2020 ANNUAL REPORT

NORWEGIAN CCS RESEARCH CENTRE

NCCS

NCCS (Norwegian CCS Research Centre) 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 it will not enter the atmosphere. EU energy and climate targets cannot be met cost effectively without CCS, while making sure we have enough energy to go around.

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

Contents

NCCS
BEST OF 2017-2020


Tweet
Kristin Jordal @abkjordal
#NCCS kick-off: @tordlien "We need to ensure that #CCS becomes a reality and deployed on a global scale" @SINTEF
Oversett tweeten
10:59 a.m. · 4. nov. 2016 · iOS


Tweet
NCCS @NCCS_FME
We are ready for #TCCS - see you soon! Streaming here: sintef.no/projectweb/tcc...
Oversett tweeten
Du og 9 andre
7:43 a.m. · 13. jun. 2017 · Twitter for iPhone
2 Retweets 2 sitat-Tweets 3 likerklikk


Tweet
NCCS @NCCS_FME
The winner of the SINTEF and NTNU CCS Award 2017 is... blog.sintefenergy.com/ccs/the-winner... #TCCS
Oversett tweeten
Du og 8 andre
1:36 p.m. · 14. jun. 2017 · Twitter for iPhone
3 Retweets 7 likerklikk


Tweet
NCCS @NCCS_FME
Another important NCCS meeting/workshop this week. NCCS researchers presented their latest results related to derisking of faults in the Smeieheia reservoir, the CO2 storage location in the Norwegian full-scale CCS project.
#ccs @InfoNGI
@UniOslo @Gassnova @forskningsradet
Oversett tweeten
6:16 p.m. · 14. feb. 2018 · Twitter Web App
3 Retweets 7 likerklikk

2016 kick off

2017

2018


Tweet
NCCS retweetet
SINTEF @SINTEF
Looking forward to the opening of the ECCSEL lab today with @NTNU and our new pan-European CCS infrastructure #energyTRD
Oversett tweeten

Du og 7 andre
8:18 a.m. · 12. jun. 2017 · Twitter for iPhone
5 Retweets 1 sitat-Tweet 7 likerklikk


Tweet
NCCS @NCCS_FME
Starting rigging next week: our new ECCSEL research facility: Horizontal and vertical flow @SINTEF #TCCS youtu.be/NMYy-Z-3KWc
Oversett tweeten

11:38 a.m. · 13. jun. 2017 · Twitter for iPhone
2 Retweets 2 sitat-Tweets 2 likerklikk


Tweet
NCCS @NCCS_FME
Great NCCS workshop today at the Klemetsrud waste to energy plant in Oslo! #ccs #wastetoenergy @OsloEnergy @PalMikkelsen #fme @forskningsradet #co2capture
Oversett tweeten
4:56 p.m. · 13. feb. 2018 · Twitter Web App
5 Retweets 12 likerklikk


Tweet
SINTEF Energy @SINTEFenergy
This week NCCS hosts the @IEA CCS International Summer School gathering students from all over the world in #Trondheim to learn more about #CCS youtu.be/nY5ZbmovRBI @SINTEF @EnergyNTNU @NCCS_FME @Gassnova @forskningsradet @Total
Oversett tweeten
IEAGHG CCS International Summer School - Amy Brunsvold
NCCS Centre Coordinator Amy explains why the IEAGHG CCS International Summer School is an important event for NCCS
youtube.com
9:44 a.m. · 27. jun. 2018 · Twitter for iPhone
Se Tweet-aktivitet
4 Retweets 7 likerklikk


Tweet
NCCS @NCCS_FME
Today at the Bergen Chamber of Commerce #grønnlunsj, NCCS Centre Manager @Amy Brunsvold conveying the value of CCS (and not just the cost) and how @NCCS_FME can help.
Oversett tweeten
3:55 p.m. · 10. sep. 2018 · Twitter Web App
2 likerklikk

Tweet

NCCS
@NCCS_FME

#TCCS10 is history. Here is a look back at some conference highlights 🌎 Thank you to all who helped make this a success! Special thanks to our sponsors @Total , @forskningsradet, CLIMIT, @Gassnova and @EquinorASA !
See you next time 🙂
@Nils_Rokke @EnergyNTNU @oeddep

Oversett tweeten

4:48 p.m. · 25. jun. 2019 · Twitter Web Client

8 Retweets 1 sitat-Tweet 15 likerklikk

Tweet

NCCS
@NCCS_FME

Prof Roland Span comments on winning the SINTEF and NTNU CCS award at #TCCS10 and the work he was awarded for. Hear his full comments in the vid below.
Read more here:
blogg.sintef.no/sintefenergy-n... @SINTEFenergy @EnergyNTNU @NTNU @SINTEF @ruhrunibochum #CCS @RolandSpan

Oversett tweeten

3:51 p.m. · 21. aug. 2019 · Twitter Web App

3 Retweets 2 sitat-Tweets 18 likerklikk

Tweet

NCCS
@NCCS_FME

CO2 DataShare launches open, digital data sharing portal for CO2 storage - a push to advance innovation and deployment of #CCS.
sintef.no/en/latest-news...
@EquinorASA @Gassnova @UniversityofIl @IEAGHG @SINTEFenergy @sintef @Mona_Molnvik @Nils_Rokke @forskningsradet

Oversett tweeten

2:19 p.m. · 4. feb. 2020 · Twitter Web App

11 Retweets 1 sitat-Tweet 28 likerklikk

Tweet

NCCS retweetet
Torund Bryhn
@Torund

Yes, @amy_brunsvold science branding matters. Yes, storytelling matters. And yes, we need a better story and brand for #CCS What new words can ignite action?
@Nils_Rokke @NCCS_FME @SINTEF @abgjorv @torp_cathrine @MetteTweets @HoyreTina @ThinaSaltvedt @LivBjerge @PalMikkelsen

Oversett tweeten

#SINTEFblog
CCS Has A Branding Problem — We Need A Solution
BY AMY BRUNSVOLD
DECEMBER 14, 2020

Anne Steenstrup-Duch og 9 andre

6:15 p.m. · 15. des. 2020 · Twitter Web App

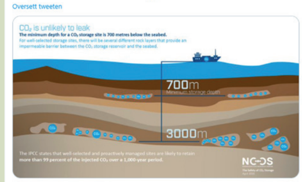
2 Retweets 8 likerklikk

Tweet

NCCS
@NCCS_FME

"CO2 stored underground will just float back up again". Sound familiar? We have summarised our research on why CO2 storage is both safe and feasible:
blog.sintef.com/sintefenergy/c...

