Annual Report 2011

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

BIGCCS Centre - International CCS Research Centre

CONTENTS

Photo front page: Thor Nielsen

1. MESSAGE FROM THE CHAIRMAN OF THE BOARD

A truly adventurous year for CCS in the sense that the disappointments have been queuing up for deployment at larger scale. Key question arise like; how did we end up here, why is there a loss of interest in climate change in general, and where are the bold investments which seemed likely just some years ago. Personally, I think this started at the Copenhagen COP15, why should we or I as an individual care about climate change when our global leaders cannot agree on measures? Obviously, it cannot be that important then. Of course, the financial and debt crisis has not helped either, but money does seem to be in shortage to try to alleviate that crisis. Global warming has not gone cold though, every year we are adding 2 ppm CO_2 to the atmosphere - and counting. The 2014 IPCC report will show even stronger indications for an imbalance in radiation to and from our planet, the result is global warming.

Studies from the IEA, OECD, EU and ZEP all say the same, without CCS we cannot quite see how we can curb our emissions fast enough and at a realistic price. And we need to respond swiftly, the "locking door enigma" – coined by the last IEA World Energy Outlook – points towards locked-in carbon dioxide emissions. Basically, we need to change our emission trajectory by 2020. The EU 2050 Energy Roadmap message is crisp and clear, we need CCS and not only for coal – gas and process industries need it as well.

It is thus extremely rewarding to be working in the field of CCS R&D, we should now point larger efforts towards gaining better understanding of the CCS complex and progress technology advances. This is what BIGCCS is all about, paving the road for CCS – in the big picture paving the road to a low carbon economy thus mitigation climate change. What can be more important?

International co-operation is instrumental for our Centre and we have during 2011 strengthened these links by events in the US and Australia. The TCCS-6 conference attracted 450 people to Trondheim last summer, we are proud that we have been able to establish this as a main scientific conference for CCS, keyword: CCS science. A close co-operation has also been established to the recently started NORDICCS Centre which is promoting CCS innovation in the Nordic countries. The spirit of BIGCCS of being open minded, curious and to say "yes" more than "no" pays off. The operations of the Centre is larger than ever and second to none in the whole CEER instrument provided by the Research Council of Norway (RCN). New R&D infrastructure has been established and we have been adding activities to the Centre. This would not have been possible without the support from our partners and the RCN, thank you all. And finally, I am curious to see what next year brings in the CCS area. I am however confident that BIGCCS will deliver excellence and continue to be relevant for solving one of our civilizations Grand Challenges.

Chairman of the Board
Nils A. Røkke
(Photo: Gry Kari Stimo)

2. MESSAGE FROM THE CENTRE DIRECTOR

Dear BIGCCS friends! This year I am even prouder than last year. We are about to exceed our ambitions as the annual turnover of BIGCCS is approaching NOK 70 million. The reason for the increased budget is our success in establishing new infrastructure projects as well as including new competence building projects under the BIGCCS consortium agreement. The competence building projects are; *CO2MIX* (2010), *BIGCLC* (2011), followed by *CAMPS* and *FEFROCK* that was funded in 2011 and is planned to be amended during the spring 2012.

In connection with the successful TCCS-6 conference in June 2011, the BIGCCS Scientific Committee (SC) met for evaluation of selected BIGCCS research tasks. The SC comprising world-leading experts in the main fields covered by BIGCCS gave valuable input to our further efforts in performing relevant research in the forefront internationally that will bring CCS closer to realization.

Further, 2011 was characterized by discussions on how BIGCCS can enhance innovation within the Centre and our partners' enterprises. It has become clear that the word *innovation* has different interpretation dependent on who is asked. This is a question we will continue to pursue and I already now look forward to the coming discussions. The struggle with establishment of large-scale CCS projects world-wide confirms the need for predictability and knowledge based on a long-term and fundamental research initiative, such as BIGCCS.

By this I would like to thank our always professional and demanding industry partners that strongly contribute to increase our ambitions and the quality of the results from BIGCCS. I would also like to thank the Centre Management Group for excellent cooperation during 2011. Last, but not least thanks to the Task leaders and the researchers who managed to deliver close to 100% in 2011.

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

3. SUMMARY 2011

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 (SC), an Exploitation and Innovation Advisory Committee (EIAC), and a Centre Management Group (CMG). 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**, 2011 has been a year according to plans. With minor deviations, deliverables and publications have been produced according to plan – 132 altogether. A total of 48 scientific publications in addition to 67 confidential reports were produced. BIGCCS **recruited** four more PhDs and one more Post-doc in 2011, and the Centre is now ahead of schedule.

On the **organizational side**, 2010 saw the establishment of the Exploitation and Innovation Advisory Committee, which is expected to be a useful instrument in identification of prospective innovation activities and of spin-off activities in general. There were no changes in membership.

On the **international arena**, BIGCCS has expanded cooperation with Sandia National Laboratory and Berkeley University through a new project and has pursued potential cooperation with The Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. BIGCCS also participated at the *Transatlantic Science Week* (California, USA).

A strategy for **innovation and centre building** was developed in 2010. One important activity in 2011 was interviews with both the industrial and research partners about their innovation expectations. Furthermore, the Exploitation and Innovation Advisory committee was established with the aim of intensifying the focus on innovation.

BIGCCS places importance in **communication and dissemination** of results to a broad audience. This year BIGCCS put significant effort into the organization of the *6th Trondheim Conference on CO_2 Capture, Transport and Storage*. A special issue of *Energy Procedia* will present some 60 papers from the conference.

BIGCCS continued its strong focus on HES in 2011. With the exception of one incident without injury to personnel or equipment, 2011 confirms that our systematic efforts are paying off. The first annual HSE report was issued.

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 by 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 six 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, eight 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.

Furthermore, it is an objective to acquire accurate experimental data on thermophysical properties of CO_2-rich mixtures at conditions relevant for operations involved in CCS chains, primarily conditioning and transport. The data will be used to improve and/or extend the range of validity of existing thermodynamic models.

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_2 storage.
- 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. Research relies on a dual 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.

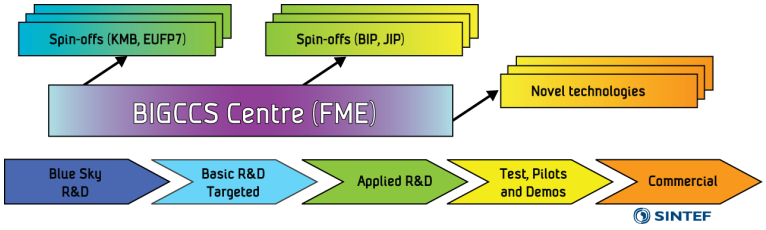
In BIGCCS, research takes place within international networks of scientists, including the participation of world-class experts. The emphasis is on building expertise through quality research at a high international level, both within the research tasks, the post-doctoral work, and through the education of PhDs. New knowledge is in part 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 exploitation, 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 stimulate innovation. 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]

BIGCCS focusses on increasing value for partners



[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*

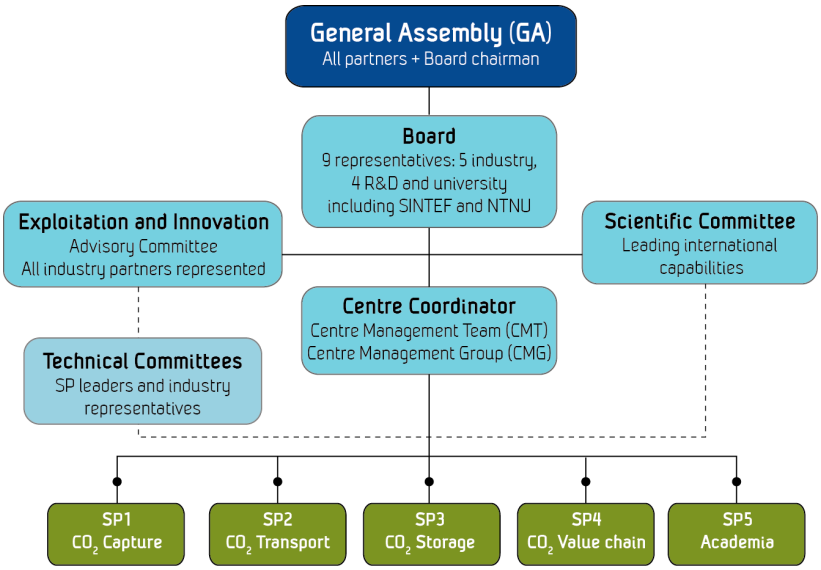
6. ORGANIZATION

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 governance 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 (SC):** advisory committee with leading international academic capabilities giving guidance to the Centre towards the scientific progress.
- **Exploitation and Innovation Advisory Committee (EIAC):** 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 (GA)**: ultimate decision-making body, ensuring that operations are carried out in accordance with the Consortium Agreement.

