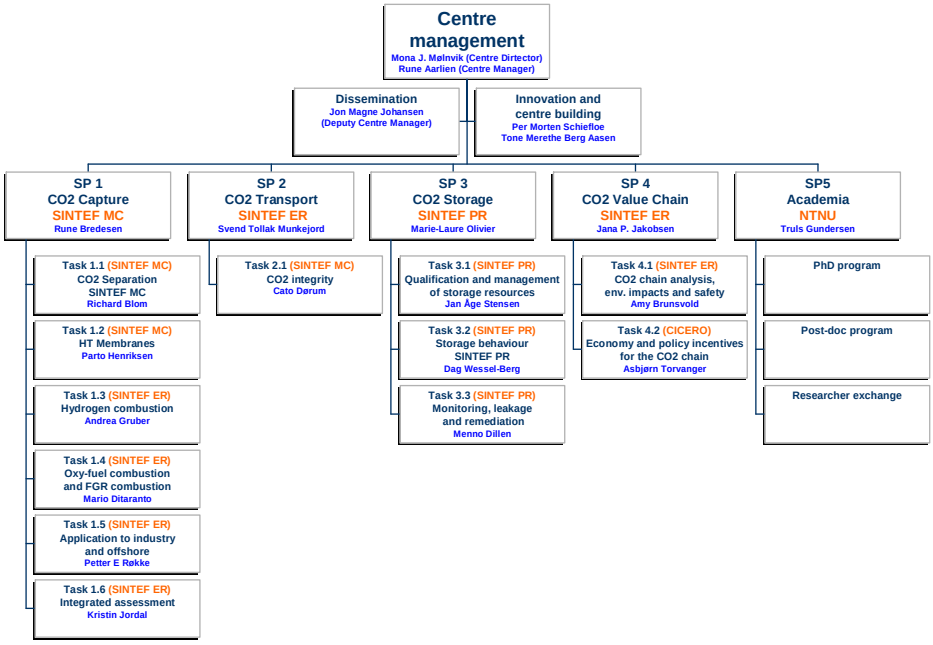


BIGCCS governance structure

- **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.

6.2 PARTNERS

The following organizations have been partners in the BIGCCS Centre during 2009:

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.
- **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 (ENCAP, CO2 Remove) and the Lacq Region Pilot. Partner in Snøhvit.

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 2009 has been put on involving all partners "as actively as possible".

SUB-PROJECTS

Sub-Project leaders coordinate the efforts of the different Tasks. At least two joint meetings are held annually for all tasks with focus on developing research strategies and on organizational issues. In 2009, such meetings have been held both with and without industrial partners. In order to stimulate the work in 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. Establishment of TCs has been discussed in 2009, and the first ones will be set up in 2010.

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 2009 Consortium Day attracted more than 70 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 had 11 meetings during 2009, and will likely have 20 or more meetings in 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 Capture: Work is devoted to solvent systems and high temperature particulate CO_2-sorbents. A solvent system model supporting the operation of power plants has been implemented for studying how the absorber works with variations in flue gas flow (dynamic modeling). An experimental setup for measurement of vapor-liquid-solid equilibriums has been designed to study the phases formed in precipitating CO_2 capture systems at real conditions. For high temperature CO_2-sorbents, the main work has been to construct a high temperature/high pressure rig for investigations of reaction kinetics and long-term stability of powders in sorption/desorption cycling. In addition to power generation, the CO_2-sorbents studied may also have other applications in CO_2 capture processes.

Task 1.2 High Temperature Membranes: Novel hydrogen separation membrane materials for hydrogen transport membranes (HTM) have been synthesized, characterized, compacted and sintered as dense pellets. The H_2 permeation was investigated at ambient pressure in the temperature range 400-800ºC with a controlled hydrogen partial pressure gradient across the membrane. The preliminary results, corrected for leakage, indicate a stable and rather high H_2 permeability at temperatures above 400ºC. A new gas system with distributed work stations suited for membrane testing in various atmospheres was installed in the new SINTEF membrane process laboratory. The gas pipeline infrastructure contains 7 standard gases and works up to 40 bar. A high pressure/high temperature balance is connected to the gas lines, while H_2S is provided through a different gas system. A PhD candidate at the University of Oslo is connected to the work on HTMs.