Oversett tweeten



2:03 p.m. · 22. jun. 2020 · Twitter Web App

10 Retweets 3 sitat-Tweets 21 likerklikk

2019

2020

Tweet

NCCS retweetet
Gassnova
@Gassnova

- #CCS (Carbon Capture and Storage) has the potential to be one of the most important measures achieving the goal of more energy and cleaner energy, says @oeddep Minister Kjell-Børge Freiberg at #TCCS10 in Trondheim today bit.ly/2Zx8Kks

Oversett tweeten

Teknisk Ukeblad og 8 andre

2:53 p.m. · 18. jun. 2019 · Twitter Web Client

12 Retweets 1 sitat-Tweet 22 likerklikk

Tweet

NCCS retweetet
SINTEF Energy
@SINTEFenergy

Creating markets (for #CCS) is important as at the moment "nobody wants to pay for climate", says @Nils_Rokke from @SINTEF to @FinancialTimes

Oversett tweeten

Carbon capture schemes urged to be more ambitious
Experts say UK must think bigger and faster to hit net zero emissions target
ft.com

5:03 p.m. · 1. jul. 2019 · Twitter for iPhone

Se Tweet-aktivitet

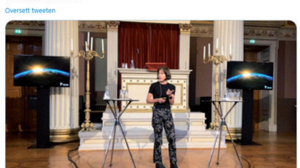
7 Retweets 12 likerklikk

Tweet

NCCS
@NCCS_FME

-The planet has fever. When we're sick we take medicine that may be expensive and have side-effects. The same goes for the environment. We must make choices that costs money and have side-effects to mitigate climate change, sais Mona Mølnvik, Centre Director. #CCS

Oversett tweeten



Norges forskningsråd og 7 andre

11:11 a.m. · 18. sep. 2019 · Twitter Web App

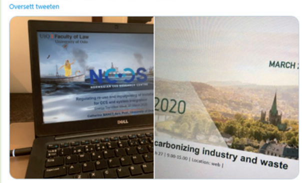
6 likerklikk

Tweet

NCCS retweetet
Catherine Banet
@catherinebanet

Ready to speak (remotely) on «re-use & repurposing of O&G installations for #CCS & energy system integration» as part of #EnergyTransitionWeek 2020 @NCCS_FME @NIFSjus #decommissioning #sectorcoupling #decarbonisation

Oversett tweeten



1:02 p.m. · 27. mar. 2020 · Twitter for iPhone

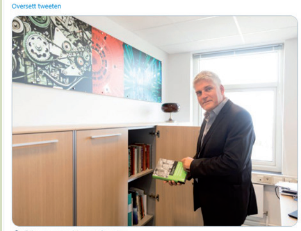
1 Retweet 7 likerklikk

Tweet

NCCS retweetet
SINTEF Energy
@SINTEFenergy

REUTERS: -The storage capacity of the Longship project could be 100 million tonnes, meaning plenty of room will be left (...) That space could be used by selling it to carbon emitters from other sectors and countries, says @Nils_Rokke
in.reuters.com/article/us-car...

Oversett tweeten



Olje- og energidep og 9 andre

11:22 a.m. · 21. okt. 2020 · Twitter Web App

Se Tweet-aktivitet

4 Retweets 18 likerklikk

@NCCS_FME

MOMENTUM IN A YEAR OF **UNCERTAINTY**

2020 was a year that none of us will ever forget. It's hard to believe that at the start of the year, no one had heard of the novel coronavirus that would so impact the world's population, healthcare systems and economies.

We know there will be many people within and close to the NCCS consortium who have been personally affected by the pandemic. To you, we offer our sincere condolences and support.

Meeting the challenges of 2020

Despite the disruption caused by the pandemic, we are fiercely proud of everything that has been achieved within NCCS during 2020. Substantial strides forward were made as we adjusted to a new way of working. Webinars were a huge success throughout the year, with more than 1,300 people interested in CCS signing up for the autumn webinar series. This was a particular highlight for us, as we were able to disseminate NCCS research to a much wider audience than before. The online Consortium Days attracted 130 people from across NCCS and injected a huge amount of energy and momentum into the centre. In 2020 we have 27 PhD and postdocs, the majority at NTNU and UiO, but also at the University Centre on Svalbard (UNIS), and RUB in Germany. We have released an open source-source code for thermodynamic calculations – Thermopack, investigated and published a blog about why CO_2-storage is safe, documented more than 25 innovations from NCCS. Now as we reach the half-way point of NCCS' funding period as an FME, we have the best possible injection of momentum to carry us forward: the announcement of Longship.

The climate crisis can't be forgotten

Amid the global health crisis, it has been easy to forget or at least deprioritise the climate crisis. Yet the announcement of an estimated NOK 16.8 billion of state funding shows that our political leaders under-stand the importance of taking action now to combat the worst impacts of climate change well into the future.

Minister of petroleum and energy Tina Bru said Longship is "the greatest climate project in Norwegian industry ever." The plans are clear, with an infrastructure that can be expanded enough to take away a significant proportion of Norway's annual greenhouse gas emissions. It can then be expanded to receive CO_2 from the rest of Europe. The Longship project also represents a potential for storing CO_2 formed in hydrogen production from natural gas. Hydrogen represents one of our major possibilities to meet the emissions goals set for 2050.

Keeping up with climate change

Through its Green Deal, the EU wants to make Europe the world's first climate-neutral continent by 2050. Ambitions for cuts in CO_2 emissions have increased, so that emissions figures from 1990 will be more than halved by 2030. A new tax system will ensure that jobs and industrial companies will be in Europe: a CO_2 limit tax to prevent CO_2 leakage.

We need a process industry with products that can compete in the European market with stricter requirements for CO_2 footprints. We have to keep up. Unless we change direction, Norway will not meet the requirements of the EU Green Deal.

We now have two choices: We can go for CO_2 leakage and move Norwegian factories – and jobs – out of the regulated area in Europe. Or we can keep the jobs and manage CO_2 emissions. We do this by developing and realizing more renewable energy and implementing all the energy efficiency measures that we can – including CCS.

Mona J. Mølnvik

Dr. Mona J. Mølnvik is the NCCS Centre Director.

She has been with SINTEF for 20 years, and has been active in CCS research since the early 2000s. Mona holds a PhD within mechanical engineering from NTNU and is Research Director for the Gas Technology department at SINTEF Energy Research.

She was central in developing and leading the centre of excellence, FME BIGCCS – International CCS Research Centre (2009-2016). Further, she has been involved in several EU-projects. Mona has been a central contributor to development of CCS research strategies, and she was the first leader of the CO_2 transport initiative under EERA JP Carbon Capture and Storage.

Bringing the momentum into NCCS

Despite the investment announcement, the implementation of full-scale CCS at the pace required to meet the 2050 climate goals still needs research to scale up and bring cost and risk down. In 2020 four new partners have joined NCCS: Baker Hughes, Wintershall DEA, Stratum, and Allton, which represent a major contribution to the momentum of NCCS since our research has a major role to play in contributing solutions in the years to come.

With a stated goal of enabling fast-track CCS deployment, NCCS is naturally aligned with the requirements of Longship. In this report you can read a detailed article about how NCCS will support the goals of longship all along the CCS chain over the four years to come.

Mona Mølnvik, Tord Lien

Tord Lien

Tord Lien is the NCCS Chairman of the Board and Regional Director for Trøndelag at The Confederation of Norwegian Enterprise (NHO).

Before joining NHO in 2017, Lien was Minister for Petroleum and Energy (2013-2016).

As Minister, Lien played a central role in developing and transitioning the Norwegian energy-, oil- and gas sector in a challenging economic period in Norway.

He represented The Progress Party in parliament (2005-2013) and has a Master's degree in history from NTNU (1999 – 2003).

