ANNUAL REPORT 2021

NORWEGIAN CCS RESEARCH CENTRE

NCCS

The Norwegian CCS Research Centre (NCCS) is a Centre for Environment-friendly Energy Research (FME).

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 (e.g. in an underground geological formation) so that it will not enter the atmosphere. Meeting EU energy and climate targets in a cost-effective way, while ensuring that we still have enough energy to go around, cannot be achieved without CCS.

The Norwegian CCS Research Centre (NCCS) aims to fast-track CCS deployment by working closely with industry on research topics designed to address major barriers to implementing CCS in Norway, Europe, and the world. NCCS is a Centre for Environment-friendly Energy Research (FME).

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MESSAGE FROM **THE DIRECTOR**

For CCS and NCCS, 2021 has been a great year in many ways. Yet, there is still so much more that we need to do before we can claim that CCS is an effective climate mitigation measure. This feels like a big, big challenge.

The global perspective

In a global perspective, 2021 has seen climate change become more integrated in politics and business strategies. For example, the EU ETS price rose by EUR 50/tonne CO_2: increasing from EUR 30/tonne in January 2021 to 80 EUR/tonne a year later. In addition, the EU taxonomy has undergone significant developments; in December, the European Commission proposed a new EU framework to decarbonise gas markets, promote hydrogen, and reduce methane emissions. This suggestion was made to facilitate renewable hydrogen (from renewable electricity) and low-carbon hydrogen (from natural gas reforming with CCS), with the aim of transitioning to a renewable energy mix from 2030. In Norway, we are following the development of the *Langskip* (Longship) project as well as several other CCS-related initiatives in the process industry and the maritime sector.

NCCS matters

For NCCS, this year has been great. In the spring, we prepared for the FME midway evaluation. Thanks to dedicated efforts from all our partners, researchers, PhD students, professors, and the Research Council of Norway, we presented NCCS to a very competent and engaged international evaluation committee. The whole process, including the follow-up in the wake of the evaluation, gave new motivation and stimuli, particularly due to the positive feedback we received. Some highlights included:

- "NCCS is a successful and impressive FME."
- "With the success of its first four years, a positive Longship investment decision, an increase in interest in CCS around the globe, and a robust funding position, the Centre is in a strong position to consider a broader, more ambitious program for its remaining four years."
- "Collaboration with international research groups: This is clearly a strong point in the Centre."
- "The Centre has an engaged board, ably led by its Chair, Tord Lien, who, as a former Minister for Petroleum and Energy, brings an excellent background and connections to the role."

Our new strategy has several pillars: focusing on strengthening EU-involvement, realising NCCS innovations, strengthening the interaction between industry and research, and continuing to pursue spin-in projects. The latter will allow for more PhD students and new partners to join current and new topics, as well as spin-off opportunities. Examples of spin-off projects in 2021 include the Green Platform project LINCCS, the ACT project RETURN, and the Horizon 2020 project ACCSESS. In 2021, we also started a new spin-in project, the KSP CCShip.

@ COP26

An important objective for all FMEs is to contribute to the development of national climate and energy policies that are based in fact. In cooperation with the FMEs NorthWind, LowEmission and NTRANS, NCCS produced the report "The North Sea as a springboard for the green transition". This document, which forms the basis of our advice to politicians and decision-makers about the green transition in the North Sea, was presented at the 2021 United Nations Climate Change Conference (COP26) in Glasgow in November. Attendance at the Conference provided valuable contact points and input that were used to refine our international strategy.

NCCS keeps growing

Growth, through the generation of new activities and inclusion of new partners, has been a priority for NCCS since the beginning. So far, eight new KSP projects have been added to the Centre portfolio, generating NOK 80 million in new funding, and adding 10 PhD candidates and four postdoc researchers. In total, NCCS has so far recruited 27 PhD candidates, 11 postdoc researchers, and around 40 master's students. Moreover, during 2021 we prepared nine additional KSP project proposals to be submitted in early 2022, with a combined budget of NOK 100 million. More important than the extra millions of NOK is the possibility this gives us to accomplish more on the road to full-scale CCS implementation.

Dissemination activities

Despite the prevailing pandemic, dissemination activities took an upturn last year. We produced 54 peer-reviewed publications (up from 24 in 2020), and held 18 webinars with around 1,000 total participants. Our activities on social media have never been higher. Furthermore, the eleventh TCCS conference was successfully organized (for the first time as a digital event), with almost 400 participants.

Gender equality

Last, but definitely not least, we are proud to say that our continued efforts to achieve a gender balance have been fruitful. In 2021, there was a 100% increase in female presenters at the Consortium Days, 67% of candidates recruited were women (bringing the total up to 38%), and we had a new female task leader. Following the midway evaluation, we established a "gender balance task force", which will continue efforts to further improve the gender balance of all NCCS groups, committees and activities.

Needless to say, we are very much looking forward to the next three years!

Mona Mølnvik,
NCCS Centre Director

Tord Lien,
NCCS Board Chair

NCCS AND COVID-19

Despite everyone's hopes, the COVID-19 pandemic continued throughout 2021, with associated measures and restrictions implemented accordingly at various points throughout the year.

The Centre leadership has kept a constant eye on COVID-19 developments, and has developed new and efficient routines to avoid and manage disruptions in our daily operations accordingly. While the situation has led to changes in the way NCCS has worked, as well as some minor delays, research activities have largely gone as planned.

The laboratories have been open throughout the entire period, with the necessary routines introduced in order to uphold social distancing regulations. This has resulted in fewer delays occurring, and we will likely be able to make up for lost time. Partners have been kept informed on decisions through regular e-mails, and the positive feedback we have received indicates that this has been successful as a communication effort. We have also increased the frequency of internal newsletters, which has been similarly well received.

Like the rest of society, we have discontinued the vast majority of travel activities and relied on digital platforms for communication and meetings, such as Microsoft Teams. The FME structure means that remote meetings were already commonplace, but the coronavirus crisis forced our hand even further.

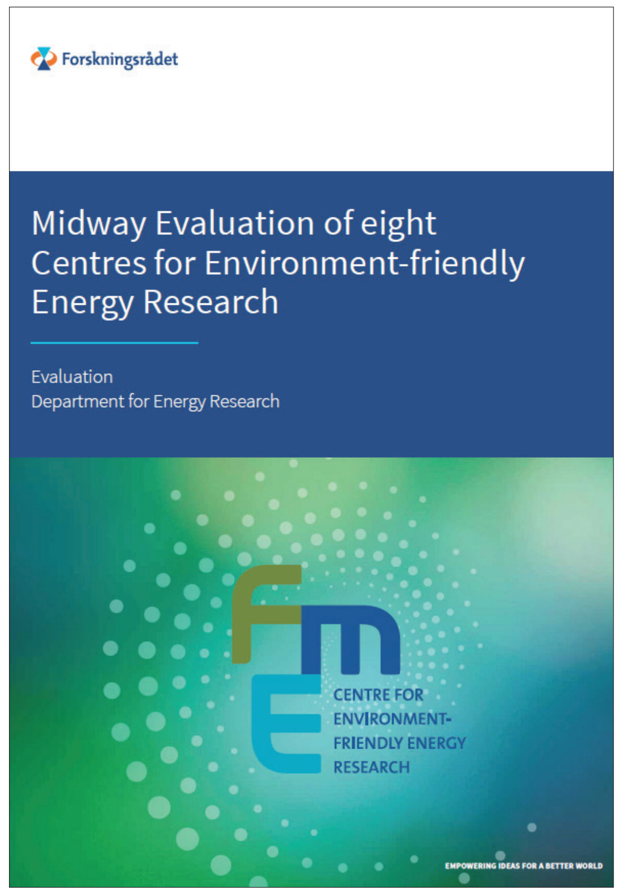
While we do miss the benefits that come from in-person meetings, and the learning curve has been steep at times, there have been benefits to the digital approach too. For example, the online TCCS-11 conference attracted a record number of international attendees, helping to expand the distribution of the Centre's research and results, and form new international connections without spending money on an expensive ticket to Trondheim. As a result, we will probably continue digital meetings to a greater degree in the future.

The COVID-19 situation appears to be improving, and we are hopeful that in 2022 we will be able to have more in-person meetings. However, we have also established the processes, tools and competence necessary to continue operations and producing results, no matter what lies ahead.

Amy Brunsvold
NCCS Centre Manager

SELECTED HIGHLIGHTS FROM **2021**

2021 has been an eventful year for the planet, with climate change, recessions and an ongoing pandemic. However, it has also been an eventful year for NCCS, and though the Centre has faced (and continues to face) challenges and minor setbacks, that does not mean we have nothing to celebrate.



MIDWAY EVALUATION

After months of preparation, NCCS underwent its midway evaluation in May 2021. In June, we found out that the Centre had successfully passed the evaluation, and was deemed a "successful and impressive FME". This means that NCCS will be granted funding for the remaining three years without any further requirements for corrective measures.

While this is a very positive and motivating message, the NCCS Board, committees, and Operation Centre will use the valuable feedback from this evaluation to further develop and expand the Centre. There is an urgent need to scale CCS up from millions of tons of CO_2 stored today to the billions needed to be stored in 2050, less than 30 years from now.

TCCS-11

The bi-annual Trondheim CCS Conference (TCCS) series is one of the leading scientific CCS technology conferences in the world, with the objective of progressing, presenting and discussing the current work being done by R&D institutions and universities and in industry.

In June 2021, the eyes of the world fell on Norway for the 11^{th} conference in this series (TCCS-11). More than 350 researchers, industry professionals and students gathered online to discuss the latest research findings and upcoming scientific challenges related to scaling CCS technologies. A total of 22 plenary talks, 93 presentations across five parallel technical sessions and 24 poster presentations gave participants plenty to discuss.

Erna Solberg gave the opening comments at TCCS-11.

Commitment from the top in Norway

TCCS-11 was opened by the Norwegian prime minister at the time, Erna Solberg. She set the conference in context, talking about the Norwegian government's backing for CCS in the form of projects such as Longship. The funding will see the establishment of a full-scale CCS implementation in Norway.

"Longship has had a promising departure and voyage so far, but we have not reached the destination yet. If carbon capture and storage is to become an efficient climate policy instrument, subsequent facilities must be established in Europe and globally, and it must be done now. The critical mass of CCS needs to be achieved within this decade," she said.

Honouring a long-term commitment to CCS research

Professor Marco Mazzotti from ETH Zürich was awarded *the SINTEF and NTNU CCS Award* at the conference. He has long been at the forefront of international CCS research, and according to SINTEF's Nils Røkke (the Conference Chair), the award committee received letters of recommendation from universities, institutes and industry from all over the world.

Professor Mazzotti was thrilled with the recognition, especially as it came from a community for which he holds a lot of respect. The following day, he gave the award winner's lecture, which focused on specific measures for the decarbonisation of Switzerland. He encouraged CO_2 capture for small organisations.

A focus on the next generation

The online format gave students from around the world the opportunity to network with leading researchers and industrial players, without an expensive trip to Trondheim. NTNU Professor Hanna Knuutila (Chair of the Scientific Committee) spoke of how the future of CO_2 capture, transport and storage is going to look very different, with multiple inputs and outputs: "I believe we need technology professionals who can see all these connections and can collaborate across disciplines. They need to be able to design tailored systems with location-specific solutions." She went on to praise industry involvement in CCS education to date, while urging industrial partners to make sure this continues. "They have provided open-ended, real-life problems, guest lectures, hosted student group visits, summer schools and open conferences."

In keeping with the message, PhD students received a subsidised registration fee, while master's students were able to attend completely free of charge thanks to the support of the TCCS-11 sponsors: Research Council of Norway / CLIMIT, Gassnova, TotalEnergies, CO_2 Technology Centre Mongstad, Equinor, Vår Energi, ECCSEL ERIC and Air Liquide.

Inspired by previous discussions on whether CCS has a branding problem, participants also discussed the future of CCS in the context of communication. A panel composed of the Council for a New Economy's Torund Brhyn, the Great Plains Institute's Brad Crabtree, and SINTEF Energy Research's Anne Steenstrup-Duch addressed the importance of language in how we communicate CCS to different target groups, including industry, media, politicians and decision-makers, and the general public.

The online format works

While virtual conferences during the pandemic were nothing new, it was the first external conference hosted by NCCS to be held online. Building on a successful webinar series in 2020, TCCS-11 attracted researchers, professionals and students from all over the world, many taking part of the first time. 28 countries were represented among the participants, a new record for TCCS.

As an indication of how keen the global CCS community was to take part in the discussions, several participants joined live in the middle of the night, including several US-based speakers. Among others, Sir Robert Watson set the scene for CCS from a biodiversity perspective with a powerful keynote, while Curtis M. Oldenburg discussed intermittent CO_2 transport. The online format also enabled participants to review all the plenary sessions, presentations, and poster sessions online. This will prove especially useful for technical sessions that were held in parallel.

The importance of the overall CCS value chain

SINTEF Energy Research's Mona Mølnvik closed the conference by summing up her learnings from the event. She said that "upscaling is of the upmost importance to get the costs down," but that it must be done separately for the capture, transport and storage elements of CCS. Yet at the same time, it is critical to not lose sight of demonstrating the worth of the overall value chain.

She also suggested adding the challenges of providing more CCS experts, the impact on biodiversity and communicating CCS to the established 'CCS barriers' of cost, risk and scaling.

NCCS CONSORTIUM DAYS 2021

In November 2021, the NCCS consortium was able to meet in person for the first time in two years for its annual Consortium Days event. Held at Trondheim's

Britannia Hotel, the event attracted almost 80 research scientists, industrial experts and leaders, university professors and PhD students to share the latest technical knowledge and developments from within the Centre, and plan for the coming years. Several more joined online.

Aage Stangeland, special adviser at the Research Council of Norway, said that gathering in person "makes a real difference" for the momentum of the Centre: "With so many good activities and new projects coming out of NCCS, this was an important time to gather. Online meetings have allowed research to continue as planned, but there is so much added value when discussing issues face-to-face."

A timely climate reminder

NCCS Consortium Days coincided with the second half of COP26. SINTEF's Nils Røkke joined via video link from Glasgow shortly after representing NCCS on a panel discussion – together with Norway's new Minister for Climate and Environment Espen Barth Eide – about the North Sea's role in the green transition.

It was a timely reminder of the importance and relevance of NCCS research for the climate solutions of tomorrow that are needed today. Røkke made it crystal clear: "When you do the maths, there's no way we can avoid CCS".

NTNU Adjunct Professor Philip Ringrose from Equinor, chair of the NCCS Scientific Committee, challenges a speaker to elaborate on the value of the research result.

SINTEF's Nils Røkke joined NCCS Consortium Days via video link from COP26 in Glasgow.

Collaboration at the heart of NCCS

An underlying theme of the event was the importance of collaboration between industry and research, as well as across borders, in order to fast-track the development of CCS. Many discussions took place about, for example, how to best accelerate the process from PhD research to industry solutions.

The event was an opportunity for NCCS-funded PhD students to meet with the industry representatives who are interested in their findings. In addition, it gave students who are normally laser-focused on a specific area the opportunity to network with others from along the CCS chain.

Mona Mølnvik was thrilled to see so many people in person, and looks forward to the opportunities it should create over the coming years: "NCCS is about far more than the research we do. It's also about the platform we create. Such connections and discussions identify challenges and potential routes forward that lead to new projects and benefit all partners in the long run."

Many new projects were announced including the Aker Solutions-led Green Platform project Carbon Links (LINCCS), supported by The Research Council of Norway, Innovation Norway, and SIVA. It was born out of a collaboration between NCCS and the LowEmission research centre, and developed during a few weeks in spring 2021. Also announced at Consortium Days, the return of the NCCS Mobility Program brings yet more opportunities for innovation networking, knowledge sharing and dissemination between NCCS partners and across international borders.

NCCS Consortium Days: The PhD perspective

At the NCCS Consortium Days, we got to ask four NCCS PhD students what they thought of the Consortium Days event.

Question: What do you think about NCCS Consortium Days?

"It's really nice to be part of a project like NCCS, where you can actually step back and see the whole thing in itself, like the system, and how it all links together – people here are doing things like pipe fracturing, which I never have to think about. I think NCCS is a very ambitious project, and it seems to all be coming together."

Siân Evans
Postdoctoral researcher in the Department of Geosciences at the University of Oslo

"You get these new perspectives on what other people are doing for this common goal – and what it takes to reach this goal. So, [NCCS Consortium Days] have always made me aware of so many things which need to be developed, and so many tools we need. Although the topics rarely touched upon my day-to-day research, like the next day I went to my desk and tried it out, what I've always taken out of these meetings was a motivation for my work."

Tobias Neumann
Joint PhD candidate at the Norwegian University of Science and Technology and Ruhr University Bochum

I really like [NCCS Consortium Days]. I tend to just focus on my own research, just my own problems and it's very narrow, and I like that if you come here, there's all these different aspects that somehow all tie together. And if you have conversations with different people in different subjects, they help give me new insights because they ask different questions. It helps me look at my own problems from a different angle – and that really helps.

Lucas Braakhuis
PhD candidate in the Department of Chemical Engineering at the Norwegian University of Science and Technology

"The NCCS Consortium Days 2021 were the first consortium days that I attended. For me, as a new PhD student in NCCS Task 9, I found it very interesting to see all the different types of research that are involved in NCCS. I also enjoyed talking to people from the different NCCS tasks and getting a better understanding of the work that they do."

Nora Holden
PhD candidate in the Department of Geosciences at the University of Oslo

THE NEXT STEPS FOR NCCS

One of the recommendations given by the Research Council of Norway was to lay down a plan for how the platform created by NCCS can continue after the current FME period ends in 2024. As part of the Consortium Days, a workshop was held wherein all partners and stakeholders had their say in the work of the Centre for the next three years and beyond.

There is no question that CCS is extremely relevant – not just for Norway, but also for Europe and the rest of the world. However, the consortium pointed out that to fully exploit the potential of CCS, it needs to continue to be developed and upscaled.

Scaling up CCS for different markets

One of the biggest barriers to CCS development identified by the consortium was that of technology. In order to fully realise all of CCS' potential applications, we need more technology and expertise.

For example, the natural gas captured by CCS can be used to create "blue hydrogen" and ammonia, which do not produce CO_2 when burned, and can act as carbon-neutral alternatives to fossil fuels.

In addition, future developments such as onshore storage could make CCS more applicable for landlocked countries such as Switzerland or Austria, while direct air capture (DAC) would enable us to extract CO_2 from the air.

NCCS is already involved in a variety of research areas related to CO_2, from thermodynamics to computational fluid dynamics (CFD) and process and gas technologies. If we are to continue our research – in other words, if we are to develop innovations that can be put into practice – we need more resources.

A fleet of longships

According to the IEA, in 2021, heavy industry was responsible for nearly 20% of global CO_2 emissions. By incorporating CCS into industrial value chains, it can be a powerful tool for decarbonising industry – even industries that have traditionally resisted carbon neutrality, such as waste-to-energy (WtE) and cement.

Therefore, partnerships with industry benefit all parties, as NCCS receives resources for CCS research in the form of funding, data and experiments, while industry receives expertise that enables them to implement CCS quickly, thereby having an immediate and significant impact on our current emissions.

A key example of this is the Longship project, which will implement CCS at both Norcem's cement factory in Brevik and Fortum Oslo Varme's waste-to-energy plant in Oslo. The carbon emissions collected from these places will then be transported and stored underground off the west Norwegian coast. Transport and storage will be overseen by the Northern Lights project.

NCCS plays a significant role in this project, with contributions along the entire CCS value chain. However, while one Longship project is an excellent start, we need many more.

The role of communication, dissemination and outreach

The consortium agreed that more could be done to communicate NCCS' work and the importance of CCS in general, and discussed methods such as scientific publications, conferences, media workshops, websites, and educational materials.

While communicating NCCS' work to industry and politicians is important, the consortium felt that more needs to be done to communicate with the public in order to increase the social acceptance of CCS. This can be done by presenting CCS in an easy-to-understand manner and addressing associated concerns, such as unions worried about losing work or the cost of implementing CCS on the general public.

Communicating work to the wider public not only creates an understanding of the work, but it can also result in people putting pressure on governments and incentivising more industries to adopt CCS.

Since its inception, NCCS has adopted a dissemination and communication approach that has sought to both share knowledge with relevant stakeholders and build public acceptance. In addition to continuing our current communication methods, NCCS hopes to focus on more on outreach and visibility.

The road to 2024

Preparing for our midway evaluation has enabled us to reflect on everything this Centre has achieved in its five years of life so far. Now that we're past the midway point, we are looking forward to everything that NCCS is yet to achieve.

"By the end of the Centre, I hope to see NCCS innovations implemented by industry, taking us closer to CCS implementations at scale," said Aage Stangeland.

Aage Stangeland (Research Council of Norway) and Mona Mølnvik (NCCS Centre Director).

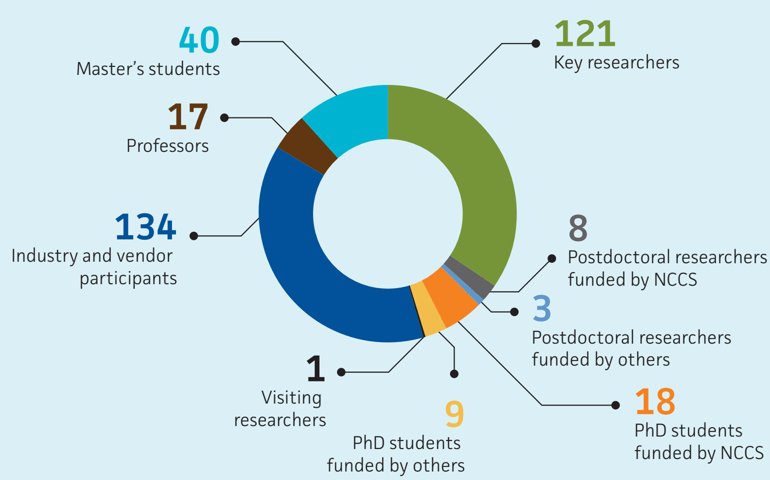
NCCS
BY NUMBERS

31 PARTNERS

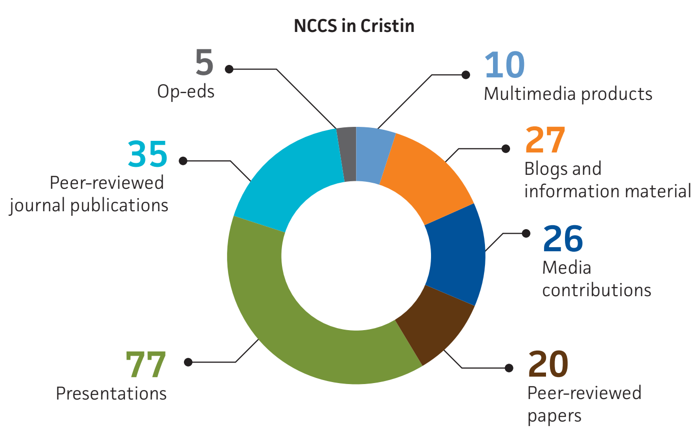
8 YEARS

465 MNOK

People (2017-2021)



Communication and dissemination 2021*



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

VISION AND GOALS

NCCS is a world-class national and international multi-disciplinary CCS partnership between operators, vendors and academia, which have united to address one of the greatest challenges of our time: climate change. Fast-tracking CCS deployment enables capacity to be built to capture, transport and store billions of tons of CO_2.

Goals

NCCS' overall objective is to fast-track CCS deployment through industry-driven, science-based innovation, addressing the major barriers identified in demonstration and industry projects, and thereby become a world-leading CCS centre.