Task 1.3 Hydrogen Combustion: The initial work is to provide a qualitative mapping and quantitative determination of the fundamental processes that characterize combustion of hydrogen rich mixtures, with focus on stable and safe flame propagation in lean pre-mixed combustion at gas turbine condition. Achievements 2009 are: 1) Formalization of collaborative work between SINTEF, UC Berkeley and Sandia NL, 2) Computer hardware acquired for extension of computational capability, 3) Preliminary setup and testing of the direct numerical simulation tool has been performed for hydrogen-air premixed flame propagation.

Task 1.4: Oxy-fuel Combustion and Flue Gas Recirculation Combustion: focuses on combustion related technological challenges associated with the implementation of oxy-fuel combustion alternatives for CCS. The main activity has been to specify and design an experimental high pressure combustion facility dedicated to the study of oxy-fuel combustion (100 kW, 10 bar). The hardware construction has been started and commissioning is planned in 2010. A preliminary testing study of a light oil burner adapted to oxy-fuel operation has been performed that highlighted the main difficulties in the retrofitting process. Emissions were however in a similar range as for air operation, but remains to be confirmed. The third axis of the Task 1.4 was collaborating with Task 1.6 in providing inputs and constraints from combustion for the analysis and efficiency evaluation of novels cycles based on oxy-fuel.

Task 1.5 Application to Industry and Offshore: The objective is to assess and evaluate the potential for CCS in other industries and offshore, hence contribute to added value for the Centre partners. The aim is also to engage the partners to ensure relevance of the work to be performed, and to ensure sufficient input data for further research. Within year 1, the work was initiated with a workshop where most industrial partners were present to discuss and give feedback on planned work. Presentations were given by four of the industrial partners, emphasising the important fields within their respective companies. More detailed plans were produced where it was suggested how to approach the case studies, ensuring a sufficient R&D content of the work.

Task 1.6: Integrated Assessment: This task is subdivided into three work packages: unit design and modelling; process design and benchmarking; and interaction between research tasks. The main 2009 objectives for the respective tasks were: initiate membrane reactor modelling and complete preparations with regard to modelling strategy and tools; build and establish reference a gas turbine cycle with exhaust gas recirculation (EGR) technology; and provide an overview and bring awareness of interdependencies between all research tasks in SP1. In the first work package a preparatory study was carried out with respect to modelling strategies and screening and selection of modelling tools. In the second, a reference case was established for gas turbines with EGR, and a journal paper about this work was written. In the third work package a memo with key parameters, boundary conditions and interdependencies for key processes in tasks 1.1–1.6 was prepared, based on information gathered from the respective ongoing activities.

7.2 CO_2 TRANSPORT – SP2

SP2 has one task:

- Task 2.1: CO_2 integrity

The main objective 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 mechanical 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 2009, a concept for a first, simplified, model was developed. This is to be implemented in 2010.

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 2009, the work resulted in one conference article and two conference presentations being published. Further, one article was submitted to a journal and one abstract to a 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

Task 3.1 Qualification and Management of Storage Resources: Work deals with *development of geomechanics and basin modelling codes.* New codes on reservoir geomechanics (MDEM – Discrete Element Method - and FLUID) were performed to improve the modelling of geomechanical behaviour during CO_2 injection. This method aims to predict the creation of new fractures or crack propagation from pre-existing fractures and faults. Furthermore, the Snøhvit area (Tubåen formation) has been evaluated to test necessary development on secondary migration codes (Pressim and Semi) for modelling long-term CO_2 migration. The Snøhvit area is believed to be an interesting test case, and this dataset has been released for this project.