NCCS IN THE YEAR OF **COVID-19**

A global health crisis on top of a climate crisis - no-one expected 2020 to turn out the way it did. While I won't pretend the year was easy, I am proud of how everyone in NCCS responded and adapted to the unique situation we found ourselves in.

The FME structure means that remote meetings were already commonplace, but the coronavirus crisis forced our hand even further. While we did miss the benefits that come from in-person meetings at the Consortium Days, the record number of attendees show that there were benefits from the digital approach too.

The same can be said for the fantastic success of the NCCS webinar series. Held throughout October, the series of webinars were heavily promoted and well-attended, introducing the work of NCCS to a much wider audience than before.

From a management perspective, the Covid-19 situation was monitored formally at each operations meeting, with decisions made to postpone or change events and adjust the work plans accordingly. That being said, the vast majority of 2020's work plan was completed as planned. For this reason, I am prouder of the work displayed in this year's annual report than any other to date.

It seems likely that a mostly digital approach will continue for some time. Last year has proved we have the processes, tools and competence in place to take another leap forward in 2021.

Amy Brunsvold
NCCS Centre Manager

SELECTED HIGHLIGHTS FROM **2020**

Thermodynamics software available to all

Building on decades of research, NCCS supported the development of software that performs thermodynamic calculations, including equations of state. The software, Thermopack, is now available for free through an MIT open-source license. Our hope and aim is that Thermopack can be helpful to our colleagues both in academia and industry that share our vision of a sustainable future.

Thermodynamics describes many things, from phenomena in the nature around us to what happens in industrial processes. When temperature, pressure and composition of a fluid are known, Thermopack can help to answer questions such as how dense the fluid is, how much energy it contains, or how much heat must be supplied to change its temperature.

Learn more at nccs.no

Impact of NCCS Innovations

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

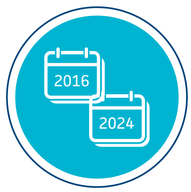
Beyond core research, a centre of excellence such as NCCS can develop many potential routes for commercialization. NCCS aims to disseminate results among partners wherever possible and secure IP rights for each partner where necessary.

Building on the methodology from the Research Council impact study and the 2019 NCCS impact study, NCCS has assessed the potential impact of eight selected innovations covering the whole CCS chain.

Learn more on page 40 and at nccs.no

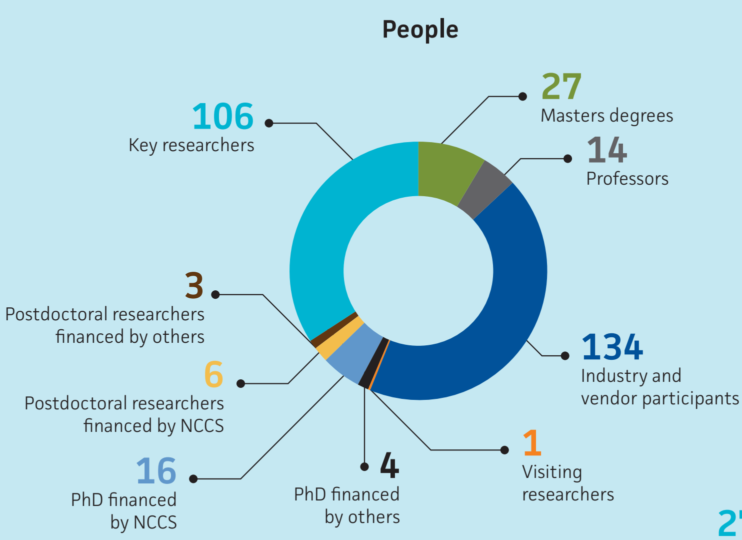
NCCS
BY NUMBERS

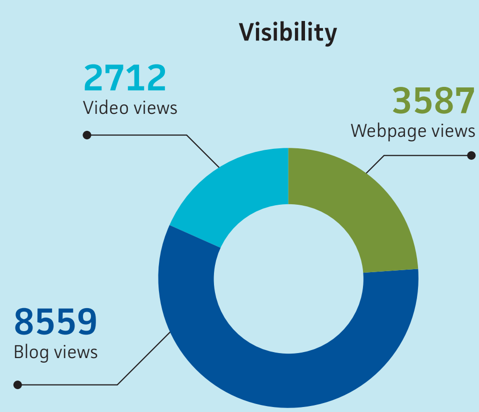
32 PARTNERS



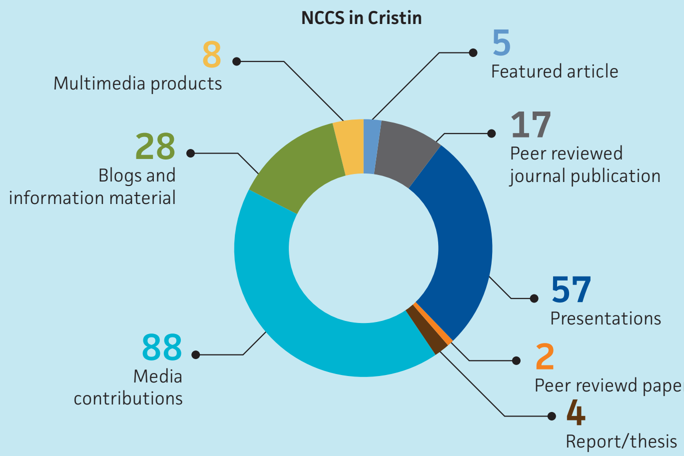
8 YEARS

465 MNOK



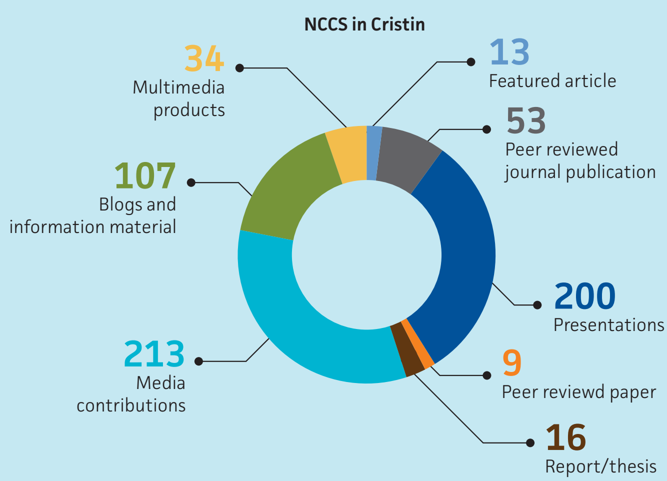


Communication and dissemination 2020*



*There might be some discrepancies between the numbers in the figures and the numbers registered in Cristin, mainly due to FME partners that no not have a university or research institute affiliation or because the FME project code har not yet been registered in the post

Communication and dissemination 2017-2020*



*There might be some discrepancies between the numbers in the figures and the numbers registered in Cristin, mainly due to FME partners that no not have a university or research institute affiliation or because the FME project code har not yet been registered in the post

LONGSHIP:
THE NEXT STEPS FOR CCS

How NCCS research will help support Norway's ambitious Longship project.

