ANNUAL REPORT 2018

NCCS
NORWEGIAN CCS RESEARCH CENTRE

NCCS

CO_2 capture, transport, and storage (CCS) is a process where waste carbon dioxide (CO_2) is captured from large industrial plants, transported in pipelines or ships, and deposited so it will not enter the atmosphere (like in an underground geological formation). EU energy and climate targets cannot be met costeffectively without CCS, while making sure we have enough energy to go around.

How can NCCS help? NCCS aims to fast-track CCS by working closely with the industry on research topics designed to address major barriers in making CCS happen in Norway, Europe, and the world.

NCCS aims to fast-track CCS deployment. NCCS (Norwegian CCS Research Centre) is a Centre for Environment-friendly Energy Research (FME).

Selected highlights from 2018

JANUARY

Mona Mølnvik at the TEKNA-conference

APRIL

JUNE

FEBRUARY

NCCS researchers with op-ed in Dagens Næringsliv

MAY

NCCS researchers with two op-eds in Dagens Næringsliv

CONTENTS

Selected highlights from 2018 - find more videos and stories on www.nccs.no/Annual report 2018

@NCCS_FME

SEPTEMBER

NCCS
@NCCS_FME
Følg

Today at the Bergen Chamber of Commerce #grønnlunsj, NCCS Centre Manager @Amy Brunsvold conveying the value of CCS (and not just the cost) and how @NCCS_FME can help.

NCCS researchers with op-ed in Dagens Næringsliv

DECEMBER

SINTEF Energy
@SINTEFenergy
Følg

#COP24 began yesterday in Poland @Nils_Rokke will be there with a key message: No one single tech or system can tackle #climatetransition alone. Hydrogen can be made clean, affordable and at scale both from electrolysis and from natural gas with #CCS
renewablesnow.com/news/hydrogen-...

AUGUST

Mona Mølnvik at Arendalsuka

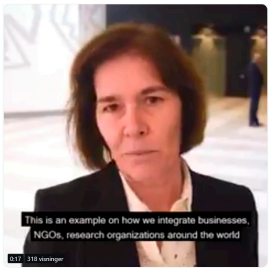
SINTEF Energy
@SINTEFenergy
Følg

- Forutsetning for SINTEF-rapporten er at Norge realiserer #CCS-fullskala, sier Mona Mølnvik fra @SINTEF og leder for @NCCS_FME

OCTOBER

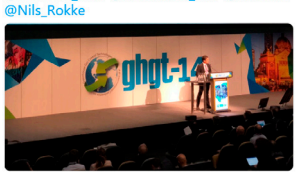
NCCS
@NCCS_FME
Følg

«Nobody can do #CCS on their own» was said repetedly at #GHGT14 In NCCS cooperation is key. Mona Mølnvik talks about value of the world comeing together to fast track CCS deployment. Also read her CCS blog blog.sintef.com/sintefenergy/v... @IEAGHG @Nils_Rokke @NTNU @EquinorASA @GlobalCCS



SINTEF Energy
@SINTEFenergy
Følg

#CCS is important to reach 1,5 degrees. @SINTEFenergy is at the #GHGT14 conference where the worlds CCS experts present the latest research and move one important step forward closer to full scale CCS. Day 1 of 4 today. @NCCS_FME @CEMCAP_CO2 @ELEGANCY_ACT @IEAGHG @Nils_Rokke



NOVEMBER

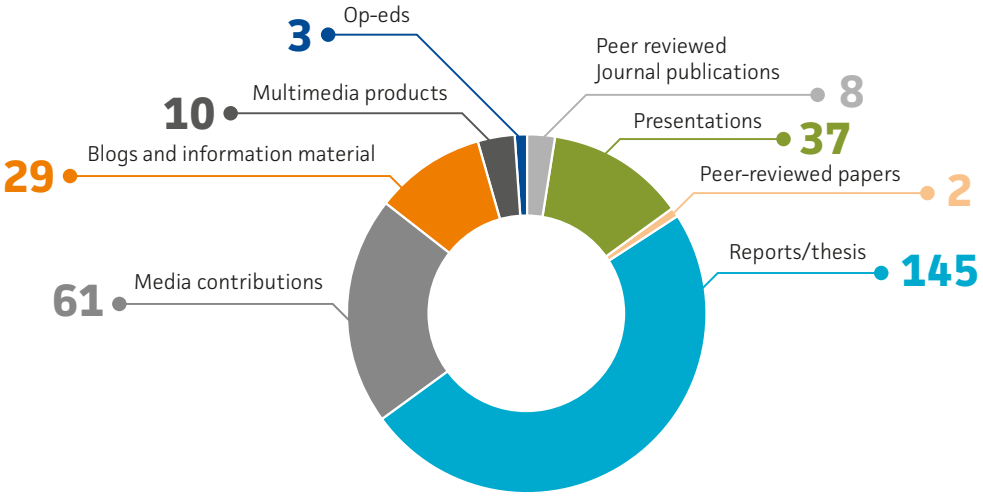
Innovation task force

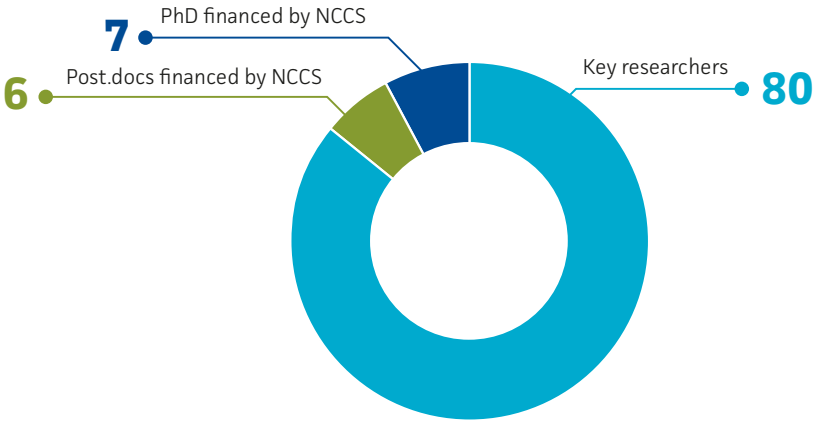
27 PARTNERS

8 YEARS

464 MNOK

2018 BY THE NUMBERS





There might be some discrepancies between the numbers in figure and numbers registered in Cristin, mainly due to FME partners that do not have a university or research institute affiliation or because the FME projectcode has not yet been registered in the post.

MESSAGE FROM **THE DIRECTOR**

Dear partners and friends of the Norwegian CCS research centre

In NCCS, we fast-track CCS deployment by joint effort from academia and industry, performing relevant CCS research in world-class ECCSEL research infrastructure along the whole CCS chain. We do this because we believe that CCS is a key technology that is needed to reduce CO_2 emissions in a scale that makes it plausible to reduce man-made CO_2 emissions enough to limit global warming to less than two degrees compared to pre-industrial temperatures.

Through the two deployment cases; *CCS for Norwegian industry and Storing Europe CO_2 on the Norwegian Continental Shelf)*, NCCS links both to the Norwegian full-scale project and the possibility to expand this into a large CO_2-storage facility receiving Europe's CO_2. 2019 has been an extremely exciting year crowned by the Effect Study handed over to the Minister of Petroleum and Energy Kjell Børge Freiberg on January 18th 2019. The achievements of NCCS so far is the result of clever and targeted work of my very skilled colleagues in the Operation Centre, the guidance from the Board lead by Dr. Per Ivar Karstad from Equinor, and the efforts made by all others involved in NCCS.

In 2018, we produced 92 deliverables, we added five new competence building projects (KPNs) expanding the total budget by ~NOK 50 million, a success achieved through the close dialogue between the user and research partners in NCCS. Further, we started six new PhD/Postdoc candidates. Furthermore, we continued holding leading positions in organizations spearheading CCS development in Europe, and we have put significant efforts in communicating our achievements.

Mona J. Mølnvik

Dr. Mona J. Mølnvik is the NCCS Centre Director. She has been with SINTEF for 20 years, and has been active in CCS research since the early 2000s.

Mona holds a PhD within mechanical engineering from NTNU and is Research Director for the Gas Technology department at SINTEF Energy Research.

She was central in developing and leading the centre of excellence, FME BIGCCS - International CCS Research Centre (2009-2016). Further, she has been involved in several EU-projects.

Mona has been a central contributor to development of CCS research strategies, and she was the first leader of the CO_2 transport initiative under EERA JP Carbon Capture and Storage.

The interaction between industry, both users and vendors, the researchers, professors and PhD/Postdoc students, as well as the Research Council of Norway, is the fundament for our achievements. Thank you so much for your dedication and efforts!

MESSAGE FROM THE **CHAIRMAN OF THE BOARD**

The UN Sustainability goals will require a balanced solution for both economic growth, food security, reliable energy supplies and reduced emissions of climate gases to the atmosphere to provide increased welfare to the global population. The transition toward a low carbon energy system is a major challenge for our society. This energy transition will require a set of new technological solutions, such as renewable energy, energy storage, low carbon transport solutions and carbon capture, utilization and storage.

Carbon capture, utilization and storage is a feasible and cost-efficient solution to combat climate change compared to other solutions. It is the only solution to cut emissions from many industrial sources, industries that produce key products to our society. However, the cost has to be reduced further.

NCCS is a key competence and research centre, already contributing with new technological solutions to ongoing development projects. The ambition is to develop new technological solutions to reduce costs significantly for future development projects. This is important to deliver cost efficient solutions for a low carbon future, ensuring the long-term welfare of our society.

Per Ivar Karstad

Per Ivar has more than 25 years of experience from the oil industry, both from field operations, business development and technology development.

Since 2011, he has been heading up several CCS development projects in Equinor such as Technology Center Mongstad, the Norwegian CO2 Storage project (Northern Lights) and a number of CCS research projects.

CENTRE MANAGER
AMY BRUNSVOLD

Dr. Amy Brunsvold is the Centre Manager of NCCS and a Research Scientist at SINTEF Energy Research. She has 10 years of experience working in R&D related to CCS and natural gas, touching on topics from techno-economic assessments of CO_2 value chains, heat transfer in liquefied natural gas heat exchangers, and CO_2 transport with impurities.

Amy has a Ph.D. in experimental physical chemistry from Montana State University where she focused on molecular beam reaction dynamic and energy transfer at high-energies, with applications to materials and low Earth orbit chemistry. As a post-doctoral fellow at UC Berkeley, she studied the dissociation dynamics of free radicals related to combustion chemistry.

The first two years of NCCS have been exciting! NCCS brings together over 100 people from research, academia, and industry in an ever-evolving R&D portfolio. NCCS' activities are tackling barriers across many disciplines, from fundamental chemistry and physics, to technology verification, to techno-economics and legal aspects.

After NCCS' second full year of operation, the centre has grown to be one of, if not the largest, centre of excellence on CCS, both in terms of people involved and results produced. This was evident at GHGT-14 in Australia that was held in June where 13 presentations, including a keynote, were given by NCCS members. NCCS has succeeding in adding five competence building projects added to the NCCS portfolio through a dedicated effort of our industry partners and the researcher teams.

The NCCS educational program has grown to eight PhD students and five postdocs who are tightly integrated in the task families. The first students are slated to graduate in 2020.

Communicating NCCS' results is crucial to make a difference for CCS. In addition to journal articles and book chapters so far, NCCS results have been communicated in blogs, newsletters, webinars, and media contributions.

I would like to thank the large NCCS team for the efforts to tackle research barriers to deploying CCS and I look forwarded to seeing the industry use the knowledge gained during NCCS' lifetime.

NCCS IN A **NUTSHELL**

CO_2 capture, transport, and storage (CCS) is a process where waste carbon dioxide (CO_2) is captured from large industrial plants, transported in pipelines or ships, and deposited so it will not enter the atmosphere (like in an underground geological formation). EU energy and climate targets cannot be met cost-effectively without CCS, while making sure we have enough energy to go around.

How can NCCS help? NCCS will aim to fast-track CCS by working closely with the industry on research topics designed to address major barriers in making CCS happen in Norway, Europe, and the world. NCCS research focuses on two *"CCS Deployment Cases": CCS for Norwegian Industry and Storing Europe's CO_2 in the North Sea*. Researchers focus on tasks related to the CCS technologies for the Norwegian full-scale case, and find clever ways to integrate capture with transport, and with storage. Any ways to reduce the cost of CCS will be a savings for each taxpayer! There is a huge potential in the North Sea to store CO_2 from all over Europe, and NCCS will unlock this potential through dedicated research that has been pointed by the industry as addressing key barriers.

Fast-tracking CCS is a joint effort. NCCS is a collaborative project between over 27 partners in industry, research institutes, universities, and other organizations, in 10 countries and on three continents. NCCS is led by SINTEF Energy Research in Trondheim.

As an industry-driven Centre, our industry partners guide and prioritize the research tasks to tackle industrial challenges related to CCS. Each task has a "family" with members who are actively engaged in the task and contribute to the development of the work plans and in the research activities. Research in NCCS is organized in 12 Tasks that together cover the whole CCS chain. The tasks address critical challenges for realizing CCS for Norwegian industry and storing Europe's CO_2 in the North Sea. In addition, efforts have been made to ensure dialogue with the Norwegian full-scale project. In 2018, NCCS held eight webinars for the partners and are available on the eRoom.

International cooperation is of essence to NCCS. We hold leading positions on the strategic arena, like in the European Energy Research Alliance (EERA), and in the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP). Furthermore, we are collaborating in several Horizon 2020 and ACT-ERA-net co-fund projects, and we are pursuing many new project calls. The NCCS Mobility program was launched in 2018 and we currently have Task 8 Leader, Sigurd W. Løvseth on a research stay at the University of Western Australia. In addition, twelve abstracts were presented at GHGT-14 in Melbourne and the Centre Director gave a keynote speech.

Education in NCCS

One of the most important tasks in NCCS is to train master and doctoral students in CCS research so they are willing and able to transfer this knowledge in future work, whether they work in industry or as researchers. Over the first two years we have employed 8 PhD students and 5 post-doctoral researchers.

12th Annual IEAGHG CCS Summer School

NCCS was pleased to have hosted the 12th IEAGHG CCS Summer School in Trondheim, with 58 students from 24 countries.

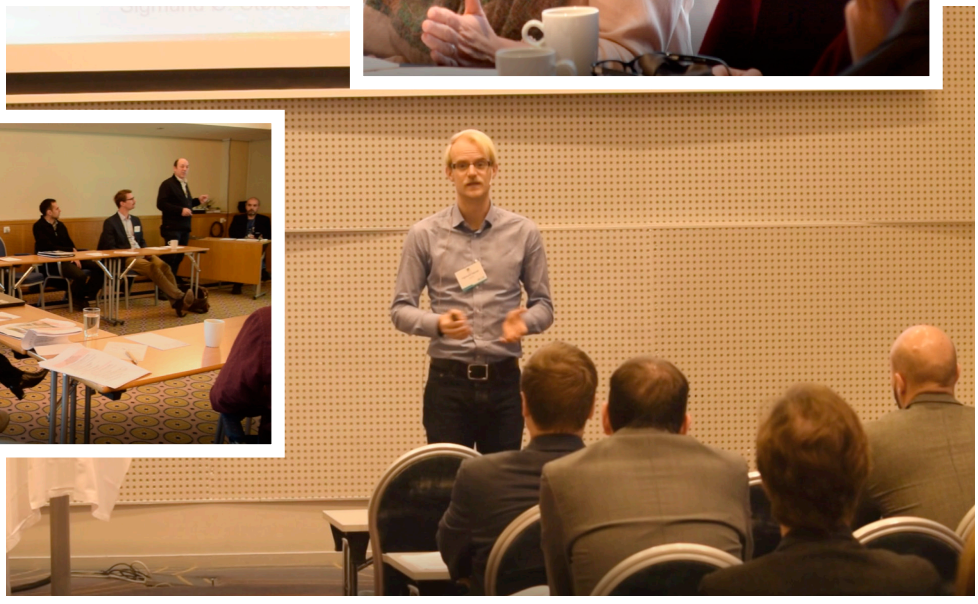
This year, in addition to covering all aspects of CCS in lectures (presented by leading international experts), the students also had group exercises in communication, designing monitoring plans, interactive careers session and the usual group project work.