Efforts are also devoted to *storage site capacity and qualification activities*. A review of current approaches for assessing CO_2 storage site capacity has been accomplished. This review will form a basis for more sophisticated dynamic flow simulation approaches for assessing storage capacity. A study on simultaneous CO_2 injection and water production was conducted for optimizing the exploitation of CO_2 storage resources. Two different aquifers in the North Sea (the Utsira and the Johansen formations) were studied. In order to utilise more than 1% of the available pore space, massive water production from the formation will be necessary to constrain pressure build-up to within safe limits and to avoid interference with other future storage projects in the same hydraulic unit. A number of large-scale flow models of Bunter Sandstone (UK sector of North Sea) have been generated. The models will assess the impact of boundary conditions, particularly at the regional scale. Results from dynamic simulations will be compared with estimates derived by existing static methods to determine the validity of static approaches for open, closed and semi-closed systems. The Cap Toscana formation at Svalbard is being studied as a potential storage formation for CO_2 from the Longyearbyen coal fired power plant. Pressure evolution in conceptual regional models in the Danish area has been studied by numerical simulation. The important decision is whether a local model can be treated as a closed system in respect to the surrounding aquifer(s) or if it should be modelled as an open system. Preliminary simulations show that the aquifer pressure evolution is fast and the pressure wave extends far away from the injected CO_2 plume.

Task 3.2 Storage Behaviour: Both experimental and theoretical studies of geochemical and geomechanical effects of CO_2 on the cap rock and reservoir are on-going. BGS has carried out a set of long-term batch experiments to assess the reactivity of CO_2 and pore water with Sleipner cap rock and wellbore materials. Tests have been running since July 2005, and will be continued to provide the longest experiments yet undertaken (up to 7 years). SINTEF Petroleum Research has carried out punch testing of shale samples in order to quantify the effect of CO_2-water on cap rock strength. The test programme will continue in 2010. A review of literature with focus on geochemical aspects of rock-water related to subsurface injection and storage of CO_2 in aquifers has been performed. GEUS has conducted experiments to study drying-out effects on various minerals and under varying conditions.

Also, a study of diffusion induced convection mechanisms in presence of heterogeneities has been performed. This study extends former work on the gravitational instability of a diffusive boundary layer in a semi-infinite anisotropic porous medium. This instability behaviour should be seen as an upside for underground CO_2 storage, as dissolution is an important aspect for retaining the CO_2 in the underground for thousands of years. The Pressim software has been evaluated for modelling the effects of CO_2 on pressure.

In terms of *dissemination and education*, mediation activities to the general public have started with "Youth Talent Climate Summit 09" and "International Youth Climate Summit – Climate-TV". Two abstracts were submitted to GHGT-10 (geomechanical properties and upscaling of CO_2 storage). Finally, the process of engaging PhD- and PostDoc candidates was started, and the evaluating and interviewing candidates are in progress.
Task 3.3 Monitoring, Leakage and Remediation: Several monitoring tools and models for CO_2 injection and storage are to be developed and tested:

- *CSEM* (Marine Controlled Source ElectroMagnetics), as an early stage feasibility study, is successful and the change in injected volume can be detected.
- *FWI* (Full Waveform Inversion): although better results can be obtained with larger offset ranges, the real offset range from the Sleipner data still allows a proper reconstruction of the Vp velocities in the CO_2 plume.
- A gravity modelling study was made to estimate if 4D CO_2 effects can be observed using gravity data. Results indicate that a CO_2 reservoir can be monitored over time.
- Accurate mapping of the development of reflectivity in the CO_2 Sleipner plume and also the velocity pushdown on deeper layers beneath the plume are challenging. So far horizons and pushdown up to the 2006 survey have been mapped.
- Time-frequency spectral decomposition techniques have been applied to the time-lapse surface seismic data (3D and high resolution 2D) at Sleipner. Application of this tool to the topmost layer on the 2006 dataset reveals strong tuning effects and the capability of mapping travel-time layer thicknesses.
- An integrated package of research into processes controlling flow of CO_2 in reservoirs and how these may be elucidated by analysis of the time-lapse seismic monitoring datasets is being developed.
- GEUS is developing a catalogue of reservoir models, using conceptual structure and actual data from geological settings giving rise to layered reservoirs, e.g. fluvial systems and near-shore depositional systems with sea-level fluctuations.

