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ScienceDirect
Energy Procedia 4 (2011) 6133–6140
Energy Procedia
www.elsevier.com/locate/procedia

GHGT-10

BIGCCS Centre - Boosting CCS research and innovation

Mona J. Mølnvik[1], Grethe Tangen, Rune Aarlien and Nils A. Røkke
SINTEF Energy Research, 7465 Trondheim, Norway

Abstract

BIGCCS Centre is an international research centre aiming at extending and releasing the potentials for large scale deployment of CO_2 capture and storage by developing new knowledge, fostering breakthrough technology and promoting innovation and future value creation at all steps along the CO_2 chain. The centre is managed by SINTEF Energy Research, it involves 22 partners from industry and academia, and administers a budget amounting to 45 million € over 8 years. The paper presents the objectives of the BIGCCS Centre, outlines the research approach and strategy for promoting innovation, and presents some results after one year of operation.

Keywords: CCS, CO_2 capture, CO_2 transport, CO_2 storage, CO_2 chain, fossil fuels, power generation, industry

1. Introduction

In 2009, BIGCCS Centre (BIGCCS) was launched as an international Centre for Environment-friendly Energy Research (CEER) [1]. Over 8 years and with a total budget amounting to 45 million €, BIGCCS will operate as a centre of excellence focusing on CO_2 capture and storage (CCS) research with a clear ambition to move the frontiers of knowledge within several scientific topics and paving the way for sustainable power generation from fossil fuels at industrial scale. Planned application of the scientific results to other energy intensive industries and to offshore oil and gas production will extend the range of uses of the technology and enable significant synergy effects. The paper presents the BIGCCS Centre, the results so far and outlines the selected strategy for implementation.

BIGCCS aims at extending and releasing the potentials for large scale CCS deployment by developing new knowledge, fostering breakthrough technology and promoting innovation and future value creation at all steps along the CO_2 chain. The expected results from BIGCCS underpin the international ambitions set forth to curb CO_2 emissions [2] depending on CCS as one of the most important means for mitigating anthropogenic global warming.

[1] Corresponding author. Tel.: +47 73597200; fax: +47 73593950
E-mail address: mona.j.molnvik@sintef.no

doi:10.1016/j.egypro.2011.02.621

Further, BIGCCS will contribute to meeting the ambitions of the Norwegian Climate Agreement[2], targeting a reduction of 15 – 17 Mt of greenhouse gases (GHG) by 2020 for Norway, comprising 30 % of today's 54 Mt CO_2 equivalents per year in Norway. BIGCCS builds on the BIGCO2[3] Research Platform [3] and is hosted and managed by SINTEF Energy Research.

The research activities of BIGCCS signify a great boost to CCS research that is complementary to and integrated with the ongoing research. Emphasis is put on advanced basic and applied research providing in-depth knowledge and tools pertaining to viable solutions for CO_2 capture in power generation, industry and offshore applications, CO_2 transport, geological CO_2 storage, and the integrated CO_2 chain. BIGCCS will maintain a continuous focus on result exploration by actively searching for and pursuing opportunities for innovation. Since innovation often proves to occur in the interface between disciplines, the centre will enhance the innovative capability of the research community in BIGCCS by facilitating work processes that increase interaction across disciplines and expert groups.

2. The BIGCCS objectives

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, in line with ambitions set by the Norwegian climate agreement, the CLIMIT Program plan[4] and EU (ZEP[5]):

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

Scientific objective: The BIGCCS Centre aims at providing 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 involvement from industry partners. The following specific scientific objectives have been defined for the BIGCCS Centre:

- **Capture and systems:** To explore novel solutions 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.
- **Transport:** To develop a coupled fluid-material fracture assessment model to enable safe and cost-effective design and operation of CO_2 pipelines by improving the fundamental understanding of the interaction between the mechanical and fluid dynamical behaviour.
- **Storage:** To develop in-depth knowledge on long-term and safe storage of CO_2 enabling qualification and management of CO_2 storage recourses, to develop improved understanding and description of the CO_2 migration and behaviour in the geological formation, and to strengthen CO_2 storage safety by combining geophysical monitoring methods with reservoir fluid flow simulations.