NCCS adopts dynamic, forward-looking approaches 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 NOK 50,000 billion profitable business.

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.

Scientific objective

To 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 objectives

- To fulfil the commercial ambitions and needs of industry and society, while maximizing innovation in deployment cases.
- To establish a targeted spin-off programme for the execution phase of innovation processes and their faster adoption.
- To establish new research projects within topics where knowledge gaps are identified.

Recruitment objectives

Recruit and educate young people, reflecting gender balance and equal opportunities, with first- class competence in CCS-related topics 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.

NCCS IN A NUTSHELL

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

Fast-tracking CCS is a joint effort. NCCS is a collaborative project between 34 partners in industry, research institutes and other organisations, in 10 countries and on three continents. The Centre also has six associated partners, and is led by SINTEF Energy Research in Trondheim, Norway.

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 and contribute to the development of the work plans and in the research activities. Research is organised in 12 tasks covering 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. Efforts have been made to ensure ongoing dialogue with the Norwegian full-scale project, now known as Longship.

New partners in 2021

All NCCS partners continue to make important contributions to our research. Thank you to all!

In 2021, we were delighted to welcome Fortum Oslo Varme as our latest NCCS partner. We continue to look for new partners to join our mission to fast-track CCS deployment through industry-driven, science-based innovation.

Gender balance

NCCS aims for equal opportunities and gender balance at all levels of the Centre's organisation, and encourages all partners to collectively achieve the EU target of recruiting at least 40% female staff in scientific positions. The academic partners encourage female applicants through open announcements, thus striving for gender balance when employing PhD candidates and Postdocs.

Following the Centre's midway evaluation, NCCS has concentrated on improving the gender balance of all groups and committees as well as the board. As part of this work, a "gender balance task force" has been established, which is led by NCCS Centre Manager Amy Brunsvold and board members Jim Stian Olsen (Aker Carbon Capture) and Gertrud Halset (Vår Energi). The task force started in December 2021.

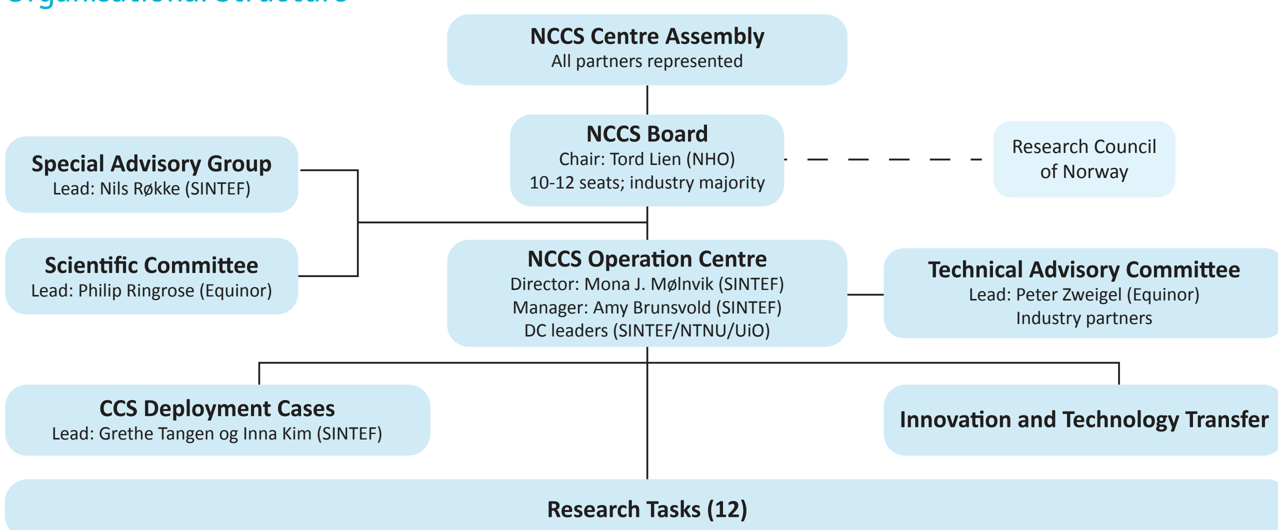
In addition, NCCS made several other improvements to the Centre's gender balance:

- The proportion of female candidates recruited to the academic programme increased from 50% in 2020 to 67%. Women now make up 38% of the academic programme.
- The number of presentations held by women at the Consortium Days increased by 100%.

As of December 2021, the Operations Centre is composed of five women and one man. A new task leader started her position in 2021, resulting in four female task leaders and eight male task leaders. Women comprised 41% of the PhD students and Postdoc researchers at NCCS in 2021.

ORGANISATION

Organisational Structure



Partners

RESEARCH PARTNERS

Norges Geotekniske Institutt

Norwegian University of Science and Technology

Ruhr – Universität Bochum

University Centre in Svalbard

University of Zürich

TNO

Technische Universität Munchen

SINTEF
SINTEF Energy Research
SINTEF Industry

The University of Western Australia

University of Oslo

INDUSTRY AND VENDOR PARTNERS

Equinor

Gassco

TOTAL Energy

Norsk Olje og Gass

Quad Geometrics

Aker Carbon Capture

Larvik Shipping

Ansaldo

Krohne

CoorsTek

NORCEM

Oslo Kommune, gjenvinningsetaten

Lundin Norway

Vår Energi

Baker Hughes

Allton

Stratum Reservoir

Fortum Oslo Varme

ASSOCIATED PARTNERS

ECCSEL

US Department of Energy

UKCCS

Scottish Carbon Capture & Storage

Lawrence Livermore National Laboratory

Sandia

Massachusetts Institute of Technology

Scientific Committee (SC)

The NCCS Scientific Committee comprises eight members from leading academic institutions in the fields of CO_2 capture, transport and storage. Its mandate is to guide the scientific progress of the Centre and to comment on the overall scientific focus and direction of NCCS.

Chaired by Prof. Philip Ringrose, NTNU & Equinor, Norway, the SC is composed of: Prof. Marco Mazzotti, ETH Zurich, Switzerland; Dr. Curtis M. Oldenburg, Lawrence Berkeley National Laboratory, USA; Prof. Martin Trusler, Imperial College London, UK; Prof. Sally Benson, Stanford University, USA; Dr. Tip Meckel, University of Texas at Austin, USA; Dr. Ziqiu Xue, RITE Research Centre, Japan.

Technical Advisory Committee (TAC)

The Technical Advisory Committee (TAC) is a body of NCCS' governance structure with the main task to advice the Board on matters of special interest for the industry partners. Every industry partner has a representative in the TAC, and it is led by one of the industry partners (Equinor).

The main input of the TAC has been three-fold:

- Key contributor to the phase-gating process, where achievements so far are evaluated and input is given about which topics should be prioritized in future work. This has resulted in changes in scope and budget allocations for various tasks.
- Quality control, particularly with respect to industrial relevance, should be visible in the Annual Work Plans (AWPs) of the technical tasks.
- Advice to the Board on the use of unallocated industrial funds. These funds have so far mainly been used to co-fund research projects largely funded by the Research Council of Norway, which complement research carried out in the NCCS tasks.

The TAC has an ambition to increase its activities to ensure even more industrial relevance of the research carried out. NCCS has already developed some promising technologies, but typically to low TRL levels. One important task for the TAC is to advise on paths for maturation of selected technologies to higher TRL levels, with the goal to implement these technologies at industrial scale. Industrial application of knowledge and products developed in the Centre is at the core of NCCS' contribution to the energy transition. Industry partners have a strong interest – and responsibility – to support this important contribution.

The Special Advisory Group (SAG)

The Special Advisory Group (SAG) advises the NCCS Board on strategic issues, such as trends and new developments, and contributes to positioning the Centre globally.

In 2021, SAG consisted of the following experts: Hans Jørgen Vinje (Gassnova), Kelly Tambimuhtu (IEA Greenhouse Gas Programme), Karen Westley (Shell), John Kristian Økland (Gassco), Niall McDowell (Imperial College London), Katherine Romanak (University of Texas, Austin), Brent Jacobs (CCS Knowledge Center), Brad Page (GCCSI), Edoardo Dellarole (Vår Energi AS / Eni SpA), Marie Bysveen (SINTEF / EERA), and Nils Røkke (SINTEF), who is the Chair.

RESEARCH PLAN

With an eye to the future, NCCS crafted a forward-looking vision, knowing that we must be prepared to adapt and change. NCCS had high ambitions to be dynamic and flexible when the proposal was written and these ambitions have not changed.

NCCS has proven itself to be dynamic and has certainly adapted to the CCS world around us and has even expanded. The scientific tasks have been assessed and reviewed yearly, with the industry partners having a key role in decisions at each gate review. NCCS has used 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 are reviewed and revised by our partners in order to set the direction required to advance technologies to a higher Technology Readiness Level (TRL).

Research contributes to advancing the 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 allows for quantification, thereby resulting in 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 also plays 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 to enable NCCS 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, carefully chosen PhD topics are tightly integrated in Centre activities.

IMPACT OF
NCCS INNOVATIONS

The value of innovations

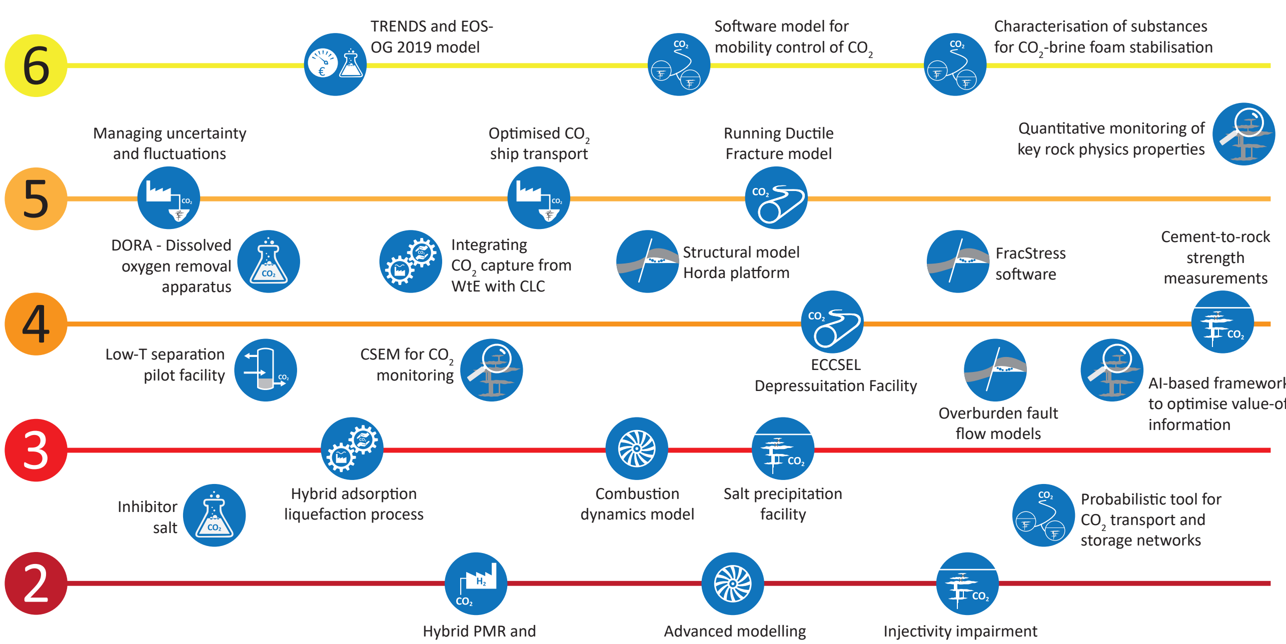
NCCS defines “innovation” as a product, a technology, a component, a process, a model, a concept, an experimental rig, or a service that is new or significantly improved with respect to properties, technical specifications or ease of use.

Through innovations, NCCS contributes to emissions reduction, economic activity (increased value creation, saved costs), improved decision making, saved energy, and industrial potential.

How innovations are developed

Maximising impact from our research is an important task for NCCS. One way that the Centre does this is through the development of numerous possible routes for the commercialisation of core research: from a single player, via a joint venture, to broad implementation for several stakeholders or markets.

Therefore, according to the “open innovation” model, commercialisation requires a IP strategy to maximise value creation for each company involved. NCCS aims to disseminate results among partners wherever possible, and secure IP rights for each partner where necessary.



In 2021, NCCS identified and described the 30 innovations being developed by the Centre so far as part of its work with developing an innovations catalogue. This catalogue will be published in 2022.

We have included two examples of these innovations below:

Task 9: Software for quick screening of critically oriented faults: FracStress

The challenge

Recent work on CO_2 storage sites has identified geomechancial characterisation as a key for safe storage development and maximize injection volume. Geomechanical analysis should be performed at an early stage of site evaluation, but current methods do requires many detailed parameters that may not be available.

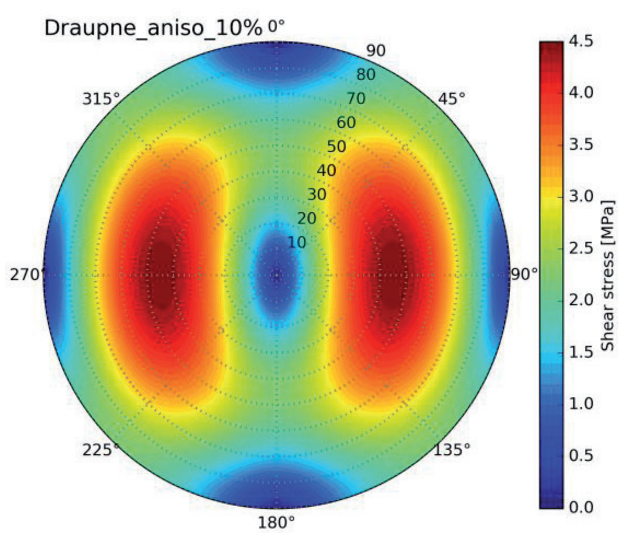


Figure showing example from the FracStress program plotting shear stress for various fracture orientaitons

The innovation (TRL 4)

FracStress, which is a program that can interpret a stress acting on fracture, have been developed in Task 9. The frac stress is a tool that can quickly identify stresses acting on fracture surfaces and screen critically oriented fractures or faults in subsurface. The tool is integrated as part of NGI workflow for defining correct stress conditions for Direct Shear Test on pre-defined fractures and slip surfaces. The tool provides easy overview of the relationship between stress condition, fault orientation and fault strength. The work provides the first step towards an improved workflow for fault slip stability screening. New detailed data on rock mechanical testing and output from 3D geomechanical models provide useful information on stress path, stress rotation and anisisotropy effects, that could be utilized for implementation in screening tools. This can improve the simple screening tools for fault stability evaluation.

Next steps

- Adding new features to the FracStress tool including: uncertainty, stress path/changes, anisotropy
- Demonstrate the tool on relevant cases

Task 12: Value-of-information-based framework for cost-effective monitoring

The challenge

Reliable CO_2 monitoring is a necessity for safe CO_2 storage, but can also potentially be very expensive. There is a need for development and demonstration of monitoring technology that enables safe operation in compliance with laws and regulations in the most cost-efficient manner. Specifically, optimisation techniques that help operators acquire the minimum amount of data required to safely and predictably perform the CO_2 storage operation should be developed.

The innovation (TRL 3)

SINTEF and NTNU have developed a framework for evaluating the Value-of-Information when gathering geophysical data for storage conformance/containment verification. The approach is based on integrating reservoir modelling, geophysical monitoring, and decision-making theory. This innovation is a first step towards a novel machine learning-based technique to support decision-making processes related to cost-efficient monitoring, measurement and verification (MMV). It is expected that any operator interested in improved (and automatised) support for decision making could benefit from this innovation. It directly targets both cost-efficiency and safety, and will most likely be even more relevant for large-scale storage and monitoring.

Next steps

- Investigate the generalisation of the method to more realistic situations, addressing various data type, as well as the frequency (in time) and sparsity (in space) of data acquisition.
- Model the value using monetary units and evaluate the performance of various machine learning approaches.
- Develop a software prototype based on the proposed framework.

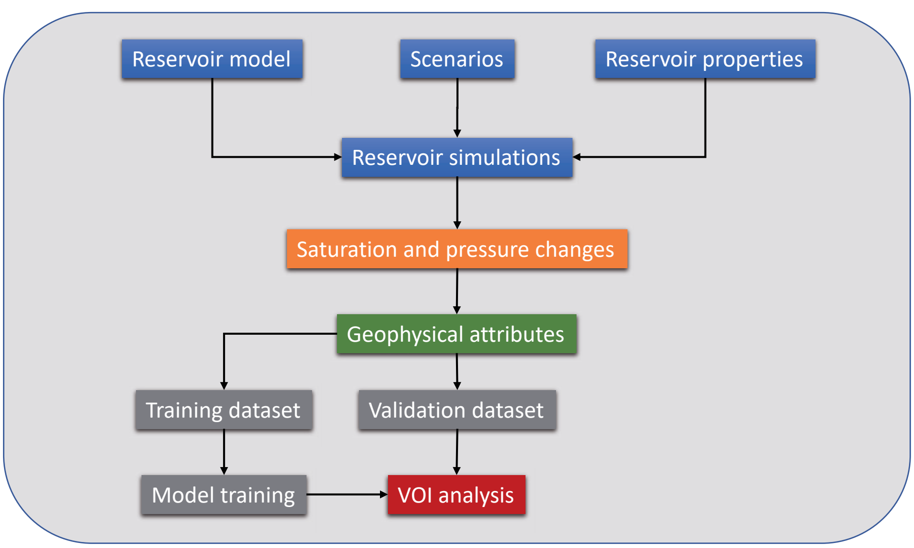


Figure showing the workflow of a Value-of-Information assessment using machine learning.

RESULTS FROM **RESEARCH TASKS**

Research in NCCS addresses challenges critical to realization of two Deployment Cases: CCS for Norwegian Industry, and Storage of Europe's CO_2 in the North Sea. The work is organised in 12 tasks, spanning the entire CCS value chain. An extra activity, Innovation and Technology Transfer, serves all 12 research tasks. In addition, as of 2021, there are eight spin-off projects associated with the Centre.

NCCS includes a comprehensive education program with fellows integrated into the Centre'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 2021.

TASK 1

This Task seeks to demonstrate the importance of CCS for decarbonising the energy and industrial sector in order to reach the goals of the Paris Agreement. 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 facilitate a faster and cheaper deployment of CCS technology.

www.sintef.no/NCCST1

Task leader:
Simon Roussanaly

The CO_2 value chain and legal aspects (Task 1)

Enabling cost-efficient implementation of CCS clusters

CCS from industrial clusters and multi-source industrial sites has been identified as a key opportunity to facilitate large-scale and cost-efficient CCS implentation. While these cases could present opportunities to reduce costs compared to stand-alone implementation, significant efforts are required to identify the best clustering strategies.

As multiple options for pooling, capturing and conditioning these CO_2 emissions can be considered, we have developed a model for planning and evaluating different strategies that could be implemented in an industrial cluster. The model allows us to assess the technical and cost characteristics of a clustering facility with an accuracy very close to that of a detailed evaluation. However, this model can perform such an evaluation in a matter of seconds or minutes, compared to the days or weeks that are needed for detailed evaluations. As a result, comparing multiple strategies (as for example illustrated in Figure 1) becomes a more manageable and accessible way of finding the most cost-efficient strategy for implementing CO_2 capture and conditioning in an industrial cluster. In 2021, this model was used to compare clustering strategies from a real industrial cluster, and in 2022, it will support the establishment of general guidelines for clustering CO_2 emissions.

How much can novel sorbents reduce the cost of post-combustion CO_2 capture?

The cost of CO_2 capture is a key driver of the cost of CCS, and, as a result, many emerging technologies are being developed to reduce this cost compared to

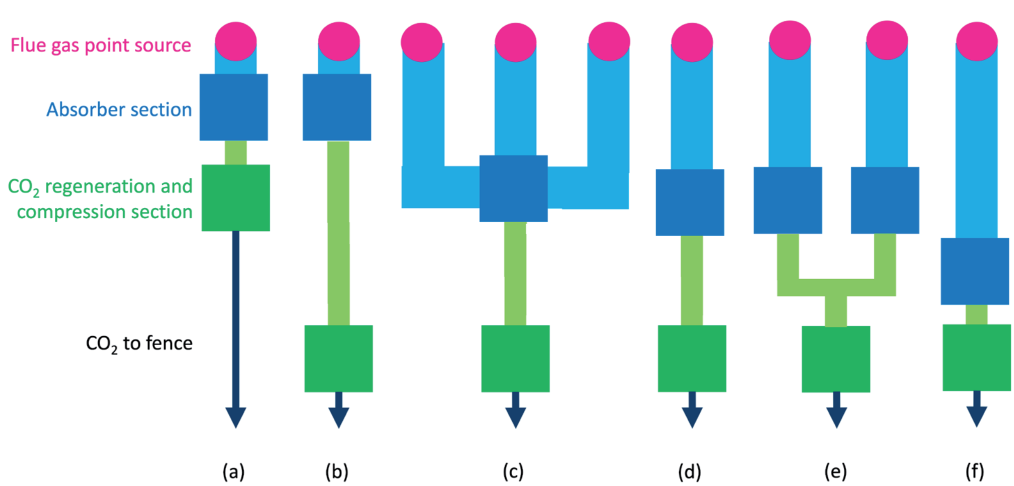


Figure 1: Illustration of different layout alternatives that could be considered for industrial clusters.

absorption-based CO_2 capture. One of these promising approaches is adsorption-based capture.

One of the main drivers of energy and cost performances of adsorption processes is the choice of adsorbents. Recent developments in material science have enabled material chemists to discover several new classes of adsorbents, such as metal-organic frameworks (MOFs), covalent-organic frameworks (COFs), etc., which can be highly tuned for CO_2 capture applications. However, not all of these possible materials result in significant cost reduction. To better understand the potential of sorbent development for reducing costs, we worked with the University of Alberta (Canada) to evaluate the lowest cost that can be achieved by adsorption-based technology for different industrial applications, as well as how this cost compared to the cost of adsorption that is based on already commercial sorbents.

The results showed that pressure-swing adsorption could only be cost attractive compared to solvent-based capture for industrial applications with high CO_2 concentrations. The results also showed that sorbents with CO_2 affinities that are close to zero are ideal for significantly reducing costs compared to commercial ones. Finally, it is important to emphasise that the optimisation of both the particle morphology and the process conditions are required.

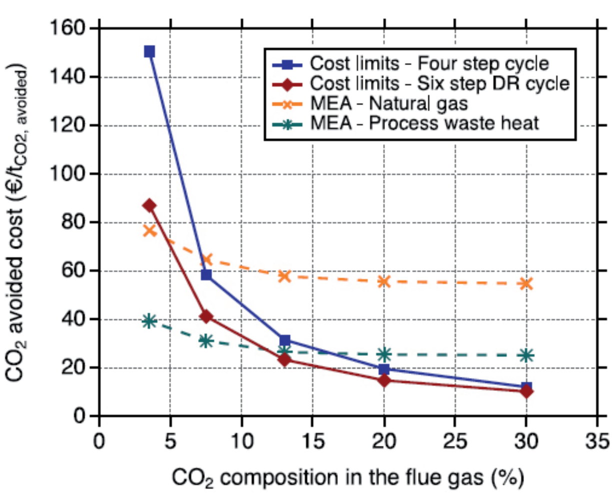


Figure 2: Comparison of the cost limits (lowest cost achievable) of both four-step and six-step DR PVSA cycles, with CO_2 avoided costs obtained using MEA-based CO_2 capture with two steam supply scenarios (natural gas boiler and waste heat recovery). CO_2 avoided costs reported here exclude CO_2 conditioning, transport and storage.