Intensive laboratory tests have been performed at SINTEF Petroleum Research to measure wave velocity changes and strain response to stress changes that mimic those occurring within a storage site and in the cap rock above it. The geomechanical response observed in these laboratory experiments indicates an increasing risk of failure in the reservoir as well as the overburden for the case of injection above the initial pore pressure. A study on the aspects of designing CO_2 wells, remediation actions, and methodology for evaluation of well integrity after permanent abandonment, were developed. The process of engaging PhD- and PostDoc candidates within "Geophysics and Geomechanics for CO_2 storage" has started.

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 develop a common framework for CCS chain assessment including analysis of techno-economic criteria, risk, and environmental impacts associated with CCS chains. In 2009, the development of the common framework was initiated during first SP4 workshop. During the workshop, common understanding of project objectives and common vocabulary were established, main challenges and milestones as well as possibilities for co-operation across the working packages were identified, and common strategy for the organization and co-operation within SP4 was established. Further important achievements on the level of the particular working package activities were:

- Establishing state-of-the-art in LCA studies on CCS including a literature review of various LCA studies on CCS chain components and a review of available LCA techniques and software.
- Choosing SimaPro 7 to be used initially to collect, analyze and monitor the environmental performance of CCS chains in SP4.
- Participation in a PhD course on Energy markets at NTNU.
- Planning future work on flexibility.
- Summary on state-of-the-art in risk management models and ongoing projects, and initial proposal for the overall conceptual model for risk assessment of CCS chains.
- Development of a common working framework for SP4 initial ideas summarized and submitted as an abstract to GHG-10.

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. In 2009, the potential of CCS to reduce global CO_2 emissions was explored, as well as CCS' dependency on major economic and policy conditions. Furthermore an economic model has been developed to analyze stakeholders' understanding of CCS technologies and related uncertainties. The major results were summarized in two technical reports:

- Technical report on prospects for CCS
- Technical report on investor decisions on CCS

The scoping study and modelling work initiated in 2009 will provide a basis for the next research phase of SP4 Task 2.

7.5 ACADEMIA – SP5

Due to later than expected signing of the Consortium Agreement for BIGCCS, with signature procedures taking place between June and September, the initial recruitment was considerably delayed. Therefore, only one PhD student was recruited in 2009 with a formal starting date of 1st September. The candidate, Alexandre Morin, is assigned to Task 2.1 on *CO_2 integrity*, and the topic of his thesis is suggested to be "Mathematical modeling and numerical simulation of two-phase multi-component flows of CO_2 mixtures in pipes". Even though the student has only been assigned to BIGCCS for four months, and the main focus in all PhD programs initially is on the compulsory courses, he produced one publication. The title was *Numerical resolution of CO2 transport dynamics*, and it was published at SIAM Conference on Mathematics for Industry: Challenges and Frontiers, San Francisco, California, USA, October, 2009.

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), *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 will play active roles within the various research tasks, and as members of the Committees. Below are listed some of the 2009 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 presently in progress, 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:

- *The 5th Trondheim Conference on CO_2 Capture, Transport and Storage*, Trondheim, June 16-17, 2009
- Preparations for *IEA Summer School* on CCS (to be held in 2010)
- *Consortium Day* for BIGCCS, Trondheim, November 17, 2009
- *BIGCCS Kick-off Seminar*, Trondheim, Norway, June 22, 2009

SCIENTIFIC COMMITTEE

Plans have been developed for establishing the Scientific Committee (SC). Of prime concern is of course to find a group of highly skilled individuals, but members will also be chosen based on international networking, i.e. engaging members outside the BIGCCS family. The SC will be formally established in 2010.

9. RECRUITMENT

The aim is for BIGCCS to produce 18 PhDs and 8 Postdoc candidates. The first announcement for PhDs and Postdocs, in total eight positions, had deadline November 20, 2009. PhD and Postdoc fellowships were announced in the following focus areas:

- Capture and separation
- Geophysics and geomechanics for CO_2 storage
- Reservoir technology and engineering for CO_2 storage
- CO_2 pipeline integrity

Results concerning quality and suitability of the applicants were variable. Nevertheless, some good candidates were selected, and others have also been identified by various means. The outlook for recruitments in 2010, therefore, is promising. It is expected that the number of PhDs and Postdocs will increase to around 15 during 2010, most of these starting their studies in the second half of 2010.