Technological objective: To foster future innovation and value creation within CCS technologies along the **whole CO_2 value chain**. Further, to create the basis for new services and products for the industry partners originating from the BIGCCS Centre activities ranging from novel separation technologies to value creation from transport and storage on the Norwegian Continental Shelf.

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

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2 http://www.norway-un.org/Selected+Topics/Climate+Change/080121_Norwegian_Climate_Agreement.htm

3 The term BIGCO2 was introduced as a designation of the KMB project (2005-2006), followed up by BIGCO2 Phase 2 (2007-2011), also building on a strategic institute project (SIP) on CO2 (2001-2005)

4 CLIMIT is the Norwegian national programme for gas power technologies with CO2 capture and storage

5 The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), Strategic Research Agenda.

3. Research approach and preliminary results

The research topics covered by BIGCCS require in-depth studies of fundamental aspects related to CO_2 capture, CO_2 transport, and CO_2 storage, relying on a dual research methodology for which both laboratory experiments and mathematical modelling are employed. 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. Through its partners BIGCCS access a comprehensive research infrastructure and several centre partners are recognised within advanced modelling and simulation in scientific areas relevant for CCS. Hence, the centre is in a good position to make scientific progress at the cutting edge of CCS technology. BIGCCS has also defined activities dedicated to evaluate the interaction of the investigated technologies and to benchmark various technologies and value chains. BIGCCS is organised in 5 sub-projects (SPs), as illustrated in Figure 1. In the following, the research tasks of each SP are summarized and some preliminary results are presented.

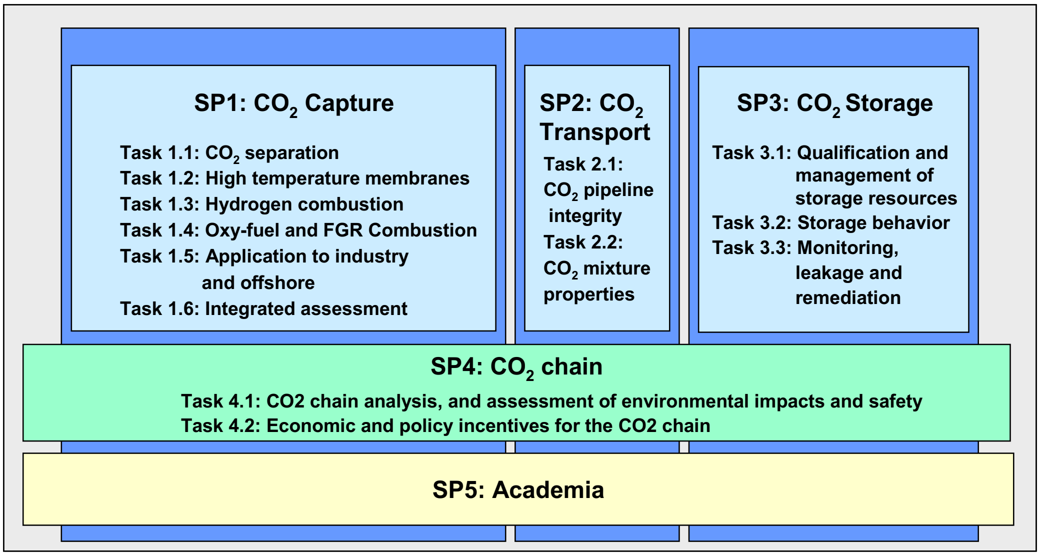

Figure 1 BIGCCS research tasks.