NCCS facilitated the communication with very up-to-date information on the development of the new Norwegian storage site and the industrial sources of CO_2, representing state-of-the-art work-in-progress information by a leading CCS country.

The IEAGHG CCS Summer School lasted for 4 days, consisting of lectures and a field trip to the CO_2 Laboratory at Tiller and a tour of SINTEF's lab facilities at NTNU.

NCCS Annual Consortium Days

On December 5-6, 2018, NCCS held its annual Consortium Days event in Trondheim with 80 attendees. The event had a mix of pitches from the tasks, extended presentations in plenum, posters, and three breakout sessions to go even deeper into the technical results. The NCCS Board also had its 5th meeting on the 6th of December.



NCCS Annual Consortium Day

VISION AND GOALS

NCCS will enable fast-track CCS deployment through industry-driven science-based innovation, addressing the major barriers identified within demonstration and industry projects, aiming at becoming a world-leading CCS centre.

NCCS is a world-class national and international multi-disciplinary CCS partnership between operators, vendors and academia that have united to address one of the greatest challenges of our time: climate change. Capacity is built to capture, transport and store billions of tons of CO_2 by fast-tracking CCS deployment. NCCS is a dynamic, forward-looking approach that will maximize new and current knowledge to make CCS happen – in time to meet EU climate targets. CCS in the North Sea Basin has the potential of becoming a 50,000 billion NOK profitable business.

Goals

The overall objective is to fast-track CCS deployment through industry-driven science-based innovation, addressing the major barriers identified within demonstration and industry projects, aiming at becoming a world-leading CCS centre.

NCCS supports and aligns with the Norwegian full-scale CCS project to realize the Government's ambition to have this operational in 2020. This includes addressing technical and legal barriers via targeted research covering the full CCS chain.

NCCS develops science-based strategies for large-scale CO_2 storage and is a key facilitator for storage in the Norwegian North Sea Basin. This includes aligning with European CCS projects, while addressing technical and legal barriers via research on the full CCS chain.

Tangible objectives

- Establish reliable prediction of storage capacity and prove strategies to ensure storage integrity.
- Enable qualification of specific CO_2 EOR projects on the Norwegian Continental Shelf.
- Ensure CO_2 transport and North Sea storage infrastructure qualified as European Projects of Common Interest (PCI – an instrument to help create an integrated EU energy market).
- Establish an engineering toolbox for CO_2 pipeline and well design.
- Establish CCS as a competitive, low-carbon technology in power generation and industry.
- Contribute more than 50 innovations for use in industry.
- Complete 24 PhD theses, with 50% of the candidates employed by an NCCS partner.
- Contribute 500 papers to peer-reviewed scientific journals.

Scientific objective

Provide a frontier knowledge base for the technology breakthroughs required to fast-track full-scale CCS, with industrial relevance, by use of decision gates and priorities of the NCCS industry partners.

Innovation objective

- Fulfill the commercial ambitions and needs of industry and society, while maximizing innovation in deployment cases.
- Establish a targeted spin-off programme for the execution phase of innovation processes and their faster adoption.
- Establish new research projects within topics where knowledge gaps are identified.
- As part of the innovation process, design a comprehensive IP strategy.

Recruitment objective

Recruit and educate young people, reflecting gender balance and equal opportunities, with first-class competence in CCS-related topics (24 PhDs, 5 post-docs, 80 MSc graduates) to ensure recruitment to both industry and research institutions.

International objective

- To be a CCS research hub benefitting from close cooperation between highly ranked academic institutions in Europe and North America.
- Influence Europe's CCS strategies by participating in the development of the SET Plan, the Integrated Roadmap for CCS and working programs in Horizon 2020 as members of the ZEP Technology Platform and the European Energy Research Alliance (EERA) on CCS.
- Support and strengthen the memorandum of understanding (MoU) between the US DOE and the Norwegian Ministry of Petroleum and Energy on CCS research by offering to operate a secretariat for the MoU initiative.

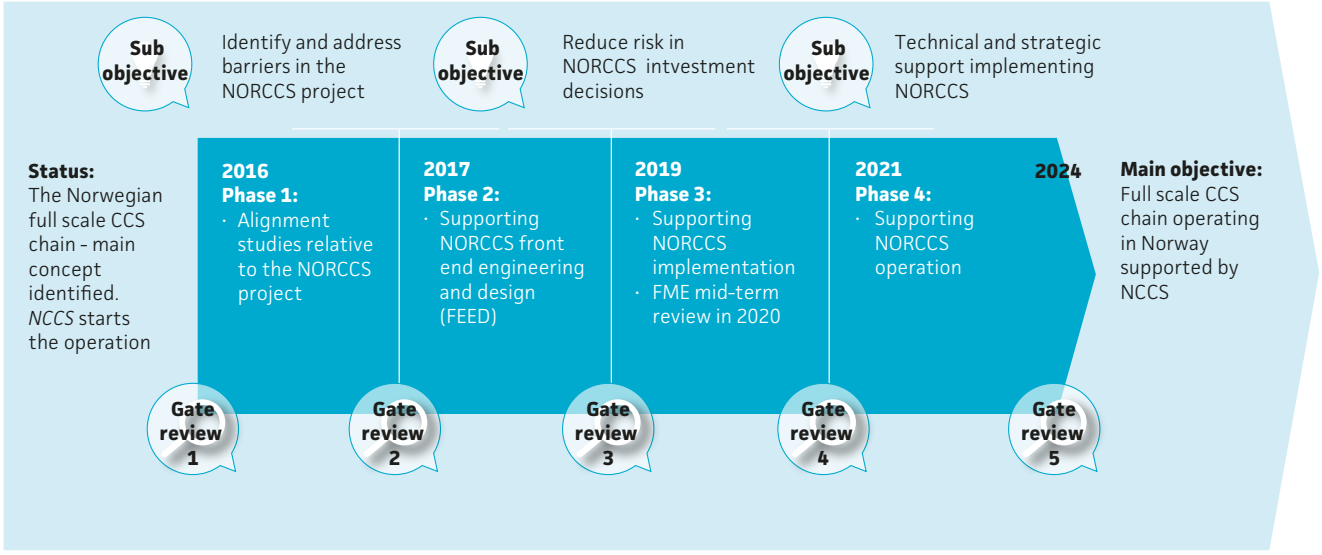
RESEARCH PLAN AND STRATEGY

Research Plan

NCCS has the ambition to be dynamic, i.e. readily suited to shift scientific focus to adapt the CCS world around us. The *NCCS industry-driven case-oriented concept* has been developed with industry partners, ensuring strong *industry ownership and governance* of the Centre. The scientific tasks are to be assessed and reviewed often. The Technical advisory committee (TAC), the Operations centre (OC), and the Board will have key roles in decisions at the gate review. NCCS can use this method to regularly evaluate the R&D profile to maintain research competitiveness, and to align with the CCS world by taking the learnings and needs from large-scale and demonstration projects (e.g. the Norwegian full-scale CCS chain) and adapting the R&D direction accordingly.

Well-structured research plans, reviewed and revised during the DC Gate Reviews, will set the direction for what is required to advance technologies to a higher Technology readiness level (TRL).

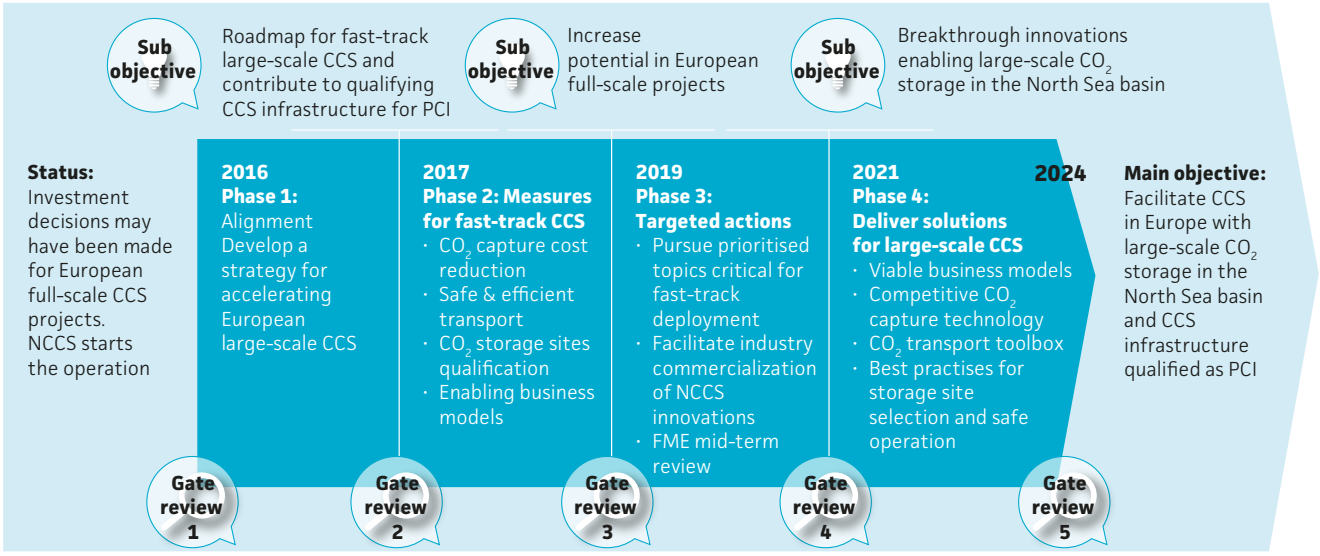
Deployment case 1, The Norwegian full scale CCS chain



Research will contribute to advancing TRL either directly in the more applied research tasks, or indirectly by supplying fundamental insights and mathematical models to other tasks along the deployment case chain. This will allow quantification, and thus give increased confidence and safety, and reduced cost. Data and knowledge from industry (e.g. Aker, Norcem and Krohne) and the Boundary Dam full-scale project will also play a key role in increasing understanding and advancing TRL.

This broad scientific approach, involving all key elements of the CCS chain, requires a considerable effort for NCCS to be able to significantly contribute to fast-track deployment of CCS in Norway and Europe. To generate the new knowledge required to overcome the barriers against CCS, a number of carefully chosen PhD topics are tightly integrated in the centre.

Deployment Case 2 Storing Europe's CO_2 in the North Sea basin

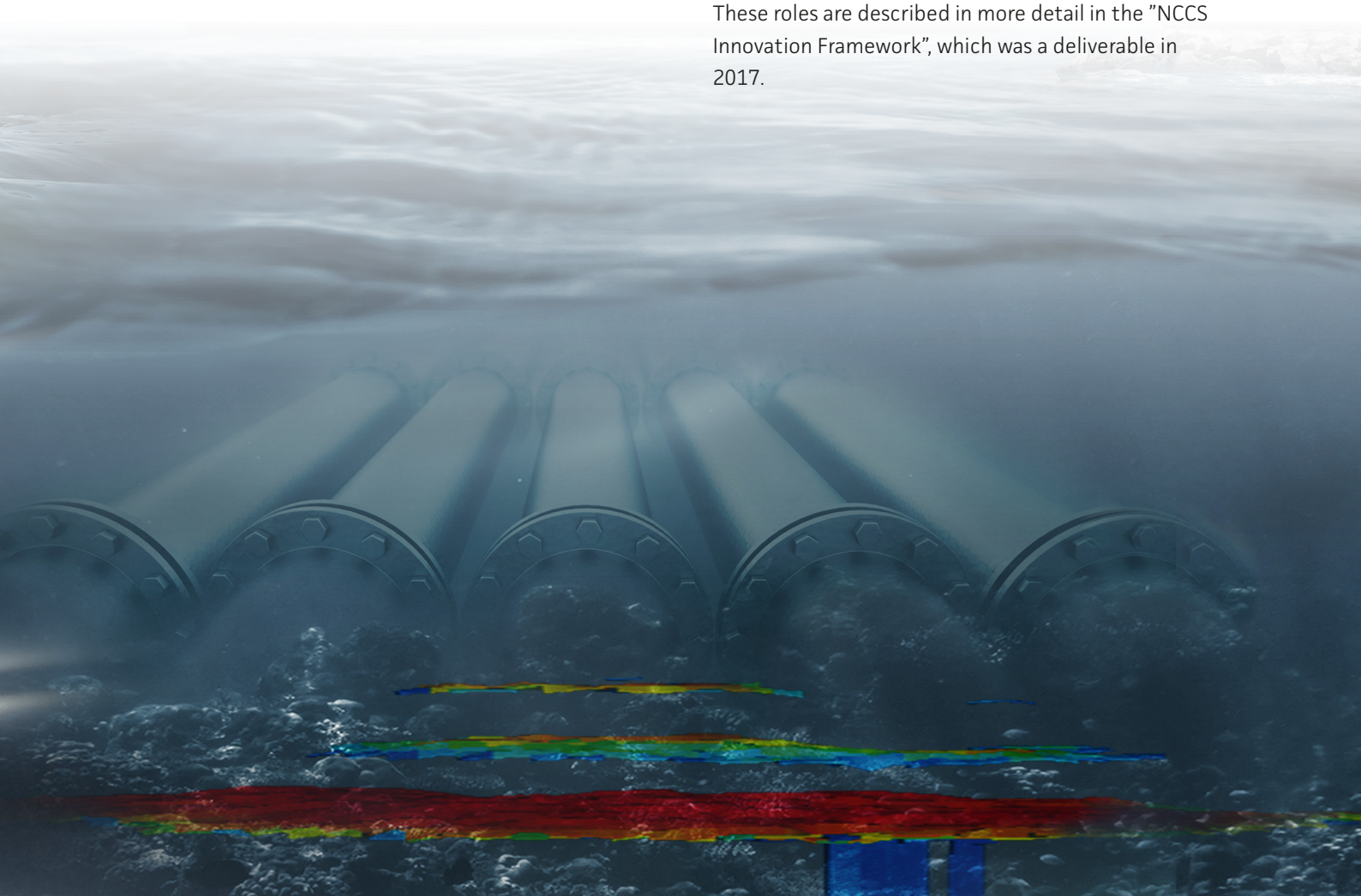


INNOVATION STRATEGY

The NCCS industry-driven case-oriented concept has been developed with industry partners, ensuring strong industry ownership and governance of the Centre. As an international CCS research hub, NCCS is built to promote open innovation processes: companies involved in the Centre will be able to commercialize ideas and emerging technology from outside their company boarders, building on others' ideas and even bringing ideas from NCCS into new and emerging markets. This model optimizes innovation and technology output across company borders and increases the potential gain for each company involved, as the pool of ideas and concepts emerging from NCCS will be larger than that of each company.