TASK 2

This Task addresses the challenges related to solvent technology, with a focus on environmental issues. We work to better understand the degradation of solvents by investigating which factors have the highest impact on the stability of amines (organic compound derived from ammonia), which are used to capture CO_2 from various flue gas sources. The work also helps to reduce the operational- and investment costs by indicating amines with a higher stability, and developing technologies to control and monitor solvent stability. Higher solvent stability means reduced costs, reduced emissions, an improved lifetime of both materials and solvents, improved safety for employees and a reduced environmental impact.

www.sintef.no/NCCST2

Task leader:
Solrun Johanne Vevelstad

Solvent technology – environmental issues (Task 2)

Solvent management by using degradation mitigation technologies

As solvent degradation leads to increased capture cost and environmental issues, several different mitigation technologies are being studied. In 2021, the technology readiness for the three degradation mitigation technologies has been increased.

For example in 2021, the dissolved oxygen removal apparatus (DORA) was successfully tested at TRL-level 4, using TNO's ODIN (Oxygen Depletion Installation) for the dense layer membrane. DORA was tested for both MEA and CESAR 1, and oxygen removal was achieved in both solvents. DORA operates using a porous membrane, and the skid design for testing (skid design and start of construction) at Waste-to-Energy plant in the Netherlands is ready. The skid construction is on-going and the test itself will start in early 2022 (successful testing will result in TRL 7). The results for the dense layer at TRL 4 and porous membrane at TRL 6 were presented in a paper in the International Journal of Greenhouse Gas Control.

Furthermore, the proof-of-concept of in-situ iron removal was also achieved in 2021, and the patent was filled. As iron is believed to have an essential role in accelerating solvents' degradation, removing it could significantly reduce solvent loss.

Finally, the work with the oxidative degradation inhibitor continued in 2021. The results from the small-scale lab experiments performed in 2020 were published in *Chemical Engineering Science*. The inhibitor was also tested in a circulative solvent degradation rig in order to understand how well the inhibitor performs in more realistic process conditions and raise the concept to TRL-level 3. The test campaign showed slightly less amine loss at standard operating conditions than the non-inhibited campaign. However, the inhibitor influenced the degradation mechanism, reducing the formation of some degradation compounds while others increased. An evaluation will be performed in 2022 to identify any operating windows where the inhibitor performs well. The results from this evaluation will decide if the developed salt concept should be taken to a pilot scale.

Understanding of solvent degradation

This is an ongoing work that resulted in several scientific publications in 2021. The findings related to the impact of the amine's structural feature on oxidative degradation were presented in *Industrial & Engineering Chemistry Research*. The work showed that steric effects play a large role in stabilising the amines under oxidative conditions, and carbamate formation plays a vital part in the degradation pathway of some solvents.

A review paper on the pilot plant testing of amine solvents for post-combustion CO_2 capture was published in the *International Journal of Greenhouse Gas Control 2021* (accepted for publication in 2020). It summarised the lessons learned in different pilot campaigns and provided recommendations on how solvent stability and emissions can be monitored and assessed.

Models to predict solvent degradation are needed in order to understand how different process conditions influence solvent degradation. Furthermore, degradation models could support and, to some extent, replace time-consuming and costly degradation experiments. Literature data was used to develop a thermal degradation model, describing the typical reactions that occur in the desorber for 2-ethanolamine (MEA). The results were presented at *PCCC-6 conference*.

Impact and innovations from 2021

The solvent technologies developed in Task 2 will positively impact the cost of CO_2 capture and CCS.

The developed solvent management technologies (DORA, in-situ iron removal, and stable salts as degradation inhibitors) aim to reduce solvent loss through reduced solvent degradation. Reduced solvent degradation directly reduces operational costs, environmental impact, and the amount of waste produced.

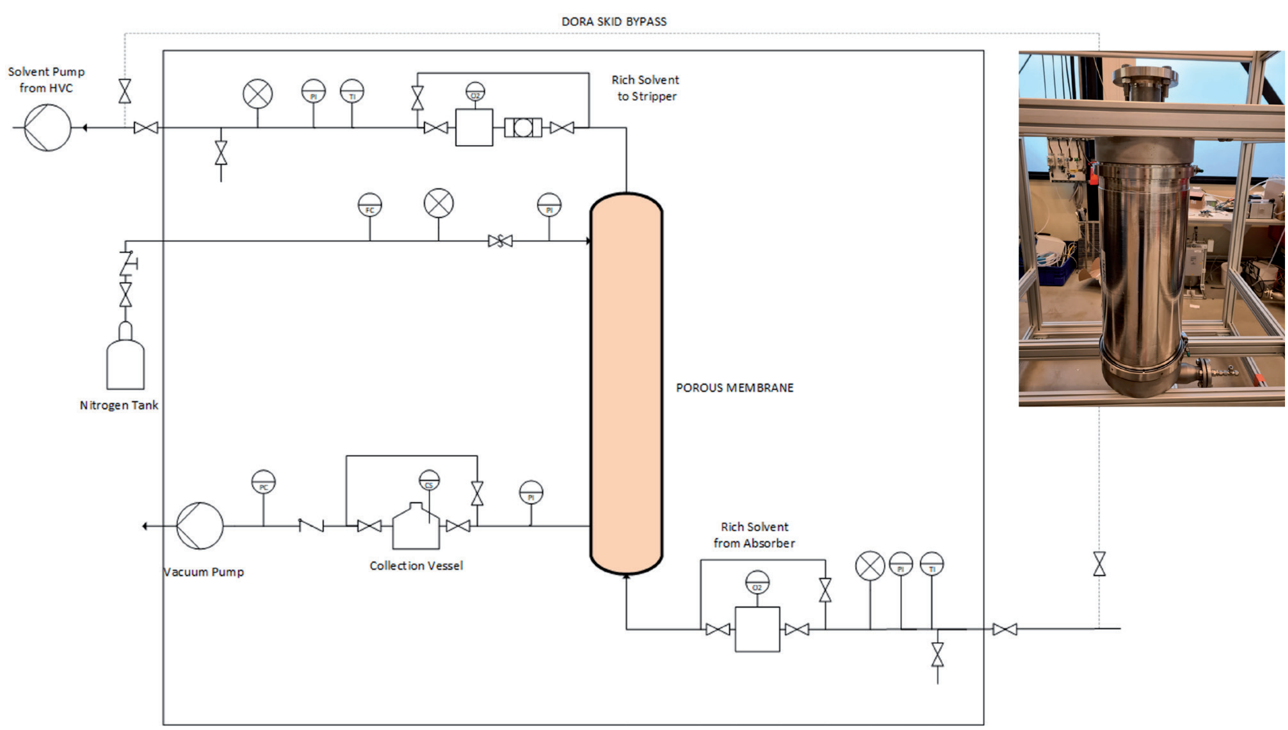


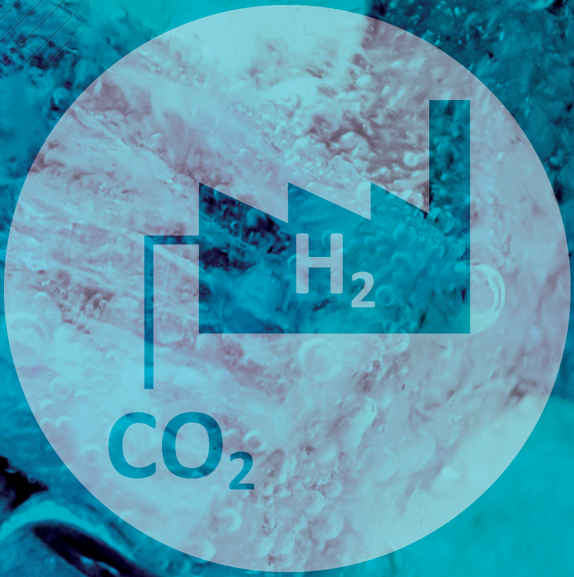
Figure 1: PID and picture of the DORA skid under construction.

TASK 3

Modular Protonic Membrane Reformer (PMR) technology developed by CoorsTek Membrane Sciences shows great promise for hydrogen production with high energy efficiency and CO_2 capture rates. The PMR technology uses electrical energy as an input, which is an increasing advantage as we transition towards renewable and intermittent energy. The goal of Task 3 is to develop the PMR technology together with CoorsTek Membrane Sciences, with an energy efficiency higher than 75% including CO_2 capture. For comparison, the energy efficiency of conventional hydrogen production by steam methane reforming without carbon capture is around 70-75 %.

www.sintef.no/NCCST3

Task leader:
Belma Talic



Low emission H_2 production (Task 3)

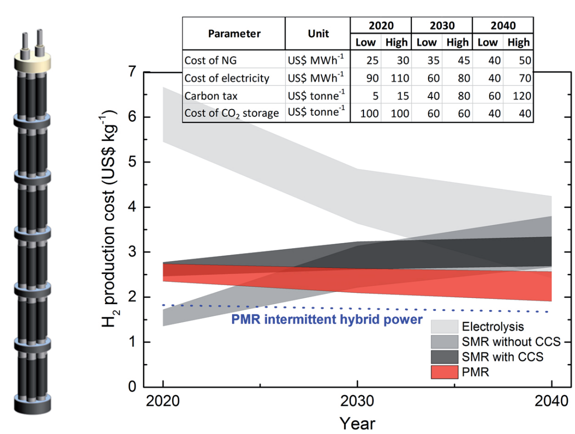
Main results 2021

- One of the previously identified potential challenges with the PMR technology is that the core material of the membrane (a $BaZrCeYO_3$ based electrolyte) is prone to degradation when it reacts with CO_2. However, we found that the currently utilized material composition can withstand being exposed to up to 10 bar of CO_2 in a wide range of relevant operating temperatures (400-800°C) without measurable degradation.
- We finalised a model description of the PMR module and used this to simulate a range of operating conditions for a given case study. The simulations allowed us to obtain performance maps according to selected key performance indicators and eventually to identify ideal operating conditions – primarily in terms of flow rates and current density – that ensure both a proper thermal integration of the process and good performance.
- In collaboration with the KSP spin-out project MACH-2, we have performed a techno-economic study of a hybrid concept that comprises the PMR and a liquefaction-based CO_2 capture system. The optimisation results demonstrate that the hybrid process is able to recover 99% of the H_2 and CO_2 generated in the system, even when the PMR is operated at a relatively low hydrogen recovery (91%). The energy conversion efficiency is about 80%, which is 12% higher than a conventional method for natural gas-based hydrogen production with CO_2 capture. Depending on the PMR module cost, the hydrogen production cost of the hybrid concept is in the range between 13.6 and 17.7 c€/Nm^3 while the reference process is at 16.5 c€/Nm^3.
- We established a new test set-up for testing single cell PMR membranes, which will be used for the long-term durability test planned in 2022. The new set-up will allow us to determine the performance of the PMR membrane with higher accuracy because the resistance contributions from the test set-up can be eliminated.

Impact and innovation potential

PMR technology utilizes electrical energy as input, which becomes an increasing advantage in the transition towards renewable and intermittent energy (see Figure 1).

Techno-economic analyses indicate that the hybrid concept of PMR and a liquefaction-based CO_2 capture system has the potential to become a more energy-efficient option for generating hydrogen with a low carbon intensity and reasonable production cost.



Parameter	Unit	2020		2030		2040	
		Low	High	Low	High	Low	High
Cost of NG	US$ MWh^{-1}	25	30	35	45	40	50
Cost of electricity	US$ MWh^{-1}	90	110	60	80	40	70
Carbon tax	US$ $tonne^{-1}$	5	15	40	80	60	120
Cost of CO_2 storage	US$ $tonne^{-1}$	100	100	60	60	40	40

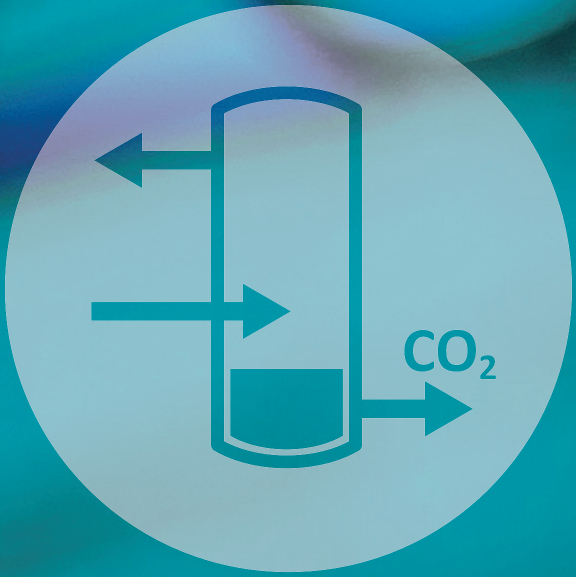
Figure 1: Module containing 36 membrane segments (left). Modeled H_2 production from PMR and competing technologies by variation of cost of natural gas, electricity, carbon tax and storage (right). Source: CoorsTek Membrane Sciences.

TASK 4

The Task looks at using low-temperature liquefaction and phase separation for the purification and transport conditioning of CO_2. The process is investigated both theoretically and experimentally. Important criteria are energy and cost efficiency, while adhering to transport specifications and safety. For the past few years, there has been a main focus on low-pressure liquefaction and the low-pressure liquid CO_2 transport chain.

www.sintef.no/NCCST4

Task leader:
Stian Trædal



CO_2 capture and transport conditioning through liquefaction (Task 4)

In the period 2019-2021, low-pressure liquefaction experiments with pure CO_2 and CO_2/N_2 mixtures were performed at the ECCSEL SEPPIL facility, located in the thermal engineering laboratories at Gløshaugen, Trondheim. From 2019-2020, experiments were conducted, wherein the final separation pressure was continuously lowered until dry ice was observed and finally clogged the product liquid CO_2 line. This was done to establish the temperature and pressure at which dry ice would form, and to investigate the robustness of the process towards clogging.

In 2021, two experiments were conducted, one with high purity CO_2 and one with a CO_2/N_2 mixture, where the liquefaction process was operated in a steady state for five hours, at a pressure slightly higher than where dry ice were observed in the first experiments. This was to ensure that there was no undetected formation and accumulation of dry ice in parts of the system that could cause issues over time. The scale of experiments is in the range of 3.6-4.8 tons of CO_2 per day, or approximately 150-200 kg per hour. These experiments demonstrate that pure CO_2 can be safely liquefied at a pressure of 5.8 bar(a) and a CO_2/ N_2 mixture can be liquefied at 6.5 bar(a) without issues related to dry ice formation. Results from six of the low-pressure liquefaction experiments conducted have been selected and published in a journal article in the *Energies Special Issue* "Advances in Carbon Capture and Storage (CCS) Deployment" (DOI: 10.3390/ en14248220).

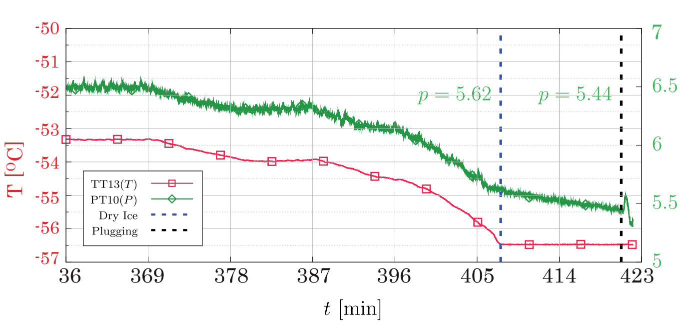
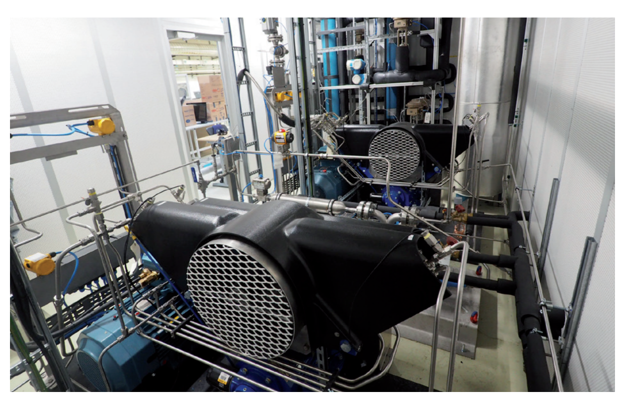


Figure 1: Liquid temperature and pressure in separator during the continuous reduction in pressure down to freeze out of CO_2 for a CO_2/N_2 mixture

To qualify a complete low-pressure liquid CO_2 chain, all chain links, such as liquefaction, transfer to temporary storage, temporary storage, loading, transport, unloading, etc. must be investigated. Theoretical investigation can increase the TRL to 2-3 (theoretical verification).

In 2021, dynamic simulations of a low-pressure liquid CO_2 terminal for ship transport were started. This activity investigates the different phases of the storage and loading cycle, taking the different transient phenomena as well as the process control measures into account. This activity is expected to provide valuable insight into the rating, design and process control, and thereby contribute to the further TRL advancement of low-pressure liquid CO_2 loading systems. A functioning dynamic model was made in 2021 and will be further developed in 2022.



TASK 5

Task 5 pertains to the use of combustion in gas turbine engines for power generation, and represents the required enabling step that completes the CCS value chain on the Norwegian Continental Shelf, throughout Europe and worldwide. The overall objective is to assess and improve the stability and operability of gas turbine combustion systems facing issues related to novel and unconventional fuel mixtures. Specific focus and significant efforts are aimed at the characterisation of "reheat" hydrogen combustion, which is a firing layout that relies on the longitudinal staging of the combustion system that is divided into two combustion zones arranged in sequence: a first "conventional" dry low-emission burner and a second "reheat" dry low-emission burner. Ultimately, Task 5 aims to assess the overall impact on power generation, thermodynamic efficiency, and pollutants emissions in order to reduce costs related to clean and efficient energy conversion in gas turbines, and improve their safety and robustness.

www.sintef.no/NCCST5

Task leader:
Andrea Gruber

Gas turbines (Task 5)

In 2021, the research work built upon the significant findings and fundamental insights about hydrogen combustion acquired in 2017-2020 to investigate more applied topics of increasing relevance to the development of fuel-flexible gas turbines.

The characteristics of hydrogen flames at reheat combustion conditions that are present in Ansaldo's GT36 gas turbine have been investigated by SINTEF using a computationally intensive numerical modelling approach named Large Eddy Simulation (LES), in order to accurately represent the reactive flow, combined with a detailed representation of the chemical reaction kinetics.

Results from the LES calculations have provided important information for combustion conditions corresponding to part- and full-load operation of the GT56 gas turbine about the response of hydrogen reheat flames to prescribed variations of the reactants' temperature. The calculations revealed a robust, stable and predictable behaviour of hydrogen reheat flames in high-pressure conditions, which is relevant to gas turbine applications.

Interestingly, a very different flame behaviour, characterised by a strong tendency of flame instability in response to temperature fluctuations, was observed for atmospheric pressure conditions. However, these are irrelevant in the context of reheat combustion. This knowledge is key to assessing and improving the robustness of gas turbine combustors that aim for stable and clean operation based on pure hydrogen firing, and will speed up combustor development by OEMs.

In parallel to the computational activity at SINTEF, the experimental activity performed at NTNU has

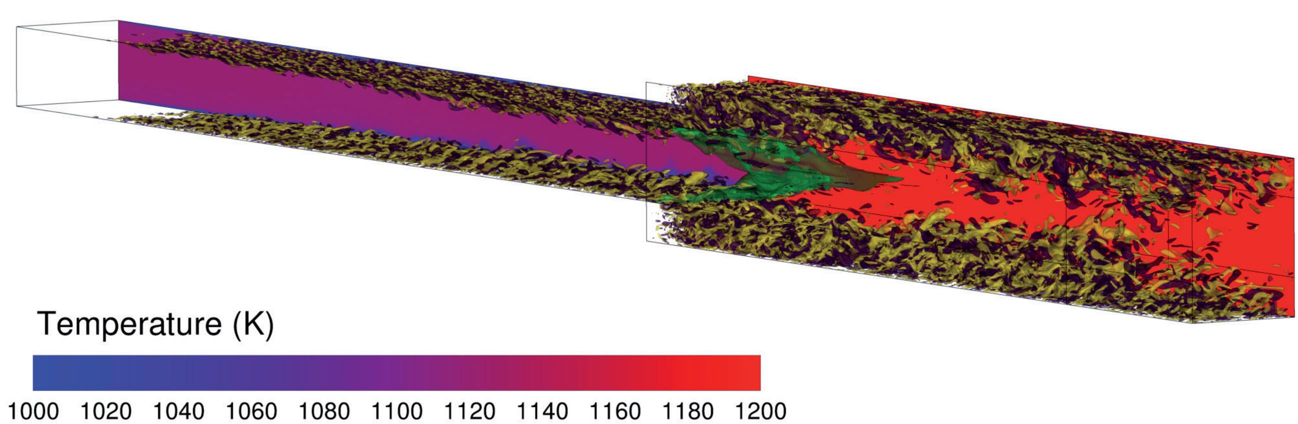


Figure 1. A hydrogen reheat flame (green isosurface) stabilised in a dump combustor at combustion conditions (25 bar, flame temperature > 1800K), which corresponds to full-load of the Ansaldo GT36 gas turbine. The vorticity structures of this strongly turbulent reactive flow are visualized by yellow and purple isosurfaces (rotating in opposed directions).

focused on the ignition dynamics and its effect on the flashback tendency of hydrogen-enriched flames (hydrogen-methane blends). The experimental work, conducted by the PhD student Tarik Yahou under the supervision of Professor James Dawson, and in collaboration with Thierry Schuller of IMFT Toulouse, revealed that the ignition dynamics cannot be fully described by classical kinematics arguments and proposed a new mechanism to explain the empirical observations.

The NCCS-sponsored KSP "Reheat2H2" complements Task 5's research activities by investigating combustion dynamics (thermo-acoustic instabilities) of hydrogen reheat flames and, based on numerical simulation and experimental measurement, is building a low-order model that can represent the flames' response to unsteady effects emerging from the surroundings (acoustic waves, reactants temperature fluctuations, heat loss etc).

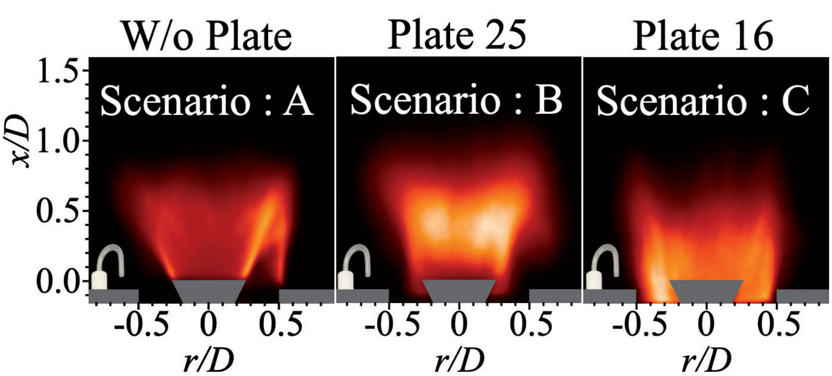


Figure 2. Hydrogen/methane flames ignition and stabilization for different back-pressure conditions.