3.1. CO_2 Capture – SP1

Task 1.1 CO_2 Separation: Work is devoted to solvent systems and high temperature particulate CO_2sorbents. A solvent system model supporting the operation of power plants is implemented to study how the absorber works with variations in flue gas flow [4]. An experimental setup for measurement of vapour-liquid-solid equilibriums has been designed to study the phases formed in precipitating CO_2 capture systems at real conditions. For high temperature CO_2 sorbents, the main work has been to construct a high temperature/high pressure test rig for investigations of reaction kinetics and long-term stability of powders in sorption/desorption cycling.

Task 1.2 High Temperature Membranes: Novel high temperature hydrogen separation membrane materials have been synthesized, characterized, compacted and sintered as dense pellets. The H_2 permeation is investigated at ambient pressure in the temperature range 400-800ºC with a controlled hydrogen partial pressure gradient across the pellet type membrane. The preliminary results, corrected for leakage, indicate a stable and rather high H_2 permeability at temperatures above 400ºC [5, 6]. A new gas system with distributed work stations suited for membrane testing in various atmospheres has been installed in the new SINTEF membrane process laboratory.

Task 1.3 Hydrogen Combustion: The initial work is to provide a qualitative mapping and quantitative determination of the fundamental processes that characterize combustion of hydrogen rich mixtures, with focus on stable and safe flame propagation in lean pre-mixed combustion at gas turbine condition. The collaborative work between SINTEF, Technische Universität München, UC Berkeley and Sandia National Laboratories was formalised in 2009. The ongoing R&D activities include: Parallel experimental and modelling investigations of a pressurized version of the "Berkeley" lifted jet flame in vitiated co-flow [7], direct numerical simulation and experimental investigation with laser diagnostics of hydrogen-air premixed flame propagation in boundary layers, building on previous work at SINTEF, and finally to contribute to the development of a new Linear Eddy Model (LEM3D) for improved prediction of fuel-oxidizer micro-scalar mixing and combustion in lean pre-mixed mode.

Task 1.4: Oxy-fuel Combustion and Flue Gas Recirculation Combustion: This task focuses on combustion-related technological challenges associated with the implementation of oxy-fuel combustion alternatives for CCS. The main activity has been to specify and design an experimental high pressure combustion facility dedicated to the study of oxy-fuel combustion in gas turbines (100 kW, 10 bar, multi-CO_2 streams) with commissioning in 2010. A preliminary testing of a light oil burner adapted to oxy-fuel operation is performed and the results highlight the main difficulties of the retrofitting process. Emissions were observed to be comparable to air operation, while the radiative heat flux at the burner increases with O_2 concentration in the oxidant. In any case, further burner optimization is necessary. The third axis of the Task 1.4 is to provide inputs and constraints from combustion aspects to Task 1.6 for the analysis and evaluation of novels cycles based on oxy-fuel combustion [8, 9].

Task 1.5 Application to Industry and Offshore: The objective is to assess and evaluate the potential for CCS in other industries and offshore, hence contributing to added value for the Centre partners. The BIGCCS partners are engaged to ensure relevance of the work to be performed, and to ensure sufficient input data for further research. A core group from SINTEF coordinates the work, organize workshops and synthesize the results from the discussions. Four cases to be further studied have been selected and the concepts are now under development. The integration of this task with the other CCS research topics under SP1 - CO_2 capture and SP4 - CO_2 value chain has a potential that will be exploited in BIGCCS.

Task 1.6: Integrated Assessment: This task is subdivided into unit design and modelling, process design and benchmarking, and interaction between research tasks. The focus so far has been to initiate membrane reactor modelling and complete preparations with regard to modelling strategy and tools. A preparatory study was carried out with respect to modelling strategies and screening, and selection of modelling tools. Further, within process design and benchmarking a reference case is established for gas turbines with EGR [8, 9]. Finally, key parameters, boundary conditions and interdependencies for key processes in Task 1.1 through Task 1.6 are established, based on information gathered from the respective ongoing activities.