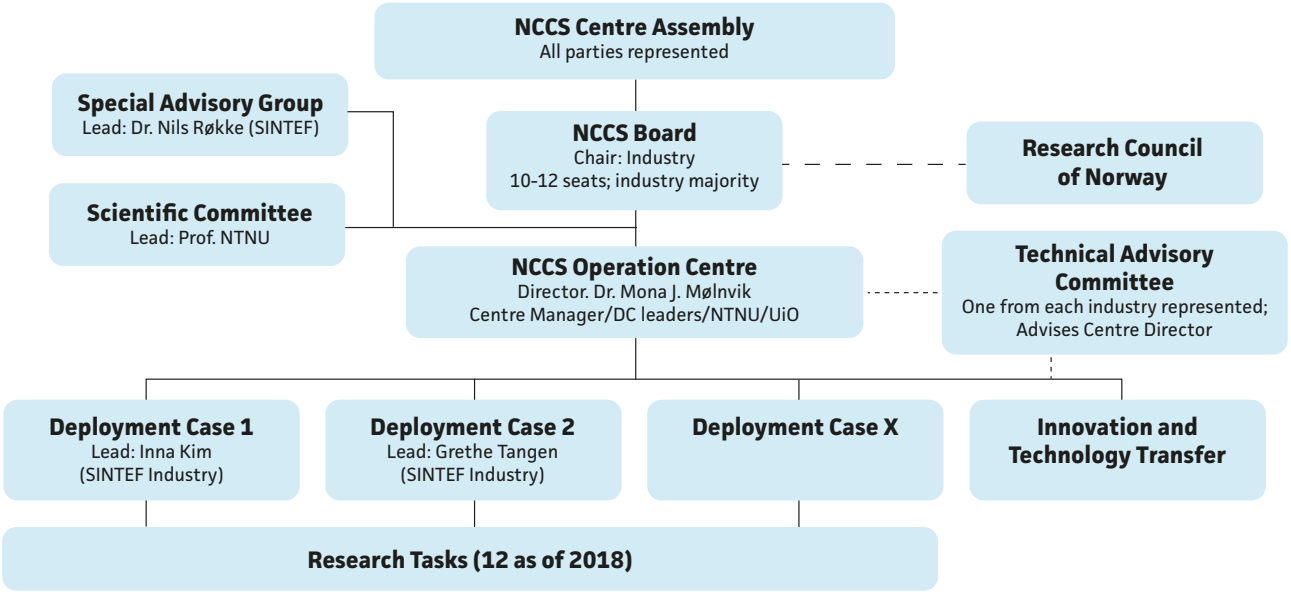
Innovation and Technology Transfer Task Ambition

The main ambition of Innovation and Technology Transfer (ITT) task is to maintain continuous focus on innovation and technology transfer from NCCS. The task aims to be an enabler within the centre, striving to promote a good environment for developing innovations through engaged and concrete cooperation between researchers and industry partners. By this, the task will contribute towards realising the NCCS centre's main goal of fast-tracking CCS. Throughout the centre lifetime, the Innovation and Technology Transfer task will essentially have five important roles within the centre: Reminder – Facilitator – Identifier – Supporter – Communicator. These roles are described in more detail in the "NCCS Innovation Framework", which was a deliverable in 2017.



ORGANISATION

Organizational Structure



Partners

RESEARCH PARTNERS

British Geological Survey

Norges Geotekniske Institutt

Norwegian University of Science and Technology

Ruhr – Universität Bochum

SINTEF Energy Research

SINTEF

SINTEF Industry

TNO

Technische Universität Munchen

The University Centre in Svalbard

University of Zürich

University of Oslo

INDUSTRY AND VENDOR PARTNERS

Equinor

Gassco

Shell Global Solutions International B.V.

Total

Norsk Olje og Gass

Aker Solutions

Ansaldo

CoorsTek

GE Power

Quad Geometrics

Larvik Shipping

Krohne

NORCEM

Oslo Kommune, gjenvinningsetaten

ASSOCIATED PARTNERS

ECCSEL

US Department of Energy

UKCCS

Scottish Carbon Capture & Storage

Lawrence Livermore National Laboratory

Sandia

Massachusetts Institute of Technology

Cooperation between partners

As an industry-led center in the start-up phase, great effort has been made to create good arenas and processes for cooperation with industry partners. An important and highly successful measure is establishing ”families” in each task. The Task families include specialists from industry and research actors with particular interest in topics addressed. Through workshops and Skype meetings, all partners are able to contribute to technical discussions and affect ambition for next year’s work program. NCCS includes a number of industry companies and most have been active contributors in one or more task families.

NCCS aims to be a dynamic center addressing challenges of high relevance to industry. An important tool for this is the Technical Advisory Committee (TAC), which was established in 2017. The committee consists of and is led by industry, and the purpose is to advise the Center Director on strategic choices of direction and prioritization of topics in the portfolio of research activities. The committee has regular meetings, and has helped the research direction of NCCS through selection and development of the 5 KPNs in 2018 and assisted in the phase-gating of NCCS which led to an adjusted R&D profile in the centre. Mr. Arve Erga (TOTAL) is the leader of the TAC.

Through the guidance from the TAC, five new competence building projects were added to the NCCS portfolio in 2018, directly targeted towards the needs of industry.

The annual NCCS Consortium Days is a central meeting place for the centre partners. In December 2018, over 100 people joined a two-day gathering that was organized with presentations by industry partners, research communities and funding initiatives. The event combined short pitches from all the activities, a workshop on scenarios for CCS deployment, and breakout technical sessions. In addition, poster sessions were set up where user partners could meet representatives from all the work packages and hear all the latest results in NCCS.

NCCS annual Consortium Day

RESEARCH ACTIVITIES AND RESULTS

Research in NCCS addresses challenges critical to realization of two different CCS scenarios, or Deployment Cases (DC): *CCS for Norwegian Industry,* and *Storage of Europe's CO_2 in the North Sea.* The work is organized in 12 work packages, or tasks, that together cover the entire CCS value chain. An extra task, serving all the 12 research tasks, is established on *Innovation and Technology Transfer.*

NCCS includes a comprehensive education program with fellows integrated into the Center's research tasks and many of the activities use laboratories established as part of ECCSEL, a distributed research infrastructure for CO_2 handling.

The following pages present highlights from 2018.

SELECTED CASES

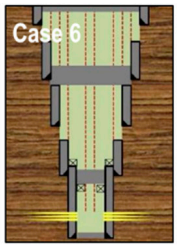
Efficient capture proccesses

Capture and liquifaction of CO_2 for ship transport

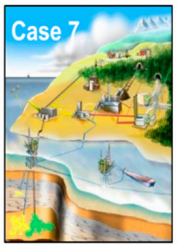
Capturing CO_2 using CLC

Avoiding running ductile fractures in CO_2 transport pipelines

Geophysical methods for monitoring storage of CO_2



Improved completion of CO_2 wells



Smart design of CO_2 value chains

Case 1: The Effect Study

The Research Council of Norway initiated what was dubbed "The Effect Study" during spring 2018. The goal of the study was to evaluate the effects of energy research, realized and potential, in Norway over the last decade. NCCS was asked to cover the CCS research area, and performed the study together with Impello Management.

Through 7 different innovations/case studies, shown in the figure, we first evaluated the potential economic benefit or effects of the CCS research, given that each of the innovations where used once in full CCS chain. Six of the seven innovations where cases brought forward either by BIGCCS, NCCS or both. Additional effects as reduced emissions, industrial potential, and improved decision making where also screened and evaluated.

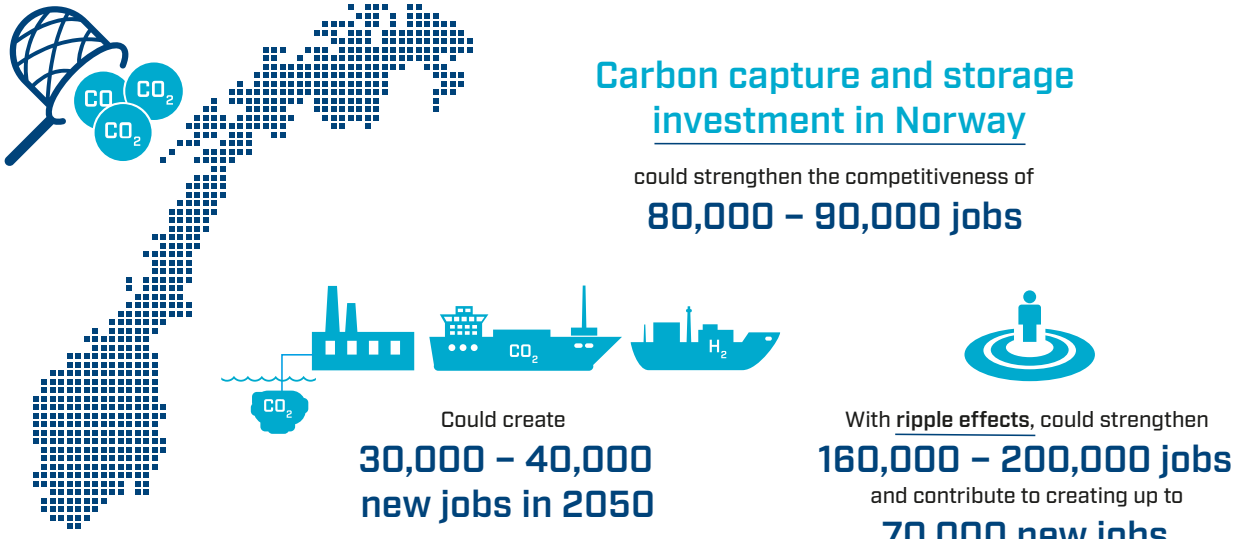
The study quite effectively showed that the economic potential from these seven innovations by far exceeds the investments made into the research, an important result for politicians and decision makers. The report was made for the Ministry of Petroleum and Energy, and will also be used extensively for communicating with politicians in Norway and abroad. A full paper has also been written from the study (in English), and was presented at the GHGT-14 conference, where the work got quite a bit of positive interest from the audience. The work will also be presented at the NCCS Consortium Days.

Minister of Petroleum and Energy Kjell-Børge Freiberg and NCCS Centre Director Mona Mølnvik 23. January 2019 when the Effect study was presented at SINTEF Energy Lab, Trondheim.

Case 2: Industrial opportunities and employment prospects in large-scale CO_2 management in Norway

During spring 2018, SINTEF, in collaboration with NTNU, completed a study entitled "Industrial opportunities and employment prospects in large-scale CO_2 management in Norway". The study was carried out on behalf of the Confederation of Norwegian Enterprise (NHO), the Confederation of Trade Unions (LO), the United Federation of Trade Unions, the Federation of Norwegian Industries, the Norwegian Oil and Gas Association and the Industri Energi trade union. The study was linked to NCCS, and was carried out by NCCS researchers from the Innovation and Technology Transfer task (ITT).

The objective of the study (assuming a commitment to large-scale CCS in Norway and subsequently in Europe and the international community) was to determine what opportunities large-scale CCS can present to Norway and Norwegian industrial operators. The study placed particular emphasis on potential value creation and employment. The main findings was that a Norwegian commitment to full-scale CCS could contribute to create 30.000-40.000 new jobs in



SINTEF

From the SINTEF report:
Industrielle muligheter og arbeidsplasser ved CO_2-håndtering i Norge

Norway by 2050, and at the same time strengthen the competitiveness of additional 80.000-90.000 jobs.

The report was launched close to the Norwegian Parliament, with members of parliament present from almost all parties. Later, the report has contributed to shaping open debate on CCS in Norway since its release. It has been mentioned in close to 40 media pieces (including the front page of Klassekampen, and full page in VG), and presented numerous times, in Norway and abroad. The Norwegian CCS-industry frequently use the report as a reference when communicating why CCS is important. The report has been translated to English, and international stakeholders has shown high interest in the work.

Case 3: SINTEF & NTNU – FME Innovation Task Force

In January 2018, SINTEF and NTNU set down an "FME Innovation Task Force", with the ambition of strengthening the work considering innovation and innovative output from all the FMEs that SINTEF and NTNU lead (which are NCCS, HighEFF, Cineldi, HydroCEN, and ZEN). The Task Force had members who had the most experience in the area from working with the FMEs, and the group was led by the NCCS ITT Task leader. The objective of the Task Force was to gather the best experiences from working with innovation on the FMEs, to give advice and best practices for all of the FMEs to learn from.

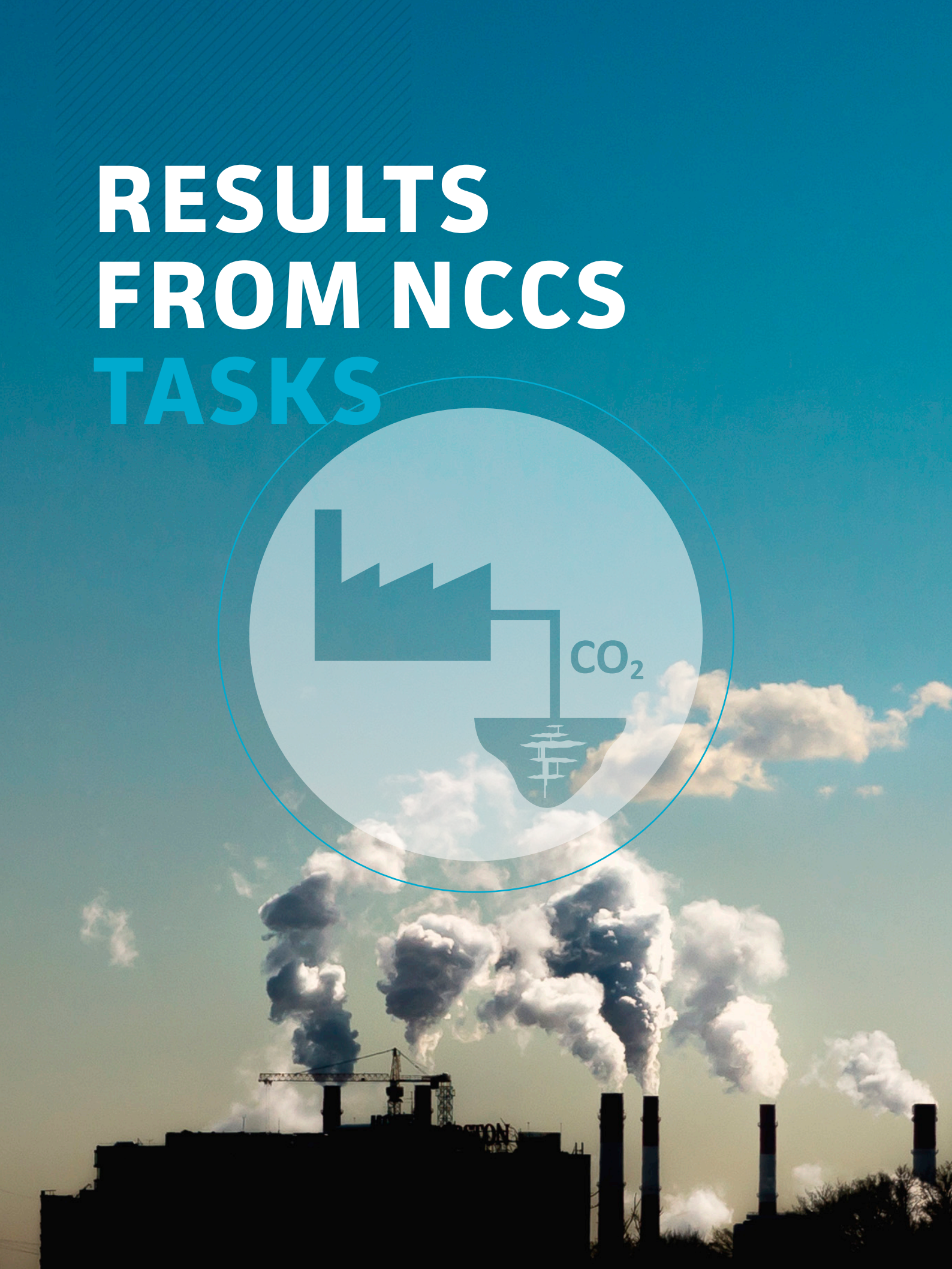
The work resulted in a short report, which was launched on November 28th, with all the FMEs present, as well as the Research Council of Norway, which has applauded the initiative. The report highlights five recommendation for the FMEs, followed by several recommended actions. The five recommendations are:

1. The center director must be engaged and committed for innovation
2. The center must have a dedicated innovation leader
3. The center must have a plan to build innovation competence
4. The center must introduce a methodology for systematic mapping of innovation
5. The center must highlight and communicate the social benefit of the innovations

In 2019, the ITT Task will work with implementing these advices in NCCS, in collaboration with the industry.

Read our digital annual report for videos and more case details www.nccs.no -> Annual report 2018

RESULTS FROM NCCS TASKS



THE CO_2 VALUE CHAIN AND LEGAL ASPECTS **(TASK 1)**

The task seeks to demonstrate the importance of CCS to decarbonize the energy and industrial sector to reach the Paris Agreement target. It will provide recommendations on the best measures to cut CCS costs and assess shortcomings in the current legal framework applicable to CCS operations at national and international levels. This will help enable a faster and cheaper deployment of CCS technology.