EXPLOITATION AND INNOVATION ADVISORY COMMITTEE

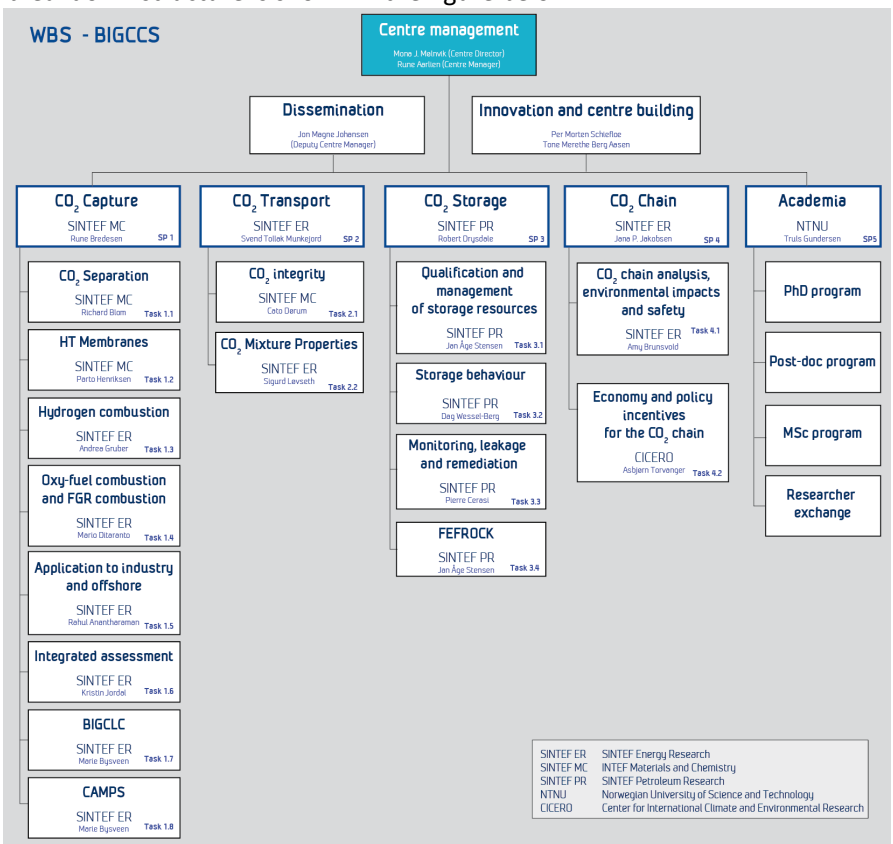
The *Exploitation and Innovation Advisory Committee* (EIAC), was established in December 2011, and will be an important advisory tool for BIGCCS in spurring innovation activities. The committee is open for participation from all industrial partners, and so far four of them have volunteered to join. Activities will commence in 2012.

SCIENTIFIC COMMITTEE

The BIGCCS Scientific Committee (SC) was established in 2010, and held its second meeting in June 2011 in conjunction with the TCCS-6 in Trondheim. At this meeting the Committee made an assessment of the scientific quality and achievements of BIGCCS so far, and reported back to the Board via the centre director. The report constituted a very useful feedback to the Centre. In general terms the committee focussed on issues such as: clarity in motivation and state-of-the-art, ambitions in terms of goals and objectives, relevance of the research, how the research fits into the global scientific landscape, and communication of results. The SC encourages more cooperation between tasks and sub-projects where relevant. Chair of the Committee is Professor May-Britt Hägg (NTNU, Norway).

WORK BREAKDOWN STRUCTURE

The work breakdown structure is shown in the figure below.



BIGCCS work structure breakdown. Task 1.8 and 3.4 were granted as KPN projects by the Research Council of Norway in 2011, and will formally become part of BIGCCS in 2012.

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 conducts 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 are 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 sub-projects are also 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 the Board to consolidate activities and budgets before Phase II and 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 2011:

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. 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 and 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, 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 "research university" in Germany.
- **University of Oslo (UiO)**: Thermo-chemical conversion, chemistry.

ASSOCIATED PARTNERS

- **Ruhr Universität Bochum**: Cooperation on fundamental properties of CO_2 (Task 2.2)
- **Sandia National Laboratories**: Combustion (Task 1.3 and 1.4)
- **University of Berkeley**: Combustion (Task 1.3 and 1.4)

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. During 2011, teleconference and video meetings have been used increasingly in order to limit time-consuming travelling. Technical meetings took place in May and December with more than 50 participants.

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 2011, such meetings were held both with and without industrial partners.

CONSORTIUM DAY

The Centre organizes an annual Consortium Day. At this event all partners and researchers are invited, and the intention is to provide a snapshot of last years' activities and results. The 2011 Consortium Day was held at Lerkendal Stadium in Trondheim, Norway, on September 15 and attracted approximately 50 attendees. The day after, a PhD seminar was held where the current BIGCCS PhD students presented progress of their work for the consortium partners. The seminar gathered roughly 35 participants.

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, SINTEF Petroleum Research, SINTEF Materials and Chemistry, as well as NTNU Social Research are present. The CMG held 21 meetings during 2011, including one full-day CMG seminar. 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.

TASK LEADER SEMINAR

A Task Leader Seminar is organized at least once every year. The intention is to bring together all Task Leaders to discuss topics of general interest to the Centre as such. This year the seminar was held at Sverresborg Museum on February 3, and the full-day event was used to discuss how to improve "quality in BIGCCS".

7. RESULTS FROM RESEARCH ACTIVITIES

7.1 EXPANDED ACTIVITIES LEVEL

During 2011, the BIGCCS activity level has increased considerably. Below are listed some of the most important achievements.

NEW ACTIVITIES

Task 1.7, *Chemical Looping Combustion* (BIGCLC), was formally included in BIGCCS in 2011. This is a KPN project lasting five years, with a total budget of NOK 27 million. The objective is to bring chemical looping combustion technology to the next level of maturity in order to become a competitive option for steam and power generation with CO_2 capture. An important part of BIGCLC is to erect a new 150 kW CLC reactor system.

Task 1.8, *Cross-Atlantic Combustion Modelling, Programming and Simulation* (CAMPS), was granted by the RCN in December, 2011. The main objective is to develop the next generation of high-fidelity numerical design tools for CCS-related combustion technologies. Secondary objectives of the project are to establish a US-Norwegian network for combustion modeling and simulation, and to enhance the competence of Norwegian combustion scientists through extended collaboration with world-leading experts in the US. The project period is three years and a total budget of NOK 20 million. CAPMS will be formally included in BIGCCS during 2012.

Task 3.4, *Fundamental Effects of CO_2 on Rock Properties* (FEFROCK), was also granted by the RCN in December 2011, and will be formally included in BIGCCS in 2012. The project aims to improve the understanding of the fundamental effects of CO_2 injection on the geomechanical and flow properties of low permeable layers in a storage reservoir and partly sealing caprock. Two work packages are proposed. The geomechanical work includes the effects on flow due to thermal stress, fracture initiation or reactivation and pressure variations, and will be supplemented by an analysis of the properties of layered reservoirs. The second work area investigates how wettability and capillary entry pressure of rocks are affected by long-term exposure to CO_2 in brine, using pore-scale investigation. The project period is three years and the overall budget is NOK 15 million.

For the first time in 2011, BIGCCS organized the *Trondheim Conference on CO_2 Capture, Transport and Storage* (TCCS). This was the 6th TCCS, which has become one of the major scientific conferences world-wide. TCCS-6 beat all previous records with 450 participants. It is likely that BIGCCS will also take an active role in the staging of the next Trondheim Conference in 2013.

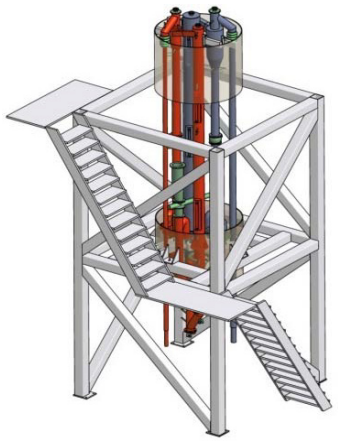
The *SINTEF and NTNU CCS Award* was instituted in 2011, and was handed out first time in conjunction with the TCCS-6. BIGCCS set up an international nomination committee, organized the selection process and designed the diploma. The intention is that this award will be handed out bi-annually in connection with the TCCS.