3.2. CO_2 Transport – SP2

Task 2.1: CO_2 Integrity: The main objective is to develop a coupled (fluid-structure) fracture assessment model to enable safe and cost-effective design and operation of CO_2 pipelines by improving the fundamental understanding of the interaction between the mechanical and fluid dynamical behaviour. The development of the coupled model will proceed in close collaboration between the two research groups, and by gradual refinement. A concept for a first, coupled fluid-structure model has been developed [10].

Task 2.2: CO_2 Mixture Properties: This task is a KMB-project (competence building project with user involvement) funded by the Climit program under the Research Council of Norway, and was established under BIGCCS as a spin-off. The objective is to increase the fundamental understanding of the behaviour of CO_2 mixtures under conditions relevant for CCS processes involved in CCS chains, primarily conditioning and transport. Such information is important for optimal equipment design in terms of safety, cost and energy efficiency. Key tasks are experimental investigations of thermo physical properties of CO_2-rich mixtures, such as phase equilibrium, density, and speed of sound. The results will be used to improve and extend the range of validity of existing thermodynamic models.

3.3. CO_2 Storage – SP3

Task 3.1 Qualification and Management of Storage Resources: Focus is on development of geomechanical modelling codes (MDEM – Discrete Element Method - and FLUID) to improve the modelling of geomechanical behaviour during CO_2 injection [11]. The Snøhvit field (Tubåen formation) has been evaluated to test necessary development on secondary migration codes (Pressim and Semi) for modelling long-term CO_2 migration. The Snøhvit field is believed to be an interesting test case, and this dataset has been released for BIGCCS. Efforts are also devoted to storage site capacity and qualification activities. A review of current approaches for assessing CO_2 storage site capacity has been accomplished. This review will form a basis for more sophisticated dynamic flow simulation approaches for assessing storage capacity. A study on simultaneous CO_2 injection and water production was conducted for optimizing the exploitation of CO_2 storage resources. A number of large-scale flow models of Bunter Sandstone (UK sector of North Sea) have been generated. The models assess the impact of boundary conditions, particularly at the regional scale. Results from dynamic simulations are compared with estimates derived by existing static methods to determine the validity of static approaches for open, closed and semi-closed systems. Preliminary simulations show that the aquifer pressure evolution is fast and the pressure wave extends far away from the injected CO_2 plume [12].

Task 3.2 Storage Behaviour: Both experimental and theoretical studies of geochemical and geo-mechanical effects of CO_2 on the cap rock and reservoir are on-going. BGS has carried out a set of long-term batch experiments to assess the reactivity of CO_2 and pore water with Sleipner cap rock and wellbore materials. Tests have been running since July 2005, and will be continued to provide the longest experiments yet undertaken (up to 7 years). SINTEF has carried out punch testing of shale samples in order to quantify the effect of CO_2-water on cap rock strength. GEUS[6] has conducted experiments to study drying-out effects on various minerals and under varying conditions. Also, a study of diffusion induced convection mechanisms in presence of heterogeneities has been performed. This study extends former work on the gravitational instability of a diffusive boundary layer in a semi-infinite anisotropic porous medium. This instability behaviour should be seen as an upside for underground CO_2 storage, as dissolution is an important aspect for retaining the CO_2 in the underground for thousands of years [13]. The Pressim software has been evaluated for modelling the effects of CO_2 on pressure [14].