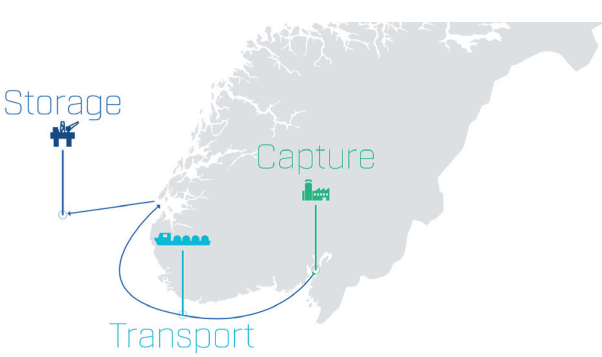
Longship: The Next Steps for CCS

Longship is one of the first industrial CCS projects to develop an open access infrastructure with the intent and the capacity to store significant volumes of CO_2 from across the European continent.

Announced in September 2020, the proposals include substantial government funding to complete a full-scale implementation of the complete CCS chain. The funding is for:

- The implementation of CO_2 capture technology at Norcem's cement factory in Brevik
- The implementation of CO_2 capture technology at Fortum Oslo Varme's waste incineration facility in Oslo, on condition that the project secures other funding
- The CO_2 transport and storage project 'Northern Lights'

Once fully implemented, CO_2 captured in Brevik and Oslo will be transported by ship to the west coast of Norway. From there, the CO_2 will be transported through a pipeline to a carefully selected location in the North Sea, where it will be injected and stored more than three kilometres below the seabed.



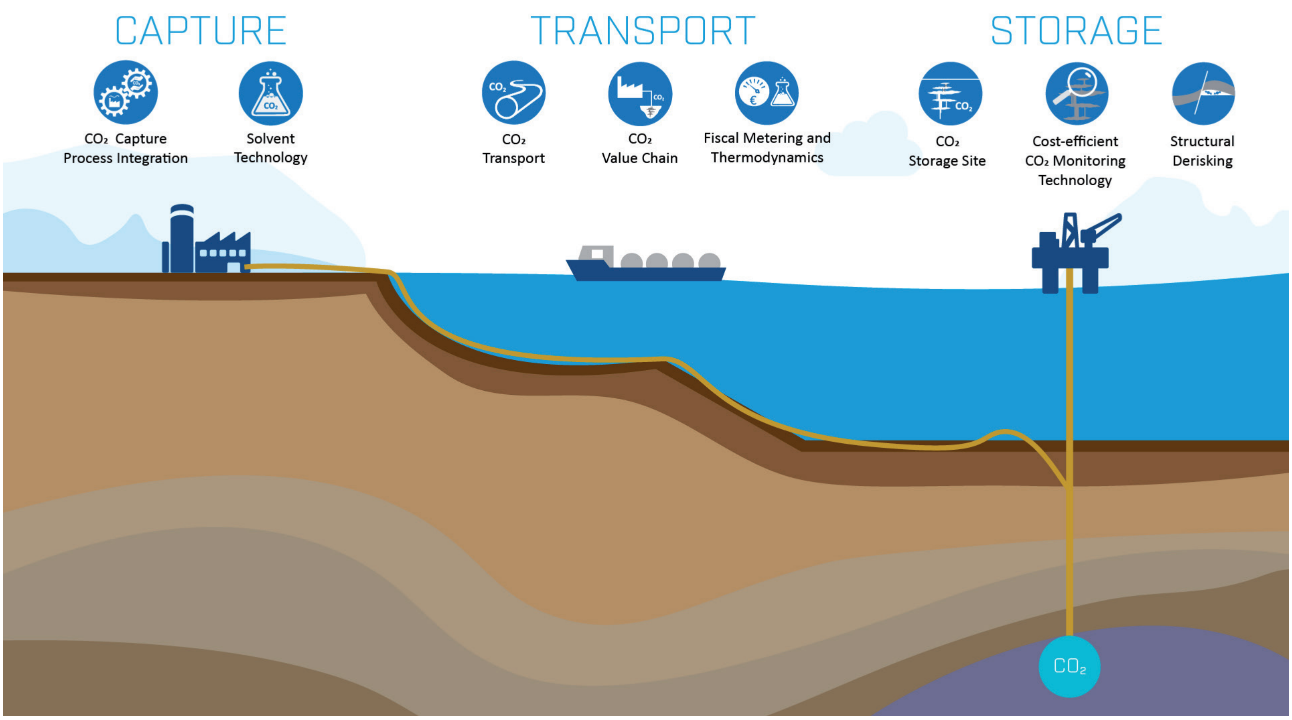
Equinor operates 'Northern Lights' in collaboration with Shell and Total. The resulting open access transport and storage infrastructure will provide capacity for CO_2 that goes well beyond what is required for the Norcem and Fortum capture sites.

The government funding proposal for the full-scale implementation of the complete CCS chain builds on years of previous projects and research, in which NCCS has played a role.

How NCCS supports the goals of Longship

Co-financed by the Research Council of Norway, industry, and research partners, NCCS aims to help facilitate CO_2 storage in the North Sea, contributing to the Norwegian government's ambition to realize the full-scale Longship project. NCCS addresses questions of cost reduction, risk reduction and scaling along the complete CCS value chain, including capture, transport, and storage.

Industry projects can benefit from the answers provided by NCCS for successful implementation, while NCCS needs industry projects for real-world examples, data and verification/validation.



This dual approach to research with commercial deployment has already proven fruitful in laying the groundwork for Longship. Continuing the same approach will help take CCS technologies to a full-scale implementation in Norway, Europe and beyond.

With a stated goal of enabling fast-track CCS deployment, NCCS is naturally aligned with the requirements of Longship. The NCCS research plan was designed to address the major barriers identified in previous and ongoing demonstration and industry projects, through industry-driven science-based innovation. NCCS works along the complete CCS value chain.

Capture

Longship, along with other major CCS projects worldwide, plans to use solvent-based CO_2 capture technologies. NCCS researchers work on solvent stability and degradation mitigation technologies that minimize the emissions and solvent losses from absorption-based CO_2 capture plants, reducing both environmental risk and cost.

While solvent-based capture technology is considered state-of-the-art for the post-combustion CO_2 capture, there is a need for more cost-efficient and environmentally friendly solutions. NCCS research on CO_2 capture solutions can be used to make recommendations for hard-to-decarbonize industries depending on their circumstances. Technologies in NCCS are being developed to increase lifetimes of solvents, reduce the environmental impacts, and improve the safety of CO_2 capture plant operations.

But the future of CO_2 capture may not rely only on solvents and perhaps not for all sources of CO_2 emissions. One specific example for Waste-to-Energy plants developed in NCCS is the novel integration of CO_2 capture using a Calcium Looping (CaL) process. This captures CO_2 from the plant and allows the production of energy improved efficiency and lower costs compared to the solvents considered state of the art today.

Hydrogen production from natural gas with the CO_2 captured is one possible driver for widespread implementation of CCS. NCCS researchers will demonstrate a low-temperature capture and separation of CO_2 at the conditions relevant for hydrogen production using third-party membrane technology. In addition, NCCS is helping a gas turbine technology vendor with detailed fundamental insight that can help them develop gas turbines that can run on 100% hydrogen fuel.

A successful demonstration will open up new economic possibilities for Norway relevant to the country's Hydrogen strategy and the Longship investment.