NEW INFRASTRUCTURE

High Pressure Oxy-Fuel Combustion Facility (HIPROX) – The HIPORX test facility has been complete. The facility is designed for oxy-fuel combustion testing at a pressure of 10 bar and a fuel power load of 125 kW_{th}. The total budget for the rig is approximately NOK 8 million, of which around 3.5 million has been allocated from BIGCCS investment funds.

CO_2 Mixture Properties – A test rig for measurements of fundamental properties is being erected in the laboratories of SINTEF Energy Research. The purpose is to measure phase equilibriums, density and speed of sound in CO_2-rich mixtures. The rig has a total budget of NOK 5.0 million, of which NOK 3.9 million will be allocated from BIGCCS investment funds. The rig will be completed during 2012.

Circulation Looping Combustion – In 2011, BIGCCS received NOK 6.0 million from the Research Council of Norway for investments in a CLC test rig. This rig will allow BIGCCS to become an internationally leading actor within the field of CLC. No CLC rigs exist at present with the same physical size and thermal output at pressurized conditions – with the same degree of flexibility represented by the innovative double-loop design. Nor has there been real long-term investigations carried out, something which is needed in order to push this technology further. Finally, no results exist in the literature on tests of advanced oxygen carriers at this pilot size. The CLC test facility in question will enable up-scaling of the CLC technology by building necessary competence within all the before mentioned areas. Design of the rig began in 2011, and completion is scheduled for 2013.



Drawing of the new CLC test rig

7.2 CO_2 CAPTURE – SP1

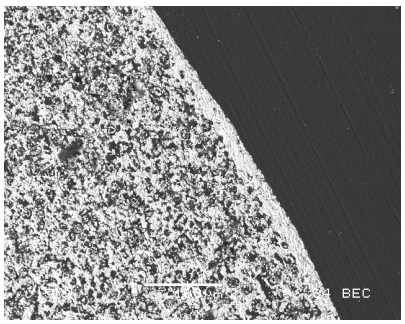
SP1 consists of the following seven tasks:

- 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 1.7: Chemical looping combustion

TASK 1.1 – CO_2 CAPTURE

WP 1.1.1 "Precipitating systems for CO_2 capture" aims at energy saving in CO_2 capture by precipitation in the absorber where only a part of the solution needs to be regenerated. Carbonates and amino acid salts that form precipitate in reaction with CO_2 are environmentally friendly, have low vapor pressure and are stable to degradation. The work focuses on finding candidate solvent system and development of methods for studying precipitation at process conditions. Two to three candidate solvents have been selected for further studies. In WP 1.1.2 "High temperature sorbents for CO_2 capture", processes that capture CO_2 by reacting with solid powder materials/oxides at 600-900°C are studied. Cheap natural materials/minerals (dolomite) are modified to increase lifetime while keeping CO_2 capture capacity at sufficient level. A series of new sorbents with improved lifetime and satisfactory capacity have been synthesized.

TASK 1.2 – HIGH TEMPERATURE MEMBRANES

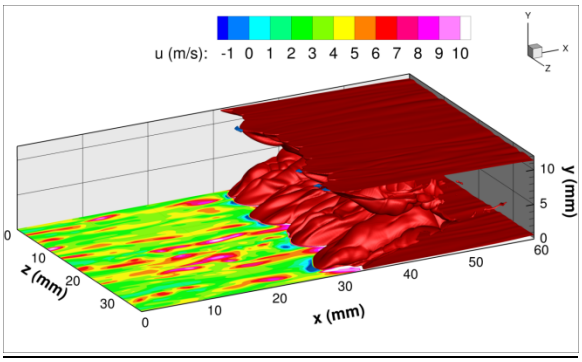


Asymmetric membrane

The work on high temperature hydrogen separation membranes has focused on the search for materials stable at operating conditions similar to those encountered in power generation plants. Several materials were found to be more stable than the state-of-the-art, doped $SrCeO_3$ material, at 10 bar pressure and 600-800^{o}C. In parallel, thin dense membranes on porous ceramic supports have been successfully fabricated. The manufacturing process is environmental friendly with the use of water-based extrusion and dip-coating technique.

TASK 1.3 – HYDROGEN COMBUSTION

The research work focuses on improving know-how and detailed understanding at the fundamental level about combustion of hydrogen-rich gaseous mixtures, which are becoming increasingly relevant in several CCS power generation schemes. The mechanism by which a hydrogen flame propagates near a solid surface has been investigated; a fundamental process that is believed to be responsible for serious issues related to flashback (flame dislacement upstream of design position) in modern gas turbine burners. A previously unknown feature of near-wall flame propagation is discovered using a very detailed numerical simulation technique (Direct Numerical Simulation or DNS) and is described in a publication to appear in the *Journal of Fluid Mechanics*.



Direct Numerical Simulation of H_2 flame flashback in turbulent channel flow in a duct

TASK 1.4 – OXY-FUEL COMBUSTION AND FLUE GAS RECYCLE

The work on oxy-fuel combustion is dedicated to solve challenges related to the burning of fuels in atmospheres of oxygen and CO_2. A new high pressure testing facility dedicated to oxy-fuel has been erected and an existing facility at DLR (Germany) has been used for *flue gas recycling* applications. It has been evidenced experimentally that the use of high levels of CO_2 dilution affects considerably the stability of the flame and can weaken the operation of realistic gas turbine burners. A scientific comparison of various post-combustion power plant alternatives has been published in the journal *Energy* showing that exhaust gas recirculation in a gas turbine based on a post-combustion CCS cycle is the most appropriate way to improve its efficiency.

TASK 1.5 – APPLICATION TO INDUSTRY AND OFF-SHORE

The potential of various capture routes for four specific cases proposed by industrial partners has been studied. As a first step, a reference case for each of the case studies was set up using MEA (monoethanolamine), an established solvent for capture. Alternative technologies were extensively studied to evaluate the potential of low temperature capture technology for a large range of process conditions:

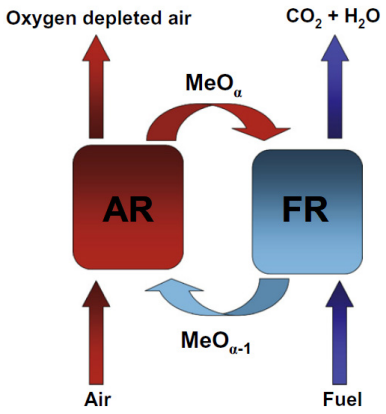
1. Floating Production Storage and Offloading (FPSO) unit: To capture CO_2 from gas turbines on-board an FPSO unit with membrane contactors (mathematical model) and dual-phase membranes (experimental study).
2. Reformer-fired heaters in refineries: The feasibility for retrofit of fired heaters for hydrogen combustion (computational fluid dynamics study) and oxy-combustion (experimental study).
3. Aluminium smelter exhaust: To increase the low partial pressure of CO_2 in aluminum exhaust, integration of the exhaust with a gas turbine, and the effect of impurities and dust on the gas turbine and amine capture system were studied.
4. Kårstø retrofit: The capture technologies related to this case study are similar to those for capture in refineries and are evaluated similarly.

TASK 1.6 – INTEGRATED ASSESSMENT

The overall purpose is to compare and evaluate power cycles with CO_2 capture and the novel process units that are required to enable the capture. Reference power plants have been simulated with a consistent set of input data, and the basis for a methodology to benchmark different CO_2 capture processes was developed. Work is started to develop mathematical models for novel process components as membrane and fluidized bed reactors that enable simultaneous CO_2 capture and hydrogen production. Furthermore, as is done every year, a description was made of the interdependencies between different tasks in *Sub-project Capture* to follow consistency and fertilise idea generation for collaborative research across the sub-project.

TASK 1.7 – CHEMICAL LOOPING COMBUSTION

In Chemical Looping Combustion (CLC) – another oxy-fuel process – the combustion process is split in two. A metal oxide material is circulated between two reactors transporting oxygen from the air reactor to the fuel reactor where the oxygen is used to combust the fuel. The exhaust consists of CO_2 and H_2O, similar to an oxy-fuel process. SINTEF and NTNU have proposed a new design for a 150 kW CLC reactor system. The viability of the new design has been extensively tested by means of a cold flow model in full scale of the hot rig design. The targeted oxygen carrier exchange of about 2 kg/s was achieved. After further design modifications and rebuilding, the system is working more stable, with increased operability, higher solid flows, higher solids concentrations up along the reactors, and potentially higher fuel conversion. The design work has been published in the *International Journal of Greenhouse Gas Control* and the first performance testing of the cold flow model has been published in *Energy Procedia*.