Task 3.3 Monitoring, Leakage and Remediation: Several monitoring tools and models for CO_2 injection and storage are to be developed and tested; i.e. *CSEM* (Marine Controlled Source Electro Magnetics), and the *FWI* (Full Waveform Inversion). A gravity modelling study was made to estimate if 4D CO_2 effects can be observed using gravity data. Results indicate that a CO_2 reservoir can be monitored over time. Accurate mapping of the development of reflectivity in the CO_2 Sleipner plume and also the velocity pushdown on deeper layers beneath the plume are challenging. So far horizons and pushdown up to the 2006 survey have been mapped. Time-frequency spectral decomposition techniques have been applied to the time-lapse surface seismic data (3D and high resolution 2D) at Sleipner. Application of this tool to the topmost layer on the 2006 dataset reveals strong tuning effects and the capability of mapping travel-time layer thicknesses. GEUS is developing a catalogue of reservoir models, using conceptual structure and actual data from geological settings giving rise to layered reservoirs, e.g. fluvial systems and near-shore depositional systems with sea-level fluctuations. Initial laboratory tests have been performed at SINTEF to measure wave velocity changes and strain response to stress changes that mimic those occurring within a storage site and in the cap rock above it, for scenarios reproducing CO_2 injection and CO_2 leakage [15].

3.4. CO2 Value Chain – SP4

Task 4.1 CO_2 Chain Analysis, Environmental Impacts and Safety: The aim is to develop a common framework for CCS chain assessment including analysis of techno-economic criteria, risk, and environmental impacts associated with CCS chains [16]. Development of the framework was initiated during the first SP4 workshop were a common understanding of project objectives and vocabulary were established. Further, main challenges and milestones as well as a common strategy for the organization and co-operation within SP4 were established. Other important achievements are: Establishing state-of-the-art in LCA studies on CCS including a literature review of various LCA studies on CCS chain components and a review of available LCA techniques and software. SimaPro 7 has been chosen to initially collect, analyze and monitor the environmental performance of CCS chains in BIGCCS. Finally, a summary on state-of-the-art in risk management models and ongoing projects, and a proposal for the overall conceptual model for risk assessment of CCS chains has been developed.

Task 4.2 Economy and Policy Incentives for the CO_2 Chain: The aim is to develop scenarios for CCS development and deployment and to develop a stochastic model for investment decisions. This work will improve stakeholders' understanding of possible future value of CCS technologies and therefore also provide a better

[6] GEUS: The Geological Survey of Denmark and Greenland

knowledge basis for investments in R&D, pilots and large-scale CCS. In 2009, the potential of CCS for reducing global CO_2 emissions was explored, as well as CCS' dependency on major economic and policy conditions. Furthermore, an economic model has been developed to analyze stakeholders' understanding of CCS technologies and related uncertainties. Further, the value of flexibility in the CCS chain has been studied [17].

3.5. Academia – SP5

20 PhD students and 8 post docs are planned in BIGCCS. The Norwegian University of Science and Technology (NTNU) is responsible for this sub-project and most of the students. Further, University of Oslo (UiO), the Technische Universität München (TUM), University of California, Berkeley and Ruhr-Universität Bochum are involved with PhD students. The students do their research in close collaboration with their supervisors and the respective research tasks with access to infrastructure and resources in BIGCCS. Currently, 11 PhD students are starting their work.

4. Organization

BIGCCS is set up with a *General Assembly*, a *Board* with ten members, a *Scientific Committee* comprising international recognized professors outside BIGCCS, and an *Exploitation and Innovation Advisory Committee*. Its management includes a centre director reporting to the Board, supported by a centre manager and a centre management group. Technical committees are established for the different sub projects. The BIGCCS consortium comprises 10 industry partners, 9 research institutes, 3 universities and the research is conducted within an international network of scientists. The partners represent different parts of the business value chain, and the consortium includes both multi-national and leading Norwegian companies. Scientific cooperation is promoted and supported within specified projects and activities and in joint meetings. To meet the challenge of collaborative research across organisations and disciplines, there is a strong focus on organisation development, leader training and team building within BIGCCS.

5. Methods for research based innovation

By conducting targeted long-term research in the early phase of the innovation chain, BIGCCS will provide future opportunities for new products and new solutions for CCS. Figure 2 illustrates the position of the centre in the innovation chain and indicates the role of BIGCCS being a driving force in accelerating the development and deployment of CCS technology.