10. COMMUNICATION AND DISSEMINATION

BIGCCS will 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 mentioned some of the work conducted in 2009.

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. The last one was held in 2009, and planning for the next one in 2011 is already in progress. It is also the ambition of the BIGCCS Centre to organize one of the next *GHGT*-conference.

WEB

An Internet homepage has been established for the Centre, see: www.bigccs.com. 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. During 2009 the work with an animation video was started. The video, which will be completed in 2010, aims at demonstrating in a simple and easy-to-understand way what CCS is and why it is important. The web-page also includes the opening address at the kick-off seminar by Norway's Prime Minister, Mr. Jens Stoltenberg.

POPULAR SCIENCE

Aiming at disseminating information also to the broad public, the popular science format will be important. In 2009, BIGCCS established contact with the magazine *Illustrated Science* (*Illustrert Vitenskap)*. Interviews have been done, and a feature article will appear in 2010. Two other popular science type articles were published in *Samfunnsøkonomen* and in the *CLIMIT Newsletter*.

NEW CENTRE PARTNERS

Quite some efforts have been undertaken during 2009 to acquire new partners to the BIGCCS Centre. Several high-ranking potential partners have been approached, and at least for a few, the possibility for joining the Centre is real.

PRESENTATIONS

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

11. INNOVATION AND CENTRE BUILDING

The starting point related to this task, was a lecture on innovation on BIGCCS internal kick-off in April 2009. Next was the organization of a workshop on BIGCCS Kick-off in June 2009. The theme for this workshop, which included all partners and participants in the centre, was "What is success in BIGCCS?" i.e. identifying expected success criteria for BIGCCS. The input from the participants were categorized related to different types of objectives: **Effect objectives** (what is the overall effect we aim for?), **result objectives** (which are the specific products we think are needed to render probable the desired effect – this is "counting edges" like number of publications, patents, students, etc), and **process objectives** (how do we cooperate to obtain the desired results, and to ensure the performance of the effect objectives). It can be noted that most suggestions about premises for success of the BIGCCS Centre were about process objectives, and than many of these suggestions were connected to a perceived need to ensure communication between all partners in the Centre. It can be mentioned that the "typology" of objectives has been used for process-oriented analytical purposes in SP4, and that the theme of communication and cooperation formed the basis for a workshop in SP1 planned and facilitated via this task.

To follow up on this work, the result from the kick-off workshop was used as input and background to start the work with a strategy for BIGCCS centre building. In addition to discussions in the regular meetings in Centre Management Group (CMG), strategic perspectives were focused in a workshop organized for CMG October 28-29, 2009. Through this work, five areas for the 'Strategy for Centre Building' were identified: (1) Internationalization, (2) Dissemination and public awareness, (3) Innovation, (4) Academic education and (5) BIGCCS centre work processes. It is probable that the work related to the development of a strategy for Centre building has contributed to the development of CMG as a team.

The next step to continue this work is to make and facilitate the production of a strategy-document during the spring of 2010. The plan will be completed in May, 2010, and the document will be presented for the Board for approval.

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 of Life Cycle Assessment (LCA) methodology for analysing environmental impacts throughout the CO_2 chain associated with alternative scenarios for CCS deployment is used.

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.

SINTEF Energy Research conducts all its projects according to the 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 planned activities.

FIRST THINGS FIRST

On a practical level, *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. *No accidents, incidents or near misses have been reported during 2009.*

SAFETY IN LABORATORIES

HSE issues have been highly focused in the establishment of two new laboratories at SINTEF Materials and Chemistry in Oslo. The Material and Process laboratories are partly funded by BIGCCS. One of these laboratories is equipped with safety measures allowing for the use of flammable and toxic gases. Preventive safety measures include hydrogen and carbon monoxide detection systems connected to automatic switches closing off the gas feeding system in case of an emergency. The other laboratory is specially equipped to test gases containing hydrogen sulphide (H_2S). The ventilation of the room has been upgraded and is now separated from the ventilation in the rest of the building. Sensors to detect leakage of H_2S have been installed, and equipment such as high pressure TG is installed in a separate hood.