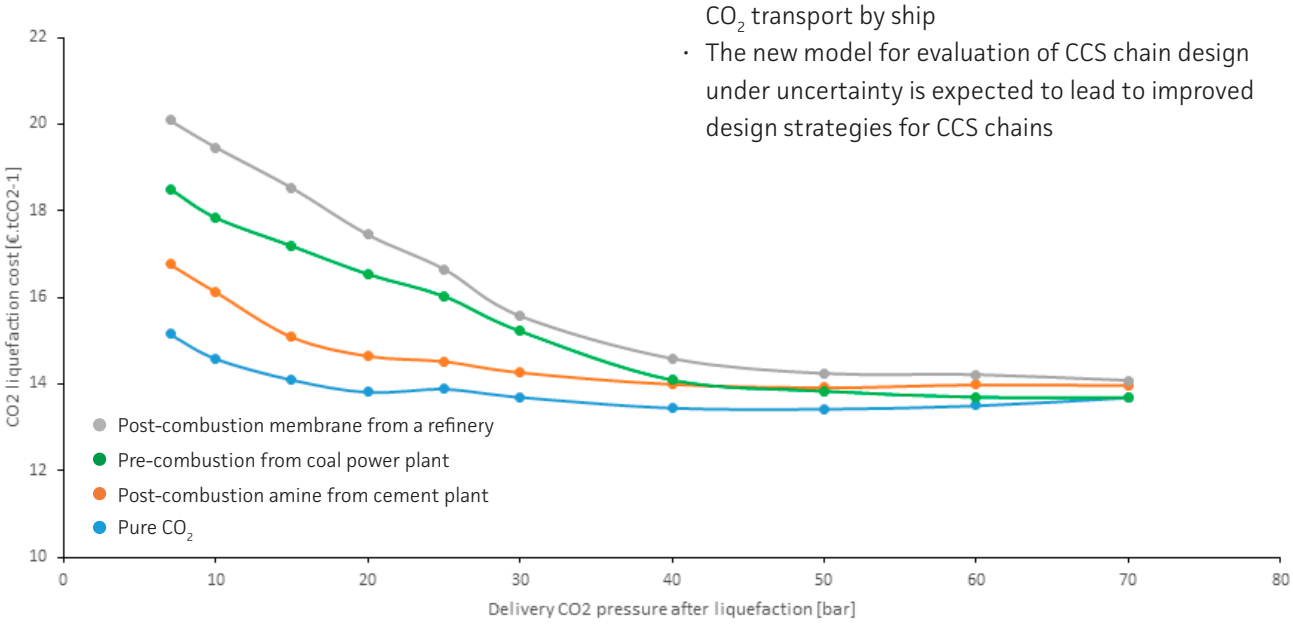
www.sintef.no/NCCST1

Main Results 2018

- Improvement of the EMPIRE model for evaluation of the role of CCS in decarbonising the power and industrial sector
- Evaluation of the impact of delivery pressure and impurities on the design and cost of CO_2 liquefaction prior to ship transport
- Development of a new model for evaluation of CCS chain design under uncertainties
- Assessing the content and implementation of the current CCS Directive on liabilities for CO_2 shipping and storage

Impact and innovations

- The work on CO_2 liquefaction is the first step toward the identification of optimal transport conditions for CO_2 transport by ship
- The new model for evaluation of CCS chain design under uncertainty is expected to lead to improved design strategies for CCS chains



Impact of the targeted delivery pressure after liquefaction on the cost of CO_2 liquefaction for different CO_2 impurity scenarios in the CO_2 stream after CO_2 capture. The results obtained will be used to identify the cost optimal conditions for transport of CO_2 by ship 2019.


CO_2

SOLVENT TECHNOLOGY – ENVIRONMENTAL ISSUES **(TASK 2)**

The task works to understand degrading of solvents better by investigating which factors has the highest impact on the stability of amines (organic compound derived from ammonia). Furthermore, the task will contribute to reduction of operational- and investment cost by indicating amines with higher stability and developing technologies to control and monitor solvent stability.

www.sintef.no/NCCST2

Main Results 2018

- Verification of experimental set-up for degradation tests and oxygen solubility.
- Effect of amine concentration, loading and temperature on O_2-solubility studied.
- Guidelines/lessons learned for evaluating solvent stability presented
- PLS model tested on real/aged MEA samples from bench scale experiments to large Pilot Plant.
- Developed techniques for oxygen removal showed good results with removal rate above 80% obtained.
- Test and scale up study of oxygen removal techniques performed

Impact and innovations

- Observation from pilot plant operations in several capture plants shows that there is a correlation between the level of dissolved oxygen in the rich absorption liquid and the degradation profile. Reduction/removal of dissolved oxygen can significantly reduce solvent degradation and then reducing operational problems and cost of carbon capture plants using amine technology.
- Reaction schemes for MEA or other amines are transferable to other amines. Data from pilots, especially, for MEA is currently available and could be used to verify different laboratory set-ups.

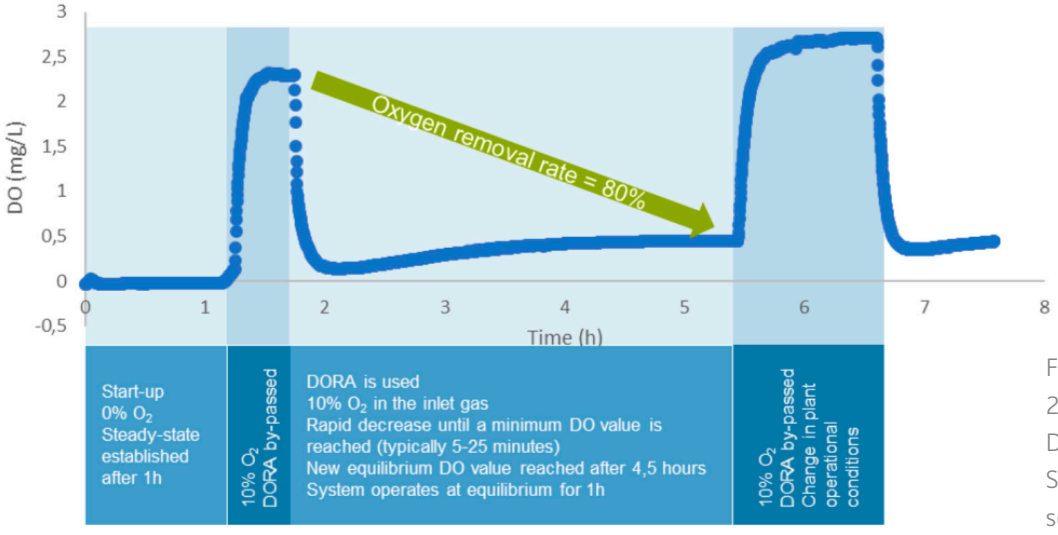
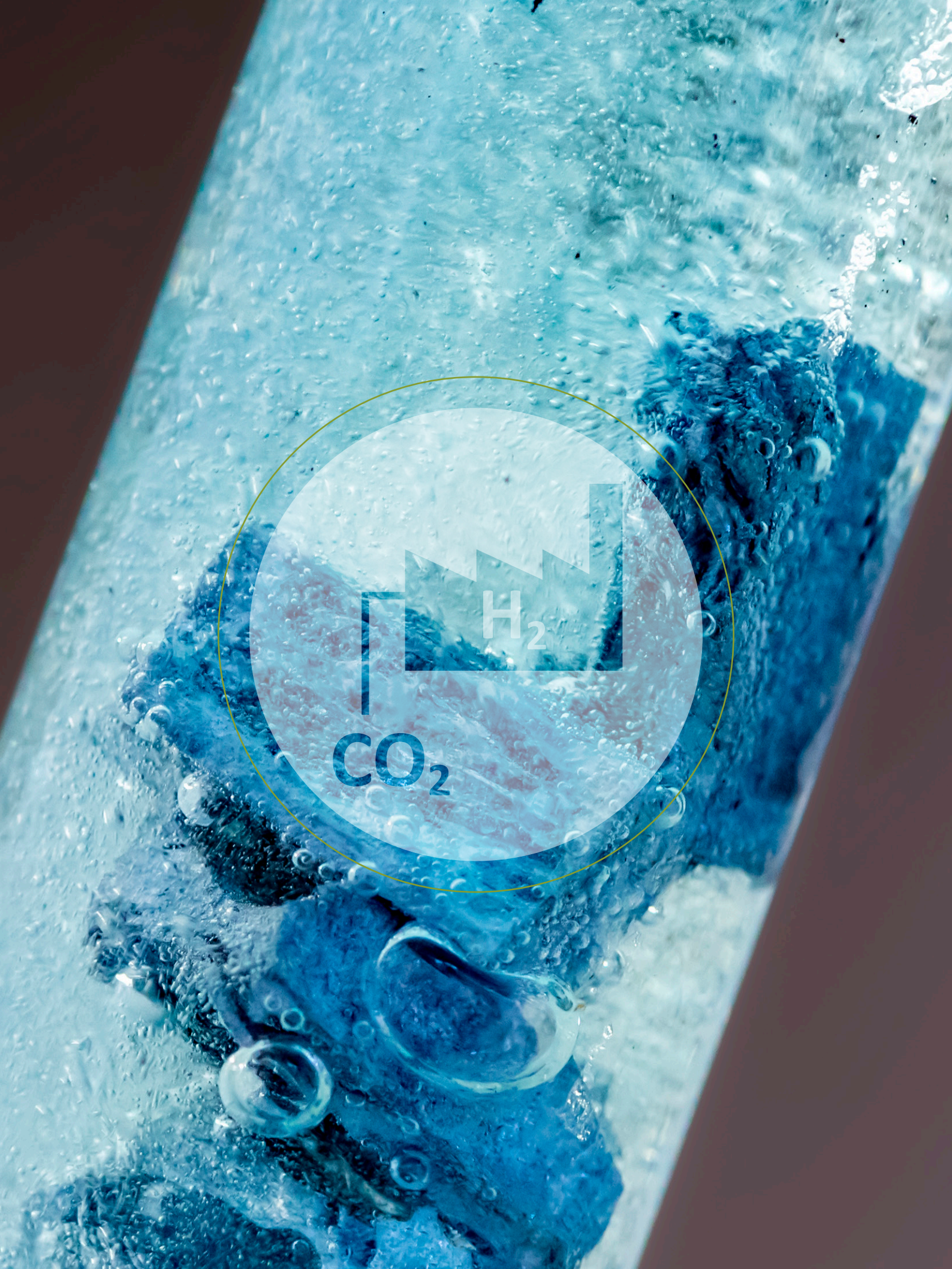


Figure illustrating 2018's main results: DORA LL MODE, Sodium Sulphite as scavanger


H2
CO2

LOW EMISSION H_2 PRODUCTION **(TASK 3)**

The current efficiency level of the H_2 production is around 60-70%. The goal of the task is to develop hydrogen production technology with an efficiency higher than 75% including capture of CO_2 to lower emissions from the H_2 industry.

www.sintef.no/NCCST3

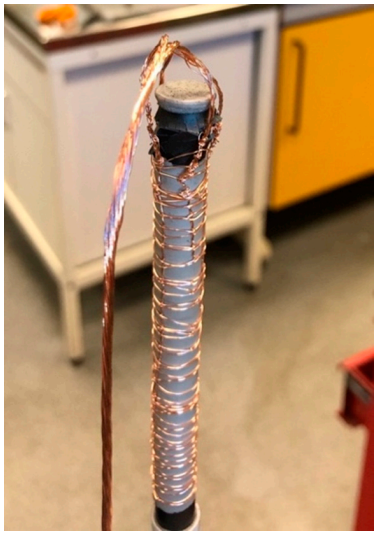
- Several modifications and improvements to the experimental setup have been performed amid significant challenges with the experimental setup.
- Simulation model for CoorsTek membranes was developed for modelling of PMR membrane and reactor.
- Paper on theoretical studies of CO_2 and H_2O co-adsorption on membrane surface accepted for publication.

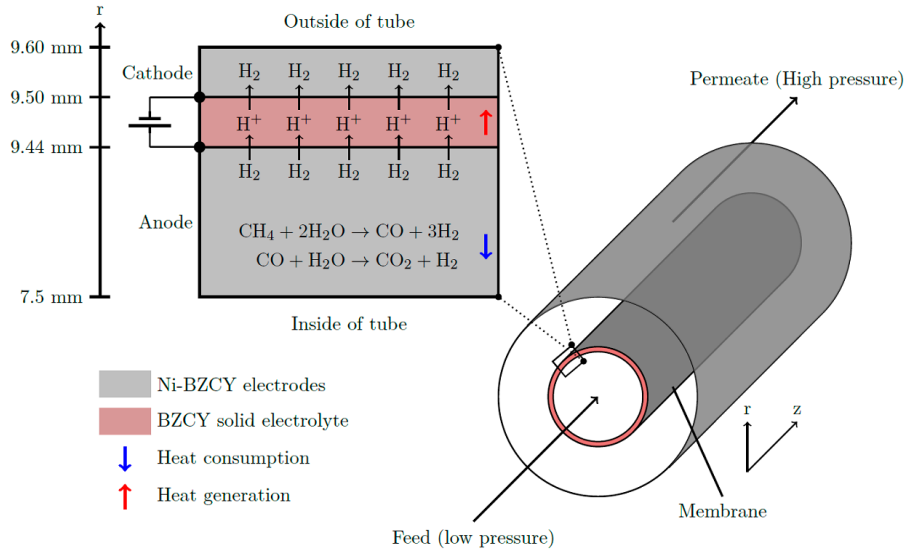
Main Results 2018

- Performance targets defined for a single PMR membrane for testing in NCCS, and for commercial deployment of the PMR technology.

Impact and innovations

- Knowledge of possible critical role of coke deposition in membrane anode.





Left: Single tubular PMR membrane (dark grey) with electrode (light grey) and Cu-wire as current collector. PMR test could not be completed due failure of the membrane (cracked at the top), ascribed to unstable steam supply and coke deposition in the inner electrode. Right: Schematic of the various components of the membrane described in the simulation model.


CO_2

CO_2 CAPTURE AND TRANSPORT CONDITIONING THROUGH LIQUEFACTION **(TASK 4)**

The task is looking to use liquefaction to optimise the transport condition of CO_2, thus making liquification a mandatory processing stage in the interface between capture and transport. To do this, an efficient CO_2 liquefier process will be derived. Important criteria are energy- and cost efficiency adhering to transport specifications and safety.

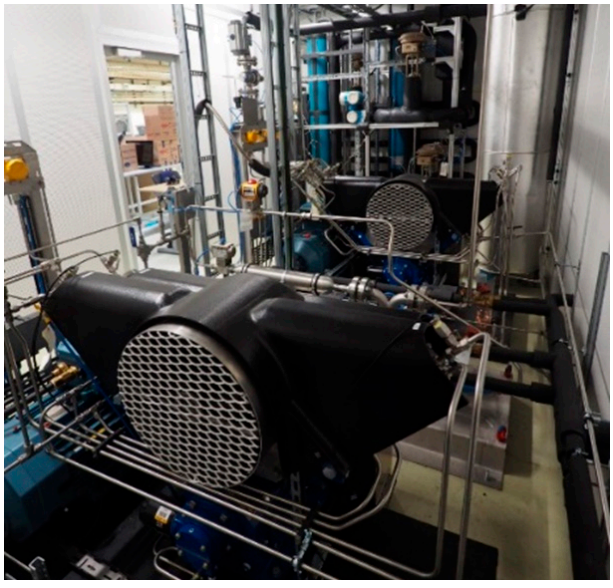
www.sintef.no/NCCST4

Main Results 2018

- Due to extremely high activity on commissioning the laboratory pilot facility, we have asked for very low budgets so far, with the aim of expanding on experimental activity beyond 2018
- Other work ongoing until the end of 2018 (comparison of two different processing routes for CO_2 liquefaction), not concluded at the time of reporting. KPIs to be compared comprise: Specific energy usage, total swept compressor volume, CO_2 purity, CO_2 recovery and more.

Impact and innovations

- In parallel with NCCS, but with high relevance to potential future NCCS work, we have successfully commissioned the 10 t/d CO_2 liquefaction pilot plant and run several tests for separation of N_2 and CO_2. This infrastructure can be very useful for NCCS in the coming years.