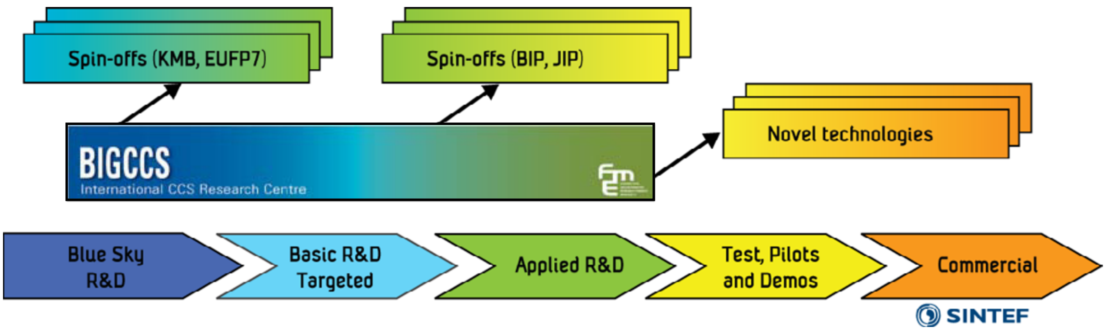

Figure 2 The role and position of BIGCCS in the innovation chain.

Successful innovation and prospects of future value creation require systematic building of alliances with the partners to include strategic actions facilitating the identification and follow-up on the commercial opportunities of evolving technologies. One important task in BIGCCS is to organise processes, meetings and discussions that enable knowledge transfer and raise all partners’ consciousness on identification of opportunities for innovation [18]. A second task is to facilitate creative workshops where identified needs are combined with the complementary comprehensions of centre partners in order to release a potential for overcoming scientific hurdles. Further, alternative innovation strategies like open user-oriented innovation will be employed to gain first-hand experience on how modern innovation theory can strengthen the innovative capability of comprehensive, collaborative research efforts. Finally, the centre follows up results and technologies evaluated as promising with regard to commercial potential to secure IPR, identify interested partners and take steps to initiate spin-off innovation projects.

Figure 3 illustrates the interplay between the scientific work and the strategic actions taken to promote innovation and value creation, both focusing on achieving the objectives set forth in BIGCCS. At the bottom of Figure 3 the fundamental issues of the sub-projects SP1, SP2 and SP3 are listed, pointing towards potentials for *Innovation from in-dept knowledge* (to the low right). The centre part of the figure indicates the SPs' expected results from research activities related to units and processes relevant for CCS, pointing at the potentials for *Innovation and value creation from new process knowledge*. On top, activities related to whole system issues of SP4 are indicated (CO_2 chain analysis, environmental assessment and safety), pointing at the potentials for *Value creation from system knowledge*. There is an extensive interaction within each sub-project as well as between the sub-projects. For instance, *CO_2 capture* (SP1) is based on fundamental research that interacts both with the *integrated assessment* and the *CO_2 value chain* (SP4).