TASK 6

Task 6 investigates the best ways to integrate the CO_2 capture processes in the CCS value chain. The overall ambition is to develop and identify cost-effective CO_2 capture technologies and their integration into industrial processes and power plants. The Task's activities include the development of the first ever solvent benchmark for post-combustion capture for a wide variety of CO_2 concentrations and at a large scale, the development of a calcium looping technology integration that shows a cost reduction potential of at least 30% compared to MEA for capture from WtE plants, and the conceptual design of Innovative Hybrid concepts. This includes the development of a novel adsorption-liquefaction hybrid process that shows potential for significant cost reduction in low to medium CO_2 concentration flue gas.

www.sintef.no/NCCST6

Marie Bysveen
(with contributions from
Rubén Mocholí Montañés
and Rahul Anantharaman)

CO_2 capture process integration (Task 6)

The Norwegian and European process industries view CCS as one of the key technologies for lowering or even eliminating their CO_2 emissions. At an EU level, the perception of CCS has moved from "something that could be used" to "a needed tool for job creation and climate change mitigation".

2021 saw the continuation of dialogue with the Norwegian process industry, with the goal of creating more spin-off projects. In particular, this resulted in the successful funding of the KSP CCShip, which is a spin-off project from Task 6.

CCShip focuses on developing cost-effective CCS solutions to be implemented on ships in order to reduce CO_2 emissions in the maritime industry. The project had its kick-off on 30 April 2021, and will run for four years.

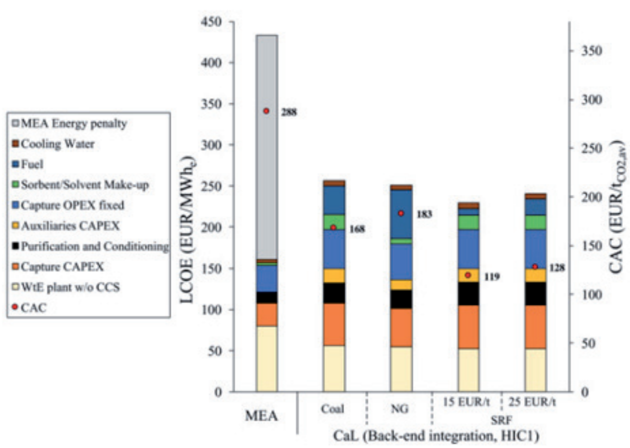


Figure 1: LCOE and CAC for the WtE plant with CO_2 capture.

Cost is a major barrier to the demonstration and implementation of CCS at an industrial scale. One of the main elements contributing to the overall cost of the CCS value chain is CO_2 capture. Therefore, innovative ways of reducing the cost of CO_2 capture can have a significant impact on the business cases for CCS for industrial processes and waste-to-energy plants. Hybrid concepts in particular can significantly reduce the cost of capture by combining different capture technologies in a way that makes them more cost-effective than if they were implemented alone.

This year, work continued on the two types of hybrid capture technologies: membrane absorption and membrane adsorption. In particular, we finalised our work on improving and updating our process models for membrane chemical absorption using solvents. The membrane module enables a standardised absorption process by producing a permeate product with a fixed CO_2 purity. Membrane CO_2 upgrading may be suitable for industrial cases (> 10 mol% CO_2) with other CO_2 capture technologies, which are cost effective when feed is rich in CO_2. The results of this work are due to be published in 2022.

2021 also saw the initiation of work on a hybrid separation process that consists of an upstream pressure swing adsorption (PSA) unit and a downstream membrane separation stage. Preliminary results on a systematic and robust techno-economic assessment in 2022 shows that this concept could be competitive with other existing capture technologies, and more in-depth assessment will be conducted in 2022.

TASK 7

Captured CO_2 must be transported from the points of capture to the storage sites. Task 7 provides knowledge and methods to ensure that the transport is safe and efficient, performing in-depth investigations into running-ductile fractures in CO_2 pipelines, ship transport, and impurities and non-equilibrium flows of CO_2.

www.sintef.no/NCCST7

Task leader:
Svend Tollak Munkejord

CO_2 transport (Task 7)

How CO_2 flows through restrictions

For the design and operation of CO_2 processing plants and transportation systems, engineers need to estimate the flow rates through restrictions such as control and safety valves. If the pressure drop across the restriction is high enough, the flow will become choked, i.e. it will attain a value that will not increase if the pressure drop increases. There is a need to develop and validate models that are generic enough to be implemented in simulation tools for CCS applications such as pipes and vessels. To amend the situation, we have performed experiments in the ECCSEL depressurization facility using two sizes of nozzles and orifices (see the figures). We have also proposed a delayed homogeneous depressurization model to account for some of the non-equilibrium phenomena occurring in the flow through the restriction. The results were encouraging, as the model provided very good predictions of literature data for flow through a converging-diverging nozzle for relatively high temperatures. However, we need to work more to describe the low-temperature case.

Figure 1: A converging 12.7 mm nozzle screwed into the depressurization tube.

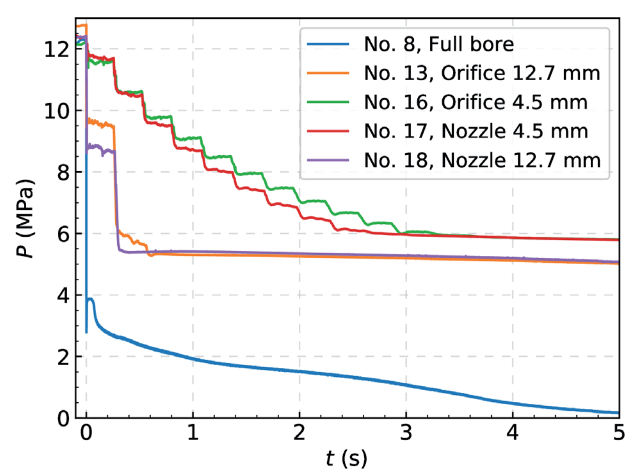


Figure 2: Pressure measured at a position 8 cm from the outlet of the depressurization tube. It can be observed that decreasing restriction diameter gives a higher pressure (and therefore lower mass-flow rate). An orifice gives a higher pressure and lower mass-flow rate than a nozzle.

Model to predict running-ductile fractures in CO_2 pipelines

We are working to improve our ability to predict running-ductile fractures in CO_2 pipelines. The work has progressed along three main lines of research. The first is to improve methods for describing the steel and crack behaviour in a finite-element modelling framework, including the consistent calibration of model parameters based on limited input from material tests. The second line of research is to describe the pressure load on the pipe walls from the escaping CO_2, properly taking non-equilibrium effects into account (see also the previous paragraph). The third line of research is to "distil" the knowledge obtained into an engineering tool.

We have previously assessed pipeline designs for the Northern Lights project. This year we wrote an update of this work together with Equinor, which will be presented at the *TFAP Conference* in March 2022.

Educating the next generation of CCS scientists

This year, we co-supervised a master's candidate from the Department of Structural Engineering at NTNU on modelling ductile fracture in steel structures. Our two PhD candidates who work on the topic of fracture mechanics related to fracture-propagation control in pipes, and on the topic of depressurization of CO_2 in pipes, have both successfully completed their first year. Both candidates are co-supervised by NTNU and SINTEF.

TASK 8

Task 8 and the ImpreCCS competence building project address the need for technology, methods, and procedures for fiscal metering in CCS, as well as bridging data gaps and improving models for relevant fluid properties in CCS.

www.sintef.no/NCCST8

Task leader:
Sigurd Weidemann Løvseth

Fiscal metering and thermodynamics (Task 8)

According to the ETS directive, CO_2 that is captured, transported and stored is not considered as emitted, and therefore emission allowances will not be required to be purchased. This is a major business driver for CCS, but a condition is that the stored CO_2 mass flow is traceably metered within defined uncertainty limits. Furthermore, the EU taxonomy for sustainable activities specifies a maximum loss of 0.5% of CO_2 during transport from the source to permanent storage. So far, no flow metering technology has qualified for the conditions, composition, and flow rates relevant for CCS, and it is presently not clear how such a qualification should be done.

Accurate thermophysical properties are needed for optimized design and operation of virtually all processes involved in CCS. Unfortunately, there are large gaps in the available data, and correspondingly large uncertainties in the associated property models.

Task 8 addresses the need for new phase equilibrium data and better reference equations of state. Furthermore, the task aims to evaluate, develop and benchmark relevant concepts for traceable fiscal flow metering, and to close knowledge gaps through experiments and modelling.

The ImpreCCS project produces data on viscosity, density, and thermal conductivity, and develops property models that will be applied in reservoir modelling. The ImpreCCS KSP project, financed by CLIMIT R&D and the NCCS industry partners, is administered under Task 8. In addition to the NCCS consortium, NORCE is research partner in ImpreCCS, and property models are developed in collaboration with NIST, USA.

Main results 2021

Fiscal metering

CO_2 is transported as pressurised liquids. Such liquids differ from fluids like natural gas and water, in that small changes in composition, temperature, or pressure could lead to large changes in properties. In addition, CO_2 has a large sound attenuation. Therefore, a facility is needed to test flow meter technologies under realistic conditions, which also could enable the calibration, and by extension the traceability, of fiscal flow meters.

Building on a design base developed in 2020, a business case study for this type of test facility was conducted in 2021. The study included an analysis of current legislation and the results of feedback from over 25 stakeholders, as well as a market forecast, cost-benefit analysis, and a risk assessment considering different strategies to realize a fiscal metering test facility.

During 2021, a static test with liquid CO_2 of a full-scale ultrasonic flow meter at a range of different pressures and temperatures was also performed. The results are expected to be published in 2022.

Measurement of fluid properties

Very little data is available on viscosity and thermal conductivity for CCS relevant mixtures, especially in the liquid phase. Therefore, estimates on laminar flow, e.g. in reservoirs, or heat transfer in CCS processes are very crude. To alleviate this situation, both the thermal conductivity of liquid CO_2 mixed with nitrogen and methane, and the viscosity of gaseous and supercritical CO_2 mixed with hydrogen and nitrogen have been measured in the ImpreCCS project. The thermal liquid CO_2 mixture conductivity measurements, first of its kind, were published in 2021, whereas the viscosity measurements have been submitted for publishing. In 2022, it is the aim to proceed with measurements of viscosity using a new ECCSEL facility of SINTEF Energy Research

Furthermore, phase equilibria have been measured for the binary system of CO_2+SO_2. Although SO_2 is an important impurity of many processes producing CO_2, most of the data on this binary system are more than 100 years old, and has low accuracy.

The measurements of thermal conductivity at University of Western Australia, viscosity at Ruhr-Universität Bochum (RUB), and phase equilibria at SINTEF Energy Research have all been enabled through international collaboration and an exchange of personnel within NCCS.

Thermodynamic modelling

Over the last decade, Task 8 partner RUB has been developing a reference equation of state, EOS-CG. It is available through the thermodynamic tool TREND, but its routines are also expected to be used in the thermodynamics of commercial process simulators, making it possible to improve the accuracy of their predictions. EOS-CG is continuously developed by adding new components and improving existing models. Some of the components that were not included in EOS-CG until recently will react chemically with other components, greatly affecting the thermodynamic properties. Therefore, an approach was developed that includes reactive mixtures in EOS-CG. This approach has facilitated the implementation and validation of the system water + CO_2 + MEA, and is available in the latest version of TREND. Two journal articles and a PhD thesis were published on the modelling activities of Task 8 in 2021, and further articles resulting from the PhD are expected in 2022.

Impact and innovations

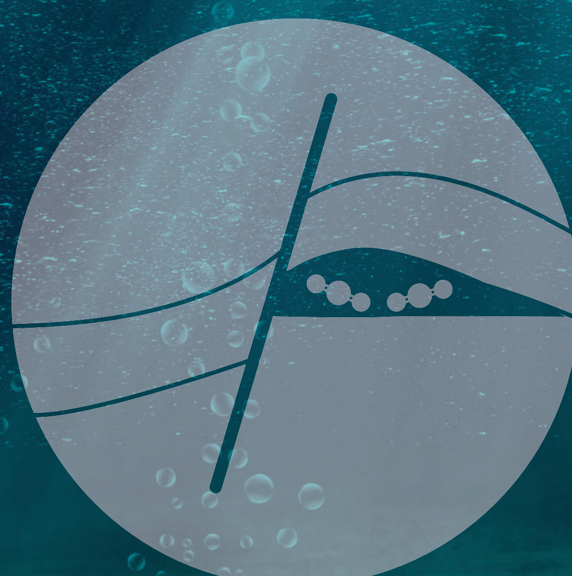
- Two new releases of the thermodynamic tool TREND with the latest models have been made available for the partners of NCCS in 2021. The models are expected to find their way into leading commercial process simulators.
- Two new facilities for accurate measurements of viscosity, density, and high pressure and complex phase equilibria with many innovative solutions have been constructed.
- A design basis for a test loop for fiscal metering has been completed. The test loop includes innovative processes, and once realized, it will enable the testing and calibration of fiscal flow meters needed to avoid the purchase of emission allowances as well as custody transfer between actors in a CCS network. Both applications are very important for large-scale deployment of CCS.
- A test rig has been designed, constructed and employed for static (i.e. no-flow) test of an ultrasonic flow meter. It includes some innovative elements to stabilize the test conditions, with process and ambient temperatures between -35 and 35°C. The tests performed on the facility have been important to evaluate the feasibility of using ultrasonic meters in CCS.

TASK 9

Task 9 focuses on reducing the risks related to the injection and storage of CO_2 on the Norwegian Continental Shelf, with a focus on the geology and faults in the Horda Platform area. Site specific knowledge building for the Smeaheia fault block within the Horda Platform area is combined with observations from field analogies and experimental investigation in order to address fault seal integrity and develop an improved workflow for dynamic up-along-fault fluid migration.

www.sintef.no/NCCST9

Task leader:
Elin Skurtveit



Structural derisiking (Task 9)

Detailed mapping of sedimentary units, faults and CO_2 traps in Horda Platform area has improved the geological understanding of the area and resulted in new geo-models for the Smeaheia and Aurora sites. Detailed characterisation of the Permian-Triassic alluvial rift system in the Horda Platform provides valuable lessons on how faulting influences reservoir deposition. This work provides new and relevant information for evaluating storage capacity in the deeper formations of the Smeaheia fault blocks and has been published as a research article in *Basin Research*. Identification of structural traps and assessment of top and fault seals for the Horda area is discussed in a paper currently being reviewed by the American Association of Petroleum Geologists (AAPG, and shows promising potential for expanding CO_2 storage in the North Sea.

Analyses of fault stability and reactivation of the Vette fault zone show that fault rock cohesion and horizontal stress acting on the fault are of high importance for the fault stability during injection. A 3D finite element geomechanical model for Smeaheia has been completed and provides an important tool for assessing the horizontal stress development in a reservoir during injection, and quantifies the uncertainties of stress within fault zones. This study indicates that if the fault stability results can be calibrated with a small safety margin, an analytical approach assuming uniaxial strain condition seem to be still a relatively accurate method to screen critically oriented faults. The new 3D geomechancial model was presented as an open webinar and will be used to further address effects of uncertainties in stress conditions and mechanical properties on fault and seal integrity.

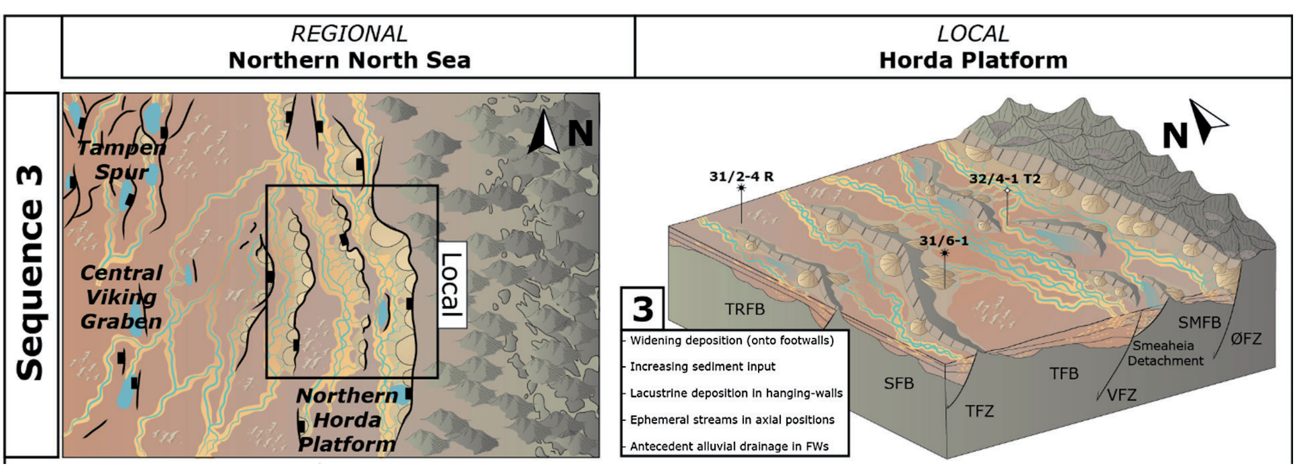
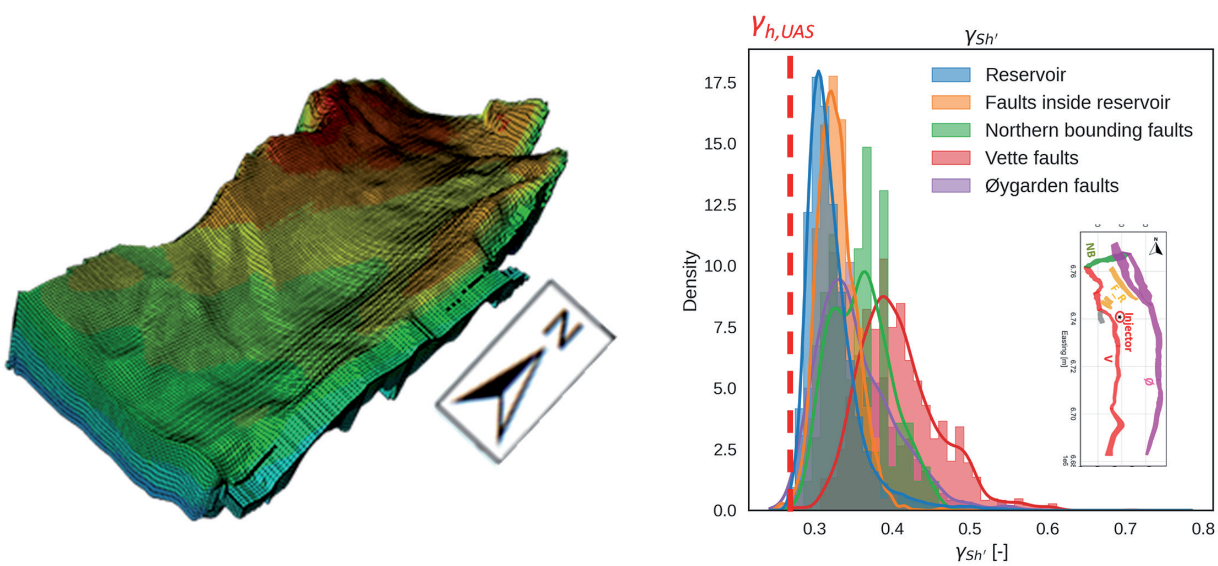


Figure 1: Example of paleogeographic reconstruction of the Triassic, based on seismic facies interpretation. Excerpt from Figure 9a of Wurtsen et al 2021.

Experimental work has been carried out based on a need for improved mechanical understanding of shale caprock and clay rich faults. Frictional properties in fault gouges are found to vary systematically with clay-sand mixing ratios, from around 20-degree friction angles in clay-dominated gouges and above 30 degrees in sand-dominated gouge, whereas interfaces between clay and sand seems to be controlled by the higher sand friction. A comprehensive experimental study on Draupne Shale that provides a thorough description of its elastic properties, anisotropy and shear strength has been published in Geosciences. The work provides an important reference study for the evaluation of seal integrity of other caprocks on the Norwegian Continental Shelf.



(a) (b)

Figure 2: Illustration of the 3D geomechanical model of the Smeaheia fault block (a) and example of quantification of variation in the horizontal effective stress path coefficient (γSh') for the reservoir and faults (b). The range of modelled horizontal effective stress path coefficient is compared with the Uniaxial Strain (UAS) conditions assumed in many analytical fault stability calculations.

TASK 10

By ensuring the containment of CO_2 in the storage reservoir, we can optimize the storage capacity and maximize the number of suitable reservoirs. These goals can only be achieved by addressing the remaining research gaps identified in the near-well area (well integrity, CO_2 injectivity) and at reservoir borders with the caprock (especially faults). Therefore, Task 10 looks at selected issues of relevance for filling these gaps, putting a special emphasis on the understanding of geomechanical aspects and developing testing methodologies to be used when considering new storage sites.

www.sintef.no/NCCST10

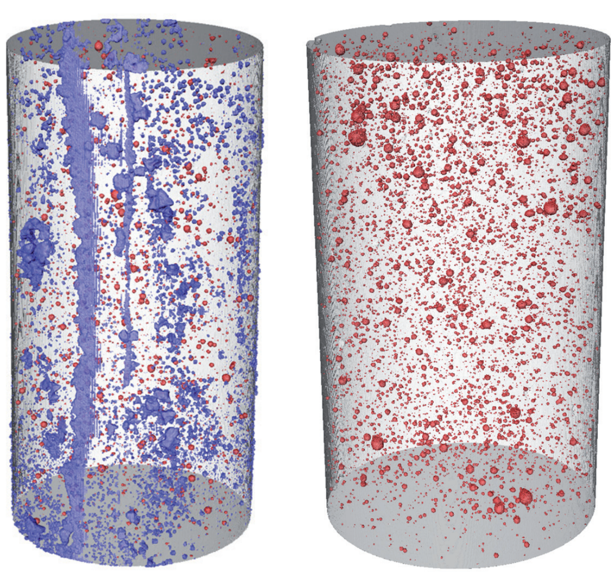
Task leader:
Pierre Rolf Cerasi

CO_2 storage site containment (Task 10)

Last year we completed the second stage of well cement qualification in terms of the bond strength to rock. This involved moving away from a simple neat cement formulation that is easy to analyse due to its simple formulation, and where the test matrix did not involve investigating the weight of many components and additives. However, relevance to field practice was limited when not considering real cement compositions used in the Norwegian offshore, and therefore constituting the main risk elements in legacy wells towards loss of CO_2 containment in the intended reservoir. In the work performed in 2021 and reported in deliverable DT10-2021-1A, the effect of adding micro-silica was investigated in the presence of carbonated brine, simulating exposure to CO_2 seeping up from the storage reservoir. This additive is used in oil and gas well cement to hinder the strength loss for high temperature conditions. The results in our study showed that strength reduction after CO_2 exposure did occur but was less than 10 % for the chosen conditions.

2021 also saw the end of our well integrity atlas activity, with a publication in the *International Journal of Greenhouse Gas Control* and the organisation by our partners in the US of a well integrity workshop in May. The journal paper combined the results from our survey, a detailed questionnaire sent to all active CO_2 injection operations worldwide, with our own and published experience from research in well integrity. The atlas provides a unique insight into which difficulties are most encountered, and where future research efforts are needed.

Collaboration with Task 9 was further strengthened in 2021, with additional funds being made available to increase common research on shale creep deformation. This is seen as an important part of the mechanical response of many caprock formations to constant stress conditions, which may play an important role in healing fractures underground, and thus further increase the confidence in the long-term soundness of geological CO_2 sequestration. The collaboration culminated in the submission of an NCCS-supported KSP application to the Research Council of Norway, in collaboration with UNIS, on the theme of shale creep



(a) (b)

Figure 1: A tomography reconstruction of macro-porosity and crystal precipitation on the surface of micro-silica containing cement plugs exposed to CO_2-brine mixture: (a) After exposure for four weeks; (b) Reference (unexposed) sample. Red – voids, blue – precipitated particles on the surface.