Transport

When Longship is fully implemented, CO_2 will be transported via pipeline to storage sites. This requires a deep understanding about the behaviour of CO_2 in pipelines. We already understand a lot about this behaviour from decades of experience with natural gas, and from CO_2 projects in Norway and North America. Further research is needed to understand processes that may not be covered by existing tools and methods to further reduce cost while ensuring safety.

Results from NCCS research into safe pipeline design have already been used by Equinor in the Northern Lights project.

The transport of CO_2 by medium-pressure shipping is already a mature technology, with a fleet of tanker vessels already in use by Norwegian company Yara International. NCCS research has shown that different shipping temperatures and pressures can further lower the cost of CO_2 transport from the east coast of Norway and Europe to the Northern Lights storage site. Operational knowledge and understanding to reduce risks associated with low pressure transport is an ongoing topic in NCCS.

Finally, flow metering is required in the first phase of Longship. An NCCS fiscal metering test loop at industrial capacity will validate fiscal meters for CO_2, which are needed for compliance with government regulations, avoidance of ETS costs, and custody transfer among actors in the CCS value chain.

Storage

The Northern Lights project has been in close dialogue with NCCS on the characterization of geological storage sites, which has supported the site selection process. Collaboration has centred on faults as lateral baffles or barriers to fluid migration, likelihood of along-fault seep, and reservoir characterization. Other geological research on qualifying satellite storage sites (in vicinity of planned infrastructure) and application of evolving methods has also been central to the collaboration with the Northern Lights team.

In some cases, faults as lateral seal and faults in the cap rock seals of potential storage sites may limit the capacity to forecast and mitigate risk. New fault seal models being developed in NCCS for site qualification can reduce uncertainty and therefore increase the available storage capacity at preferred sites.

Storage operators make seismic data and other measurements available to researchers worldwide, including NCCS, for testing, iteration and improvement of imaging methods and data models. NCCS researchers work together with industry experts to analyse monitoring data from Sleipner and, in future, Northern Lights. Collaborations between research partners with long experience in CO_2 monitoring, involvement of vendors with expertise from oil and gas exploration and monitoring, and a close dialogue with industry partners ensures that NCCS research activities have the highest possible relevance for the Northern Lights project.

THE SAFETY OF CO_2 STORAGE

Over its years of development, CCS has faced questions about its technical feasibility and safety. This article draws on scientific research to address the key issues of safety and risk of a full-scale CCS implementation in Norway.

The Safety of CO_2 Storage

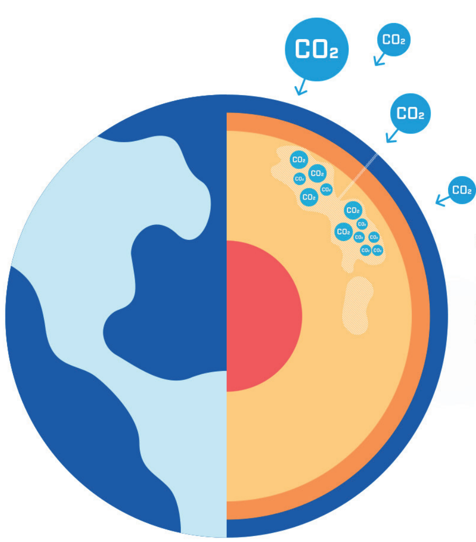
While we focus on offshore storage under the seabed, many of these principles also apply to underground storage onshore. The National Energy Technology Laboratory (NETL) recently published a technical report on safe geologic storage onshore which can be read in conjunction with this article.

What CCS is – and why it matters

Carbon Capture, Transport & Storage (CCS) is a series of technologies and processes that aim to significantly cut carbon dioxide (CO_2) emissions. This is achieved by capturing and concentrating waste CO_2 from industrial processes instead of releasing it into the air, then transporting and injecting it deep underground. In Norway, this is done beneath the seabed into saline aquifers (porous geological formations containing water) and sealed reservoirs that once held fossil fuels.

While renewable energy and energy efficiency measures have a major part to play in combating climate change, the International Energy Agency (IEA) estimates that energy demand could increase by as much as 45% by 2030. Decarbonizing the non-renewable portion of that energy generation is a must as we move through the green transition. CCS is also the only technology that can decarbonise critical industrial sectors, such as cement and metal production and waste incineration.

The Intergovernmental Panel on Climate Change (IPCC) found that to meet the challenging targets of the Paris Agreement, global CO_2 emissions must be reduced by 50-85 % by 2050. IEA findings say that to meet these targets, 14% of the total emissions reduction by 2060 must come from CCS.

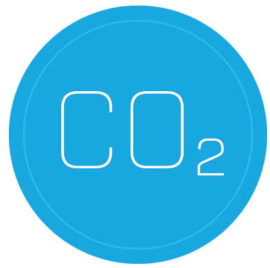


14%
of the total emissions reductions by 2060 **must come from CCS.**

Source: ***IEA***

NCCS NORWEGIAN CCS RESEARCH CENTRE
The Safety of CO_2 Storage
April 2020

The world's first offshore CCS storage site at Sleipner in the North Sea **has been operational since 1996.**



Around **one million tonnes** of CO_2 has been successfully stored there **every year.**

40 sites around the world have or are presently involved in **safely injecting CO2 into underground storage sites.**

NCCS NORWEGIAN CCS RESEARCH CENTRE
The Safety of CO_2 Storage
April 2020

Safe CO_2 storage around the world

With vast storage opportunities available around the world combined with decades of relevant industrial experience, CCS can provide a major part of the answer to the climate challenge. Ongoing industry projects have proven the technology. Several operational and research projects now underway (including NCCS) will improve the technology and processes.

The key issues of safety and risk of a full-scale CCS implementation in Norway fall into three broad categories:

1. CCS is proven technology

CCS moved from theory to practical implementation long ago. More than 40 sites around the world have been or are presently involved in safely injecting CO_2 into underground storage sites.

Since 1996, the operations run by Equinor and their partners at the **Sleipner** field in the North Sea has injected CO_2 into the **Utsira formation**. Since then, around one million tonnes of CO_2 has been stored in Sleipner every year. Storage has also taken place at the **Snøhvit** field since 2008.

Following a feasibility study from the Norwegian government, a project was launched to develop a full-scale CCS value chain in Norway by 2024.

As part of this initiative, Equinor, Total and Shell are working together on the Northern Lights project that could enable up to 1.5 million tonnes of CO_2 storage capacity per year in its first phase. Further expansions, currently limited by the planned pipeline size, could take the available capacity up to 5 million tonnes per year.

The accumulated experience in Norway and around the world has proven that there are no technical barriers preventing the implementation of CO_2 storage at scale. Research within NCCS and elsewhere continues to tackle questions related to technical optimisation, overcoming legal barriers, reducing cost, and scaling up operations.

There is no shortage of space, so CO_2 storage sites can be carefully chosen

The IEA estimates that more than 100 billion tonnes' worth of storage capacity is needed to meet the 14% contribution target. A potential capacity of many times more has been identified worldwide.

In Norway alone, theoretical estimates show that 70 billion tonnes of storage is available in saline aquifers and former oil and gas reservoirs, although not all of that is technically or economically feasible to use. If 10% of the storage space were to be utilised, it could provide storage for roughly 40 years of emissions from the European cement industry.