The chemical looping combustion principle. The metal oxide material (MeO) is circulated between the air reactor (AR) and the fuel reactor (FR). The resulting effect is that oxygen level in the fuel reactor is increased.

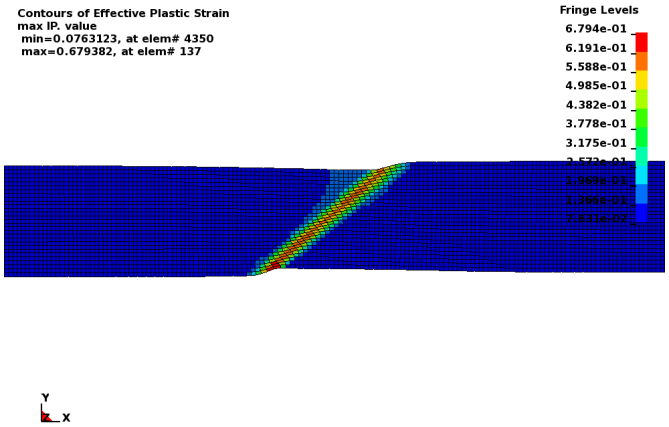
7.3 CO_2 TRANSPORT – SP2

SP2 has two tasks:
- Task 2.1: CO_2 pipeline 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 Energy Research (thermo and fluid dynamics) and SINTEF Materials and Chemistry (structural mechanics). The development of the coupled model will proceed in close collaboration between the two research groups, and by gradual refinement. The work in 2011 concentrated on the modelling of shear instabilities and on robust and accurate calculation of the thermodynamic properties of CO_2.



2D numerical simulation of deformation of a material exposed to tension. The colour indicates the level of deformation.

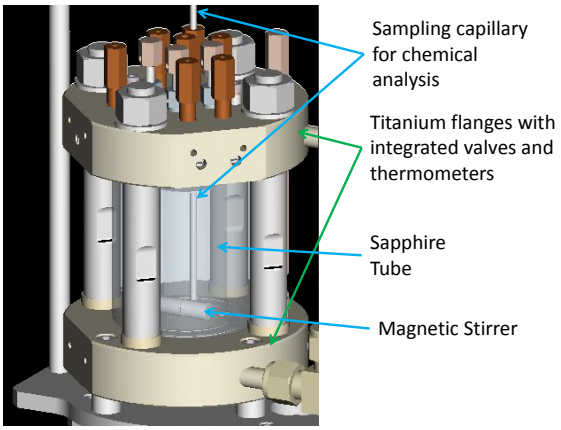
Two PhD candidates and one Post-doc will work in this task. The first PhD candidate was employed in September 2009, and the working title of the doctoral project, to be completed in 2012, is "Mathematical modelling and numerical simulation of two-phase multi-component flows of CO_2 mixtures in pipes".

In 2011, the work resulted in one journal paper, one conference article (to be published in 2012) and two conference presentations.

TASK 2.2 – CO_2 MIXTURE PROPERTIES

This task was planned as a KMB (KPN) 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 thermodynamical 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 Energy Research, 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 2012. The main task of this student will be to perform phase equilibrium measurements.



Test cell for measurement gas-liquid composition of CO_2-rich mixtures at equilibrium

In 2011, the focus of the work has been to design and build the experimental rigs needed for the measurements. The rigs for phase equilibrium measurements, density, and speed of sound will be completed in 2012. The task was presented at the 6th Trondheim CCS Conference (TCCS-6).

In addition to the consortium day presentations, the work in SP2 was presented to the BIGCCS partners in two separate technical meetings, taking place in May and December.

7.4 CO_2 STORAGE – SP3

SP3 consists of the following three 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

An important focus within this activity has been the development of computer software for improved modelling of CO_2 underground storage. Prediction of underground CO_2 storage capacity is based on computer modelling and so depends heavily on reliable methods and correct input values.

The recent development of a 3-dimensional code for predicting possible fracturing of the underground rock due to overpressure caused by CO_2 injection may be essential to avoid serious leakage from the reservoir. Further testing of the software is needed to verify the results.

A new approach for modelling CO_2 movement underground over thousands of years is being investigated, using the *basin modelling technique* from oil exploration. The objective is to give more correct prognoses of possible CO_2 leakage paths and thereby long-term leakage rates, which is valuable information for storage selection and site management. Preliminary results are promising, but further development and testing for verification is needed.

In addition, storage studies have been performed on specific areas in order to improve knowledge of potential CO_2 storage capacities, mainly offshore Norway, Denmark and UK. An interactive database is under construction to collate and provide access to the relevant data.

TASK 3.2 – STORAGE BEHAVIOUR

This activity studies the basic mechanisms related to CO_2 in underground storage, involving work within geochemistry, geology, basic flow mechanisms and pressure management. The main activity aims to improve the understanding and modelling capabilities of so-called *convective mixing*. Convective mixing is a gravity-driven mechanism which increases the dissolution rate of CO_2 into the aquifer brine. Dissolution is one of several CO_2 trapping mechanisms by which CO_2 will be retained underground for millennia and faster dissolution may imply that higher injection rates are possible.

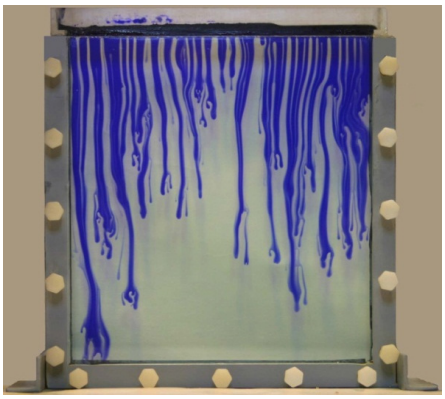


Image of a preliminary experiment on convective mixing in a Hele-Shaw cell using saline water of different densities

Much of the work in 2011 has been on theoretical derivation of the minimum time until the onset of convective mixing and for the first time calculating an exact value for this. However, to allow this work to be used for practical analysis of CO_2 storage it is also important to scale-up the model for use in field-scale simulations. Some results have been obtained in 2011, both theoretical and numerical and in 2012 efforts will focus on the impact of fine scale heterogeneities on these matters.

In order to visualise convection effects, preliminary experiments have been performed in a large scale 2D Hale-Shaw cell. The aim is to produce high quality films of CO_2 dissolution in such cells, including representations of realistic geological heterogeneities. Such films will contribute to public understanding and acceptance of underground CO_2 storage.

TASK 3.3 – MONITORING, LEAKAGE AND REMEDIATION

It is generally accepted that the various geophysical surveying techniques offer the best methods for monitoring the location of CO_2 stored underground. Various improved techniques are being investigated including *Full Waveform Inversion* of seismic data over several time-steps to follow the migration of the CO_2 plume with greater resolution and perhaps to quantify CO_2 saturations, i.e. where has the CO_2 got to and how much is there?

Controlled Source Electromagnetic monitoring is another promising surveying technique and the first indications from synthetic data suggest that smaller CO_2 plumes will be detectable, with CO_2 saturation changes as small as 10%. This type of technology would be very useful in monitoring storage sites for leakage, in which detection of smaller leakage volumes means earlier warning and faster remediation.

Various other techniques being developed include changes in seismic velocity "pull-down" as an indicator of very small CO_2 saturations and spectral decomposition of seismic data to detect thin fingers of CO_2 which spread out laterally from the main deposit.

The most likely cause of leakage from CO_2 storage has been identified as being via the wells drilled into the geological structures used for storage, i.e. man-made leakage points. More specifically, the weakest spot in the wells with respect to integrity is believed to be the annular cement bond between the rock and the well casings. Possible causes for this leakage scenario have been studied during 2011 and a programme of experiments will start in 2012 to analyse the failure mechanism in more detail.