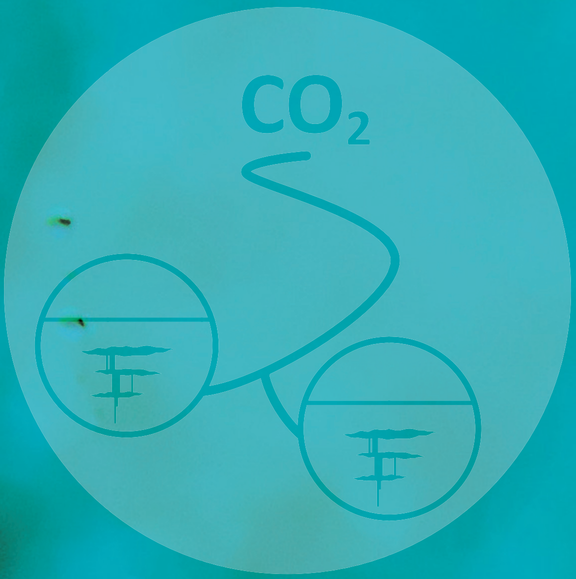
laboratory testing and modelling. A second proposal was chosen by NCCS involving Task 10 and Task 12 on well integrity, with a focus on laboratory testing using the ECCSEL well integrity research infrastructure and the newly installed industrial CT scanner. The theme of this second proposal was the experimental investigation of fracture network development in the near well area and early warning geophysical methods of fracture and leakage detection. In addition, collaboration with University of Pittsburgh and Colorado School of Mines, as well as Queen Mary University of London, will make for additional laboratory and modelling contributions, not the least formulation of remediation fluids that can be tested in the ECCSEL rig.

TASK 11

Task 11 develops technologies for the optimal utilisation of available storage space, and the efficient utilisation of CO_2 for enhanced oil recovery (CO_2-EOR). Investment in both characterising a storage site and developing injection facilities (pipelines, well templates and the wells themselves) is costly and needs to be done before injection can start. Therefore, the operator needs to be confident that the storage site can be used to its full potential. Technologies for this are addressed in Task 11's two activities: mobility control for increased efficiency of CO_2-EOR and aquifer storage, and optimisation of storage site portfolios.

www.sintef.no/NCCST11

Task leader:
Alv-Arne Grimstad



Reservoir management and EOR (Task 11)

In 2021, the work on CO_2 mobility control was presented at two conferences. The work on CO_2 transport and storage network studies resulted in two industry workshops and a journal manuscript. In addition, we welcomed a new vendor with in-kind contributions as a member of the Task 11 family.

Stratum Reservoir, a service provider for the petroleum industry with expertise in core analysis, joined NCCS at the end of 2020. In 2021, their in-kind contribution included a core-flooding experiment to extend the test matrix for CO_2 mobility with commercial surfactants. Work in 2020 investigated the effect of surfactant concentration on foam strength for surfactant systems with high and low partition coefficients (i.e., how much the surfactant prefers to dissolve in CO_2 rather than in brine). In addition, SINTEF Industry and Stratum Reservoir cooperated to identify experimental conditions where relevant surfactant systems have intermediate partition coefficients, and to run a core flooding experiment under these conditions. The results strengthened the hypothesis that surfactant systems with a higher partition coefficient have a more abrupt increase in foam strength as the surfactant concentration increases. This behaviour will be important for selecting surfactant systems for field application, since it can be beneficial that foam strength is maintained also for lower concentrations. With the current experimental results, it seems like this behaviour will be found in surfactants that preferentially dissolve in brine. Placement of the surfactant solution in the storage reservoir could then be a challenge, as it will involve a water injection phase prior to the start of CO_2 injection.

Simulation of CO_2 mobility control was presented in two conference contributions: modelling on core scale at the *GHGT-15 conference* in March and modelling on field scale for heterogeneous reservoirs at the *TCCS-11 conference* in June. Both were oral presentations, with short papers for the proceedings.

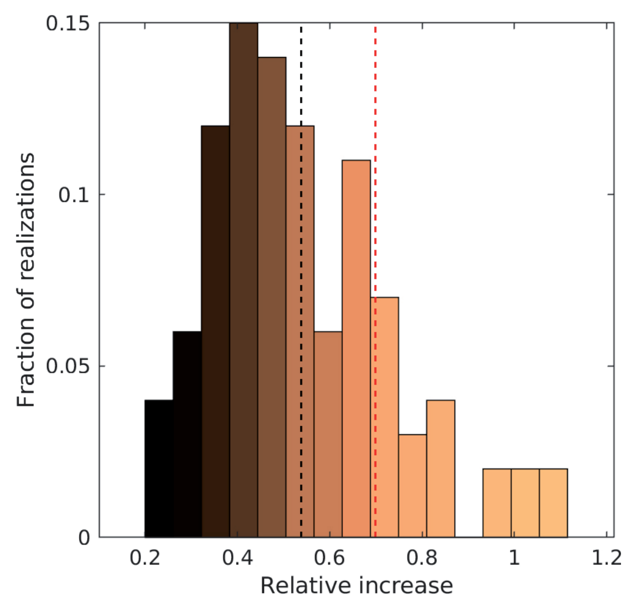


Figure 1: CO_2 break-through time is simulated for 100 stochastic realizations of a heterogeneous quarter-five-spot-model both with CO_2 mobility control and with normal CO_2 mobility. The histogram shows the distribution of the relative increase in storage efficiency between normal CO_2 injection and CO_2 injection with mobility control for each realization. The relative increase ranges from 20% to more than 100%. The mean increase (black dashed line) is 54%. The red dashed line indicates the increase for a homogeneous model.

For the field scale, earlier work to study increased storage efficiency was performed with homogeneous reservoir properties. This year's work extended this to simulations on a stochastically generated ensemble with heterogeneous reservoir porosity and permeability. The newly developed ensemble simulation facilities of the Matlab Reservoir Simulation Toolbox (MRST) were employed in this work. With heterogeneous properties, the increase in storage efficiency is still significant when mobility control is used; however, the relative increase also shows a large variation from one realization to another (see Figure 1).

Work on transport and storage network reliability continued. Networks involving several injection sites with varying degrees of built-in surplus transport and injection capacity were subjected to random injection well failures (e.g. due to operational issues that require prolonged maintenance work). The effect of well failure on missed injections (target injection rate minus injection capacity) was calculated in each instance. Results show that the potential costs (emission allowances) of missed CO_2 injection could be of the same magnitude as the cost of increasing the flexibility of the network to a sufficient level (see Figure 2).

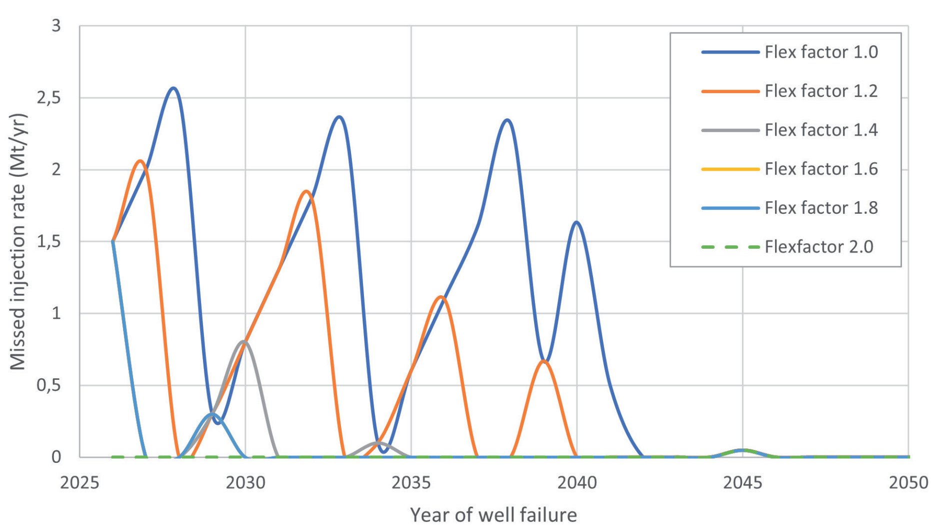


Figure 2: Missed CO_2 injection rate in case of a well failure in a network where injection capacity is gradually increased to match anticipated increasing CO_2 supply. For low flexibility factors (little additional capacity), a well failure will lead to relatively large missed injection rate (vented or not captured). Missed injection rate is particularly large in years where the increasing supply rate almost catches up with installed injection capacity. For increasing flexibility factors the potential missed injection rate is quickly reduced. As the cost for emission allowances is currently at 60 €/tonne and is expected to increase over time, the cost of missed injection is comparable to the cost of increased flexibility (more wells).

TASK 12

Reliable monitoring of a CO_2 storage site is essential for safe and efficient operation, as well as for public acceptance. By carefully monitoring the site before, during, and after CO_2 injection, the risk of very costly intervention, remediation, or site closure is significantly reduced. Such surveillance can potentially be very expensive. The main ambition of Task 12 is to develop and demonstrate monitoring technology that will enable safe operation in compliance with laws and regulations in the most cost-efficient manner.

This is achieved by research on five topics:

1. methods for assessing cost vs value-of-information for geophysical data acquisition
2. ways of extracting all available information from acquired geophysical data
3. strategies for comparing/combining prior reservoir modelling to geophysical observations for containment and conformance verification
4. unconventional data acquisition technologies and survey layouts
5. use of machine learning for geophysical monitoring

www.sintef.no/NCCST12

Task leader:
Peder Eliasson

Cost-effective monitoring technology (Task 12)

During 2021, Task 12 and its associated spin-off projects EM4CO2 and TOPHOLE successfully published several important research results. In addition to publishing papers on “Combined geophysical and rock physics workflow for quantitative CO_2 monitoring” and on “Assessing the value of seismic monitoring of CO_2 storage using simulations and statistical analysis” (both in *the International Journal of Greenhouse Gas Control (IJGGC)* and submitted already in 2020), several other studies culminated in publications:

- Watson F., Andersen O., and Møll Nilsen H. (2021), “Rapid Optimisation of the New Sleipner Benchmark Model”, SINTEF Proceedings
- Dupuy B., Romdhane A., Nordmann P.-L., Eliasson P., and Park J. (2021), “Bayesian rock physics inversion: application to CO_2 storage monitoring”, GEOPHYSICS 86: M101-M122.
- Smith S. A. (2021), “Seismic Wave Propagation Across Single Fractures” (MSc thesis)
- Hosseini S. E., Zonetti S., Romdhane A., Dupuy B. and Arntsen B. (2021), “Artificial intelligence for well integrity monitoring based on EM data”, SINTEF Proceedings
- Emmel B., Zonetti S., Romdhane A., Dupuy B. and Torsæter M. (2021), “From pre-screening to monitoring of plugged and abandoned marine exploration wells – Enabling reuse of reservoirs for CO_2 storage through geophysical monitoring”, SINTEF Proceedings
- Emmel B. and Dupuy B. (2021), “Dataset of plugging and abandonment status from exploration wells drilled within the Troll gas and oil field in the Norwegian North Sea”, Data in Brief, Vol. 37, 107165
- Gehrmann R., Romdhane A., Park J., Eliasson P., Chen H., and Gelius L. (2021), “CSEM for CO_2 storage – Feasibility study at Smeaheia to optimise acquisition”, SINTEF Proceedings

The focus on methods for the optimal use of geophysical information continued, with further development of the method for rock physics inversion that this year focused on a framework for inversion based on selected machine learning algorithms. Four different algorithms were tested with respect to their efficiency at determining porosity, bulk and shear modulus from a velocity model.

Initial studies were also carried out to better understand the potential use of PS-converted seismic waves for the discrimination of pressure and saturation changes in the subsurface. The results were encouraging but obtained using a highly simplified synthetic model. The plan for 2022 is to carry out similar tests with a much more realistic model and potentially later with real data, adding significant complexity.

While much of the focus in Task 12 is on monitoring Norwegian CO_2 storage projects, a major study has also been initiated relateing to the characterization and modelling of the Bunter Sandstone Formation saline aquifer in the southern North Sea. In 2021, a model of the area was constructed and large-scale injection modelling carried out. Additional geomechanical modelling indicated a level of subsurface displacement that may be observed using InSAR if a suitable set of point sources overlay the region. It was pointed out that planned windfarms in the region may provide a suitable monitoring reflector to assess seabed movement. In addition, a set of seabed tiltmeters may provide the necessary resolution for the regional geomechanical monitoring.

Within the EM4CO2 project, some of the most important results include the demonstration of the feasibility of using CSEM for monitoring at Smeaheia, how CSEM survey layouts can be minimised without a loss of information, and how to account efficiently for infrastructure effects during EM modelling. The feasibility study showed promising results, with the CO_2 plume after 25 years of simulated injection being clearly visible on inversion results. Using a recently developed survey optimisation approach, it was also verified that a significantly reduced, but a wisely designed survey gave a nearly equally well imaged plume (see Figure 1). Another highlight in the EM4CO2 project was the recruitment of a postdoc researcher who will work on a new approach for time-lapse CSEM inversion.

For the TOPHOLE project, the year meant further work on the monitoring concept integrating the screening of legacy wells, and the localisation, characterisation and monitoring of these wells with non-invasive methods. The screening approach has been tested on a large number of wells in the Troll area (see Figure 2), and more recently as part of a detailed study for the Smeaheia structure, where the full concept has been applied. The interest in and need for this type of tool has resulted in plans for preparing a professional version of the tool during 2022. Experimental work has been started and is focusing on acoustic measurements on a well replica and testing the leakage detection abilities of accelerometers and fiber optics. Ehsan Hosseini (NTNU PhD student) has been working on electromagnetic modelling of well signatures and effects of cement and corrosion on the recorded signals.

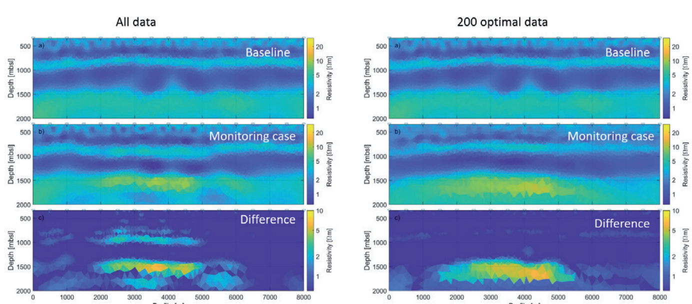


Figure 1: Resistivity models obtained using CSEM inversion for a synthetic Smeaheia model. The top row shows the inversion of baseline data before injection, while the middle row shows the inversion of data after injection. The bottom row models show the difference before and after injection. [left column] Results using all data (approximately 17000 data points) from a dense survey. [right column] Results using 200 carefully selected data points. Results are similar despite the significant reduction in acquired data.

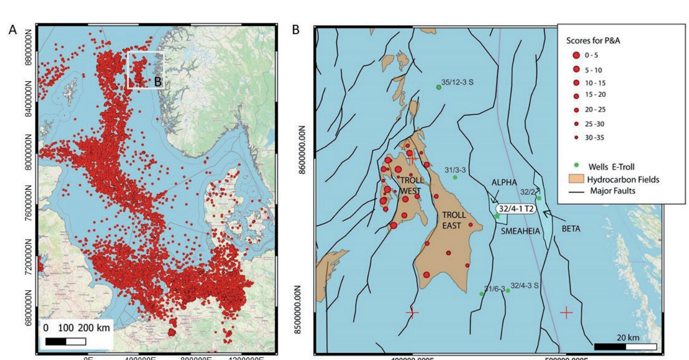


Figure 2: (A) Map of the North Sea, with well locations and a white square indicating the studied area. (B) Map of the Troll area offshore SW Norway, with well integrity screening results for 93 P&A wells indicated by red dots (Emmel and Dupuy, 2021). Major faults are shown and the location of well 32/4-1 T2 within the Smeaheia alpha structure is highlighted and marked with a green star. From (Romdhane et al., 2022).

SPIN-IN PROJECTS

Ongoing spin-in projects in 2021

Preventing loss of near-well permeability in CO_2 injection wells (POREPAC)

The primary objective of this project is to develop data and models on near-well processes affecting injectivity that can be used by the industry to better predict and mitigate injectivity issues.

Partners: SINTEF Industry, SINTEF Digital, UiO, IRIS
Funding: CLIMIT
Total budget: NOK 11.38 million
Duration: 2018 – 2021
PM: Malin Torsæter, SINTEF Industry
Task: 10

Impact of CO_2 impurities and additives in CCS (ImpreCCS)

The primary objective of this project is to reduce costs and risks of CO_2 storage by predicting the impact of important impurities and additives on CO_2 viscosity, density, and thermal conductivity.

Partners: SINTEF Energy Research, NTNU, NORCE; University of Western Australia
Funding: CLIMIT
Total budget: NOK 13.3 million
Duration: 2018 – 2022
PM: Sigurd W. Løvseth, SINTEF Energy Research
Task: 8

Membrane-assisted CO_2 capture through liquefaction for clean H_2 production (MACH-2)

The primary objective of this project is to develop and demonstrate the potential of an innovative hybrid technology for H_2 production with CO_2 capture enabling high carbon capture rates with high purity CO_2 and H_2 and a hydrogen cost comparable to conventional technologies without capture.

Partners: SINTEF Industry, SINTEF Energy Research, NTNU and West Virginia University. CoorsTek has an active role in the project.
Funding: CLIMIT
Total budget: NOK 10.123 million
Duration: 2019 – 2023
PM: Thijs Peters, SINTEF Industry
Task: 3/4

Quantification of fault-related leakage risk (FRISK)

The primary objective of this project is to reduce the uncertainty in fault-related leakage risk for large-scale CO_2 storage by developing an improved fault derisking framework that includes dynamic pressure changes and along-fault fluid migration.

Partners: NGI, UiO, NORCE (Uni Research) and UiB. Collaboration with UK and US research institutions and geological expertise from Switzerland.
Funding: CLIMIT, Equinor and TotalEnergies

Total budget: NOK 13.308 million
Duration: 2019 – 2023
PM: Elin Skurtveit, NGI
Task: 9

Tophole monitoring of permanently plugged wells (TOPHOLE)
The primary objective of the project is to develop a novel cost-efficient method for tophole/non-invasive monitoring of permanently plugged wells that are cut below surface/seafloor.

Partners: SINTEF Industry, SINTEF Digital, NTNU, Lawrence Livermore National Laboratory. Aker Solutions has an active role in the project.
Funding: PETROMAKS2
Total budget: NOK 10.2 million
Duration: 2019 – 2023
PM: Bastien Dupuy, SINTEF Industry
Task: 12

Accelerating CSEM technology for efficient and quantitative CO_2 monitoring (EM4CO2)
The primary objective of this project is to develop and apply a cost-efficient CO_2 monitoring concept using time-lapse CSEM and demonstrate its readiness for the future Norwegian large-scale CO_2 storage project (Smeaheia/Johansen).

Partners: SINTEF Industry (hosting a postdoc) , NGI, UiO, and University of Southampton. Allton is an advisor in the project.
Funding: CLIMIT
Total budget: NOK 9.2 million
Duration: 2019 – 2023
PM: Anouar Romdhane, SINTEF Industry
Task: 12

Towards clean and stable hydrogen reheat combustion in gas turbines (Reheat2H2)
The primary objective of this project is to build a knowledge-based stability model for H_2 reheat flames to enable hydrogen end-use for largescale power generation in pre-combustion CCS (CLIMIT scope) and power-to-H_2-to-power (ENERGIX scope) schemes.

Partners: SINTEF Energy Research, NTNU, TUM, Sandia National Laboratories, Computational Thermal Fluids Laboratory of the University of Connecticut, ETH Zürich. The project works closely with Ansaldo Energia Switzerland.
Funding: EnergyX
Total budget: NOK 14.948 million
Duration: 2019 – 2024
PM: Jonas Moeck, NTNU
Task: 5

New spin-in projects in 2021

Deploying Carbon Capture and Storage for ships to enable maritime CO_2 emission mitigation (CCShip)
The primary objective of this project is to develop cost-effective CCS solutions for ships, as well as to understand when CCS can be a more attractive technology than alternative solutions for reducing CO_2 emissions from ships.

Project partners: SINTEF Energy, SINTEF Ocean, NTNU, UiO, SNU, NCCS, Klaveness, Wärtsilä, Calix
Funding: Maroff, The Research Council of Norway
Total budget: NOK 14.23 million
Duration: 2021 – 2025
PM: Stefania Osk Gardarsdottir
Task: 6

Total KSP budget sum: NOK 96.689 million

Collaborations with other FMEs

The North Sea as a platform for the green transition
NCCS collaborated with three other FMEs, NorthWind, LowEmission and NTRANS, to create “The North Sea as a platform for the green transition” report.

The report highlighted the potential of the North Sea to decarbonise the economy. It underlined the importance of large-scale carbon capture and storage to reach emission reduction targets, and advocated for a stronger focus on these technologies.

It also outlined how the North Sea can be home to offshore wind, zero-carbon fuels production and distribution and an international network of subsea cables – which can together pave the way for a zero-carbon economy in Norway and Europe.

"The North Sea offers the perfect place for secure storage of CO_2. Vast storage capacity is available, enough for Norway to create a new export industry for European countries needing a safe storage site. CCS also enables the production of blue hydrogen required to scale Norway and Europe's hydrogen infrastructure over the decades to come," said Mona Mølnvik, NCCS Centre Director.

The report was part of the Centres’ common goal of contributing to fact-based policymaking. It was presented at both the Norwegian political festival Arendalsuka, and constituted the foundation for advice to policymakers at COP26.

Linking large-scale, cost-effective, permanent offshore storage across the value chain (LINCCS)
In 2021, NCCS and LowEmission launched a joint innovation sprint for Norway’s Grønn platform (Green platform) initiative. LINCCS was awarded in September 2021, and will be led by Aker Solutions.

LINCCS accelerates the creation of green jobs in Norway, while providing a substantial contribution to mitigating climate change, by:

1. Developing and deploying selected cost-effective technologies to enable distributed capture and storage of CO_2 at large scale, and
2. Repurposing the valuable infrastructure and solid competencies present on the Norwegian Continental Shelf (NCS) towards climate friendly business models.

The LINCCS project will kick-off in 2022.

SINTEF Energy Research’s Francesco Finotti presents LINCCS on behalf of Aker Solutions.

The Norwegian Continental Shelf: A Driver for Climate-Positive Norway (NCS C+)

NCS C+ is a KSP project associated with LINCCS, and led by SINTEF Energy.

Its goal is to advance the development of four climate-positive solutions to achieve Norway’s and Europe’s climate-neutral ambitions, and, in doing so, leverage the assets of the Norwegian Continental Shelf to enable a Norwegian leadership on climate-positive technologies.

NCS C+ will kick-off in 2022.