Ongoing NCCS research into reservoirs will reduce the uncertainty on the suitability of many of these sites, providing a more accurate capacity estimate in the years to come.

The abundant capacity worldwide means that we can characterise and select storage sites based on research results and long-established industrial practices, among others. However, this work takes time and needs to be started early in the process.

The storage sites at Sleipner and Snøhvit, and the candidate sites for the Northern Lights project, are all sealed with several hundred metres of cap rock. In some cases, faults in the cap rock for a potential storage site may limit the capacity. New fault seal models being developed in NCCS for site qualification can reduce uncertainty and therefore increase the available storage capacity.

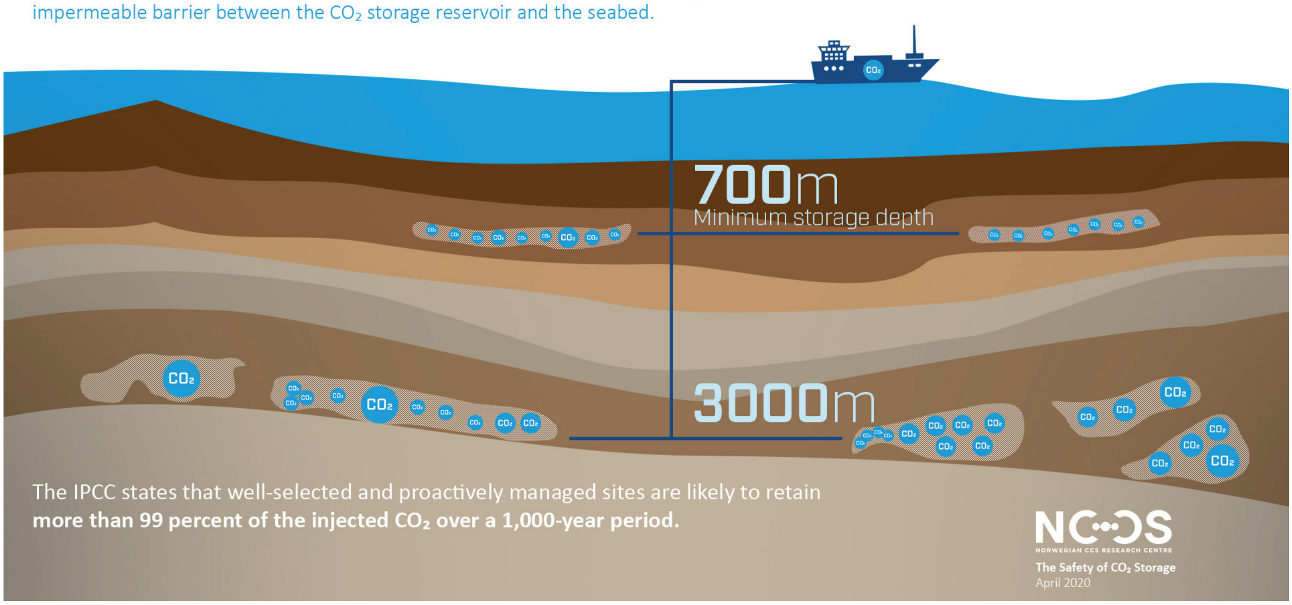
2. CO_2 storage is a well-understood, low-risk process

We have many decades of dealing with CO_2 in gas or liquid form, and in atmospheric or pressurised environments. Many industries use it for cooling and the production of chemicals and metals, among other uses. The safe handling of CO_2 is therefore well-understood.

CO_2 is unlikely to leak

The minimum depth for a CO_2 storage site is 700 metres below the seabed.

For well-selected storage sites, there will be several different rock layers that provide an impermeable barrier between the CO_2 storage reservoir and the seabed.



CO_2 is unlikely to escape

The minimum depth for a CO_2 storage site is 700 meters below the seabed so that the temperatures and pressures are high enough to keep the CO_2 in the liquid or supercritical state. However, many projects, including the Northern Lights Project, are as deep as 3,000 metres below the seabed. For well-selected storage sites, there will be several different rock layers (typically shale layers) that provide an impermeable barrier between the CO_2 storage reservoir and the seabed.

There are four natural mechanisms that play a role in keeping injected CO_2 safely in place:

- Structural trapping: Above the porous rock, impermeable layers of cap rock provide no escape routes
- Residual trapping: Porous rock in the storage site acts like a sponge, trapping droplets of CO_2
- Solubility trapping: CO_2 dissolves into salt water or brine already present in the porous rock
- Mineral trapping: Over time, dissolved CO_2 can react with minerals and bond to rock

These processes are well understood, helping us to characterise and select only the most suitable storage sites at appropriate depths.

The IPCC[1] states that well-selected and proactively managed sites are likely to retain more than 99 percent of the injected CO_2 over a 1,000-year period. Since 1996, many millions of tonnes of CO_2 have been injected and stored, with no evidence of escaping.

In the unlikely event of a leak, research published in *Nature Climate Change* shows that the impact of any potential CO_2 escaping from underground reservoirs is unlikely to cause long-term harm to human life or the environment. Tests showed the biological impact and footprint of a small leak analogue is confined to a few tens of metres.

CO_2 storage sites are closely modelled and monitored

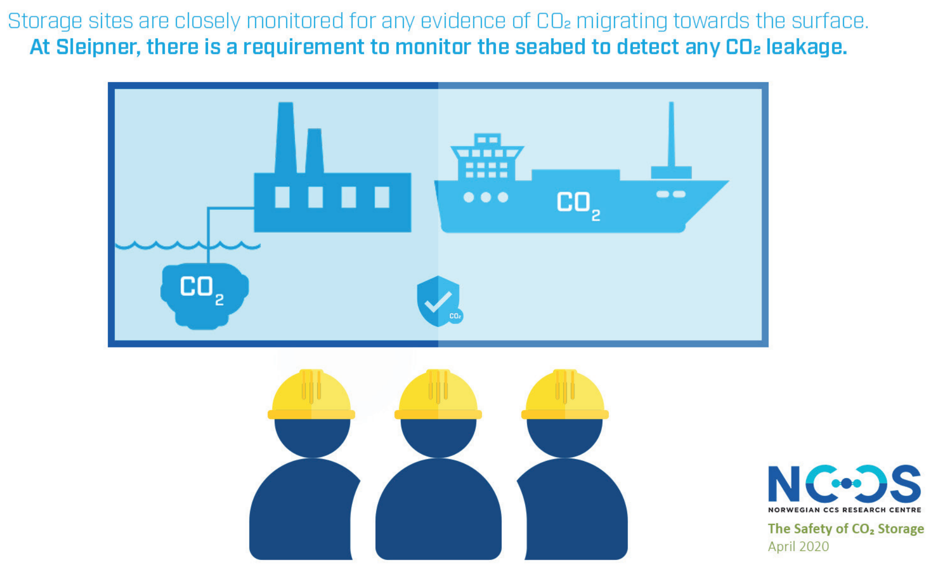
In addition to natural mechanisms keeping CO_2 safely trapped, storage sites are closely monitored for any evidence of CO_2 migrating towards the surface. There are a range of mechanisms to control and prevent an identified risk from becoming a leak, which are based on decades of operational experience.