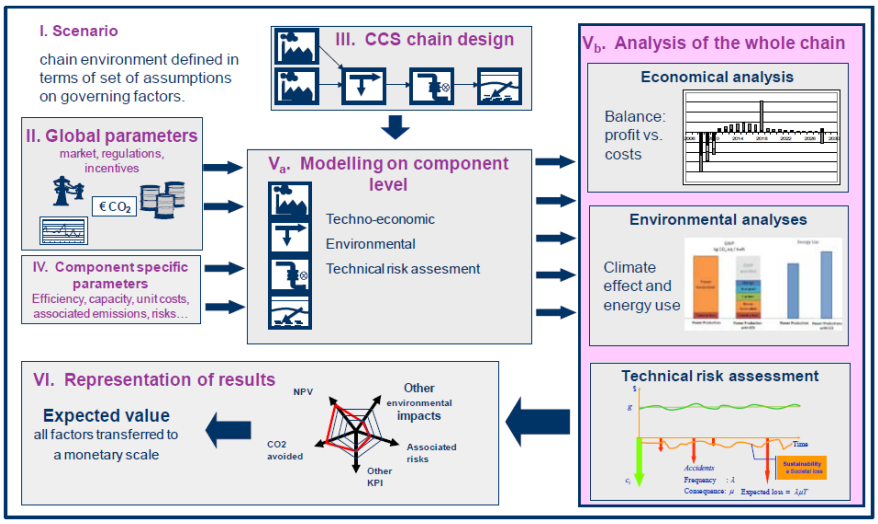
7.5 CO_2 VALUE CHAIN – SP4

SP4 has two tasks:

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

TASK 4.1 – CO_2 CHAIN ANALYSIS: TECHNO-ECONOMICAL AND ENVIRONMENTAL IMPACTS AND SAFETY

The main objective is to enable CCS value chain assessment as a means for selecting the most cost-effective, environmental friendly and safe options for CCS. In 2011, Task 4.1 continued to develop the methodology for a multi-criteria assessment of CCS chains. The approach is flexible and modular. This means that modules are developed for capture, transport, and storage that can be used as basic buildings bricks and connected freely in order to create various chain designs. In 2011, the work focused on developing the capture module (for post-combustion amine absorption capture) by performing the techno-economic modeling in *AspenPlus* and *Aspen Economic Analyzer* and also developing a consistent method for connecting the LCA assessment of capture to the techno-economical data in a proper manner. The use of the module was illustrated by a simple case study on the impact of CO_2 concentration and steam supply. A study on flexibility of power production with capture was also performed. This work will continue in 2012 by extracting "parameterized" cost and LCA key performance indicator functions for post-combustion with amine capture module. In 2012, work will also focus on development of transport modules for on-shore and ship transport and again on illustration of their functionalities on simple case studies.



SP4 Framework for a multi-criteria assessment of CCS chains

TASK 4.2 – ECONOMIC AND POLICY INCENTIVES FOR THE CO_2 CHAIN

One of the objectives is to take better advantage of the *learning-by-doing potential* of CCS. In 2011, the Task worked on gaining a better understanding of the learning potential of CCS for enhancement of innovation of the CCS technologies. Learning by doing can substantially reduce the cost of most energy technologies over time. Reduced costs are particularly important in the case of CCS given the present large gap between valuation of avoiding the release of one ton of CO_2 to the atmosphere and the cost of handling this ton through a CCS chain. In the innovation phase large investments are needed for CCS capture technologies, e.g. for building demonstration plants, and payback time is uncertain. This indicates a role for government support. The government's resources are limited, so decisions must be made on *how many* and

what capture technology candidates should be supported. We show that a government's best option is to balance benefits of learning and spreading of risk across technology candidates with uncertain payback time through supporting a focused portfolio of emerging technologies.

In 2011, work also focused on designing efficient incentives for CCS invention, innovation, and dissemination. Due to present economic and political conditions, private incentives for CCS innovation are insufficient to meet the climate change challenge and society's potential value of this technology. In this situation an important research question becomes how efficient incentives for CCS invention and innovation can be designed, and the potential for commercialization of CCS and establishing working markets for capturing, transporting, and storing CO_2. Focusing on the storage phase of the CCS chain, we study the value of CO_2 storage relative to energy technologies not producing CO_2, and find that this relative value depends on the discount rate, the development of climate change damage over time, and the time profile of CO_2 leakage. Another aspect of efficient incentives for CCS dissemination relates to investments in CCS by power producers. In a study building on an *American case* we analyze investments in power production under three policies that include a new source performance standard and two variations that introduce flexibility (e.g. a flexible emissions rate standard that imposes a surcharge for emissions in excess of the standard). The study finds that this type of flexibility leads to earlier investment in CCS, lower emissions, and higher profits for power producers.

7.6 ACADEMIA – SP5

Following a very strong *recruitment* effort in 2010, when nine PhDs and two Post-docs were added to the team, things were (as planned) slower in 2011. Nevertheless, three more PhDs and one Post.doc were recruited in 2012. The total work force of PhDs and Post-docs is now 17 PhDs and tree Post-docs. One Post-doc has already completed his project. Se Chapter 9 for more details.

The volume of *publications* in 2011 has increased rather nicely following low activity in 2010. There is a natural inertia in this respect, since the PhD students are occupied by compulsory courses for a good part of their first year. The accumulated list of publications by the end of 2011 shows the following statistics:

- Journal Publications: 8 (5 during 2011)
- Conference Publications: 25 (18 during 2011)

Some of the conference publications will be converted into journal publications. It should be noted that the list of publications here only refers to publications where one or more of the PhDs and Post-docs recruited in BIGCCS are among the authors, so this is not representative for the entire publication efforts in BIGCCS.

Regarding highlights from the *research* activities that the PhD students and Post-docs are involved in; these are more appropriately reported under the headings of the relevant Sub-Projects.

7.7 DELIVERABLES

BIGCCS had planned for 132 deliverables in 2011 – 132 were delivered on time. This includes publications, technical reports, status reports, technical memos, and anything that can be associated with the regular and planned operation of the Center. The table below shows how the deliverables are distributed among the Sub-projects:

Sub.project	Planned	Extra	Deleted	Total
SP1	57	0	0	**57**
SP2	22	0	0	**22**
SP3	34	0	0	**34**
SP4	12	2	3	**11**
Centre mgmt	7	1	0	**8**
Total	**132**	**3**	**3**	**132**

BIGCCS deliverables in 2011

Three deliverables were not produced (deleted) owing to a change in strategy by one of the BIGCCS partners. They were compensated for by three *extra* deliverables.

8. INTERNATIONAL COOPERATION

International cooperation is a central and integrated part of the BIGCCS activities. Through the participation of strong European industry partners and highly ranked international R&D providers, the BIGCCS Centre maintains a high international profile. Seven nations are currently represented, including the industrial participants: *ConocoPhillips* (USA/Norway), *GDF Suez* (France/Norway), *TOTAL* (France/Norway), *Shell* (Netherlands/Norway), and 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 different BIGCCS committees. Below are listed some of the 2011 activities.

COOPERATION WITH INTERNATIONAL RESEARCH GROUPS OUTSIDE BIGCCS

BIGCCS continues cooperation with *University of Berkley* (California, USA). Partial funding is provided for two PhD candidates. Headed by Professor Robert Dibble, University of Berkley is one of the world leading research groups on combustion. Studying turbulent combustion, the PhD candidates are already well into 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 renewed five year MoU between SINTEF and Sandia was signed in December 2011.

From the signing of the renewed 5 year MoU between Sandia National Laboratory and SINTEF in December 2011

During 2011, a new project has been prepared. Titled *Cross-Atlantic Combustion Modelling, Programming and Simulation* (CAMPS), the project aims to develop the next generation of high-fidelity numerical design tools for CCS-related combustion technologies. The project builds on the strong collaboration between SINTEF, Sandia National Laboratories, UC Berkeley, and Stanford University, and will also include premier institutions such as Georgia Tech University, North Carolina State University, Brigham Young University and National Renewable Energy Laboratory. This project was granted by the RCN in December 2011, and will formally become Task 1.8 of BIGCCS in 2012. The duration is four years, and the total budget is NOK 20 million.

In 2011, the Chairman of the Board, Nils A. Røkke visited the Commonwealth Scientific and Industrial Research Organization (CSIRO) with the aim of investigating the potential for cooperation. CSIRO is Australia's national science agency and one of the largest and most diverse research agencies in the world, and is heavily involved in both climate change and energy issues. Very useful contacts were established and the potential for further cooperation will be followed up in 2012.

COOPERATION WITH INTERNATIONAL ORGANIZATIONS

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).

2011 saw the establishment of the *Nordic CCS research Centre* (NORDICCS). This is first and foremost a networking collaboration between R&D institutes and the industry in the Nordic countries with focus on CCS deployment. With differing and complementary focus, the potential for cross-fertilization between NORDICCS and BIGCCS is eminent, and a close cooperation is established. More information on NORDICCS can be found here: http://www.sintef.no/NORDICCS.