Interior of the 10 t/d CO_2 liquefaction and separation pilot facility

GAS TURBINES **(TASK 5)**

Task 5 aims to enable deployment of carbon storage on the Norwegian continental shelf through O&G rigs, and throughout Europe with gas turbine engines. The overall objective is to assess the stability and operability of gas turbine combustion systems. Ultimately, the task will evaluate their impact on power generation, thermodynamic efficiency and pollutants emissions.

www.sintef.no/NCCST5

Main Results 2018

- "Strategy" to start & stabilize reheat flame of 100% hydrogen is established.
- Comprehensive validation of skeletal chemical kinetics scheme for H_2/CH_4 fuels.
- First laboratory experiments on combustion dynamics of H_2/CH_4 flames.

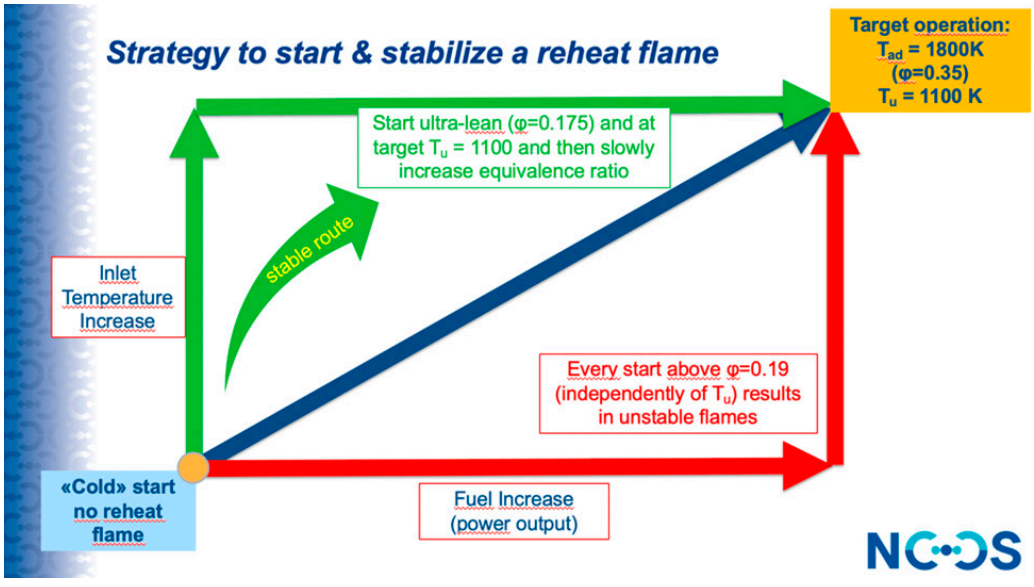


Figure 1 – Strategy to start and stabilize a 100% hydrogen flame at reheat conditions: first reach target inlet temperature, establish ultra-lean flame and then add hydrogen fuel to reach target conditions


CO_2

CO_2 CAPTURE PROCESS INTEGRATION **(TASK 6)**

Task 6 investigates how to best integrate the capture process in the CCS value chain. A generic methodology for post-combustion CO_2 capture in waste to energy plants will be developed. The methodology will be used to redesign plants so they can support flexibility between heat (steam) and electricity output. The task will also develop a systematic approach to link solvent properties and cost reduction in end-of-pipe CO_2 capture.

www.sintef.no/NCCST6

Main Results 2018

- Initiated development of a methodology for identifying the potential for cost reduction in end-of-pipe capture using solvents. An absorber model was developed as part of this work in 2018.
- Preliminary work on identifying the potential of different capture process routes – membranes, PSA, absorption and CO_2 liquefaction. Identified that for pressure-based separation processes (membranes and PSA) using a hybrid membrane-liquefaction or hybrid PSA-liquefaction process should always be better than a 2-stage process.

Impact and innovations

- The methodology for cost reduction is in its initial phase of development. When completed it is expected to provide directions for potential cost reduction when using solvents for post-combustion CO_2 capture.
- The basis for a subsequent thermodynamic evaluation of capture processes has been established. In subsequent years, with development of this methodology, it is expected to identify novel processes, configurations and identify improvements in standard capture processes through thermodynamic insights.

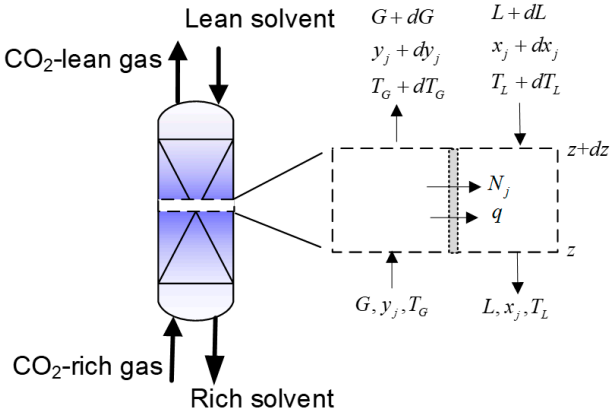
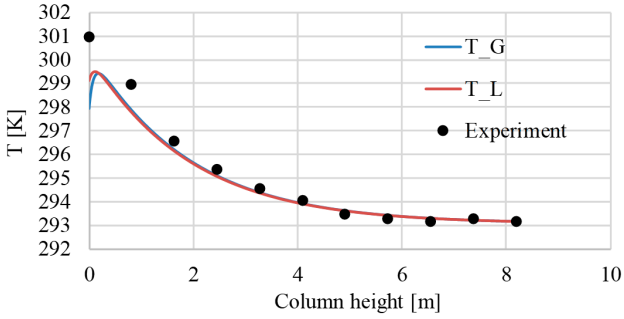


Illustration of a differential section of the absorber



Model validation
- Temperature profile along the column height


CO_2

CO_2 TRANSPORT (TASK 7)

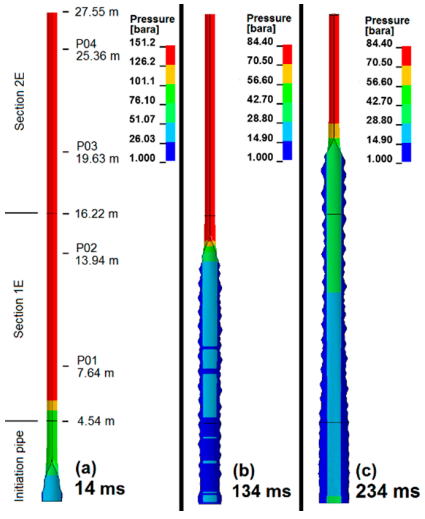
CO_2 transport has hazards and uncertainties. Task 7 will provide knowledge to ensure safe and efficient CO_2 transport. E.g. running-ductile fractures in CO_2 pipelines, ship transport, impurities and non-equilibrium flow of CO_2 will be investigated.

- Develop improved models for the prediction and description of running-ductile fractures (RDF) in CO_2 pipelines.
- Perform depressurization experiments to develop and validate fast-transient flow models taking impurities and non-equilibrium flow into account.
- Perform experiments and modelling studies related to efficient transport of CO_2 by ship.
- Develop efficient and robust numerical methods for multiphase flow of CO_2 with impurities.

Main Results 2018

- Commissioning of the ECCSEL depressurization facility brought much closer.
- Further validation of SINTEF coupled FE-CFD model for fracture-propagation control, published at IPC2018.
- Battelle two-curve tool software updated with new functionality, including GERG-2008 and EOS-CG equations of state.

www.sintef.no/NCCST7



Left: Visit at ECCSEL depressurization vessel, April 2018. Middle: Depressurization tube, November 2018.
Right: Simulation of RDF for a CO_2-rich mixture: Calculated crack positions for different times (Gruben et al, IPC2018).

FISCAL METERING AND THERMODYNAMICS **(TASK 8)**

Accurate thermophysical properties are needed for optimized design and operation of virtually all processes involved in CCS. This task aims to provide improved experimental data and models on properties of CO_2-rich fluids relevant for CCS, and facilitate fiscal metering of the same fluids.

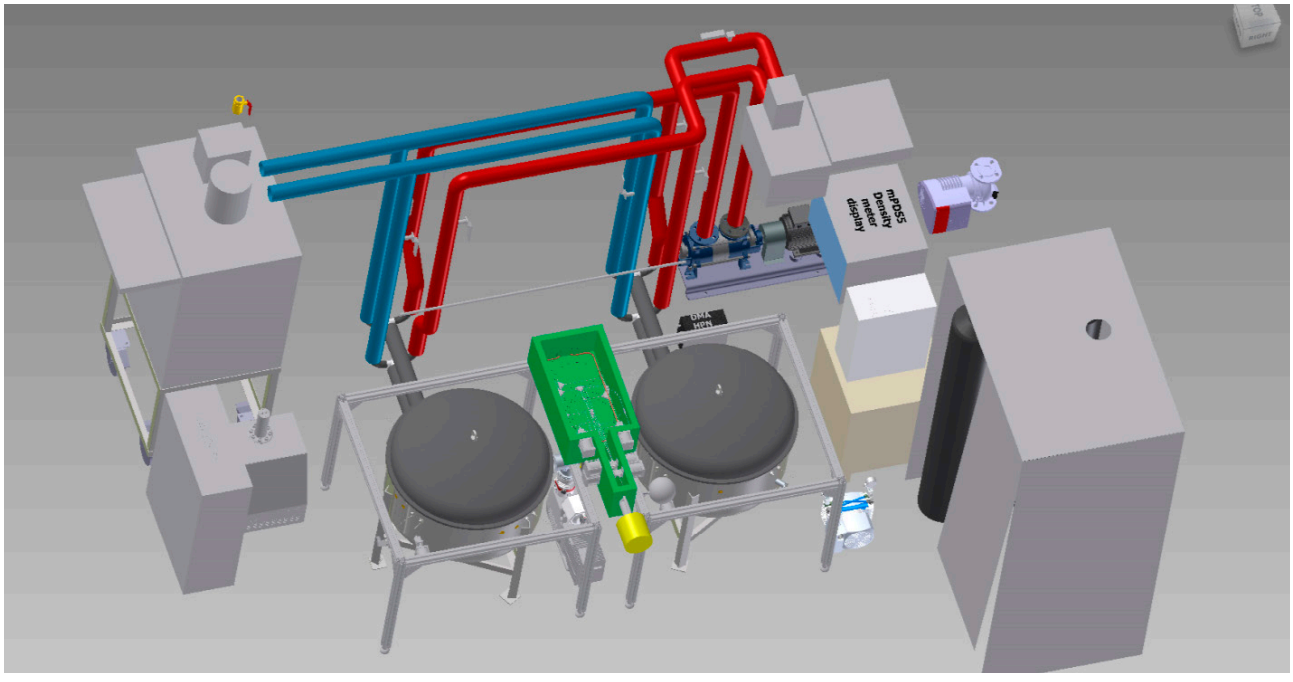
www.sintef.no/NCCST8

Main Results 2018

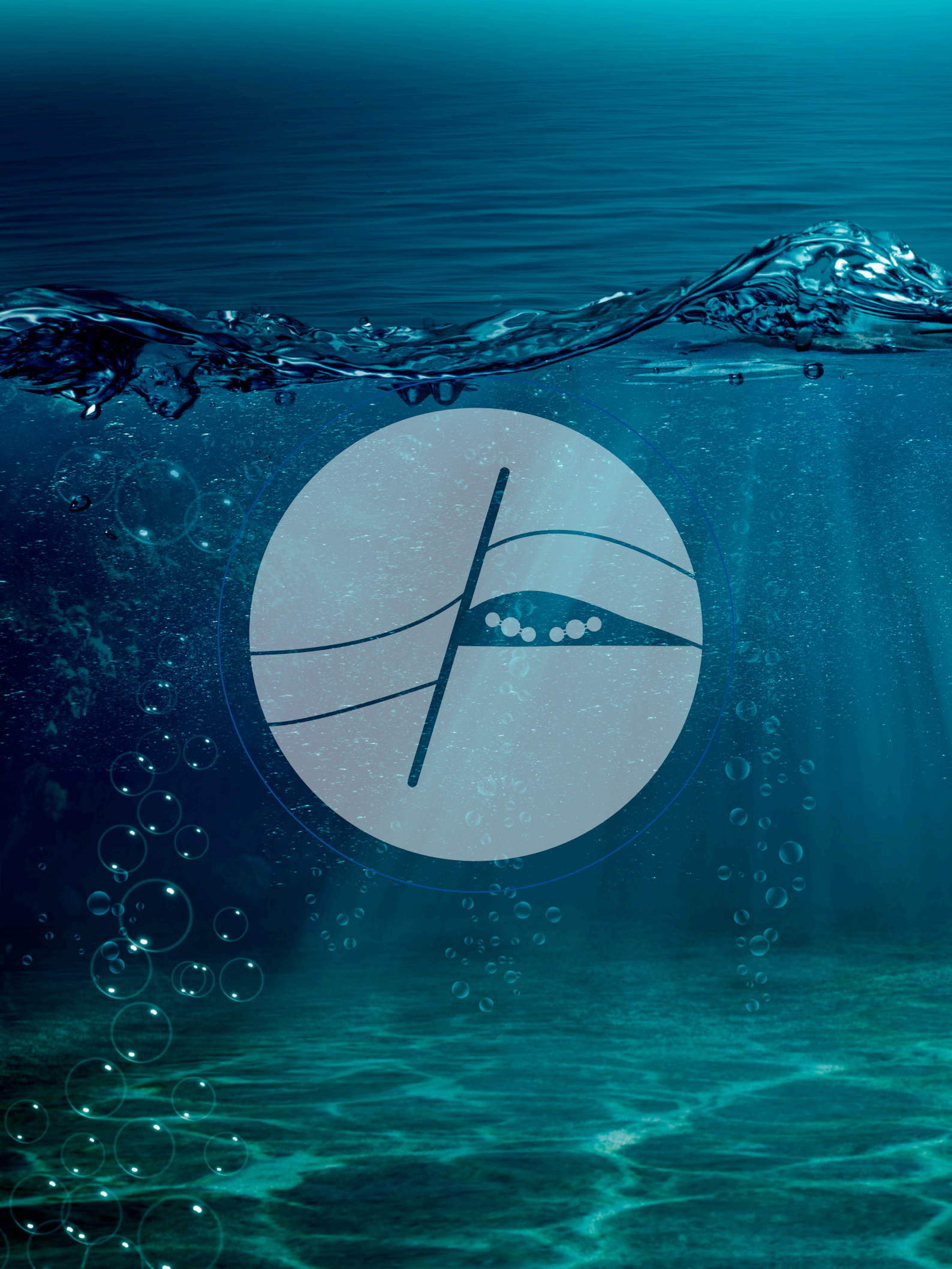
- First benchmarking of fiscal metering technologies for CO_2 and strategy for verification test plan
- Measurement of VLE on the ternary system CO_2-N_2-CH_4
- Improved models of the minor components in CCS mixtures, as well as CO_2-CO, CO_2-Ar, and initiation of work to include reactive mixtures
- Initiation of NCCS / CLIMIT KPN "Impact of CO_2 impurities and additives in CCS" (ImpreCCS)

Impact and innovations

- New TREND library to be released, including the new mixture models
- Published measurements are available also for other groups developing property models
- New innovative experimental setup for viscosity and density measurements
- Preparation for fiscal metering verification underway



Viscosity setup to be used in ImpreCCS



STRUCTURAL DERISKING **(TASK 9)**

The main ambitions are to reduce risk related to injecting and storing CO_2 in the continental shelf, and contribute to maximize the CO_2 injection volume for the Smeaheia region (Norwegian Continental Shelf storage region) as well as develop techniques to address fault-sealing and integrity.

www.sintef.no/NCCST9

Main Results 2018

- Extensive fault mapping using Gassnova 3D seismic completed for Alpha structure providing a detailed (academic) fault dataset as basis for further fault seal analysis and migration models
- Complexity for polygonal faults and faulting of beta structure documented and detailed interpretation in progress
- Fault slip stability screening performed identifying the fault rock properties as the most critical parameter for fault slip risk
- Machine learning algorithm for evaluation of leak of test (LOT) data established

Impact and innovations

- The extensive fault mapping and geological system characterization for the Smeaheia area was shared with Northern Lights project.
- The fault derisking work has resulted in an increasing awareness of the need for better understanding of risk related to faults in order to utilize the large potential of storage volume within faulted reservoirs.