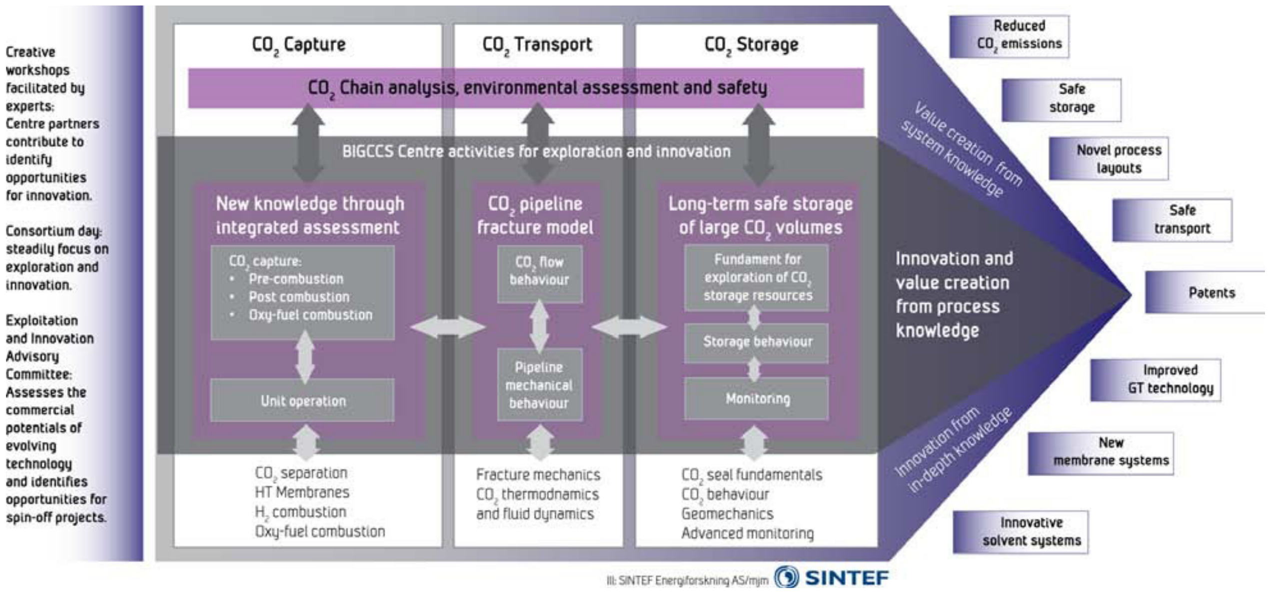

Figure 3 The innovation processes in BIGCCS. Strategic actions are listed to the left and the scientific work is pictured in the main part of the arrow. Technological objectives are indicated to the right.

6. Conclusion

In 2009, BIGCCS Centre was launched as a comprehensive collaborative research effort bringing together 22 industry companies and academic institutions with the common ambition to advance technology at all steps of the CO_2 chain. After one year of operation the organisation that constitutes the BIGCCS Centre has settled, adequate work processes are established and the research activities are making progress. For instance, within CO_2 capture preparatory experimental work is carried out to investigate equilibrium measurements for post-combustion solvents, kinetics and stability of CO_2 sorbents, H_2 permeation of high temperature H_2 membranes, and fundamental processes that characterise hydrogen combustion and oxy-fuel combustion. In addition, large efforts are put into modelling, simulation and analyses of all capture technologies to be explored. The groundbreaking work on the integrity of pipelines for CO_2 transport is underway together with an initial activity on CO_2 mixture properties. Within CO_2 storage, experimental activities on storage behaviour and monitoring are well underway and accompanying work on modelling and simulation has started. Dynamic simulations are carried out to investigate aquifer pressure evolution to enable improved modelling of geomechanical behaviour during CO_2 injection. In CO_2 value chain, work is progressing to develop a common framework for CCS chain assessment including techno-economic criteria as well as risk and environmental impacts. Finally, potentials of CCS to reduce global CO_2 emissions are investigated together with issues such as dependency on major economic and political conditions and the value of flexibility in the CCS chain. As education and competence building is a key issue for development and implementation of CCS, action is taken to facilitate start up the 11 first of in all 20 PhD students.

Acknowledgements

This publication is produced with support from the BIGCCS Centre, performed under the Norwegian research program *Centres for Environment-friendly Energy Research (FME)*. The authors acknowledge the following partners for their contributions: Aker Solutions, ConocoPhilips, Det Norske Veritas AS, Gassco AS, GDF SUEZ, Hydro Aluminium AS, Shell Technology AS, Statkraft Development AS, Statoil Petroleum AS, TOTAL E&P Norge AS, and the Research Council of Norway (193816/S60).

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