ORGANIZATION OF CONFERENCES, WORKSHOPS AND SEMINARS

BIGCCS was in 2011 responsible for the organization of *The 6th Trondheim Conference on CO_2 Capture, Transport and Storage* (TCCS-6). With 450 attendees from 22 countries, 146 oral presentations and 112 posters, the conference positions itself among the top current CCS events world-wide. The focus of the conference is highly scientific, and approximately 60 of the presentations will be published in a special issue of *Energy Procedia* in 2012. At the conference the first SINTEF and NTNU CCS Award was given to Dr. Erik Lindeberg of SINTEF Petroleum Research. The prize, which will be awarded every second year, is meant to be a recognition for international and substantial contributions to the development of the CCS area. Dr. Lindeberg received the award for his pioneering CCS activities over the last two decades. More information can be found here: http://www.sintef.biz/Projectweb/TCCS-6/.

Winner of the "SINTEF and NTNU CCS-Award 2011", Dr. Erik Lindeberg, SINTEF Petroleum Research, receives the prize from Professor May-Britt Hägg, leader of the Scientific Committee, and Dr. Nils Røkke, Conference Chair

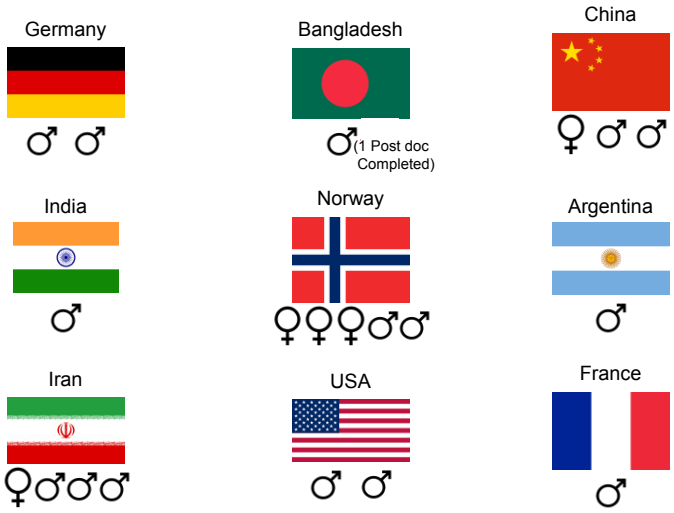
The Trans-Atlantic Science Week 2011 was staged at University of Berkeley and Stanford University, California, USA (October 25-28). BIGCCS shared the responsibility of organizing a side event with focus on CO_2 storage, and with a presentation in the session "Climate and CO_2 management" by Dr. Nils Røkke.

9. RECRUITMENT

The overall recruitment objective is for BIGCCS to produce 18 PhDs and eight Post-doc candidates. Three PhDs and one Post-doc were recruited in 2012. The total work force of PhDs and Post-docs is now as follows:

- 13 PhDs and 3 Post-docs
  - 11 PhDs and 3 Post-docs (NTNU)
  - 1 PhD (University of Oslo)
  - 1 PhD in (Technical University of Munich)
- 1 PhD funded as "in-kind" from University of Oslo
- 3 PhDs funded by associated partners
  - 2 at University of California at Berkeley
  - 1 at Ruhr University, Bochum
- Total workforce is then 20 researchers, one of these (Post-doc) finished in 2011
- 5 of the 20 are female researchers
- 9 countries are represented, thus a highly international group of researchers

The distribution of candidates between county and gender is shown in the figure below.



Distribution of PhD and Post-doc candidates between country and gender

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 2011.

CONFERENCES

The BIGCCS Centre received a high public profile by organising t*he Trondheim Conference on CO_2 Capture Transport and Storage* (TCCS-6), which has become a major scientific CCS conference. BIGCCS had a central role in organizing the conference in 2011, and contributed 23 presentations – eight oral and 15 poster presentations. More than likely, BIGCCS will also assume a central role in the organization of TCCS-7 in 2013.

It is, further, the ambition of the BIGCCS Centre to take an active role in the organization one of the next *GHGT*-conferences. A joint NTNU-SINTEF expression of interest has been submitted to host the GHGT-13 in 2016.

SPECIAL ISSUE OF ENERGY PROCEDIA

All authors, both oral and poster, at the TCCS-6 conference has been offered the possibility to make scientific publications of their contributions. A special issue will be made from the conference through Energy Procedia. This issue will be published in the summer of 2012, and will contain approximately 60 papers.

WEB

BIGCCS's internet homepage has been has been maintained during 2011, 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 shall contain information relevant to all BIGCCS target groups.

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 project. The roadmap has been updated in 2011.

CCS Animation Movie

A CCS animation movie was produced in 2010. 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) and on YouTube where it has had more than 2300 hits. The movie comes with both English and Polish language. The Polish version was requested and paid for by *The Polish Energy Group*.

BOARD MEETINGS AND GENERAL ASSEMBLY

BIGCCS held two Board meetings in 2011: on May 4 and December 2 (both in Trondheim). The General Assembly was held in Trondheim on September 16.

11. INNOVATION AND CENTRE BUILDING

The core of BIGCCS's mandate is to develop research-based knowledge and technologies that contribute towards realizing efficient industrial carbon capture, transport, and storage. In so doing, the center is given a significant social mission for reducing the carbon footprint of fossil-based energy production. In BIGCCS, *NTNU Samfunnsforskning, Studio Apertura*, assumes a particular responsibility for the continued focus on innovation processes and centre building. In 2011, emphasis has been put on three areas which together are believed to strengthen the overall focus on innovation opportunity in BIGCCS. These areas are:

- Innovation processes
- Innovation management
- Framework conditions for innovation in the field of CCS.

Based on structured conversations with BIGCCS researchers and representatives from industry partners, together with an analysis of current media discourses on CCS, suggestions for the further focusing on innovation in BIGCCS have been developed. We find that the actual expectation about innovation as expressed by the Norwegian Research Council and by some of the industry partners appears unclear to many of BIGCCS members. Accordingly, BIGCCS Centre management will continue to address the issue of 'innovation expectations'. Furthermore, most BIGCCS user partners do not view themselves as a customer of BIGCCS research, but call for the supplier industry to be more closely involved. Inherent in this is a potential challenge that CCS technologies may not be considered profitable by the supplier industry without an appropriate regulatory regime for CCS technologies.

To strengthen the focus towards the above challenges, the *Exploitation and Innovation Advisory Committee* (EIAC) was formally established in December 2011. In accordance with the EIAC mandate, all industrial partners were invited to appoint a representative to the committee. At present, four industrial partners have accepted the invitation. Their work is supported by a member of the BIGCCS Centre Management Group. EIAC will meet once a year in connection with the annual BIGCCS Consortium Day. The committee will provide for evaluation of the commercial potential of developed technologies based on specifications prepared by task leaders. By these evaluations, the focus towards innovation and value creation in BIGCCS as well as identification of opportunities for future activities, including spin-off projects, will be strengthened.

The innovation and centre building activities include the exploration of BIGCCS experiences as basis for academic and popular science contributions within the fields of research and innovation management. In 2011, this activity resulted in one conference presentation, one conference poster, two journal papers (to be published in 2012), and a feature article:

- Aasen, TMB, Mølnvik, MJ, Aarlien, R, Johansen JM, Bredesen, R, Munkejord, ST, Drysdale, R, Brunsvold, A, Gundersen, T (2011) International CCS Research Centre: Managing Innovation in Heterogeneous Research Consortia. Poster presented at TCCS-6 conference, Trondheim, June 2011.
- Røyrvik, J., Schei Olsen, M., Aasen, T.M.B. (2011) Political rationality and CCS discourse. Presentation at TCCS-6 conference, Trondheim, June 2011.
- Aasen, TMB, Mølnvik, MJ, Aarlien, R, Bredesen, R, Munkejord, ST, Drysdale, R, Brunsvold, A (2012) Innovation in a heterogeneous CCS research centre, managerial and organizational challenges. Energy Procedia (forthcoming).
- Røyrvik, J., Schei Olsen, M., Aasen, T.M.B. (2012) Political rationality and CCS discourse. Energy Procedia (forthcoming).
- Aasen, T.M.: Forskning for et grønnere samfunn. Forskning nr.1/2012

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.

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.

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 CMG meeting starts with a discussion of such reports and conditions that should have been reported.