INTERNATIONAL **COOPERATION**

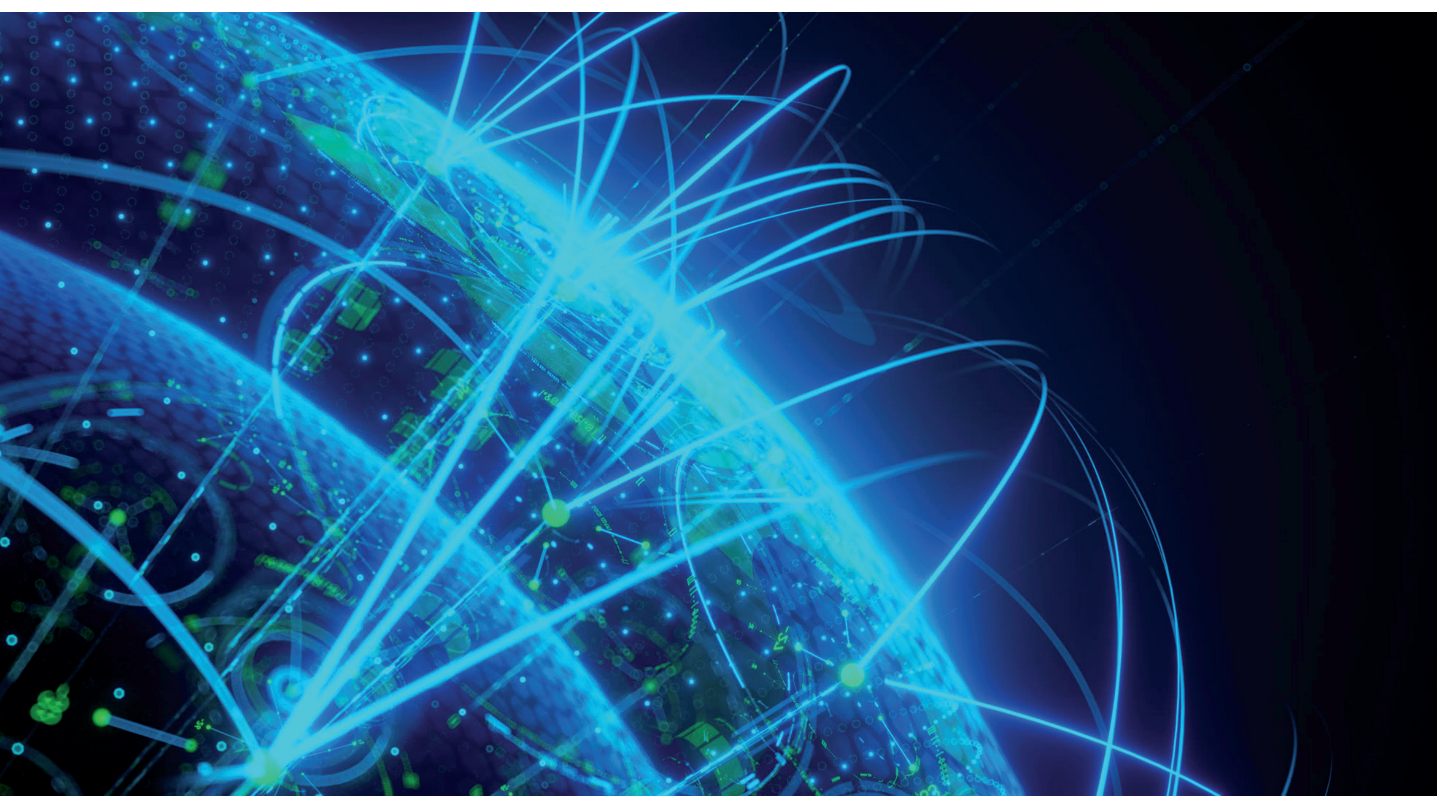
Strategic activities in Europe

Active participation in organisations spearheading strategic CCS development across Europe is a priority for NCCS.

In this way, NCCS and Norway can contribute to the agenda-setting of CCS.

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



Since 2010, Nils Røkke has 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. A focus on improving the CCS funding situation in the recently released FP9 (Horizon Europe) program continues.

NCCS interacts with the US National Energy Technology Laboratory (NETL), and the UK CCS Research Centre (UKCCSRC). The NCCS Centre Director has a seat in the UKCCSRC Board.

ACT Projects (as of 2021)

NCCS collaborates on several projects through the **Accelerating CO_2 Technologies (ACT**) scheme, which is co-funded by ERA-NET. Although ACT was initially a European initiative, it later opened for applications from all countries. It was open for funding applications from 2016 to 2021.

Name	Accelerating Carbon Capture using Oxyfuel technology in Cement production (ACO^{2}CEM)
Description	AC^{2}OCem is exploring the 1st generation oxyfuel for retrofitting, focusing on optimization of the oxyfuel calciner operation and advancing the kiln burner technology for combusting up to 100% alternative fuels with high biogenic share to bring this Bio-CCS solution to TRL6.
Duration	2019-2023

Name	Process-Informed design of tailor-made Sorbent Materials for energy-efficient carbon capture (PrISMa)
Description	The PrISMa project aims to accelerate the transition of energy and industrial sectors to a low-carbon economy by developing a technology platform to tailor-make cost-efficient carbon capture solutions for a range of different CO_2 sources and CO_2 use/destinations.
Duration	2019-2022

Name	Lowering absorption process uncertainty, risks and costs by predicting and controlling amine degradation (LAUNCH)
Description	LAUNCH is a three-year project aimed at accelerating the implementation of carbon dioxide (CO_2) capture across industry and enabling the development of novel solvents to support widespread deployment of carbon capture, utilization, and storage (CCUS).
Duration	2019-2022

Name	Reusing existing wells for CO_2 storage operations (REX-CO_2)
Description	REX-CO_2 increases the technical feasibility and economic competitiveness of high-potential depleted hydrocarbon fields earmarked for CO_2 storage.
Duration	2019-2022

Name	Re-use of depleted oil and gas fields for CO_2 sequestration (RETURN)
Description	The RETURN project aims to enable safe and cost-efficient long-term CO_2 storage in depleted O&G reservoirs by understanding and handling cooling and CO_2 phase change effects during injection.
Duration	2021-2024

Name	Sustainable OPEration of post-combustion Capture plants (SCOPE)
Description	SCOPE aims to accelerate large scale CO_2 capture projects by providing critical data, methodologies and tools that are essential for plant owners and regulators engaged in managing emissions and permitting processes. This project will also enable connections between diverse stakeholders to facilitate much-needed knowledge exchange on technical and regulatory developments.
Duration	2021-2024

Name	SHARP Storage
Description	SHARP Storage aims to increase the accuracy of subsurface CO_2 storage containment risk management through the improvement and integration of subsurface stress models, rock mechanical failure and seismicity observations.
Duration	2021-2024

Other European projects (as of 2021):

Name	ACCSESS
Description	The ACCSESS concept is centred around the project vision to develop replicable CCUS pathways towards a climate-neutral Europe in 2050. ACCSESS will improve CO_2 capture integration in industrial installations (20-30% cost cuts) as a key element to accelerate CCUS implementation, address the full CCUS chain and the societal integration of CCUS.
Initiative	H2020 Innovation Action
Duration	2021-2024

Name	CCUS Projects Network
Description	The CCUS Projects Network comprises and supports major industrial projects under way across Europe in the field of carbon capture and storage (CCS) and carbon capture and utilisation (CCU). The Network aims to speed up delivery of these technologies, which the European Commission recognises as crucial to achieving 2050 climate targets.
Initiative	H2020 CSA
Duration	2019-

Name	ECCSELERATE
Description	ECCSELERATE is an EU-funded Horizon 2020 project aimed at increasing the use and ensuring the long-term sustainable operation of the ECCSEL ERIC RI. ECCSEL is currently in its early operational phase as a European Research Infrastructure Consortium (ERIC), and needs to ramp-up to an advanced stage of operation.
Initiative	H2020 Research and Innovation Action
Duration	2020-2023

Name	Chinese-European Emission-Reducing Solutions (CHEERS)
Description	The CHEERS project involves a 2nd generation chemical-looping technology tested and verified at laboratory scale (up to 150 kW_{th}). Within five years, the core technology will be developed into a 3 MW_{th} system prototype for demonstration in an operational environment. This constitutes a major step towards large-scale decarbonisation of industry, offering a considerable potential for retrofitting industrial combustion processes.
Initiative	H2020 Research and Innovation Action
Duration	2017-2022

Name	Subsurface Evaluation of Carbon Capture and Storage and Unconventional Risk (SECURe)
Description	SECURe gathers scientific evidence relating to monitoring the environment and mitigating risk in order to guide subsurface geoenergy development. It produces a set of best practice recommendations for establishing environmental baseline conditions for unconventional hydrocarbon production and the geological storage of anthropogenic CO_2, including outputs addressing how to develop effective communications strategies with different stakeholder groups. The two technologies have different applications and end results while sharing some similarities in approach, which necessitate safe and monitored deployment.
Initiative	H2020 Research and Innovation Action
Duration	2018-2021

Name	IMPACTS9
Description	IMPACTS9 supports the delivery of the R&I activities outlined in the implementation plan for CCUS through the provision of coordination and support to the key public and private stakeholders that are well placed to progress the SET-Plan Implementation Plan actions in the near term.
Initiative	Horizon 2020 project (Coordinated and Support Action)
Duration	2019-2022

Name	Decarbonising refineries through CCUS (REALISE CCUS)
Description	The REALISE CCUS project unites industry experts and scientists from different nations in a concerted drive to support the refinery sector's decarbonisation ambitions.
Initiative	H2020 Innovation Action
Duration	2020-2023

NCCS Mobility Program

Researcher mobility can be a catalyst for innovation, networking, knowledge sharing, and dissemination between research institutions and partners that cannot be achieved as effectively remotely. Therefore, NCCS has launched a dedicated mobility program to facilitate these activities. As of 2021, eight mobility grants have been funded.

Unfortunately, due to restrictions on travel in connection with the COVID-19 pandemic, the Mobility Program had to be put on hold in 2020. However, the program was officially relaunched on 10 November 2021, with funding to be made available from January 2022, based on first come-first serve applications.

2020 Mobility Award Recipient Sai Gokul Subraveti now works as a research scientist at SINTEF Energy Research.

Strategic cooperation with other countries (2021)

Canada

Cooperation with University of Alberta is ongoing with focus on reducing costs for low carbon hydrogen production based on adsorption-based CO_2 capture technologies. Former PhD candidate at the university, Sai Gokul Subraveti, now works as a research scientist at SINTEF Energy Research, and is part of Task 1.

USA

Sandia NL at Combustion Research Facility, Livermore, CA is a very active research partner contributing to hydrogen combustion activities [Task 5].

One publication is written as a cooperation between Ruhr Universität Bochum and NIST (USA). Title: Fundamental Thermodynamic Models for Mixtures Containing Ammonia. Sent to Fluid Phase Equilibria [Task 8].

Cooperation with University of Texas Austin and their projects in the Gulf of Mexico is established under the new spin-off project FRISK. PhD student Johnathon Osmond has received a NCCS mobility stipend and will visit Austin on a mobility grant after COVID-19 [Task 9].

Fruitful cooperation with Staff Scientist Jaisree Iye from Lawrence Livermore and Research Engineer Greg Lackey from National Energy Technology Laboratory about the Well Integrity Atlas. LLNL is partner in NCCS and NETL has obtained additional funding from the US Department of Energy [Task 10].

Cooperation with Lawrence Livermore National Labs on monitoring of well integrity [Task 12].

Other countries (2021)

Cooperation with TU Munich (Germany) as part of the KSP project "ReHeat2H2". TUM is providing a unique experimental setup [Task 5].

Collaboration with the Toulouse Institute of Fluid Mechanics (IMFT) (France) on numerical simulations of H2 combustion is ongoing. As part of this work, PhD student Tarik Yahou is spending approximately 1/3 of his time at IMFT [Task 5].

Cooperation with the Mont Terri laboratory (Switzerland) and Herriot Watt University in Edinburgh (Scotland) has been established for the FRISK KSP project. As part of this work, PhD student Peter Betlem had a short research stay in Netherlands, where he spent time with Shell's DETECT project and Vrije Universiteit Amsterdam [Task 9].

Cooperation with University of Southampton (Great Britain) for EM4CO2, with the aim of developing electromagnetic methods for CO_2 monitoring [Task 12].

Cooperation with BGS (Great Britain), which contributes with analysis methods for seismic data. [Task 12].

NCCS **AWARDS**

Two best paper awards

Two papers authored by NCCS consortium members won awards in 2021:

1. A joint NTNU-Ansaldo paper, *Acoustic-Convective Interference In Transfer Functions of Methane/ Hydrogen and Pure Hydrogen Flames* by Eirik Æsøy, José G. Aguilar, Mirko R. Bothien, Nicholas A. Worth and James R. Dawson, was chosen as one of the Best Papers by the Combustion, Fuel, and Emissions Committee at the 2021 ASME Turbo Expo Virtual Conference.

According to the Committee: "Each year, the Technical Committees select a paper published at ASME TURBO EXPO to receive their committee's Best Paper award. This is an opportunity to recognize outstanding technical papers, to acknowledge the author's contributions to the gas turbine industry, and to support and maintain the high quality of papers presented by each committee."

2. *Predicting the influence of hydrogen in combustion instabilities* by Jose Aguilar, Eirik Æsøy and James Dawson won the Best Fundamental Paper award at the Symposium on thermacoustics in Combustion: Industry meets academia (SOTIC conference).

Other awards

Professor Marco Mazzotti from ETH Zürich was awarded the *SINTEF and NTNU CCS Award* at TCCS-11. He has long been at the forefront of international CCS research and according to SINTEF's Nils Røkke, the award committee received letters of recommendation from universities, institutes and industry from all over the world.

His award winner's lecture focused on specific measures for the decarbonisation of Switzerland. He encouraged CO_2 capture for small organisations.

Tobias Neumann received his double PhD degree from Ruhr University in Germany (supervised by Professor Roland Span) and NTNU in Norway (supervised by Professor Jana Jakobsen). His dissertation received the *Eickhoff-Preis* award from the Ruhr University Bochum for the best dissertation in 2021 of the whole faculty of mechanical engineering. This amazing achievement exemplifies a special case of international collaboration and education within NCCS.

EDUCATION & **RECRUITMENT**

One of the most important tasks in NCCS is to train master's and doctoral candidates and post-doctoral researchers in CCS research. In doing so, the Centre contributes to renewing the pool of able scientists who will soon shoulder the responsibility of addressing technical challenges and furthering our knowledge and expertise – in industry, research and academia.

The work undertaken by our candidates is an integral part of achieving the objectives of the NCCS research program. Candidates solve real technical problems! By working closely with task families, candidates are exposed to "real-life" activities – together with industry partners and researchers – and produce highly relevant results. Their contributions are disseminated in high-impact journals, at international conferences, in blogs and in webinars. In 2021, our candidates produced 40 peer-reviewed journal articles.

We are pleased to see that the proportion of female candidates recruited to the academic programme increased to 67% in 2021 from 50% in 2020. Women now comprise 25% of PhD candidates and 45% of postdoc researchers recruited so far. However, we are not yet satisfied and will continue our efforts to achieve a more equal gender balance.

The 2021 Consortium Days event was an opportunity for candidates to meet and interact with industry representatives, who showed great interest in their findings. The event gave students, who are normally laser-focused on a specific area, the opportunity to network with others from along the CCS chain.

PhD Candidate Peter Betlem and Postdoctoral Researcher Siân Evans both gave presentations on their work at the NCCS Consortium Days event.

PhD Students working in 2021

Name	Affiliation	Funding	Task	Gender	Nationality	Period
Vegard Bjerketvedt	NTNU	NCCS	1	M	Norway	11/2017-2022
Olaf Lehn Tranås	NTNU	NCCS	1	M	Norway	09/2020-08/2023
Heidi Syndes Egeland	UiO	NCCS	1	F	Norway	11/2020-11/2024
Lucas Braakhuis	NTNU	NCCS	2	M	Netherlands	10/2019-10/2022
Vanja Buvik	NTNU	NCCS	2	F	Norway	09/2017-08/2021
Eirik Æsøy	NTNU	NCCS	5	M	Norway	03/2018-03/2022
Tarik Yahou	NTNU	NCCS	5	M	Algeria	10/2020-10/2023
Alexandra Metallinou Log	NTNU	NCCS	7	F	Norway	08/2020-08/2023
Anne-Sophie Sur	NTNU	NCCS	7	F	Germany	01/2020-01/2023
Tobias Neumann	RUB/NTNU	NCCS	8	M	Germany	01/2017-12/2021
Johnathon Osmond	UiO	NCCS	9	M	USA	10/2017-12/2021
Peter Betlem	UNIS	NCCS	9	M	Netherlands	03/2019-03/2023
Magnus Soldal	NTNU	NCCS	9	M	Norway	06/2019-08/2022
Camilla Louise Würtzen	UiO	NCCS	9	F	Denmark	10/2018-03/2022
Nora Holden	UiO	NCCS	9	F	Norway	08/2021-02/2025
Marcin Duda	NTNU	NCCS	10	M	Poland	01/2018-2022
Shamim Homaei	NTNU	NCCS	1	F	Iran	10/2021-10/2024
Florian Franke	TUM	KSP ReHeat2H2	5	M	Germany	09/2019-08/2022
Seyed Ehsan Hosseini	NTNU	KSP TOPHOLE	12	M	Iran	02/2020-02/2023
Mohammad Masoudi	UiO	KSP POREPAC	10	M	Iran	11/2018-12/2021
Amirreza Mottaghitalab	NTNU	KSP CCShip	6	M	Iran	08/2021-08/2024
Bahareh Khosravi	NTNU	NCCS	8	F	Iran	12/2018-11/2022
Zhongxuan Liu	NTNU	KSP MACH-2	3	F	China	06/2020-06/2021
Harish Subramanian	NTNU	KSP ReHeat2H2	5	M	India	01/2020-01/2023

Postdocs working in 2021

Name	Affiliation	Funding	Task	Gender	Nationality	Period
Mark Mulrooney	UiO	NCCS	9	M	Ireland	09/2017-09/2021
Viktor Weber	UiO	NCCS	1	M	Hungary	08/2018-09/2021
Sian Lianne Evans	UiO	NCCS	9	F	UK	12/2020-06/2024
Emma Michie Haines	UiO	KSP FRISK	9	F	UK	02/2020-08/2023

COMMUNICATION

Achieving the Centre's vision of fast-tracking CCS deployment requires sharing knowledge and findings within the CCS scientific community, and with industrial and political stakeholders. Results can also help to build public acceptance. Therefore, dissemination and communication activities play a key role in reaching the Centre's goals.

Against the continued backdrop of the pandemic, digital communication continued to play a vital role throughout 2021. Digital tools have been utilised throughout NCCS' lifetime, but they have proved much more important over the past two years, not least in the successful online execution of the TCCS-11 conference. That being said, the Communications team was also on hand to support Consortium Days, the first in-person NCCS event in more than 18 months.

Strategic communication efforts

Together with several other FMEs, NCCS took part in the important political events Arendalsuka in Norway and COP26 in Glasgow. The Centre supported the conception and development of a North Sea strategy document in both Norwegian and English.

At COP26, Nils Røkke (in person) and Mona Mølnvik (via video) participated in a side event focused on the North Sea as a springboard for the future green economy. The event was live-streamed.

Media appearances

Centre Director Mona Mølnvik made a number of appearances in Norwegian-language media over the course of the year.


Forskningsrådet

NYSGJERRIGPER

MENY

Vis lenker

Hvor mye hjelper det å fange CO2?

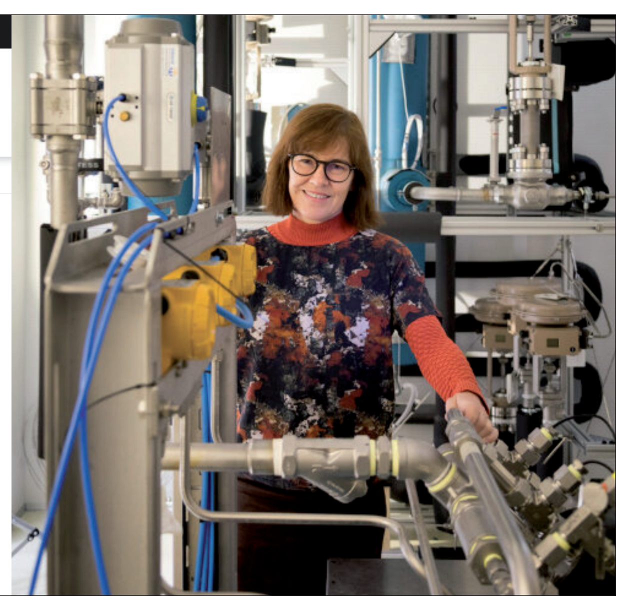
Vi må slippe ut mindre klimagasser, sier forskerne. CO2-fangst er bare én del av løsningen.

Av Marianne Nordahl | Publisert 01.02.2021 — Del | Last ned

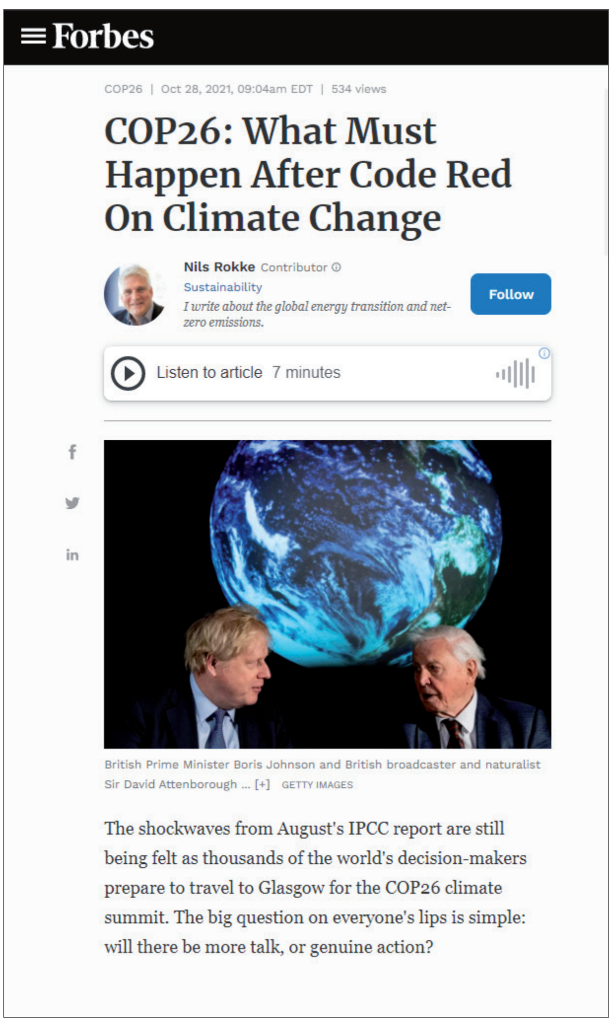
Det viktigste verden kan gjøre, er å erstatte kull, olje og gass med fornybar energi fra sol, vind, vann, biologisk materiale og lignende, sier klimaforsker Helge Drange til Nysgjerrigper.

Energi fra olje, gass og kull – såkalt fossil energi – slipper ut ekstremt mye av verdens CO2.

Utslippet er stort når den fossile energien produseres, og enda større når energien brukes.



Back in February, she was interviewed for a story by *Nysgjerrigper*, the magazine and website (www.nysgjerrigper.no) from the Research Council of Norway aimed at curious schoolchildren. Later in the year, she also appeared on an episode of the SINTEF podcast *Smart Forklart* (Cleverly Explained) to discuss the potential for CCS and how the technology works. At Consortium Days, Mona was interviewed by Norwegian newspaper *VG* for an explainer video that came out in early 2022. In international media, Nils Røkke made several mentions of the work of NCCS in his regular sustainability column at *Forbes*.



Forbes

COP26 | Oct 28, 2021, 09:04am EDT | 534 views

COP26: What Must Happen After Code Red On Climate Change

Nils Rokke Contributor
Sustainability
I write about the global energy transition and net-zero emissions.