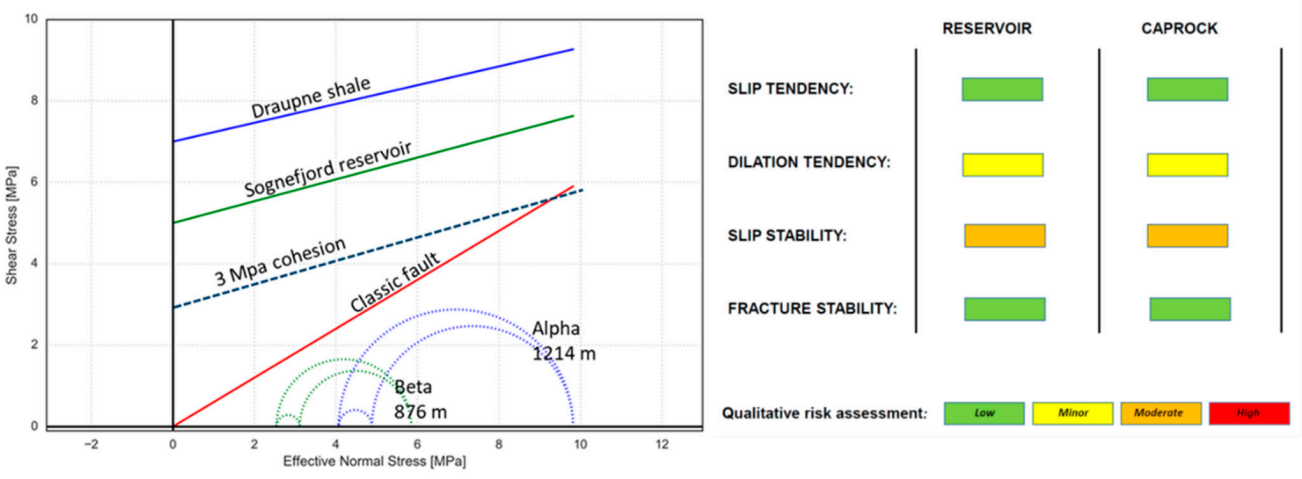


Figure illustrating 2018's main results from fault slip stability screening illustrating the need to better constrain the fault streng properties (cohesion) for Smeaheia in order to reduce the risk related to fault reactivation. Qualitative risk level shown for differnet methods adressed.


CO_2

CO_2 STORAGE SITE CONTAINMENT **(TASK 10)**

The focus is on leakage issues affecting sub-sea wells and the near-well area. The task is looking to maximise storage capacity with minimum risk of significant leakage. Through the research an atlas will be developed. The atlas will contain a check-list of well integrity issues compromising CO_2 storage success.

www.sintef.no/NCCST10

Main Results 2018

- Successful measurement of the interface tensile strength between cement and caprock.
- A further injection test was carried out with somewhat higher $scCO_2$ inflow rate and the same counterflow of brine as before. The test resulted again in massive clogging of the rock core, this time on a larger volume and without helical instability.
- Formulation of Atlas of well integrity questionnaire in the USA.

Impact and innovations

- Work in Task 10 addresses face on the most pressing well integrity and near-well effects needing to be addressed in order to open for massive and large-scale sequestration of CO_2. These are the issues remaining where especially legacy wells and high rate injection could compromise safe CCS operations.
- The innovation resides in the new laboratory methods used to simply isolate the identified weak elements in all researched topics, so as to address the highest remaining risks at the lowest cost and most effective manner.

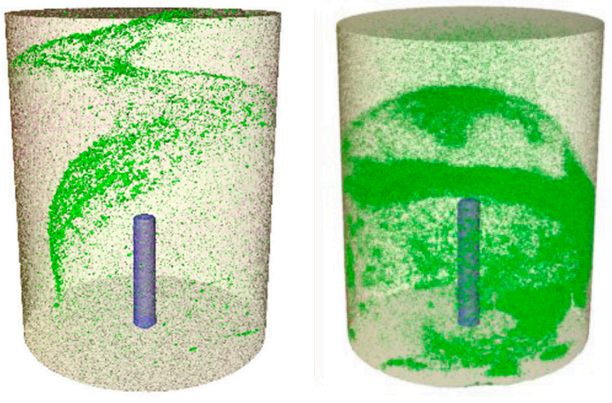


Figure illustrating 2018's main results: (left) precipitated salt in 2 Berea sandstone plugs submitted to different CO_2 injection flow rates (increasing from left to right). Right: Shale (to the right) and cement (to the left) surfaces of flat (top) and roughned (bottom) samples after tensile failure.


CO_2

RESERVOIR MANAGEMENT AND EOR **(TASK 11)**

By pumping CO_2 into oil reservoirs and storing it there, we can extract more oil. This technique is called enhanced oil recovery (EOR). But, the cost of CCS is still too high, meaning the process capturing the CO_2 one intends to pump into the reservoirs is too expensive. Therefore, reducing net cost of the overall CCS chain is the main barrier addressed in this task. Good reservoir management is a huge part of that, as it will be imperative to minimize storage-related costs.

www.sintef.no/NCCST11

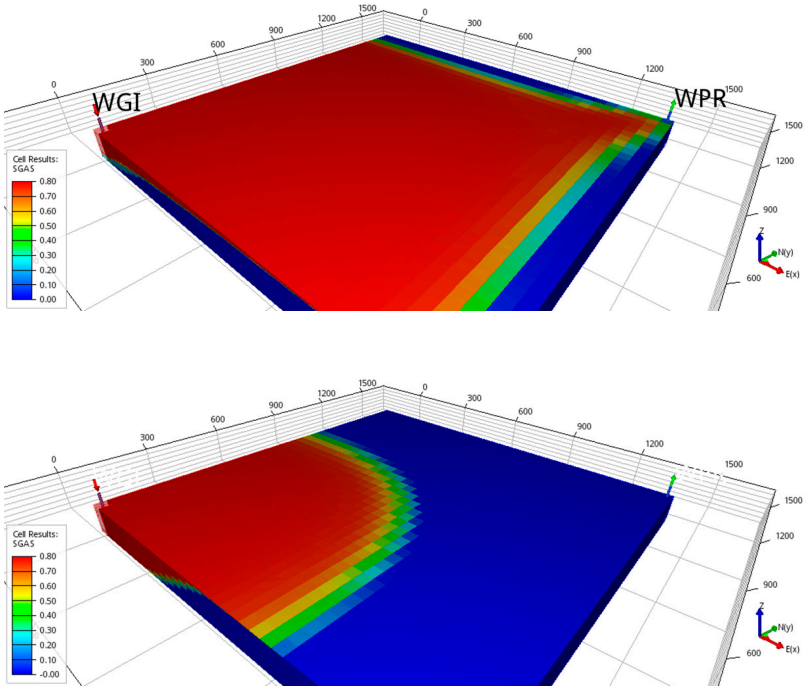
Main Results 2018

- Laboratory testing of foam-generating properties of synthetized nanomaterials. Results for first batch mainly negative. Design directions for next batch discussed.
- Synthetized next batch of nanomaterials for CO_2/brine foam generation
- Working version of MRST CO_2-foam module. Simulations with Eclipse and with MRST presented in GHGT-14 publication. Demonstrate >100% increase in CO_2 storage efficiency for five-spot CO_2-injection/brine-extraction patterns.
- Initial work to optimize cost/benefit for mobility control in CO_2 storage.
- Development of a storage site optimization work flow.

Demonstration of the effect of mobility control for CO_2 in a five-spot well pattern. CO_2 injected at a rate of 0.5 Mt/year through the well in the left corner into a 100-m thick reservoir section with horizontal dimensions 1400x1400 m, while brine is produced at the opposite corner.

Top: After 6 years the CO_2 has reached the location of the production well, and this section of the reservoir will have to be closed soon thereafter.

Bottom: if mobility control can be implemented, the injected CO_2 will move much more slowly across the reservoir section and will not reach the opposite corner until several years later, giving 50 % increased storage capacity in the shown example.



COST-EFFECTIVE MONITORING TECHNOLOGY **(TASK 12)**

One of the keys for safe CO_2 storage is that industry operators comply with monitoring regulations. Monitoring the storage site is potentially very expensive. The main ambition is to develop and demonstrate monitoring technology which will enable safe operation in compliance with laws and regulations in the most cost-efficient manner.

www.sintef.no/NCCST12

Main Results 2018

- Smeaheia baseline geophysical models and rock physics models built using Gassnova seismic data (Fig. 1)
- Sensitivity test of CO_2 injection on seismic observables at Smeaheia
- Initial sensitivity studies for use of CSEM at Smeaheia (Fig. 1)
- Demonstration of joint rock physics inversion approach at Sleipner using CSEM and seismic 2008 datasets
- Validation of compressive sensing strategy for improved cost-efficient imaging
- New survey optimization strategy tested
- Work on combined modelling-monitoring and "history matching" initiated
- Evaluation of cost-saving potential of NCCS CO_2 monitoring developments

Impact and innovations

- First application of FWI to get most out of Gassnova's 3D seismic data at Smeaheia could become useful for Northern Lights project for reservoir seal characterization and monitoring planning
- The compressive sensing approach can help to reduce the need for dense (and expensive) seismic surveys

Survey optimization technique and combined modelling-monitoring workflow will help to find cost-efficient ways of confirming site conformance during injection

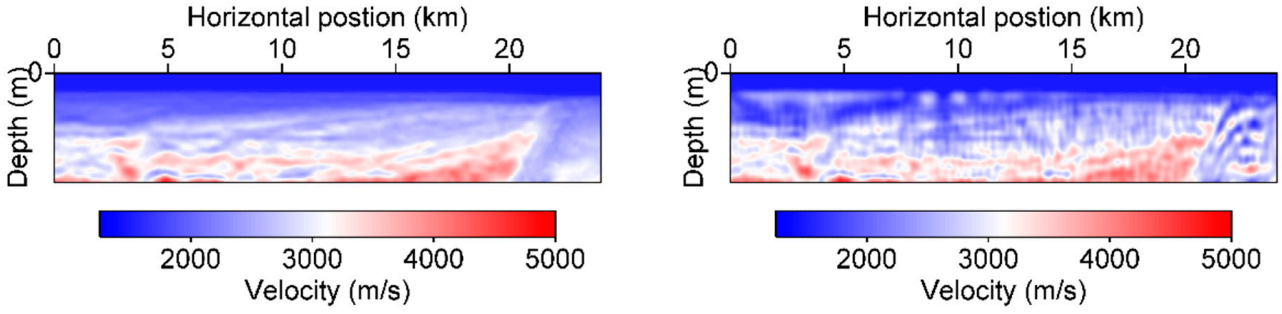
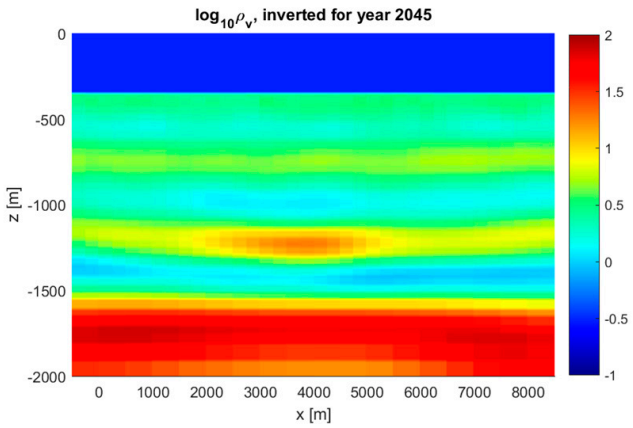
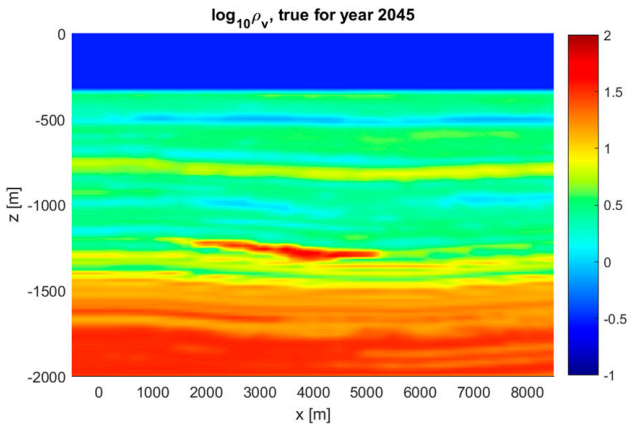
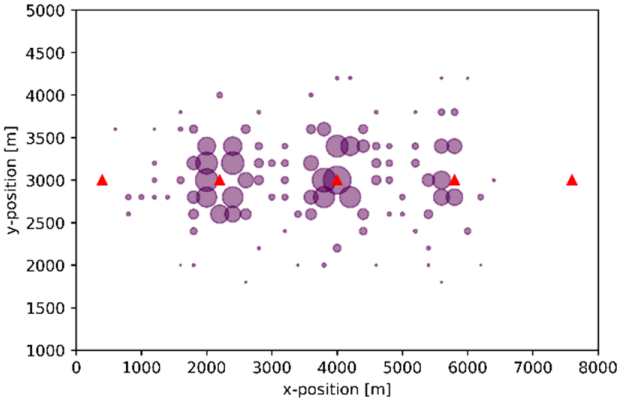


Figure 1: Selected results from Task 12 in 2018. [left] P-wave interval velocity model in depth for a subset of the Inline 1024 from Gassnova's seismic cube GN1101. [right] P-wave velocity model derived from FWI for the subset of Inline 1024 (from Dupuy et al. 2018, to be published).







[upper left] 2.5D true resistivity models for simulated injection at Smeaheia until 2045. [upper right] CSEM inversion results. [bottom] A survey optimization strategy was developed and tested for synthetic Sleipner CSEM case. Circles representing optimal lateral source position and sensitivity (area). Each source is used together with all five receivers (represented by red triangles).

INTERNATIONAL COOPERATION

NCCS hosted the 12th Annual IEAGHG CCS Summer School – from blog

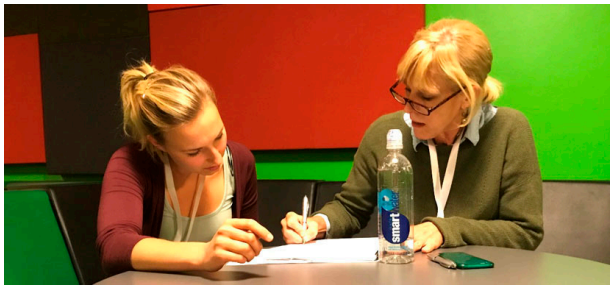
NCCS was pleased to have hosted the 12th IEAGHG CCS Summer School in Trondheim, with 58 students from 24 countries.

NCCS facilitated the communication with very up-to-date information on the development of the new Norwegian storage site and the industrial sources of CO_2, representing state-of-the-art work-in-progress information by a leading CCS country.

Enjoying the excursion at Munkholmen

Broad range of topics

This year, in addition to covering all aspects of CCS in lectures (presented by leading international experts), the students also had group exercises in communication, designing monitoring plans, interactive careers session and the usual group project work.



Snapshot from the interactive careers session.

Four days including a fieldtrip and laboratory tour

The IEAGHG CCS Summer School lasted for 4 days, consisting of lectures and a field trip to the CO_2 Laboratory at Tiller and a tour of SINTEF's lab facilities at NTNU.

Funding partners of the IEAGHG CCS Summer School
NCCS expresses our gratitude to IEAGHG for the opportunity for hosting the summer school and to our funders, the UK Department for Business, Energy & Industrial Strategy (BEIS), Swiss Federal Office of Energy (SFOE), Shell, Total, and the Research Council of Norway through the FME programme and the CLIMIT programme.

Engaging presentations and enthusiastic students
Thanks also to the speakers, experts and mentors who gave their time and shared their knowledge. The speaker presentations were engaging and of very high quality! And the biggest thank you to all the students who were excellent, enthusiastic, full of energy, and asked great questions to the experts and mentors.