One incident was reported in relation to BIGCCS activities in 2011. The incident happened in SINTEF Energy's laboratory. At one of the test rigs a water hose burst and water sprayed out around the set-up. The reason was that the plastic hose for cooling water came in contact with a hot chamber during experiments. Fortunately, no negative consequences materialized, but the result could have been burns on operators had personnel been around. Also, equipment could have been damaged. Corrective measures were taken immediately, by fixing the new hose securely in order to avoid future contact with hot parts of the test rig.

The first BIGCCS HSE Annual Report was completed in 2011. The report describes: 1) the BIGCCS HSE policy, 2) HSE requirements, 3) How BIGCCS works with HSE, 4) Activities and statistics for the last year, and 5) Plans for the next year. In addition, it contains an attachment where the research partners – in a form – document and sign that their activities are performed in accordance with the HSE requirements set by the BIGCCS Consortium Agreement.

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
Cerasi, Pierre	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, experim'l mechanics
Gruber, Andrea	SINTEF ER	1	Combustion
Gundersen, Truls	NTNU	5	Process technology, pinch point analysis
Henriksen, Partow	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
Langørgen, Øyvind	SINTEF ER	1	Chemical looping combustion
Løvseth, Sigurd	SINTEF ER	2	CO_2 mixture properties
Munkejord, Svend T.	SINTEF ER	2	Modeling of fluid flow
Drysdale, Robert	SINTEF PR	3	Reservoir engineering
Anantharam, Rahul.	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
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

Taheri, Amir	Iran	2010-2014	M	Experimental study of CO_2 dissolution in brine aquifers
Soroush, Mansour	Iran	2010-2014	M	Modelling 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 CO_2 injection
Vøllestad, Einar	Norway	2010-2014	M	Characteristics of mixed proton cond. materials
Ma, Xiaoguang	China	2010-2014	M	Absorption in precipitating Systems
Wegge, Robin	Germany	2010-2013	M	CO_2 mixture properties
Enaasen, Nina	Norway	2011- 2013	F	CO_2 separation
Soundararajan, R.	India	2011-2014	M	Oxy-fuel combustion
Nilsen, Espen Birger	Norway	2011-2014	M	Monitoring, leakage and remediation

POST-DOC STUDENTS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

Name	Nationality	Period	Sex	Topic
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.
Zhang, Xiangping	China	2010-2013	F	CO_2 chain analyses.

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 2011

Name	Company	Country
Chadwick, Andy	British Geological Survey	UK
Lindefjell, Ole	ConocoPhilips	Norway
Lorentsen, Odd Arne	Hydro Aluminium	Norway
Morin, Pascale	TOTAL E&P	France
Myhr, May Britt	SINTEF Petroleum Research	Norway
Røkke, Nils A. (Chair)	**SINTEF Energy Research**	**Norway**
Solgaard Andersen, Henrik	Statoil	Norway
Steinskog, Tom	GDF Sues	Norway
Svendsen, Hallvard	NTNU	Norway
Viksund, Randi Isaksen	Gassco AS	Norway

GENERAL ASSEMBLY MEMBERS 2011

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
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
Nordby, Truls	University of Oslo	Norway
Ringrose, Philip	Statoil	Norway
Røkke, Nils A.	SINTEF Energy Research	Norway
Sattelmayer, Thomas	Technische Universität München	Germany
Steinskog, Tom	GDF SUEZ	Norway
Svendsen, Hallvard	NTNU	Norway
Svendsen, Pål Tore	Hydro	Norway
Teigland, Rune	TOTAL E&P	Norway
Torvanger, Asbjørn	Cicero	Norway
Tweeddale, Adrian	Shell Technology Norway	Norway
Vaggen Malvik, Håvard	Statkraft	Norway
Viksund, Randi I. (Chair)	**Gassco**	**Norway**
Slagtern, Åse (observer)	Research Council of Norway	Norway

SCIENTIFIC COMMITTEE MEMBERS 2011

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

EXPLOITATION AND INNOVATION ADVISORY COMMITTEE MEMBERS 2011

Name	Company	Country
Berger, Bjørn (Chair)	**Statoil**	**Norway**
Langelandsvik, Leif I	Gassco	Norway
Mostad, Helle Britt	Statoil	Norway
Saysset, Samuel	GDF SUEZ	France
Tweedale, Adrian	Shell Technology Norway	Norway

A2. ACCOUNTING REPORT

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

ACTUAL COSTS	
Personnel and indirect costs	11.889.987
Purchases of R&D services	34.276.617
Equipment	315.536
Other operating costs	2.730.624
Total	**49.212.764**
FUNDING	
Host institution	9.809.935
Private funding	16.400.598
International funds	3.002.231
Research Council of Norway	20.000.000
Total	**49.212.764**

A3. PUBLICATIONS

JOURNAL PAPERS (WITH REFEREE)

1. Bergmo, P. E. S., A.-A. Grimstad, et al. (2011). "Simultaneous CO_2 injection and water production to optimise aquifer storage capacity." International Journal of Greenhouse Gas Control **5**(3): 555-564.

2. Berstad, T., C. Dørum, et al. (2011). "CO_2 pipeline integrity: A new evaluation methodology." Energy Procedia **4**: 3000-3007.

3. Bischi, A., Ø. Langørgen, et al. (2011). "Performance analysis of the cold flow model of a second generation chemical looping combustion reactor system." Energy Procedia **4**(0): 449-456.

4. Bischi, A., Ø. Langørgen, et al. (2011). "Design study of a 150kWth double loop circulating fluidized bed reactor system for chemical looping combustion with focus on industrial applicability and pressurization." International Journal of Greenhouse Gas Control **5**(3): 467-474.

5. Haitham, A. and et.al (2011). " Modeling Fracturing in Rock using a Modified Discrete Element Method with Plasticity." Key Engineering Materials **452-453**: 861-864.

6. Husebye, J., R. Anantharaman, et al. (2011). "Techno-economic assessment of flexible solvent regeneration & storage for base load coal-fired power generation with post combustion CO_2 capture." Energy Procedia **4**: 2612-2619.

7. Jakobsen, J. P., A. Brunsvold, et al. (2011). "Comprehensive assessment of CCS chains-Consistent and transparent methodology." Energy Procedia **4**: 2377-2384.

8. Li, H., M. Ditaranto, et al. (2011). "Technologies for increasing CO_2 concentration in exhaust gas from natural gas-fired power production with post-combustion, amine-based CO_2 capture." Energy **36**(2): 1124-1133.

9. Li, H., G. Haugen, et al. (2011). "Impacts of exhaust gas recirculation (EGR) on the natural gas combined cycle integrated with chemical absorption CO_2 capture technology." Energy Procedia **4**: 1411-1418.

10. Li, H., J. P. Jakobsen, et al. (2011). "PVTxy properties of CO_2 mixtures relevant for CO_2 capture, transport and storage: Review of available experimental data and theoretical models." Applied Energy **88**(11): 3567-3579.

11. Lindeberg, E. (2011). "Modelling pressure and temperature profile in a CO_2 injection well." Energy Procedia **4**: 3935-3941.

12. Lindeberg, E. and D. Wessel-Berg (2011). "Upscaling studies of diffusion induced convection in homogeneous and heterogeneous aquifers." Energy Procedia **4**: 3927-3934.

13. Mølnvik, M. J., G. Tangen, et al. (2011). "BIGCCS Centre-Boosting CCS research and innovation." Energy Procedia **4**: 6133-6140.

14. Smith, D. J., D. J. Noy, et al. (2011). "The impact of boundary conditions on CO_2 storage capacity estimation in aquifers." Energy Procedia **4**: 4828-4834.

15. Tangen, G., M. J. Mølnvik, et al. (2011). "BIGCO2 R&D Platform Breakthrough CCS technologies enabling large-scale CO_2 chains." Energy Procedia **4**: 6077-6084.

16. Torvanger, A. and J. Meadowcroft (2011). "The political economy of technology support: Making decisions about carbon capture and storage and low carbon energy technologies." Global Environmental Change **21**(2): 303-312.

PUBLISHED CONFERENCE PAPERS

1. Anantharaman, R., K. Jordal, et al. (2011). Benchmarking Methodology for CO_2 Capture Processes using Minimum Capture Work Targets. ECOS 2011, Novi Sad, Serbia.

2. Bhuiyan, A. and e. al: (2011). CSEM sensitivity study of CO2 layers with uniform versus patchy saturation distributions. SEG, 81st annual meeting.