Follow

Listen to article 7 minutes

British Prime Minister Boris Johnson and British broadcaster and naturalist Sir David Attenborough ... [+] GETTY IMAGES

The shockwaves from August's IPCC report are still being felt as thousands of the world's decision-makers prepare to travel to Glasgow for the COP26 climate summit. The big question on everyone's lips is simple: will there be more talk, or genuine action?

A digital approach to TCCS-11

A lot of communications effort went into the planning and promotion of TCCS-11. As a fully digital event, the requirements for online marketing and promotion were significant. The work began with the development of a strategy to attract a more global audience and more students following the decision to make the event free for Master students and heavily discounted for PhDs. The production of a media kit, blog posts and interviews with key speakers were other important communication activities.

During the event, a number of blog posts and news releases were published. The communications team were also on hand to support queries from media representatives that were in attendance.

Given the digital nature of the event, TCCS-11 attracted interest from more journalists than in previous years. It is hoped that these relationships will prove fruitful for more media coverage in the years to come.

Autumn webinars

Following on from the great success of the 2020 webinar series, researchers took to the popular video presentation format to communicate their results once again in 2021. Approximately 1,000 people in total participated in 18 webinars in the latter half of the year, building on the success of TCCS-11 and firmly cementing digital events as a cornerstone of our dissemination and communication strategy.

Blogs, website & newsletters

Researchers are encouraged to create blog posts about their tasks throughout the year. Many blog posts summarise project results or scientific publications, but targeted at different groups such as private industry or decision-makers in governments. Other blogs are aimed at fellow researchers working in CCS and related fields.

During 2021, 12 blogs were published across a variety of topics. The post titled 'Is CCS really so expensive?' was only published on December 13, but was still read by more than 1,000 people before the end of the year.

The blog post titled 'NCCS Research & Norway's Longship' was published in 2020 but continued to perform well throughout 2021. A total of 376 pageviews shows the long-term value of producing searchable, findable content for the web.

#ENERGY CCS

Is CCS Really So Expensive?

BY NCCS
DECEMBER 13, 2021

COMMENTS 3

AUTHORS: SIMON ROUSSANALY (SINTEF), ANDREA RAMIREZ (TU DELFT) AND ELDA RODRIGUEZ (TU DELFT)

Results from a collaboration between SINTEF and Delft University of Technology (TU Delft), in connection with the Norwegian CCS Research Centre (NCCS), show that CCS implementation can have a minimal cost impact for end users while avoiding a significant amount of CO_2 emissions.

100 seconds to midnight

On 27 January 2021, the Bulletin of the Atomic Scientists announced that the Doomsday Clock continued to read 100 seconds to midnight, citing human-

#ENERGY CCS

NCCS Research & Norway's Longship

BY AMY BRUNSVOLD
DECEMBER 22, 2020

COMMENTS 1

WITH CONTRIBUTIONS FROM MONA MØLNVIK, GRETHE TANGEN, INNA KIM, ALVAR BRAATHEN, ELIN SKURTVEIT, PIERRE CERASI, PEDER ELIASSON, ALV-ARNE GRIMSTAD, SIMON ROUSSANALY, SOLRUN VEVELSTAD, JONATHAN POLFUS, DAVID BERSTAD, STIAN TRÆDAL, ANDREA GRUBER, RUBEN MOCHOLI MONTANES, SVEND TOLLAK MUNKEJORD, SIGURD W. LØVSETH AND MARIE BYSVEEN

What CCS is – and why it matters

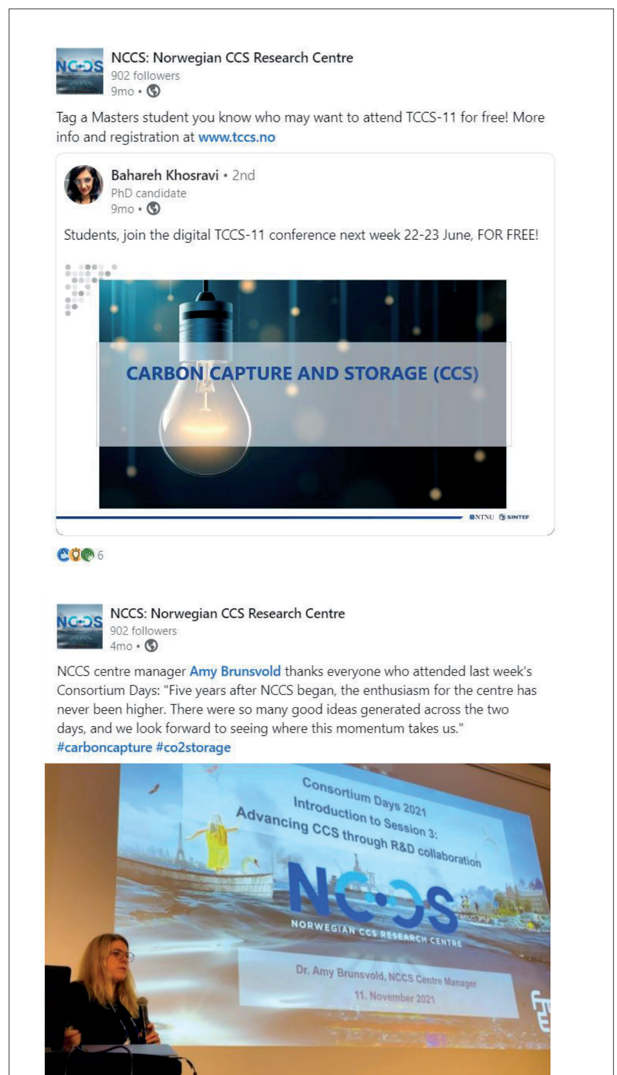
Carbon Capture, Transport & Storage (CCS) is a series of technologies and processes that aim to significantly

The website www.nccs.no was updated throughout the year with the latest news, as was the standalone website for TCCS-11 at www.tccs.no.

Nine newsletters were sent to the main NCCS newsletter list, which now has 391 subscribers. More NCCS-related newsletters were sent to a specific webinar newsletter list, established during the year, and the TCCS newsletter list.

Social media

The NCCS LinkedIn page has been established for little over a year but has already become the primary social media channel for engagement. The number of followers increased from 300 to more than 750 over the course of the year.



NCCS: Norwegian CCS Research Centre
902 followers
9mo •

Tag a Masters student you know who may want to attend TCCS-11 for free! More info and registration at www.tccs.no

Bahareh Khosravi • 2nd
PhD candidate
9mo •

Students, join the digital TCCS-11 conference next week 22-23 June, FOR FREE!

CARBON CAPTURE AND STORAGE (CCS)

6

NCCS: Norwegian CCS Research Centre
902 followers
4mo •

NCCS centre manager Amy Brunsvold thanks everyone who attended last week's Consortium Days: "Five years after NCCS began, the enthusiasm for the centre has never been higher. There were so many good ideas generated across the two days, and we look forward to seeing where this momentum takes us."
#carboncapture #co2storage

It's noticeable how the followers on LinkedIn have an excellent match with the target audiences of NCCS communications work, and how much more reach there is compared with other social networks. Despite the page having 750 followers, several posts reached thousands of relevant people.

The NCCS communications team also maintains a Twitter account (@FME_NCCS). At the end of 2021 it had 875 followers, an increase of 175 over the past 12 months.

Communications survey

As the Centre is now five years old, we decided to conduct a communications survey among the partners to adjust the communications strategy for the changing needs of the Centre.

While the results were not intended for public dissemination, the survey turned up several interesting suggestions that the communications team will consider taking forward, including social events, audio interviews, educational material and more dissemination events aimed at specific target groups.

Welcome to Jessica

The end of 2021 also saw a change in the main communications contact for NCCS. David Nikel is leaving SINTEF Energy Research and has handed over responsibility for communications to Jessica Scott. Jessica is a native English speaker with fluent Norwegian skills and an academic background. Many of you will have met Jess at the NCCS Consortium Days, and she looks forward to helping you share the best stories from your NCCS research in the months and years to come.

APPENDIX

NCCS Publications Registered in Cristin

Peer Reviewed Journal Publications

Search criteria: From 2021. Sub-category: Academic article. Sub-category: Academic literature review. Sub-category: Short communication. *All publishing channels*

1. Michie, Emma Alexandra Harrower; Kaminskaite, Ieva; Cooke, Andrew; Fisher, Quentin J.; Yielding, Graham; Tobiss, Samuel. Along-strike permeability variation in carbonate-hosted fault zones. Journal of Structural Geology 2021; Volume 142.
2. Banet, Catherine. Regulating the reuse and repurposing of oil and gas installations. #SINTEFblog 2021. UiO
3. Betlem, Peter; Roy, Srikumar; Birchall, Thomas; Hodson, Andrew; Noormets, Riko; Römer, Miriam; Skogseth, Ragnheid; Senger, Kim. Modelling of the gas hydrate potential in Svalbard's fjords. Journal of Natural Gas Science and Engineering 2021; Volume 94. UNIS UiO HVL
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74. Torsæter, Malin; Dupuy, Bastien; Romdhane, Mohamed Anouar; Zonetti, Simone. Avoiding CO_2 leakage through active and abandoned wellbores. EAGE Transition Series, Putting carbon underground; 2021-04-27 - 2021-04-27. SINTEF
75. Vevelstad, Solrun Johanne; Grimstvedt, Andreas Magnar; da Silva, Eirik F. Current state of understanding of degradation of amines used for post-combustion CO_2 capture. Post Combustion Capture Conference (PCCC6); 2021-10-19 - 2021-10-21. SINTEF
76. Vevelstad, Solrun Johanne; Grimstvedt, Andreas Magnar; Haugen, Geir; Wiig, Merete; Vernstad, Kai. Evaluation of results from SDR campaigns and pilot data. Trondheim Carbon Capture and Storage Conference (TCCS-11); 2021-06-22 - 2021- 06-23. SINTEF
77. Xie, Xiyang; Edvardsen, Laura; Cerasi, Pierre. CO_2-Induced Creep on Draupne Shale and Impact on Cemented Wellbore Integrity. 55th U.S. Rock Mechanics/ Geomechanics Symposium, Virtual, June 2021.; 2021-06-18 - 2021-06-25. SINTEF

NCCS Papers Registered in Cristin

Peer Reviewed Papers

Search criteria: Sub-category: Academic chapter, article and conference paper. *All publishing channels*

1. Banet, Catherine. Regulering av karbonfangst, transport og lagring i norsk rett. I: Klimarett - internasjonal, europeisk og norsk klimarett mot 2030. Universitetsforlaget 2021 VAVis.L_Isbn 9788215043425. VAVis.T_Side-Forkortelse520-556.UiO
2. Berge, Runar Lie; Gasda, Sarah Eileen; Keilegavlen, Eirik; Sandve, Tor Harald. Effective permeability of deformation bands in fault damage zones – Can deformation bands reduce the risk of fault leakage?. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. UiB NORCE

3. Bjørnarå, Tore Ingvald; Haines, Emma Michie; Skurtveit, Elin. Upscaled Geocellular Flow Model of Potential Across-and along-Fault Leakage Using Shale Gouge Ratio. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse366-373. UiO NGI
4. Braakhuis, Lucas; Knuutila, Hanna K. Modelling and Evaluating Carbamate Polymerization of Monoethanolamine in Post-Combustion Carbon Capture. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse212-217. NTNU
5. Buvik, Vanja; Strimbeck, Richard; Knuutila, Hanna K. Experimental Assessment of the Environmental Impact of Ethanolamine. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse207-211. NTNU
6. Buvik, Vanja; Thorstad, Silje; Ramos Wanderley, Ricardo; Knuutila, Hanna K. Introduction of Potassium Iodide as an Inhibitor for Oxidative Degradation of Amines. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse91-95. NTNU
7. Emmel, Benjamin; Zonetti, Simone; Romdhane, Mohamed Anouar; Dupuy, Bastien; Torsæter, Malin. From Pre-Screening to Monitoring of Plugged and Abandoned Marine Exploration Wells - Enabling Reuse of Reservoirs for CO_2 Storage through Geophysical Monitoring. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse254-258. SINTEF
8. Gehrmann, Romina; Romdhane, Mohamed Anouar; Park, Joonsang; Eliasson, Peder. CSEM for CO_2 Storage – Feasibility Study at Smeaheia to Optimise Acquisition. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse455-461. SINTEF NGI
9. Grimstad, Alv-Arne; Klemetsdal, Øystein Strengehagen. Efficiency of CO_2 Foam Mobility Control with Heterogeneous Reservoir Properties. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse398-403. SINTEF
10. Haines, Emma Michie; Braathen, Alvar; Alaei, Behzad. How Fault Interpretation Method may Influence the Assessment of a Fault-Bound C02 Storage Site. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse297-303. UiO
11. Hosseini, Seyed Ehsan; Zonetti, Simone; Romdhane, Mohamed Anouar; Dupuy, Bastien; Arntsen, Børge. Artificial Intelligence for Well Integrity Monitoring Based on EM Data. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse152-154. SINTEF NTNU
12. Khosravi, Bahareh; Løvseth, Sigurd Weidemann; Austegard, Anders; Einen, Caroline; Stang, Hans Georg Jacob; Snustad, Ingrid; Jakobsen, Jana Poplsteinova; Rekstad, Inge Håvard. A new facility on accurate viscosity and density measurements. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse443-449. ENERGISINT NTNU
13. Løvseth, Sigurd Weidemann; Arellano Prieto, Yessica Alexandra; Deng, Han; Finotti, Francesco; Jukes, Edward; Bottino, Gerard. Enabling CCS via fiscal metering. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse474-481. ENERGISINT
14. Neumann, Tobias; Bernhardsen, Ida; Knuutila, Hanna K; Jakobsen, Jana Poplsteinova; Span, Roland. Thermodynamic Properties of The Binary Mixture of Monoethanolamine and Carbon Dioxide. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag

2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse143-148. NTNU

15. Rahman, Md Jamilur; Choi, Jung Chan; Fawad, Manzar; Mondol, Nazmul Haque. Probabilistic Analysis of Draupne Shale Caprock Reliability of the Alpha Prospect - A Potential CO_2 Storage Site in the Smeaheia Area, Northern North Sea. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse127-134. UiO NGI
16. Soldal, Magnus; Skurtveit, Elin; Choi, Jung Chan. Poroelastic and Mechanical Anisotropy of the Draupne Caprock. I: 55th U.S. Rock Mechanics/Geomechanics Symposium. American Rock Mechanics Association (ARMA) 2021 VAVis.L_Isbn 978-0-9794975-6-8. NGI UiO
17. Sævareid, Ove; Mykkeltvedt, Trine Solberg; Gasda, Sarah Eileen. PVT and flow behaviour of impure CO_2 in aquifers. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse415-419. NORCE
18. Tangen, Grethe; Kim, Inna; Brunsvold, Amy; Mølnvik, Mona J.; Vevelstad, Solrun Johanne; Skurtveit, Elin; Roussanaly, Simon; Munkejord, Svend Tollak; Cerasi, Pierre; Eliasson, Peder. Impact of innovations from the Norwegian CCS Research Centre - NCCS. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse541-546. ENERGISINT NGI SINTEF
19. Vevelstad, Solrun Johanne; Grimstvedt, Andreas Magnar; Haugen, Geir; Wiig, Merete; Vernstad, Kai. Evaluation of Results from SDR Campaigns and Pilot Data. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse35-39. SINTEF
20. Watson, Francesca; Andersen, Odd; Nilsen, Halvor Møll. Rapid Optimisation of the New Sleipner Benchmark Model. I: TCCS–11. CO_2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021. Short Papers from the 11th International Trondheim CCS Conference. SINTEF akademisk forlag 2021 VAVis.L_Isbn 978-82-536-1714-5. VAVis.T_SideForkortelse291-296. SINTEF

NCCS Multimedia Products Registered in Cristin

Multimedia Products

Search criteria: Sub-category: Multimedia product
All publishing channels

1. Brunsvold, Amy. A review: CCS and branding. Torund Bryhn 2021. ENERGISINT
2. Mølnvik, Mona J. CCS er Karbonfangst og lagring | Fangst og lagring av CO_2 | Teknologihovedstaden.no. Teknologihovedstaden.no 2021. ENERGISINT
3. Mølnvik, Mona J. Koster milliarder - slik skal Norge fange CO. VG TV 2021. ENERGISINT
4. Mølnvik, Mona J. Slik fungerer CO_2-fangst og -lagring. SINTEF Energi AS Trondheim2021
5. ENERGISINT
6. Mølnvik, Mona J. 4 år med NCCS forskning. SINTEF Energi 2021. ENERGISINT
7. Røkke, Nils Anders. Arendalsuka: Nordsjøen som plattform for grønn omstilling. SINTEF Energi 2021. ENERGISINT
8. Røkke, Nils Anders. Møt oss på Arendalsuka 16 august. SINTEF Energi 2021. ENERGISINT
9. Røkke, Nils Anders; Hustad, Johan Einar. North sea - three recommendations. SINTEF Energi 2021. ENERGISINT NTNU
10. Røkke, Nils Anders; Hustad, Johan Einar. 3 råd: Slik kan Nordsjøen bli en plattform for grønn omstilling. SINTEF Energi 2021. ENERGISINT NTNU

NCCS Op-eds Registered in Cristin

Op-eds

Search criteria: Sub-category: Feature article. Sub-category: Editorial. *All publishing channels*

1. Røkke, Nils Anders. Ammonia: A Sustainable Fuel Option For Shipping. Forbes (online edition) 2021. ENERGISINT
2. Røkke, Nils Anders. Blue Hydrogen Isn't The Climate Enemy, It's Part Of The Solution. Forbes (online edition) 2021. ENERGISINT
3. Røkke, Nils Anders. COP26: What Must Happen After Code Red On Climate Change. Forbes (online edition) 2021. ENERGISINT
4. Røkke, Nils Anders. Why Bioenergy Matters In Our Future Sustainable Energy System. Forbes (online edition) 2021. ENERGISINT
5. Røkke, Nils Anders; Hustad, Johan Einar. Slik kan vi gjøre norsk sokkel til Europas grønne muskel. Dagens næringsliv 2021. ENERGISINT NTNU

NCCS Blogs and Information Material Registered in Cristin

Blogs and Information Material

Search criteria: Main category: Information material(s)
All publishing channels

1. Aarlien, Rune. TCCS goes virtual. ENERGISINT
2. Aarlien, Rune. TCCS-11: A Virtual Success. ENERGISINT
3. Aarlien, Rune. TCCS-11: Discount for Easter Early Birds. ENERGISINT
4. Aarlien, Rune. TCCS-11 Plenary Program Announced. ENERGISINT
5. Aarlien, Rune. TCCS-11: The Impact of Climate Change on Biodiversity. ENERGISINT
6. Bruhn, Rikke; Catherine, Braathen. https://www.mn.uio.no/geo/english/research/projects/nccs-geo-uio/. UiO
7. Buvik, Vanja; Knuutila, Hanna K. When little things have a big impact. NTNU
8. Egeland, Heidi Sydnes. Incentivising Carbon Capture and Storage under the Emission Trading System – Accommodating Mobile CO Transport. UiO
9. Gardarsdottir, Stefania Osk. Skal forske på CO_2-fangst på skip. ENERGISINT
10. Grimstad, Alv-Arne. CCS: How Much Does It Cost To Increase Storage Efficiency?. SINTEF
11. Grimstad, Alv-Arne; Raphaug, Martin Hagen; Todorovic, Jelena; Cerasi, Pierre. Salt Precipitation Experiments for Improved CO Storage. SINTEF
12. Mølnvik, Mona J. NCCS 2020 annual report. ENERGISINT
13. Mølnvik, Mona J. TCCS-11: A Virtual Success. ENERGISINT
14. Mølnvik, Mona J. TCCS-11 Plenary Program Announced. ENERGISINT
15. Mølnvik, Mona J. TCCS-11: Recognising Breakthroughs in CCS Research. ENERGISINT
16. Mølnvik, Mona J. TCCS-11: The Impact of Climate Change on Biodiversity. ENERGISINT
17. Roussanaly, Simon. CCShip: Cutting CO Emissions from Shipping. ENERGISINT
18. Roussanaly, Simon. Er CO-fangst og lagring dyrt?. ENERGISINT
19. Roussanaly, Simon. Is CCS Really So Expensive?. ENERGISINT
20. Røkke, Nils Anders. Tre råd til politikere for grønn omstilling av Nordsjøen. ENERGISINT
21. Røkke, Nils Anders; Hustad, Johan Einar. Arendalsuka 2021: Tre råd til politikere for grønn omstilling av Nordsjøen. ENERGISINT NTNU
22. Røkke, Nils Anders; Tomasgard, Asgeir. #COP26: The North Sea as a springboard for the green transition Three recommendations. ENERGISINT NTNU
23. Røkke, Petter Egil; Hustad, Johan Einar. Tre råd til politikere for grønn omstilling av Nordsjøen. ENERGISINT NTNU
24. Scott, Jessica Ruth. 'Welcome Back': NCCS Consortium Days 2021. ENERGISINT
25. Tande, John Olav Giæver; Kvamsdal, Trond. Høringssvar om havvind fra SINTEF og NTNU Kunnskapsbasert utvikling, kvalitative konkurranser og raskt tempo. ENERGISINT NTNU
26. Tande, John Olav Giæver; Røkke, Nils Anders. SINTEF at COP26: SINTEF Climate Fund, North Sea, market mechanisms and green shipping on the agenda. ENERGISINT
27. Tangen, Grethe. CODataShare Releases Smeaheia CO Storage Dataset. SINTEF

NCCS Media Contributions Registered in Cristin

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

1. Betlem, Peter; Expedition 396 Scientists, IODP. Livestream from the IODP drillship the JOIDES Resolution. Zoom session [Internet] 2021-10-29. UNIS
2. Melteig, Elina; Bruhn, Rikke Elsøe; Bjartnes, Anders. Karbonfangst og -lagring kan bli en norsk eksportvare. Titan [Internet] 2021-10-08. UiO
3. Mølnvik, Mona J. Aker : and Partners Aim to Reduce CO_2 Transportation and Permanent Storage Costs by 70 Percent. Marketscreener [Internet] 2021-09-07. ENERGISINT
4. Mølnvik, Mona J. AKER SOLUTIONS LAUNCHES RESEARCH PROJECT TO SIGNIFICANTLY REDUCE CARBON-STORAGE COSTS. Chemical engineering [Business/trade/industry journal] 2021-09-09. ENERGISINT
5. Mølnvik, Mona J. Ga aldri opp fangst og lagring. NRK [Internet] 2021-05-06. ENERGISINT
6. Mølnvik, Mona J. Hvor mye hjelper det å fange CO_2?. Nysgjerrigper [Internet] 2021-02-01. ENERGISINT
7. Mølnvik, Mona J. Kan vi fange klimagassen og sende den til havets bunn?. Nysgjerrigper [Internet] 2021-02-01. ENERGISINT
8. Ringrose, Philip; Mølnvik, Mona J. The Longship that could help save the planet. NTNU 2021. ENERGISINT NTNU