SINTEF Energy Research will, during 2010, introduce a mandatory CO_2 safety course for all laboratory personnel working with CO_2. The course focuses on the potentially harmful physiological effects of CO_2, potential consequences of the high pressures, problems with dry ice, and public regulations.

HES ANNUAL REPORT

The Board has suggested that a separate HSE annual report is produced each, and the first one will be issued for 2010. The format for such a report is under development.

ATTACHMENTS

ATTACHMENT 1: PERSONNEL

ATTACHMENT 2: ACCOUNTING REPORT

ATTACHMENT 3: PUBLICATIONS

A1. PERSONNEL

KEY RESEARCHERS

Name	Institution	SP	Main Research Area
Berstad, David	SINTEF ER	1	CO_2 capture technology
Blom, Richard	SINTEF MK	1	Process chemistry, physical chemistry
Bredesen, Rune	SINTEF MK	1	Membrane technology
Brunsvold, Amy	SINTEF ER	4	CO_2 chain analysis
Dillen, Menno	SINTEF PR	3	Storage, monitoring and leakage of CO_2
Ditaranto, Mario	SINTEF ER	1	Combustion, measurements in fluid flow
Dørum, Cato	SINTEF MK	2	Structural engineering, experimental mechanics
Gruber, Andrea	SINTEF ER	1	Combustion
Gundersen, Truls	NTNU	5	Process technology, pinch point analysis
Henriksen, Parto	SINTEF MK	1	Sequestration, gas sorption
Jakobsen, Jana P.	SINTEF ER	4	CO_2 chain analysis
Jordal, Kristin	SINTEF ER	1	CO_2 capture technology, process simulation
Munkejord, Svend T.	SINTEF ER	2	Modeling of fluid flow
Olivier, Marie-Laure	SINTEF PR	3	Reservoir engineering
Røkke, Petter E.	SINTEF ER	1	Combustion
Stensen, Jan Åge	SINTEF PR	3	Reservoir engineering
Torvanger, Asbjørn	CICERO	4	Environmental effects of CO_2
Wessel-Berg, Dag	SINTEF PR	3	Reservoir engineering

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

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 2009

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
Svendsen, Hallvard	NTNU	Norway
Viksund, Randi Isaksen	Gassco AS	Norway
Aam, Sverre (Chairman)	SINTEF Energy Research	NORWAY

GENERAL ASSEMBLY MEMBERS 2009

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
Christensen, Cato	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
Riis, Trygve (observer)	Research Council of Norway	Norway
Sattelmayer, Thomas	Technische Universität München	Germany
Solgaard Andersen, Henrik	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
Aam, Sverre	SINTEF Energy Research	Norway

A2. ACCOUNTING REPORT

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

Actual costs	
Personnel and indirect costs	11.965.083
Purchases of R&D services	22.506.534
Equipment	666.958
Other cocst	3.591.569
Total costs	**38.730.144**
Funding	
Host institution	3.233.663
Private funding	16.469.481
Research Council of Norway	19.000.000
Total funding	**38.703.144**

A3. PUBLICATIONS

PUBLISHED CONFERENCE PAPERS

Title	Author(s)	Conference
Numerical Resolution of CO_2 Transport Dynamics	Alexandre Morin, Peder K. Aursand, Tore Flåtten, Svend T. Munkejord	SIAM Conference on Mathematics for industry, October 9-10, 2009, San Francisco, California
BIGCCS - A centre of excellence targeting global presence	Nils Røkke	The 5th Trondheim Conference on CO2 Capture, Transport and Storage, 16-17 June, 2009, Trondheim Norway
Hydrogen flux through selected HTM membranes	Y. Larring, M.L.Fontaine, and R. Bredesen,	Euromembrane 2009

POPULAR SCIENCE ARTICLES

Title	Author(s)	Magazine
"Kan karbonhandtering redde klimaet?	Torvanger	Samfunnsøkonomen, No. 7, 2009
Nøkkelen til billigere CO2-fangst	Claude Olsen, Mona J. Mølnvik	Climit nyhetsbrev no. 5, 2009

BIGCCS – future technology with a greener footprint…