3. White, J. C., G. A. Williams, et al. (2011). Estimating seismic velocity and thickness of a CO_2 layer in the Sleipner plume. European Geosciences Union (EGU) General Assembly - Geophysical Research Abstracts. Vienna, Austria. **Vol. 13:** 3296.

PRESENTATIONS, INCL. POSTERS

1. Aasen, T., M. Mølnvik, et al. (2011). Managing Innovation in Heterogeneous Research Consortia. Presented at The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

2. Anantharaman, R. and M. Seljeskog (2011). CO_2 capture from industry and offshore: Opportunities and challenges. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

3. Arstad, B., J. Prostak, et al. (2011). Development and application of high temperature CO_2 sorbents. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

4. Berstad, D., R. Anantharaman, et al. (2011). Potential for low-temperature capture technologies in different CCS applications. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

5. Berstad, D., P. Nekså, et al. (2011). Potential for Low-Temperature Concepts in Different CCS Applications. The 23rd IIR International Congress of Refrigeration. Prague, Czech Republic.

6. Chadwick, R. A., J. D. O. Williams, et al. (2011). Measuring pressure performance of a large saline aquifer during industrial-scale CO_2 injection: the Utsira Sand, Norwegian North Sea. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

7. Chikukwa, A., N. Enaasen, et al. (2011). Dynamic modeling of post-combustion (chemical absorption-based) CO_2 capture – A review. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

8. Dahl, P. I., F. Ahouanto, et al. (2011). Stability and performance of studied HTM. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage, Trondheim, Norway

9. Ditaranto, M. (2011). Description of a High Pressure Oxy-Fuel Combustion Facility HIPROX. 2nd Oxyfuel Combustion Conference. Queensland, Australia.

10. Eichler, C., G. Baumgartner, et al. (2011). Experimental Investigation of Turbulent Boundary Layer Flashback Limits for Premixed Hydrogen-Air Flames Confined in Ducts. ASME Turbo Expo Vancouver, Canada.

11. Frederick, D., A., North, et al. (2011). Analysis of Flame Propagation and Autoignition for a Lifted Nitrogen-Diluted Hydrogen Turbulent Jet Flame in a Vitiated Coflow. 2011 Fall Technical Meeting of the Western States Section of the Combustion Institute, University of California at Riverside, Riverside, CA.

12. Jordal, K., Ø. Wilhelmsen, et al. (2011). Integrated Assessment of Water-Gas Shift Pd-Membrane Reactor for CO_2 Capture The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

13. Kim, I., X. Ma, et al. (2011). Solubility measurements of piperazine. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage Trondheim, Norway.

14. Li, H., M. Ditaranto, et al. (2011). Modifications of the supplementary fired combined cycle integrated with CO_2 chemical absorption. 3rd International Conference on Applied Energy. Perugia, Italy.

15. Løvseth, S. W., J. H. G. Stang, et al. (2011). Experimental Investigation of Selected Thermo-Physical Properties of CO_2 Mixtures Relevant for CCS. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

16. Ma, X., I. Kim, et al. (2011). Precipitation of piperazine in the piperazine-H_2O-CO_2 system. ISIC-18,. Zurich, Switzerland.

17. Morin, A., Kragset, et al. (2011). Pipeline flow modelling with source terms due to leakage: The straw method. Numerical Approximations of Hyperbolic Systems with Source Terms and Applications. Roscoff, France.

18. Nielsen, C.M., P. Frykman (2011). Regional model development and study of pressure propagation. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

19. Nord, J., Z. Du, et al. (2011). Feasibility study of CO_2 monitoring using Controlled Source Electro-Magnetics, CSEM. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

20. Nort, A., R. W. Dibble, et al. (2011). Liftoff Heights of Lifted N_2-in-H_2 Jet Flames Issuing into a Vitiated Co-flow Measured Using Schlieren Imaging. 7th US National Combustion Meeting, Georgia Institute of Technology, Atlanta, GA, USA.

21. North, A., R. Dibble, et al. (2011). Liftoff Heights of N_2-in-H_2Jet Flames in a Vitiated Co-flow Measured Using SchlierenImaging. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

22. North, A. J., R. W. Dibble, et al. (2011). Liftoff Heights of Lifted N_2-in-H_2 Jet Flames Issuing into aVitiated Co-flow Measured Using Schlieren Imaging. 7th US National Technical Meeting of the Combustion Institute, Georgia Institute of Technology, Atlanta, GA, USA.

23. Peters, T., M.-L. Fontaine, et al. (2011). Dual phase membranes for post-combustion capture of GT exhaust. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

24. Peters, T. A., M. L. Fontaine, et al. (2011). Membrane systems for CO_2 capture from industrial and offshore sources. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage.

25. Røyrvik, J., M. Schei Olsen, et al. (2011). Political rationality and CCS discourse. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage. Trondheim, Norway.

26. Sanchez, R. A., J. Solvik, et al. (2011). Modeling and simulation of Cold Flow Fluidized Bed Reactors. 2nd Trondheim Gas Technology Conference. Trondheim, Norway.

27. Seljeskog, M. and M. Ditaranto (2011). Oxy-fuel retrofitting of heavy fuel oil fired refinery heaters – a two-step experimental approach. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage, Trondheim, Norway.

28. Weydahl, T., M. Seljeskog, et al. (2011). Pursuing the pre-combustion route in oil refineries - The impact on fired heaters. The 6th Trondheim Conference on CO_2 Capture, Transport and Storage, Trondheim, Norway.

29. Wilhelmsen, Ø., R. Anantharaman, et al. (2011). Multi-Scale modelling of a membrane reforming power cycle with CO_2 capture. 21st European Symposium on Computer Aided Process Engineering – ESCAPE 21, Chalkidiki, Greece.

30. Xiangping, Z., T. Gundersen, et al. (2011). Assessment on Resource Utilization with CCS along the Carbon Chain. The 6th Asia Pacific Chemical Reaction Engineering Symposium, Beijing, China.

REPORTS

67 Confidential Reports

Aarlien, R. (2011). Annual Report 2010: BIGCCS International CCS Research Centre, SINTEF Energy Research: 38 p.

POPULAR SCIENCE ARTICLES

Aasen, T.M.: Forskning for et grønnere samfunn. Forskning nr.1/2012

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Leader SP4	Ms. Jana Poplsteinova Jakobsen E-mail: JanaPoplsteinova.Jakobsen@sintef.no Telephone: +47-73 59 38 69
Leader SP5	Mr. Truls Gundersen E-mail: truls.gundersen@ntnu.no Telephone: +47-73 59 37 21

BIGCCS animation movie – QR:

BIGCCS – future technology with a greener footprint…

BIGCCS Partners

Research Institutes:

- BGS - Natural Environment Research Council
- CICERO Center for International Climate and Environmental Research
- Deutsche Zentrum für Luft- und Raumfahrt
- GEUS - Geological Survey of Denmark and Greenland
- Geological Survey of Norway
- NTNU Social Research AS
- SINTEF Petroleum Research
- SINTEF Energy Research (Host Instituition)
- SINTEF Foundation

Universities:

- Norwegian University of Science and Technology
- University of Oslo
- TU München by Lehrstul Für Thermodynamik

Industry:

- Aker Solutions AS
- ConocoPhillips Skandinavia AS
- Det Norske Veritas AS
- Gassco AS
- GDF SUEZ
- Hydro Aluminium AS
- Shell Technology Norway AS
- Statkraft Development AS
- Statoil Petroleum AS
- TOTAL E&P Norge AS

The CEER Scheme

The Centres for Environment-friendly Energy Research (CEER) scheme is an initiative to establish time-limited research centres conducting concentrated, focused, and long-term research of high international calibre in order to solve specific challenges in the field of energy and environment. The centres were selected early 2009 via a detailed review process administered by the Research Council of Norway.

Two main assessment criteria formed the basis for the selection of the CEERs: relevance and potential for innovation and value creation, and scientific merit. One prerequisite for achieving the status of CEER is that the centres consist of a distinct combination of researchers, research institutions, organizations, industry and private enterprises. The CEERs receive NOK 10-20 million annually from the Research Council of Norway for five years, with a possibility for a three year extension.

The CEER scheme is a direct follow-up of the broad-based political agreement on climate change policy adopted by the Norwegian Parliament in 2008, and of the national R&D strategy Energy21 of that same year.

More information about the CEER scheme can be found at:
www.forskningsradet.no/energisenter

The Research Council of Norway

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

BIGCCS International CCS Research Centre
www.BIGCCS.no

Photo: Thor Nielsen/SINTEF