Activities on the strategic arena

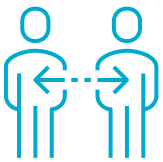
Active participation in organizations spearheading the strategic CCS development on the European arena, is a priority for NCCS. In this way, Norway and NCCS is able to contribute in the stage-setting of the research agenda in the field of CCS.

Dr. Nils Røkke (Chair of the NCCS Special Advisory Group and the Centre Assembly) is the current Chair of the *European Energy Research Alliance (EERA)*. With 175 research centre and university members from 27 countries, EERA's objective is to build on national and EU research initiatives and to be the cornerstone in the *European Strategic Energy Technology Plan*.

The *CCS Joint Programme* under the EERA (EERA JP-CCS) is an authority on CCS RD&I. The CCS-JP provides strategic leadership to its partners, and coordinates national and European RD&I programs to maximize

[top] Katherine Romanak (UT Austin) presents outstanding poster awards to Charlotte Mitchell (University of Edinburgh) and Tjerk Lap (University of Groningen).

[left] Tim Dixon (IEAGHG) and John Kaldi (University of Adelaide) awarding Corey Myers (Waseda University) and Pooya Hoseinpoori (Imperial College) as the Most Outstanding Students



synergies, facilitate knowledge sharing and deliver economies of scale to accelerate the development of CCS. Dr. Marie Bysveen has held the coordinator role in JP-CCS since 2015.

Dr. Nils A Røkke has since 2010 been co-chair of the *European Technology Platform for Zero Emission Fossil Fuel Power Plants* (ZEP). ZEP is a coalition of stake-holders united in their support for CO_2 capture and storage as a key technology for combating climate change. ZEP serves as advisor to the EU Commission on the research, demonstration and deployment of CCS. Focus on improving the CCS funding situation in the recently-released FP9 (Horizon Europe) program will continue in 2019.

NCCS has interacted with the *US National Energy Technology Laboratory* (NETL), and the UK CCS Research Centre (UKCCSRC). The Centre Director has a seat in the UKCCSRC Board and the Centre Manager helped co-organize a CCS Experts Forum in Italy in 2018, together with Imperial College and NETL.

Collaboration with the US

As part of the Memorandum of Understanding (MoU) between the US Department of Energy and the Norwegian Ministry of Petroleum and Energy, CCS is a strategic area of joint interest for the countries. NCCS has been active in bilateral MoU meeting preparation and the event held in Oslo on May. Many of the tasks in NCCS collaborate with US national labs and universities, such as Lawrence Livermore National Lab, National Energy and Technology Laboratory, Sandia, etc.

NCCS Special Advisory Group

The *NCCS Special Advisory Group* (SAG) has been established with world leading experts in the CCS field. The Committee consists of: Kelly Tambimuhtu (IEAGHG), Karen Wesley (Shell), Niall Mac Dowell (Imperial College London), Katherine Romanak (Univ. Texas), Julio Friedman (Energy Futures Initiative), Mike Monea (SaskPower), Brad Page (Global CCS Inst.), Jon K. Økland (Gassco), Hans J. Vinje (Gassnova), Marie Bysveen (EERA), and Nils Røkke (SINTEF). The group shall advise the NCCS Board on strategic issues such as trends and new developments, and help position the Centre globally. Two meetings have led to a "live" list of activities NCCS should consider to develop or expand in NCCS.

NCCS Mobility

Facilitating *mobility of researchers and students* is another NCCS priority. As important as sending NCCS personnel to external organizations, is to attract NCCS externals to the Centre. In 2018, Ruhr University is sharing one PhD student with NTNU (2 yrs), a variety of international students have assisted as summer students, and the Task 8 Leader will move to Australia in December 2018 to spend 6 years with the University of Western Australia. New applications for the NCCS Mobility program are due in January for activities in 2019.

Other initiatives

NCCS participates in ongoing H2020 projects, including *CO_2 capture from cement* (CEMCAP, 2015-2018). Also, NCCS partners are leading and/or active in five *ACT-ERA-Net Cofund* projects starting in 2017. The project owner is involved or leading several *ACT-ERA-Net Cofund* proposals that have been invited for Phase 2 in 2018.

RECRUITMENT

One of the most important tasks of NCCS is to educate master's and doctoral students in CCS research so that they can continue this knowledge in the work of CCS, whether they work in industry or as researchers. During the first two years, 8 PhD fellows have been recruited and 5 postdoctoral fellows are in the starting pit and are tightly integrated into the Task families.

Postdoctoral researchers with financial support from the Centre budget

Name	Nationality	Period	Sex M/F	Topic	Task
Barbara Re	Switzerland	20180101 - 20191231	F	Large-scale transient behaviour of CO_2-transport pipelines	7
Mark Mulrooney	Canada	09/2017 - 08/2021	M	Structural de-risking of the Smeaheia CO_2 storage prospect	9
Viktor Weber	Norway	20180801 - 20200830	M	Long-term liability for CO_2 storage activities	1
Ozgu Turgut	Turkey	12/2017 - 11/2019	F	Value chain optimization of carbon capture and storage for stationary emitters	1
Jose Aguilar	Mexico	20180801 - 20210801	M	Modelling thermoacoustic instabilities	5

PhD students with financial support from the Centre budget

Name	Nationality	Period	Sex M/F	Topic	Task
Vanja Buvik	Norway	09/2017 - 08/2021	F	Effect of amine structure on solvent stability of CO_2 absorbents	2
Stefan Herrig	Germany	10/2013 - 07/2018	M	New Helmholtz-energy models for pure fluids and CCS-relevant mixtures	8
Jonathon Osmond	USA	10/2017 - 09/2021	M	3D structural characterization and containment risk analysis of two CO_2 storage prospects in the Smeaheia area of the Northern Horda Platform, Norwegian North Sea	9
Camilla Louise Würtzen	Germany	09/2018 – 09/2021	F	Satellite storage Smeiheia - jurassic	9
Eirik Æsøy	Norway	01/2018 – 02/2022	M	Experimental investigations into forced and self-excited azimuthal combustion dynamics modes	5
Vegard Skonseng Bjerketvedt	Norway	01/2017 – 01/2020	M	Optimal design and operation of CCS value chains with focus on the transport system	q
Marcin Duda	Poland	01/2018 – 12/2020	M	Low frequency laboratory tests	10
Tobias Neumann	Germany	07/2018 - 07/2021	M	CCS mixture reference EOS development (EOS-CG)	8

PhD students working on projects in the centre with financial support from other sources

Name	Funding	Nationality	Period	Sex M/F	Topic
Mats Rongved	KPN project	Norway	08/2015 - 03/2018	M	Hydraulic fracturing for enhanced geothermal systems

COMMUNICATION

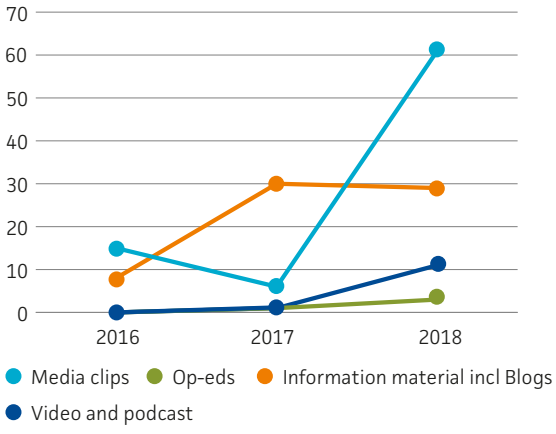
Reaching NCCS' vision of fast-tracking CCS deployment requires both industrial and political willingness as well as public acceptance. Communication from the Norwegian CCS Research Centre is an important strategic activity in order to reaching the Centre's goals.

Communication in NCCS aims to extend communication beyond the NCCS consortium and scientific community to provide facts in the public CCS debate, promote innovations to industry and help increase public support for CCS.

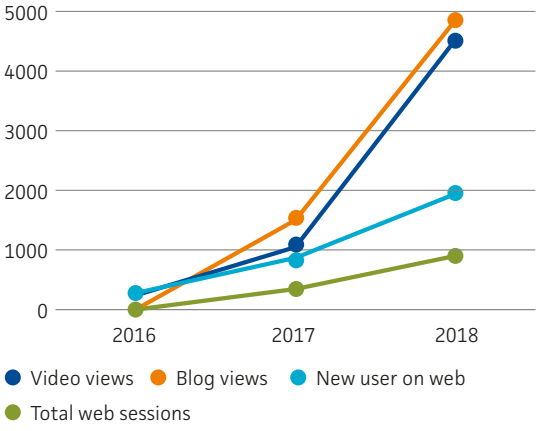
To strengthen NCCS' communication activities in 2018 we engaged the Communication department of SINTEF Energy Research to work for us. Focus areas for the increased communication effort has been high-quality scientific blogs at #SINTEFblog, video content and keeping nccs.no up-to-date. As a result, there has been an increase in the communication activity, especially when it comes to media clips, op-eds and videos. High-quality content has also given NCCS a much higher digital visibility.

By the numbers

Cristin registrations



Digital Visibility



A simplified graphic representation of the FME NCCS Communication plan.

Vision	Why? FME Goal	Who? Target groups	What? Message	How? Channel/media	Results
 **NCCS – Industry driven innovation for fast track CCS deployment**	In order to become a success in: · research activity · innovation/value creation · internationalisation · training/recruitment · funding · organisation	· Industry · Politicians · Funding parties: RCN/EU+ · Public/NGOs · Partners in the centre · International research organisations · Europa-beslutnings-takere og industri	· The world needs CCS · CCS can create new green industries and jobs · Without CCS many industries will not be able to cut emissions · NCCS supports the Norwegian full-scale project · CCS som en del av den europeiske løsningen	· Webpage · Scientific dissemination · #SINTEFblog · Media · Events · Newsletter · Annual report · SoMe · Webinars	KPI: Increased visibility and knowledge KPI: Increased positive reputation KPI: Increased internal engagement Achieving FME goals

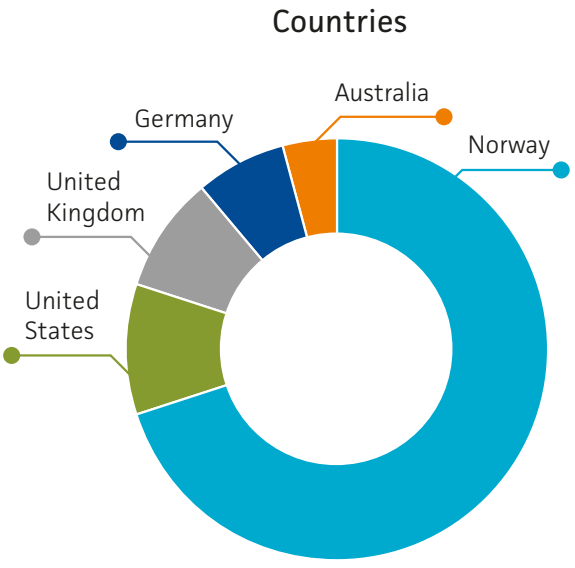
evaluation - reporting - learning

How the Centre has used its communication channels

Web

The NCCS web-page provides information about the Centre, its research and other activities like events and conferences.

The top 5 countries to visit nccs.no in 2018 were:



Newsletter

In 2018, 5 newsletters were sent mainly to the Consortium:

- December 19, 2018 NCCS Newsletter #5 - 2018
- October 11, 2018 NCCS newsletter #4 – 2018
- October 3, 2018 NCCS newsletter #3 – 2018
- May 16, 2018 NCCS newsletter #2 – 2018
- April 30, 2018 NCCS newsletter #1 – 2018

Twitter

The NCCS Twitter account (@NCCS_FME) is used to share news about Centre activities, popular science publications like videos, posts on #SINTEFblog and conference news.

The target groups of the Twitter account are consortium members, potential partners, researchers, governments (domestic and international) and the "interested public".

In 2018, NCCS had:

412 followers

59 000 tweet views

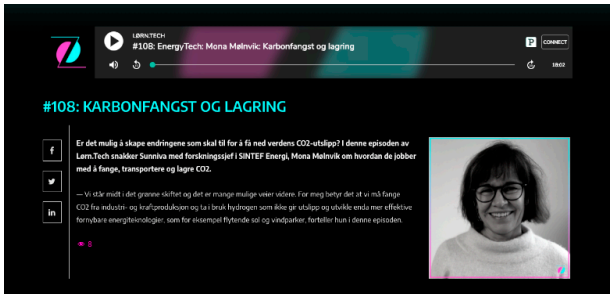
34 tweets

The most successful month on Twitter in 2018 was October, with almost 11 000 views and 38 new followers to the Twitter account.

Visibility

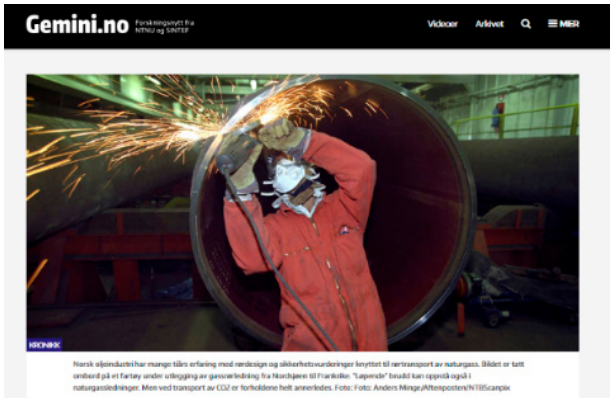
In order to reach a wide audience NCCS has published op-eds and contributed to media coverage of CCS. In total, NCCS had 61 media clips (this does not include all CCS-report mentions) and 3 Op-eds, and 11 videos and podcasts in 2018. Here are four examples:

#1 Centre Director Mona Mølnvik attended the technology podcast Lørn.Tech, one of Norway's biggest technology podcasts. There she explained what CCS technology is, why we need it and how NCCS is working to fast-track CCS deployment.



#2 Arendalsuka is a national annual event held every August. It is a politically independent forum where every-day citizens meet political leaders, business leaders, entrepreneurs, governmental organizations, media and NGO's. This year Mona Mølnvik was invited to present the report "Industrial opportunities and employment prospects in large-scale CO_2 management in Norway", that NCCS, SINTEF and NTNU carried out on behalf of the Confederation of Norwegian Enterprise, the Confederation of Trade Unions, the United Federation of Trade Unions, the Federation of Norwegian Industries, the Norwegian Oil and Gas Association and the Industri Energi trade union.

#3 Task 7 leader, Svend Tollak Munkejord, together with SINTEF Research Scientists Gaute Gruben and Håkon Nordhagen wrote an Op-ed published in Dagens Næringsliv December 13, 2018 called *Slik tøyles CO_2 i rør (CO_2 in pipelines)*. It was later published on gemini.no as well.



#4 Dr. Nils Røkke (Leader of NCCS Strategic Advisory Group) published an Op-Ed in Dagens Næringsliv on May 10, 2018 called *Må få på plass CO_2 håndering (We must get CCS going).*

Må få på plass CO_2-håndtering

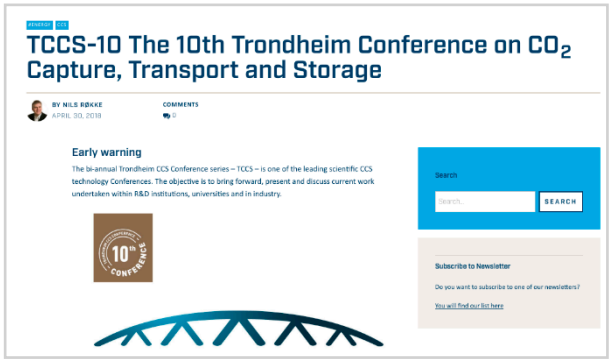
Norges planlagte utstillingsvindu for CO2-håndtering åpner for omgjørelse av naturgass til «rent drivstoff» – hydrogen – i stor skala.

Teknologi
Nils A. Røkke

Blogs

NCCS has contributed to 29 blogs in 2018, all of which has been published on www.blog.sintef.com (#SINTEF-blog). 2018 was a very good year for NCCS blog posts as can be seen in the examples below.