9. Roussanaly, Simon; Gardarsdottir, Stefania Osk. Skal forske på CO_2-fangst på skip. Metal supply [Business/trade/industry journal] 2021-05-26. ENERGISINT
10. Røkke, Nils Anders. Advantages and disadvantages of hydrogen as an alternative fuel. National Geographic [Journal] 2021-12-08. ENERGISINT
11. Røkke, Nils Anders. Antagelser – på godt og vondt. Dagens Næringsliv [Newspaper] 2021-08-30. ENERGISINT
12. Røkke, Nils Anders. Bellona readies its 'blue zone' presence at Glasgow's COP26. Bellona [Internet] 2021-10-14.
13. Røkke, Nils Anders. COP26 Event: Hvilken rolle har CCS i nullutslippssamfunnet 2050?. [Internet] 2021-11-03. ENERGISINT
14. Røkke, Nils Anders. Cost of polluting in EU soars as carbon price hits record €50. Daily UK News [Newspaper] 2021-05-04. ENERGISINT
15. Røkke, Nils Anders. CO_2-håndtering: Konferansen TCCS-11 arrangeres digitalt for første gang. [Newspaper] 2021-06-17. ENERGISINT
16. Røkke, Nils Anders. Digitalisation of energy. By innovation [Internet] 2021-01-20. ENERGISINT
17. Røkke, Nils Anders. Ferske energiprognoser fra IEA: Verden har passert «peak fossil». Cnytt.no [Internet] 2021-05-28. ENERGISINT
18. Røkke, Nils Anders. Hvordan Nordsjøen kan drive den grønne omstillingen. NordicNews [Internet] 2021-11-23. ENERGISINT
19. Røkke, Nils Anders. Is this breakthrough moment for carbon capture and storage?. Reuters events [Newspaper] 2021-04-07. ENERGISINT
20. Røkke, Nils Anders. Klimatoppmøtet bør ta grep der markedet ikke duger. E24 [Newspaper] 2021-10-27. ENERGISINT
21. Røkke, Nils Anders. LYTT and SINTEF to build CCS monitoring solutions. Oil Rreview Africa [Business/trade/industry journal] 2021-09-01. ENERGISINT
22. Røkke, Nils Anders. LYTT collaborates with SINTEF to support global climate targets. Oil Review Middle East [Business/trade/industry journal] 2021-09-01. ENERGISINT
23. Røkke, Nils Anders. Løsning i hallene. Stavanger Aftenblad [Newspaper] 2021-11-10. ENERGISINT
24. Røkke, Nils Anders. Netto null, ikke tull. Nidaros [Newspaper] 2021-05-23. ENERGISINT
25. Røkke, Nils Anders. Norwegian Prime Minister To Open Global Carbon Capture Summit. CleanTechnica [Business/trade/industry journal] 2021-05-11. ENERGISINT
26. Røkke, Nils Anders. Norwegian Prime Minister to Open Global Carbon Capture Summit. Oil and gas press [Newspaper] 2021-05-11. ENERGISINT

Financial statement for 2021

Costs	NOK
Personnel and indirect costs	25 264 000
Purchased R&D services	38 466 000
Equipment	1 587 000
Other operational costs	2 863 000
Total costs	**68 180 000**

Funding	NOK
Own funding	6 817 000
Other public funding	9 055 000
Other private funding	23 931 000
International funding	3 178 000
RCN funding	25 199 000
Total funding	**68 180 000**

Personnel

Master's degrees

Name	Sex M/F	Topic	Task	Year
Isabella Stellwag	F	Testing of Oxygen Removal technology	2	2017
Avinash S.R. Subramanian	M	Reducing Energy Consumption in the Production of Hydrogen from Natural Gas	6	2017
Niklas Hunka	M	Description of accurate viscosity setup for CCS	8	2017
Hong Yan	F	Rock physics inversion for CO2 characterization at Sleipner	12	2017
Veronica Alejandra Torres Caceres	F	Seismic Wave Attenuation in Partially Saturated Sandstone and AVO Analysis for Carbon Dioxide Quantification at Sleipner	12	2017
Morten Heide Feiring	M	Legal aspects of CO2 storage	1	2018
Henderson Pinto	M	2-D Full waveform inversion analysis for quantifying the injected CO2 at the Sleipner field	12	2018
Isa Adi Subagjo	M	Rock Physics Inversion for CO2 Characterization at Sleipner: Sensitivity Tests of multiphysics inversion	12	2018
Robin David Kifle	M	Geophysical data sensitivity in Smeaheia field	12	2018
Laura Sole Montana	F	Oxidative degradation of water lean solvents	2	2019
Marianne Laukvik	F	Quantification of nitrogen loss in oxidative degradation experimants using total nitrogen analyser	2	2019
Tonje Laukvik	F	Quantification of nitrogen loss in oxidative degradation experimants using total nitrogen analyser	2	2019
Sindre Ottøy	M	Investigation of CO2-N2-CH4 mixture: VLE measurements and analysis of Helmholtz energy-based EOS	8	2019
Elias Heimdal Leon	M	3D seismic characterisation of the “plumbing system” affecting the Smeaheia prospect: Discerning the connectivity between tectonic faults in the reservoir and polygonal faults and palaeo-pockmarks in the overburden. Qualitative characterisation using topology	9	2019
Jens Kolnes	M	Reconstruction of the uplift and subsidence history of Smeaheia, a proposed CO2 injection and storage site	9	2019
Sharon Harris	F	The uplift and subsidence history of the Cenozoic depositional sedimentary successions in Smeaheia, a proposed CO2 injection and storage site, and influence on overburden properties	9	2019
Ådne Bjerkeli	M	A detailed structural analysis of the Øygarden Fault and footwall bock. Implications for CCS in the Smeaheia prospect	9	2019
Scott Bunting	M	Value of information analysis in the context of leakage detection in CO2 storage	12	2019
Heidi Sydnes Egeland	F	CCS under the EU ETS: legal consequences of different methods for transporting CO2	1	2020
Johannes Dahlen Giske	M	Incentivising low carbon products under public procurement rules	1	2020
Alexandra Metallinou Log	F	Development and investigation of HLLC-type finite-volume methods for one and two-phase flow in pipes with varying cross-sectional area	7	2020
Helge Nipen	M	Tectonostratigraphic study in the triassic, Smeaheia	9	2020

Name	Sex M/F	Topic	Task	Year
Karoline Helene Løvlie	F	Structural deformation and mineralogy of the Agardhfjellet and Rurikfjellet formations in central Spitsbergen, Svalbard	9	2020
Lise Nakken	F	A caprock integrity evaluation of the lower Agarhdfjellet Formation for CO2 sequestration purposes	9	2020
Shajahat Ahmed	M	Structural analysis of Horda Platform and Stord Basin in the Norwegian North Sea using Machine Learning method	9	2020
Silje Thorstad	F	Experimental assessment of the oxidation inhibitor KI on fresh and pre-used amines	2	2021
Ingvild Emilie Solnes	F	Machine Learning Modelling of the Oxidative and Thermal Degradation of Monoethanolamine (MEA)	2	2021
Ida Ullsfoss	F	Modelling of thermal degradation	2	2021
Øyvind Lille-Mæhlum	M	Modelling Solvent Degradatio in Amine-based Post-combustion Carbon Capture	2	2021
Kristoffer Frøyd Eriksen	M	Modelling of Ductile Fracture in Steel Structures	7	2021
Nora Holden	F	Fault seal juxtaposition and CO2 migration in the early Jurassic Johansen Formation, Horda Platform	9	2021
Diana Carolina Alves Da Silva	F	Experimental study addressing fault slip stability	9	2021
Tord Alexander Buvik	M	Micromechanics and shear strength of fractured rocks	9	2021
Scott Adam Smith	M	Effects of fractures on seismic velocities in fault zones	12	2021
Eirik Nordås	M	Fault interpretation and characterization using machine learning	9	2022
Adrian Smith	M	Fault and fracture characterization in basement rocks of western Norway	9	2022
Ingrid Grendahl Vold	F	Structural analysis of the Gamma closure, northern Horda Platform	9	2022
Joseph Gubbi	M	Structural analysis of the Øygarden Fault Complex, Horda Platform, northern North Sea	9	2022
Haakon C. Nedberg	M	Fault reactivation potential of the Horda Platform, northern North Sea: Implications for successful storage of CO2	9	2022
Wiktor Bönke	M	Fault and fracture characterization in basement rocks of western Norway	9	2022
Anders Bjørnstad	M	Fault gouge characterization in the Øygarden complex in SW Norway – relevance for offshore CO2 storage	9	2022
Maren Bruflodt	F	De-risking CO2 storage sites: Sedimentary facies distribution and fault deformation at the Aurora prospect	9	2022
Adrian Øwre Ryvoll	M	Simulating fluid flow surrounding carbonate fault zones	9/ FRISK	2022
Viktor Styrmo Hansen	M	Statistical de-risking of faults associated with picking strategies: Implications for assessing fault seal for CO2 storage in the northern Horda Platform	9/ FRISK	2022

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

Name	Funding	Nationality	Period	Sex M/F	Topic	Task	Completed (X)
Seyed Ehsan Hosseini	KSP: TOPHOLE	Iran	02/2020-02/2023	M	Innovative geophysical and AI approaches to monitor plugged and abandoned wells	12	
Florian Franke	KSP: ReHeat2H2	German	09/2019-08/2022	M	Low-frequency combustion instabilities in reheat gas turbine combustion systems	5	
Harish Subramanian	KSP: ReHeat2H2	India	01/2020-01/2023	M	Dynamics and stability of hydrogen reheat flames	5	
Mohammad Masoudi	KSP: Porepac	Iran	11/2018-12/2021	M	Modeling nucleation reactions	10	
Dongchan Kim	KSP: ImpreCCS	South Korea	08/2019-04/2020	M	Working on measurements of thermal conductivity	8	
Amirreza Mottaghitalab	KSP: CCShip	Iran	08/2021-08/2024	M	CO2 solvent capture for application on board of ships	6	
Bahareh Khosravi	KSP: ImpreCCS	Iran	12/2018-12/2022	F	Viscosity and density measurements of CO2 and CO2-rich mixtures at conditions relevant for CCS	8	
Zhongxuan Liu	KSP: MACH-2	China	06/2020-06/2021	F	Modeling of hybrid processes (H2 production and CO2 liquefaction)	3	X
Donghoi Kim	KSP: MACH-2	South Korea	"07/2019-04/2020 (100%) 05/2020-07/2020 (20%)"	M	Modeling of hybrid processes (H2 production and CO2 liquefaction)	3	

PhD students with financial support from the Centre budget

Name	Nationality	Period	Sex M/F	Topic	Task	Completed (X)
Vegard Bjerketvedt	Norway	11/2017-2022	M	Optimal design and operation of CCS value chains with focus on the transport system	1	
Olaf Lehn Tranås	Norway	09/2020-08/2023	M	Modeling the role of CCS in decarbonising the power and industry sectors in Europe, with focus on flexibility, sector coupling and uncertainties	1	
Heidi Sydnes Egeland	Norway	11/2020-11/2024	F	Incentivising or impeding carbon capture, utilisation and storage technologies in Europe (CCS/CCUS) – the application of climate mitigation legal frameworks to carbon capture technologies for emission reduction purposes	1	

Name	Nationality	Period	Sex M/F	Topic	Task	Completed (X)
Lucas Braakhuis	Netherlands	10/2019-10/2022	M	Reclaiming	2	
Vanja Buvik	Norway	09/2017-08/2021	F	Amine structure relationship to degradation and corrosion	2	X
Eirik Æsøy	Norway	03/2018-03/2022	M	Gas turbine combustion instabilities for H2/CH4 blends	5	
Tarik Yahou	Algerie	10/2020-10/2023	M	Combustion dynamics in hydrogen rich combustion	5	
Alexandra Metallinou Log	Norway	08/2020-08/2023	F	Depressurization of CO2-rich mixtures in pipes	7	
Anne-Sophie Sur	Germany	01/2020-01/2023	F	Running ductile fracture in pressurised steel pipelines	7	
Stefan Herrig	German	06/2017-07/2018	M	CCS mixture reference EOS development (EOS-CG	8	X
Tobias Neumann	Germany	01/2017-12/2021	M	Improved description of minor components relevant for the transport of CO2-rich mixtures including	8	X
Johnathon Osmond	USA	10/2017-12/2021	M	3D structural characterization and containment risk analysis of two CO2 storage prospects in the Smeaheia area of the Northern Horda Platform, Norwegian North Sea	9	
Peter Betlem	Dutch	03/2019-03/2023	M	Geological and geophysical analysis of overburden for CO2 storage sites	9	
Magnus Soldal	Norway	06/2019-08/2022	M	Effects of anisotropy and stress path on the mechanical behavior of a North Sea cap rock and implications for fault stability during CCS operations.	9	
Camilla Louise Würtzen	Denmark	10/2018-03/2022	F	Tectonostratigraphic analysis of CO2 storage reservoirs in the Upper Triassic alluvial Lunde Formation in the Smeaheia area, Norwegian North Sea	9	
Nora Holden	Norge	08/2021-02/2025	F	Geological analysis of CO2 storage sites, Horda Platform	9	
Marcin Duda	Poland	01/2018-2022	M	Overburden pore pressure changes due to fluid injection	10	
Shamim Homaei	Iran	10/2021-10/2024	F	Decision support for design and operation of value chains for carbon capture and storage in Europe	1	

Postdoctoral researchers working on projects in the Centre with financial support from other sources

Name	Nationality	Period	Sex M/F	Topic	Task	Completed (X)
Donghoi Kim	South Korea	"07/2019-04/2020 (100%) 05/2020-07/2020 (20%)"	M	Modeling of hybrid processes (H2 production and CO2 liquefaction)	3	X
Emma Michie Haines	UK	202002-20230817	F	Structural geology	9/FRISK	X
Julien Porté	France	01/2022-12/2023	M	Accelerating CSEM technology for efficient and quantitative CO2 monitoring	12/ EM4CO2	

Postdoctoral researchers with financial support from the Centre budget

Name	Nationality	Period	Sex M/F	Topic	Task	Completed (X)
Tamara Makuni	UK	08/2017-01/2018	F	Experimental investigations into forced and self-excited azimuthal combustion dynamics modes	5	X
Mark Mulrooney	Ireland	09/2017-09/2021	M	Structural analysis and geomodel for fault modelling	9	X
Ozgu Turgut	Turkey	11/2017-11/2020	F	The role of CCS in decarbonising the power and industry sectors in both Europe and Norway	1	X
Viktor Weber	Hungary	08/2018-09/2021	M	Legal aspects of CO2 transport and storage with a focus on liabilities	1	X
Barbara Re	Switzerland	01/2018-12/2019	F	Large-scale transient behaviour of CO2-transport pipelines	7	X
Jose Aguilar	Mexican	08/2018-07/2020	M	Gas turbine combustion instabilities for H2/CH4 blends	5	X
Sian Lianne Evans	UK	12/2020-06/2024	F	Structural de-risking of potential CO2 storage sites on the Norwegian Continental Shelf	9	

Visiting researchers

Name	Affiliation	Nationality	Sex M/F	Duration	Topic	Task
Martin Khamphasith	UWA	Australia	M	08/2019-05/2020	VLE measurements	8

Key researchers

Name	Institution	Main research area	Task
Aslak Myklebostad	Allton	CO2 monitoring	12
Svein Ellingsrud	Allton	CO2 monitoring	12
Tore Karlsson	Allton	CO2 monitoring	12
Kjetil Eide	Allton	CO2 monitoring	12
Gerard Bottino	Baker Hughes	CO2 Fiscal metering	8
Jim White	BGS	CO2 monitoring	12

Name	Institution	Main research area	Task
Hayley Vosper	BGS	CO2 monitoring	12
Gareth Williams	BGS	CO2 monitoring	12
Paul Bridger	BGS	CO2 monitoring	12
Harald Malerød-Fjeld	CoorsTek Membrane Sciences	Ceramic Membranes	3
Edward Jukes	KROHNE Ltd	CO2 Fiscal metering	8
Elin Skurtveit	NGI	Structural geology	9
Jung Chan Choi	NGI	Geomechanics	9
Joonsang Park	NGI	CO2 monitoring	12
Guillaume Sauvin	NGI	CO2 monitoring	12
Luke Griffith	NGI	CO2 monitoring	12
Tore Ingvald Bjørnarå	NGI	Flow modelling	9/FRISK
Asgeir Tomasgard	NTNU	Industrial economics	1
Vegard Bjerketvedt	NTNU	Industrial economics	1
Ruud Egging	NTNU	Industrial economics	1
Olaf Lehn Tranås	NTNU	Industrial economics	1
Hanna Knuutila	NTNU	Post combustion CO2 capture	2
James R Dawson	NTNU	Experimental combustion dynamics	5
Nicholas Worth	NTNU	Experimental combustion dynamics	5
Jana P. Jakobsen	NTNU	CO2 Thermophysics	8
Bahareh Khosravi	NTNU (SINTEF Energy Research)	CO2 Thermophysics	8
Ola Eiken	Quad Geometrics	CO2 monitoring	12
Roland Span	Ruhr Universität-Bochum	CO2 Thermophysics	8
Tobias Neumann	Ruhr Universität-Bochum/ NTNU	CO2 Thermophysics	8
Andrea Gruber	SINTEF	Numerical modelling of reactive flows	5
Gonzalo del Alamo	SINTEF	Chemical kinetics modelling	5
Øystein Klemetsdal	SINTEF Digital	CO2 Storage	11
Odd Andersen	SINTEF Digital	CO2 monitoring	12
Francesca Watson	SINTEF Digital	CO2 monitoring	11, 12
Halvor Møll Nilsen	SINTEF Digital	CO2 monitoring	11, 12
Simon Roussanaly	SINTEF Energy Research	CO2 value chain and techno-economic modelling	1
Geir Skaugen	SINTEF Energy Research	Thermodynamic and process optimisation	1
Han Deng	SINTEF Energy Research	Thermodynamic and process optimisation	1
Rahul Anantharaman	SINTEF Energy Research	CO2 capture process integration and design	1
Luca Riboldi	SINTEF Energy Research	CO2 capture process integration and design	1
Sai Gokul Subraveti	SINTEF Energy Research	Adsorption-based capture	1
Geir Skaugen	SINTEF Energy Research	Membrane modelling	3
Luca Riboldi	SINTEF Energy Research	Membrane modelling	3
David Berstad	SINTEF Energy Research	CO2 liquefaction	4
Stian Trædal	SINTEF Energy Research	CO2 liquefaction	4

Name	Institution	Main research area	Task
Jacob Stang	SINTEF Energy Research	CO2 liquefaction	4
Ingrid Snustad	SINTEF Energy Research	CO2 liquefaction	4
Martin Johansson	SINTEF Energy Research	CO2 liquefaction	4
Rahul Anantharaman	SINTEF Energy Research	CO2 capture process integration and design	6
Chao Fu	SINTEF Energy Research	Process modelling and integration	6
Marie Bysveen	SINTEF Energy Research	Task Leader	6
Kristin Jordal	SINTEF Energy Research	CO2 capture process integration and design	6
Svend Tollak Munkejord	SINTEF Energy Research	CO2 transport	7
Morten Hammer	SINTEF Energy Research	CO2 transport	7
Han Deng	SINTEF Energy Research	CO2 transport	7
Hans L. Skarsvåg	SINTEF Energy Research	CO2 transport	7
Sigurd Weidemann Løvseth	SINTEF Energy Research	CO2 Thermophysics / Fiscal metering	8
Jacob Stang	SINTEF Energy Research	CO2 Thermophysics / Fiscal metering	8
Han Deng	SINTEF Energy Research	CO2 Fiscal metering	8
Yessica Arellano	SINTEF Energy Research	CO2 Fiscal metering	8
Ingeborg Treu Røe	SINTEF Energy Research	CO2 Fiscal metering	8
Martin Viktor Johansson	SINTEF Energy Research	CO2 Thermophysics	8
Elvia Sanchez	SINTEF Energy Research	CO2 Thermophysics	8
Anders Austegard	SINTEF Energy Research	CO2 Thermodynamics and transport properties / Fiscal metering / transport	7 & 8
Jon Magne Johansen	SINTEF Energy Research	Innovation management	OC
Rune Aarlien	SINTEF Energy Research	Management	OC
Anka Aalberg	SINTEF Energy Research	Management	OC
Amy Brunsvold	SINTEF Energy Research	Management	OC
Mona J Mølnvik	SINTEF Energy Research	Management	OC
Nils Røkke	SINTEF Energy Research	Management	OC
Jessica Scott	SINTEF Energy Research	Communication	OC
Anne Steenstrup-Duch	SINTEF Energy Research	Communication	OC
Rubén M. Montañés	SINTEF Energy Research	CO2 Capture Process modelling and integration	6
Donghoi Kim	SINTEF Energy Research	Process Modeling	6
Solrun Johanne Vevelstad	SINTEF Industry	Post combustion CO2 capture	2
Andreas Grimstvedt	SINTEF Industry	Post combustion CO2 capture	2
Merete Wiig	SINTEF Industry	Post combustion CO2 capture	2
Inna Kim	SINTEF Industry	Post combustion CO2 capture	2 / OC
Actor Chikukwa	SINTEF Industry	Post combustion CO2 capture	2
Geir Haugen	SINTEF Industry	Post combustion CO2 capture	2
Belma Talic	SINTEF Industry	Ceramic membranes	3
Thijs Peters	SINTEF Industry	Ceramic membranes	3
Elena Stefan	SINTEF Industry	Ceramic membranes	3
Einar Vøllestad	SINTEF Industry	Ceramic membranes	3

Name	Institution	Main research area	Task
Stéphane Dumoulin	SINTEF Industry	CO2 transport	7
Gaute Gruben	SINTEF Industry	CO2 transport	7
Malin Torsæter	SINTEF Industry	Well integrity, leakage de-risking	10
Jelena Todorovic	SINTEF Industry	Well integrity, injectivity impairment	10
Torbjørn Vrålstad	SINTEF Industry	Well integrity, injectivity impairment	10
Alv-Arne Grimstad	SINTEF Industry	CO2 storage	11
Per Bergmo	SINTEF Industry	CO2 storage	11
Torleif Holt	SINTEF Industry	CO2 storage	11
Albert Barrabino	SINTEF Industry	CO2 storage	11
Monika Pilz	SINTEF Industry	CO2 storage	11
Juan Yang	SINTEF Industry	CO2 storage	11
Eirin Langseth	SINTEF Industry	CO2 storage	11
Peder Eliasson	SINTEF Industry	CO2 monitoring	12
Bastien Dupuy	SINTEF Industry	CO2 monitoring	12
Anouar Romdhane	SINTEF Industry	CO2 monitoring	12
Amir Ghaderi	SINTEF Industry	CO2 monitoring	12
Michael Jordan	SINTEF Industry	CO2 monitoring	12
Cathrine Ringstad	SINTEF Industry	CO2 monitoring	12
Pierre Cerasi	SINTEF Industry	Geomechanics, leakage de-risking	9, 10
Grethe Tangen	SINTEF Industry	CO2 storage	OC
Roberta V. Figueiredo	TNO	Post combustion CO2 capture	2
Peter van Os	TNO	Post combustion CO2 capture	2
Earl Goeether	TNO	Post combustion CO2 capture	2
Juliana Garcia Moretz-Sohn Monteiro	TNO	Post combustion CO2 capture	2
Filp Neele	TNO	CO2 storage	11
Daniel Loeve	TNO	CO2 Storage	11
Catherine Banet	UiO	Legal	1
Viktor Weber	UiO	Legal	1
Heidi Sydnes Egeland	UiO	Legal	1
Alvar Braathen	UiO	Structural geology	9
Jan Inge Faleide	UiO	Geophysics	9
Nazmul Haag Mondol	UiO	Rock physics	9
Ivar Midtkandal	UiO	Geology	9
Ingrid Anell	UiO	Geology	9
Rikke Elsøe Bruhn	UiO	Geology	9
Kim Senger	UNIS	Structural geology	9
Arvind Rajendran	University of Alberta	Adsorption-based capture	1

NCCS – Industry driven innovation for fast-tracking CCS deployment
NCCS is a Centre for Environment-friendly Energy Research (FME).
The objective of the FME-scheme is to establish time-limited research centres that conduct concentrated, focused and long-term research of high international calibre.

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH
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