In Norway, legal requirements are in place for the monitoring of CO_2 storage sites that go beyond what is required for the established oil and gas industry. Operators must demonstrate conformance to regulations and assurance of containment. At the Sleipner site, there is a requirement to monitor the seabed to detect any CO_2 leakage.

CO_2 storage operators make seismic data and other measurements available to researchers worldwide, including in NCCS. This allows the testing, iteration and improvement of imaging methods and data models for future projects. NCCS researchers have been able to work together with industry experts analysing monitoring data from both Sleipner and in the future, the Northern Lights project.

Such monitoring data also proved that the biogenic gas detected to be leaking from the Hugin fracture in 2012 had no relation to the storage operations at Sleipner. At the Sleipner site, independent researchers analysed data using seismic-reflection surveys of the deep subsurface before CO_2 injection and then at two-year intervals. They found excellent performance of the storage site, with no evidence of any CO_2 leakage. Analysis of the Hugin fracture site, located 25km northeast of Sleipner, was presented in a technical paper at Near Surface Geoscience 2014 - 20th European Meeting of Environmental and Engineering Geophysics.

Monitoring data were also used effectively to de-risk storage at Snøhvit, allowing the team to modify the injection to access a better reservoir when pressure build up was detected early.



The behaviour of CO_2 in underground storage

We also understand the characteristics of stored CO_2 from the naturally occurring CO_2 that has been trapped underground for many thousands of years.

NCCS researchers are also looking at how to increase the amount of CO_2 that can be stored safely in certain formations, which will feed into strategic decision-making around site selection. One study presented at the 10th Trondheim CCS Conference in 2019 shows how chemicals developed for mobility control could cause CO_2 to displace water more easily, optimising the storage capacity of an aquifer.

Building on methodology from natural gas distribution networks, a new risk calculation tool helps with strategic storage optimisation and a long-term risk analysis, removing some of the financial uncertainty.

Solid understanding of well integrity

The wells themselves remain the most likely cause of potential leakage because of the artificial (man-made) routes from reservoir to the seabed. Injection of CO_2 will cool the rock close to the well. Research is ongoing into the effects of the resulting thermal stresses in proximity to the well. Much NCCS research is focused on how to avoid seepage near the well by ensuring there are multiple barriers between the stored CO_2 and the surface.

Research into the quality of cement used in oil wells has been done for more than 20 years. NCCS researchers have studied the characteristics of cement with exposure to CO_2, in particular in old, abandoned wells that may be located close to some potential storage sites. Results show that the degradation of cement, if it were to happen at all, would be just a few millimetres over the course of a thousand years.

NCCS has made recommendations for both optimal design and selection of materials for new wells in addition to evaluation of legacy wells. A spin-off project from NCCS will continue to look at integrity monitoring of old wells together with industry partners.

How CO_2 behaves during transport

We understand a lot about its behaviour in pipelines from decades of natural gas industry experience. Today, CO_2 is transported through a 150km-long seabed pipeline from the Snøhvit field to the Norwegian mainland. In North America, there are thousands of kilometres of CO_2 pipeline installed and operational. Results from NCCS research into pipeline corrosion have been used by Equinor in the Northern Lights project.

As an alternative to pipelines, shipping of CO_2 (at roughly 15 bar) is a mature technology. Norwegian company Yara International has a fleet of tanker vessels dedicated to transporting CO_2. Each one can carry up to 1,800 tonnes of liquid CO_2 safely and cost-efficiently. For the Northern Lights project, the 15-bar pressure shipping option has been selected. For future solutions, NCCS has suggested lower shipping pressures can potentially be a safe option and can decrease the cost of CO_2 transport significantly.

3. The seismic risks of CO_2 injection and storage

Many human activities carry a risk of inducing minor seismic activity, including oil and gas operations and geothermal energy production. However, the scale of seismic activity required to cause an earthquake that can be felt by humans (generally above magnitude 4) is generally only possible through natural forces.

In the event of seismic activities, the risk to CO_2 storage is low. North Sea oil and gas reservoirs regularly experience minor earthquakes, with no detected leaks of oil and gas caused by the seismic activity. Recently a magnitude 6 earthquake occurred near a pilot CO_2 storage site in Japan. The earthquake was proven unrelated to the injection process and the storage site was so secure that no leak of CO_2 was detected.

Managing fault activation risk through pressure limits
The topic of fault activation (induced seismicity) has been intensely studied in recent years in relation to hydraulic fracturing. NCCS research is addressing the risks of fault reactivation in the context of CCS. Models are being developed to assess the impact of different levels of injection pressure in order to define a safe pressure limit. In the United States, injection- induced seismicity and micro-earthquakes have been studied extensively in the Illinois- Basin Decatur project. Results have shown that these events occur often too deep to affect the integrity of the caprock or allow CO_2 to escape.

Our experience from CCS demonstration projects in Norway show that micro-seismic events are both low in frequency and magnitude. As micro-seismic activity could be an early indicator of bigger seismic events, other research projects related to this topic are ongoing within SINTEF, the Norwegian Geotechnical Institute and the Norwegian Seismic Array, NORSAR.

Conclusion: CO_2 storage is a safe solution for the climate challenge

With deep understanding of the gas in all its forms and decades of relevant industrial experience, CO_2 storage in Norway is a safe option for the decarbonisation of industry across Europe. With rigorous procedures for the selection, operation and monitoring of selected storage sites, the safety bar for Norwegian CO_2 storage sites is extremely high.

The storage capacity and expertise available in Norway means the country is well-positioned to be a CO_2 storage provider for much of Europe. NCCS research is building on that basis to provide additional insights to create a safer, cheaper operation at scale.

This article was originally published during 2020 as an NCCS memo and as a blog post. The authors were: Amy Brunsvold, Mona Mølnvik, Grethe Tangen, Inna Kim, Philip Ringrose, Elin Skurtveit, Pierre Cerasi, Peder Eliasson, Alv-Arne Grimstad, David Nikel

VISION AND GOALS

NCCS fast-tracks CCS deployment through industry-driven science-based innovation, addressing the major barriers identified within demonstration and industry projects, aiming at becoming a world-leading CCS centre. NCCS aims to be a world-class national and international multi-disciplinary CCS partnership between operators, vendors and academia that have united to address one of the greatest challenges of our time: climate change. Capacity is built to capture, transport and store billions of tons of CO_2 by fast-tracking CCS deployment. NCCS is a dynamic, forward-looking approach that will maximize new and current knowledge to make CCS happen – in time to meet EU climate targets. CCS in the North Sea Basin has the potential of becoming a NOK 50,000 billion profitable business.

Goals

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

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

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

Scientific objective

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

Innovation objective

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

Recruitment objective

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 the industry on research topics designed to address major barriers in making CCS happen in Norway, Europe, and the world. NCCS research has focused on two 'CCS Deployment Cases': CCS for Norwegian Industry and Storing Europe's CO_2 in the North Sea. A third has now been added to provide a base for the NCCS impact analysis.

Fast-tracking CCS is a joint effort. NCCS is a collaborative project between 30 partners in industry, research institutes and other organisations, in 10 countries and on three continents. NCCS also has seven associated partners. NCCS 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 in NCCS 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.