The top three blogs in 2018 were:



TCCS-10 The 10th Trondheim Conference on CO_2 Capture, Transport and Storage

BY NILS RØKKE
APRIL 30, 2018
COMMENTS

Early warning

The bi-annual Trondheim CCS Conference series – TCCS – is one of the leading scientific CCS technology Conferences. The objective is to bring forward, present and discuss current work undertaken within R&D institutions, universities and in industry.

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TCCS-10 The 10th Trondheim Conference on CO_2 Capture, transport and Storage had 1368 views (Third most in #SINTEFblog history)

Future Business Models for CCS: Hydrogen from natural gas

BY MONA J. MØLNVIK
MARCH 21, 2018
COMMENTS

This blog on the possibilities in hydrogen from natural gas is based on a presentation held at the GCCSI Seminar 21.-22. March 2018 in Oslo, Norway. Mona Mølnvik is the Centre Director for Norwegian CCS Research Centre NCCS.

Thank you, Global CCS Institute, for inviting me to speak here today. I hope to be able to present a few new perspectives on natural gas, hydrogen and CCS.

The potential of supplying large amount of clean hydrogen will pave the road for a fully renewable energy system in the longer run.

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Future Business models for CCS: Hydrogen form natural gas had 1124 views (Fifth most in #SINTEFblog history)

Industrial opportunities and employment pro-spects in large-scale CO_2 management in Norway

BY SIGMUND STØRSET
MAY 3, 2018
COMMENTS

SINTEF, in collaboration with NTNU, has completed a study entitled "Industrial opportunities and employment prospects in large-scale CO_2 management in Norway". The study was carried out on behalf of the Confederation of Norwegian Enterprise (NHO), the Confederation of Trade Unions (LO), the United Federation of Trade Unions, the Federation of Norwegian Industries, the Norwegian Oil and Gas Association and the Industri Energi trade union.

- Read the full report here.

The objective of the study (assuming a commitment to large-scale CCS in Norway and subsequently in Europe and the international community) was to determine what opportunities large-scale CCS can present to Norway and Norwegian industrial operators. The study placed particular emphasis on potential value creation and employment.

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Industrial opportunities and employment prospect in large-scale CO_2 management in Norway had 576 views

NCCS PUBLICATIONS REGISTERED IN CRISTIN

(CURRENT RESEARCH INFORMATION SYSTEM IN NORWAY)

Peer reviewed Journal publications

Search criteria:

From: 2018 *sub-category:* Academic article *sub-category:* Academic literature review *sub-category:* Short communication *All publishing channels*

Aditya, Konduri; Gruber, Andrea; Xu, Chao; Lu, Tianfeng F.; Krisman, Alex; Bothien, Mirko R.; Chen, Jacqueline H..
Direct numerical simulation of flame stabilization assisted by autoignition in a reheat gas turbine combustor. *Proceedings of the Combustion Institute* 2018
ENERGISINT

Lavrov, Alexandre; Torsæter, Malin.
All microannuli are not created equal: Role of uncertainty and stochastic properties in well leakage prediction. *International Journal of Greenhouse Gas Control* 2018 ;Volume 79. p. 323-328
SINTEF

Møyner, Olav; Nilsen, Halvor Møll.
Multiresolution coupled vertical equilibrium model for fast flexible simulation of CO2 storage. *Computational Geosciences* 2018 p. 1-20
NTNU SINTEF

Polfus, Jonathan M.; Yang, Jing; Yildiz, Bilge.
Interplay between H2O and CO2 coadsorption and space-charge on Y-doped BaZrO3 surfaces. *Journal of Materials Chemistry A* 2018 ;Volume 6. p. 24823-24830
SINTEF

Polfus, Jonathan M.; Yildiz, Bilge; Tuller, Harry; Bredesen, Rune.
Adsorption of CO2 and Facile Carbonate Formation on BaZrO3 Surfaces. *Journal of Physical Chemistry C* 2018 ;Volume 122.(1) p. 307-314
SINTEF

Torsæter, Malin; Cerasi, Pierre.
Geological and geomechanical factors impacting loss of near-well permeability during CO2 injection. *International Journal of Greenhouse Gas Control* 2018 ;Volume 76. p. 193-199
SINTEF

Westman, Snorre Foss; Austegard, Anders; Stang, Hans Georg Jacob; Løvseth, Sigurd Weidemann.
Vapor-liquid equilibrium data for the carbon dioxide and carbon monoxide (CO2 + CO) system at the temperatures 253, 273, 283 and 298 K and pressures up to 13 MPa. *Fluid Phase Equilibria* 2018 ;Volume 473. p. 37-49
ENERGISINT

Yan, Hong; Dupuy, Bastien; Romdhane, Mohamed Anouar; Arntsen, Børge.
CO2 saturation estimates at Sleipner (North Sea) from seismic tomography and rock physics inversion. *Geophysical Prospecting* 2018
NTNU SINTEF

Presentations

Search criteria:

Main category: Conference lecture and academic presentation *All publishing channels*

Banet, Catherine.
Bioenergy with carbon capture and storage (Bio-CCS): moving from carbon neutrality to carbon negativity as a legal requirement.. Colloque INGILAW «Tempête sur la planète: penser le droit et les politiques de l'ingénierie climatique et environnementale à l'heure de l'anthropocène»; 2018-10-11 - 2018-10-12
UiO

Brunsvold, Amy.
NCCS, activities, plans, and collaboration. CO2lagringsforum; 2018-11-20
ENERGISINT

Brunsvold, Amy.
NCCS: Collaboration with the United States. US Norway Bilateral Meeting on CCS; 2018-05-02 - 2018-05-03
ENERGISINT

Brunsvold, Amy.
The Norwegian CCS Research Centre. Norwegian Oil and Gas; 2018-02-09
ENERGISINT

Brunsvold, Amy.
Welcome to the IEAGHGCCS Summer School: This is NCCS. IEAGHG; 2018-06-24
ENERGISINT

Brunsvold, Amy; Tangen, Grethe; Størset, Sigmund Østtveit; Dawson, James; Braathen, Alvar; Aarlien, Rune; Steenstrup, Anne; Mølnvik, Mona J..
The Norwegian CCS Research Centre (NCCS): Facilitating industry-driven innovation for fast-track CCS deployment. GHGT-14; 2018-10-22 - 2018-10-25
ENERGISINT NTNU SINTEF UiO

Buvik, Vanja; Knuutila, Hanna K.
Oxygen solubility in selected amine solvents. NCCS Webinar; 2018-11-21
NTNU

Buvik, Vanja; Knuutila, Hanna K.
Review of oxidative degradation of 30 wt. % MEA in pilot campaigns. University of Texas 4th Conference on Carbon Capture and Storage UTCCS-4; 2018-01-30 - 2018-01-31
NTNU

Cerasi, Pierre.
Migration pathways. IEAGHG Summer School; 2018-06-24 - 2018-06-29
SINTEF

Cerasi, Pierre; Lavrov, Alexandre; Torsæter, Malin; Ytrehus, Jan David; Taheri, Amir.
Enhancing CO2 well integrity by improving primary cement jobs. GHGT-14; 2018-10-23
NTNU SINTEF

Cerasi, Pierre; Stroisz, Anna Magdalena.
Laboratory testing of cement-rock bonding strength for improved well integrity. Interpore 2018; 2018-05-13 - 2018-05-17
SINTEF

Choi, Jung Chan; Skurtveit, Elin; Grande, Lars.
Prediction of leak-off pressure in Norwegian offshore using NPD factpages and deep neural network. International Symposium on Energy Geotechnics (SEG) 2018; 2018-09-25 - 2018-09-28
NGI

Deng, Han; Roussanaly, Simon; Skaugen, Geir.
Toward the identification of optimal conditions for transport of CO2 by ship: Part I - CO2 liquefaction. 14th Greenhouse Gas Technology Conference (GHGT-14); 2018-10-21 - 2018-10-25
ENERGISINT

Grimstad, Alv-Arne; Bergmo, Per Eirik Strand; Nilsen, Halvor Møll; Klemetsdal, Øystein.
CO2 storage with mobility control. GHGT-14; 2018-10-21 - 2018-10-25
NTNU SINTEF

Herrig, Stefan; Bell, Ian H.; Neumann, Tobias; Span, Roland.
An extended fundamental equation of state for thermodynamic properties of mixtures relevant for CCS-applications. Twentieth symposium on thermophysical properties; 2018-06-24 - 2018-06-29
NTNU

Løvseth, Sigurd Weidemann; Austegard, Anders; Stang, Hans Georg Jacob; Westman, Snorre Foss.
Accurate Phase Equilibrium Measurements for CCS Using an Analytical Method. Twentieth symposium on thermophysical properties; 2018-06-24 - 2018-06-29
ENERGISINT

Løvseth, Sigurd Weidemann; Westman, Snorre Foss; Austegard, Anders; Stang, Hans Georg Jacob.
Need and Measurements of Accurate Thermodynamic Data for CCS. Greenhouse Gas Control Technologies (GHGT-14); 2018-10-22 - 2018-10-25
ENERGISINT

Mulrooney, Mark Joseph; Osmond, Johnathon Lee; Skurtveit, Elin; Wu, Long; Braathen, Alvar.
Smeaheia, A Potential Northern North Sea CO2 Storage Site: Structural Description And De-Risking Strategies. Fifth CO2 Geological Storage Workshop; 2018-11-21 - 2018-11-23
UiO NGI

Munkejord, Svend Tollak.
CO2 Transport by pipeline. IEAGHG Summer School; 2018-06-25 - 2018-06-29
ENERGISINT

Mølnvik, Mona J..
CCS - innovasjoner og implementasjon i full skala. TEKNA CO2-konferansen 2018; 2018-01-17 - 2018-01-17
ENERGISINT

Mølnvik, Mona J..
Industrielle muligheter og arbeidsplasser ved storskala CO2-håndtering i Norge. Arendalsuka; 2018-08-13 - 2018-08-15
ENERGISINT

Mølnvik, Mona J..
NCCS - Norweigen CCS Research Centre - Industry-Driven Innovation for Fast-Track CCS Deployment. GHGT-14; 2018-11-21 - 2018-11-25
ENERGISINT

Neumann, Tobias; Herrig, Stefan; Span, Roland.
A New Fundamental Equation of State for the Binary Mixture of Carbon Dioxide and Argon. Twentieth symposium on thermophysical properties; 2018-06-24 - 2018-06-29
NTNU

Polfus, Jonathan M.; Yang, Jing; Tuller, Harry; Yildiz, Bilge; Bredesen, Rune.
Coadsorption of H2O and CO2 on BaZrO3-based proton-conducting electrolytes. International Conference on Inorganic Membranes; 2018-06-18 - 2018-06-22
SINTEF

Polfus, Jonathan M.; Yang, Jing; Tuller, Harry; Yildiz, Bilge; Bredesen, Rune.
Interplay between H2O/CO2 coadsorption and space-charge on Y-doped BaZrO3 surfaces. Workshop on Ion conducting ceramic electrochemical devices: how interfaces and surfaces affect performance and lifetime; 2018-04-19 - 2018-04-20
SINTEF

Rongved, Mats; Bauer, Andreas; Lavrov, Alexandre; Larsen, Idar; Lothe, Ane Elisabet; Cerasi, Pierre.
Along-fault permeability modelling with modified discrete element method(MDEM). CO2Geonet Open Forum; 2018-04-23 - 2018-04-25
NTNU SINTEF

Rongved, Mats; Delbar, Anthony; Cerasi, Pierre; Bauer, Andreas.
Modelling leakage risk along a fault using modified discrete elements. GHGT-14; 2018-10-22 - 2018-10-25
NTNU SINTEF

Skurtveit, Elin; Choi, Jung Chan; Mulrooney, Mark; Osmond, Johnathon Lee; Braathen, Alvar.
3D fault integrity screening for Smeaheia CO2 injection site. GHGT-14. International Conference on Greenhouse Gas Control Technologies; 2018-10-21 - 2018-10-26
NGI UiO

Skurtveit, Elin; Choi, Jung Chan; Osmond, Johnathon Lee; Mulrooney, Mark Joseph; Braathen, Alvar.
3D fault integrity screening for Smeaheia CO2 injection site. NCCS Webinar (results from task 9, Structural derisking); 2018-10-17 - 2018-10-17
NGI UiO

Skurtveit, Elin; Mulrooney, Mark; Osmond, Johnathon Lee; Choi, Jung Chan; Braathen, Alvar.
Structural derisking for Smeaheia - Improved fault characterization workflow. 3rd International Workshop on Offshore Geologic CO2 Storage May 3 - 4, 2018. Research Council of Norway Oslo, Norway; 2018-05-03 - 2018-05-04
NGI UiO

Størset, Sigmund Østtveit; Tangen, Grethe.
Profiting from CCS innovations: A study to measure potential value creation from CCS research and development. GHGT 14; 2018-10-22 - 2018-10-25
ENERGISINT

Todorovic, Jelena; Raphaug, Martin Hagen; Øia, Thomas; Grimstad, Alv-Arne; Cerasi, Pierre.
The effect of brine supply on CO2 injectivity impairment due to salt precipitation. GHGT-14; 2018-10-22 - 2018-10-25
SINTEF

Torsæter, Malin.
CCS in Norway and research in FME NCCS. UiO CCS course; 2018-06-05 - 2018-06-05
SINTEF

Torsæter, Malin.
CO2 Well Integrity Challenges and Relevant New Technology/ materials. CCS Miniseminar for OD og PTIL; 2018-08-30
SINTEF

Torsæter, Malin.
Effect of Intermittent CO2 injection on Well Integrity and Injectivity. IEAGHG-EERC Modelling and Risk Management Network Meeting 2018; 2018-06-18 - 2018-06-22
SINTEF

Torsæter, Malin.
FME NCCS som plattform for CCS FoU porteføljeutvikling. Møte i CLIMIT Programstyre; 2018-10-17
SINTEF

Torsæter, Malin.
WELLBORE INTEGRITY. IEAGHG Summer School; 2018-06-24 - 2018-06-29

Peer-reviewed papers

Search criteria:

sub-category: Academic chapter/article/Conference paper
All publishing channels

Gruben, Gaute; Dumoulin, Stephane; Nordhagen, Håkon Ottar; Hammer, Morten; Munkejord, Svend Tollak.
Simulation of a Full-Scale CO2 Fracture Propagation Test. I: *2018 12th International Pipeline Conference - IPC2018*. ASME Press 2018 ISBN 978-0-7918-5188-3. p. -
ENERGISINT SINTEF

Subagjo, Isa Adi; Dupuy, Bastien; Park, Joonsang; Romdhane, Mohamed Anouar; Querendez, Etor; Stovas, Alexey.
Joint Rock Physics Inversion of Seismic and Electromagnetic Data for CO2 Monitoring at Sleipner. I: *Proceedings 24th European Meeting of Environmental and Engineering Geophysics*. European Association of Geoscientists and Engineers 2018 ISBN 9789462822634. p. -
NGI NTNU SINTEF

Media contributions

Search criteria:

Main category: Media contribution *sub-category:* Popular scientific article *sub-category:* Interview Journal *sub-category:* Article in business/trade/industry journal *sub-category:* Sound material *All publishing channels*

Aarlien, Rune.
På sommerskole hos SINTEF for å løse utfordringer i verdensklasse. enerWe [Business/trade/industry journal] 2018-06-25
ENERGISINT

Aarlien, Rune.
2018 IEAGHG International CCS Summer School. International CCS Knowledge Centre [Internet] 2018-06-25
ENERGISINT

Bantle, Michael.
Wie CO2 unter den Ozean kommt – oder in die Kühltruhe. Badische-Zeitung [Business/trade/industry journal] 2018-06-11
ENERGISINT

Braathen, Alvar; Skurtveit, Elin.
Norges neste CO2-lager?. http://www.geoforskning.no/nyheter/klima-og-co2/1860-norges- [Internet] 2018-09-24
UiO

Brunsvold, Amy.
CO2-månelanding havnet i sement. Dagens Næringsliv [Newspaper] 2018-06-18
ENERGISINT

Brunsvold, Amy.
IEAGHG CCS International Summer School - Amy Brunsvold. YouTube [TV] 2018-06-27
ENERGISINT

Brunsvold, Amy.
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