NCCS Annual Consortium Days

NCCS held its annual Consortium Days on November 4 and 5. The fourth edition of the event was held entirely online and attracted a record 130 attendees from the NCCS consortium. After two days filled with presentations, pitches, and a dedicated academic program session, partners are more aligned and up to date on the status within the centre and on the international scene.

New partners in 2020

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

In 2020, we were proud to welcome four new partners to NCCS: Baker Hughes, Wintershall DEA, Stratum, and Allton. We continue to look for new partners to join our mission to fast-track CCS deployment through industry-driven science-based innovation.

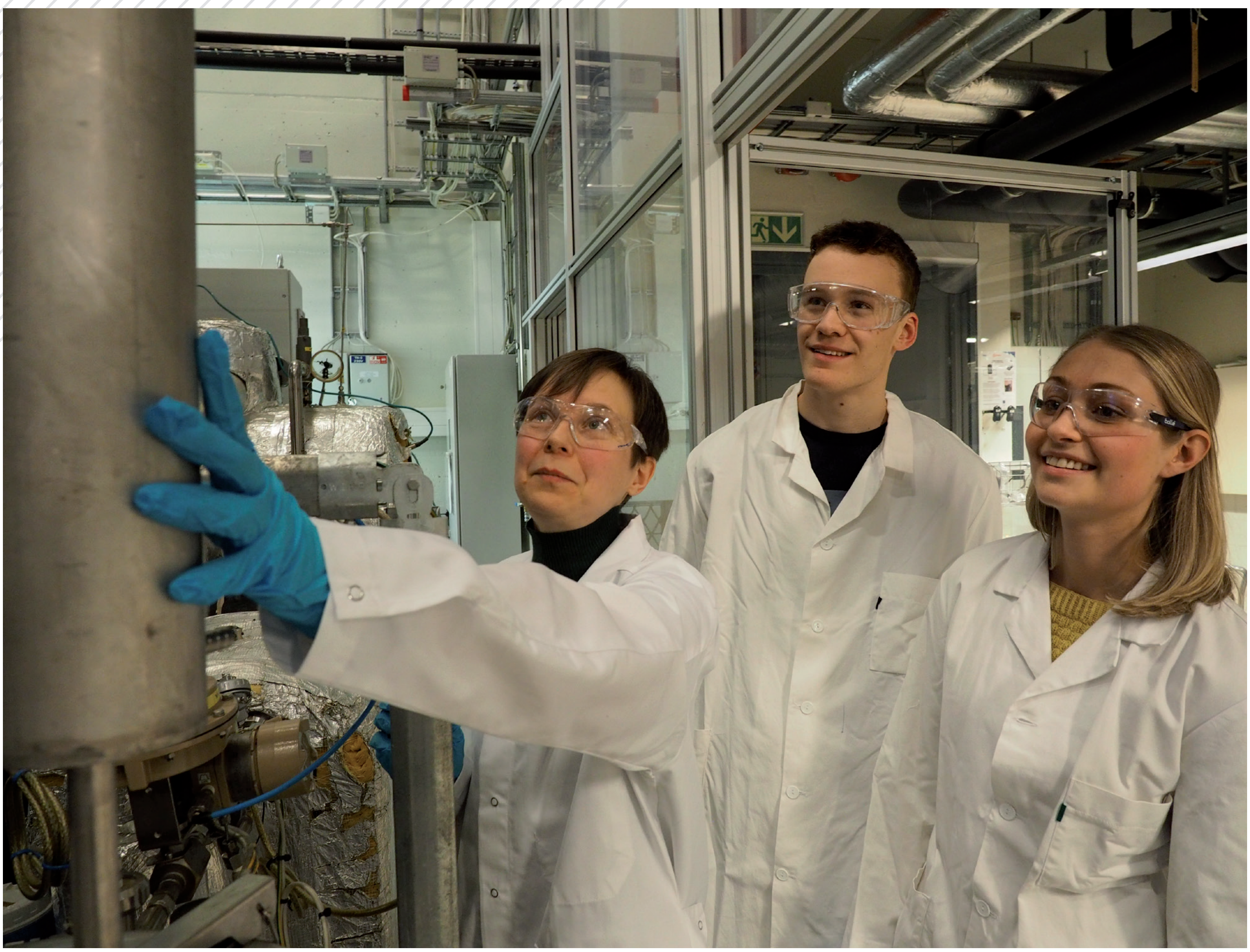
Gender balance

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.

Improving gender balance was a priority issue for the Operations Centre during 2020. Several achievements were made:

NCCS took a more active role in the recruitment of younger women to the field of CCS, so participating at student recruitment campaigns at NTNU is a prioritized activity. The educational program has significantly increased its percentage of female participants from 30% to 48% over the past two years.

NCCS works to increase the number of female NCCS task leaders. In 2021, a new female task leader begins her post. As of December 2020, the Operations Centre is composed of five women and one man. NCCS also aims to increase the visibility of female researchers at the NCCS Consortium Days. This has increased since the beginning of the Centre, with a target for each subsequent event now set at 40%.



Education plays an important role in achieving the goals of NCCS. Hanna Knuutila (pictured) is heavily involved with PhD students in the field of solvent technologies.

WHAT NEXT? LOOKING AHEAD TO 2024 & BEYOND

The importance of adapting to changing conditions

NCCS is a dynamic and flexible centre with an ambitious vision. We have adapted to the changing CCS world around us and the organization of the scientific activities has been adapted accordingly.

Norway's dedication to CCS research over the last four decades has been crucial, yet the NCCS proposal was developed at a time when CCS policy and political support was at an all-time low. The stability of research such as the FME platforms has helped maintain efforts in CCS and has been key in communicating the need and value of Longship. Many of the scientific results have been and will be implemented in the planning, development, and deployment of Longship and other demonstration projects.

The current research in NCCS is targeted so that the next phases of CCS in Norway and Europe are achieved in a cost-efficient, safe way, and that we spread our knowledge, broadly communicate the results, and reach out to other industries in need of CCS. R&D will continue to be necessary to improve all aspects of the CCS chain, stepwise and radically, and everything in between.

High relevance to industry

NCCS' significance and relevance for the business sector has only strengthened. Norway's ambitions to build the first open-access industrial CCS project are underway and interest in CCS is at an all-time high. While a clear business model for CCS is still lacking, the potential for CCS and technology vendors for CCS is increasing.

NCCS has developed and updated roadmaps so that researchers, vendors, and industry can work together to plan the research and point at potential spin-offs and commercialization opportunities in the various research tasks.

The scientific tasks have been assessed and reviewed yearly with industry partners playing a key role in decisions. 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 and adapting the R&D direction accordingly.

Deployment cases

To help structure and align its research and to support the ambition to overcome critical research barriers, NCCS has outlined three deployment cases (DCs). The NCCS Deployment Cases (DC) are:

DC2025 - CCS for Norwegian Industry is similar to the Norwegian Full-scale Project and includes CO_2 capture from industry sources and transport with ship to ensure a flexible solution for CO_2 storage on the Norwegian Continental Shelf (NCS). One storage site in offshore aquifers is anticipated, with a capacity of 1-1.5 Mt/year in 2025.

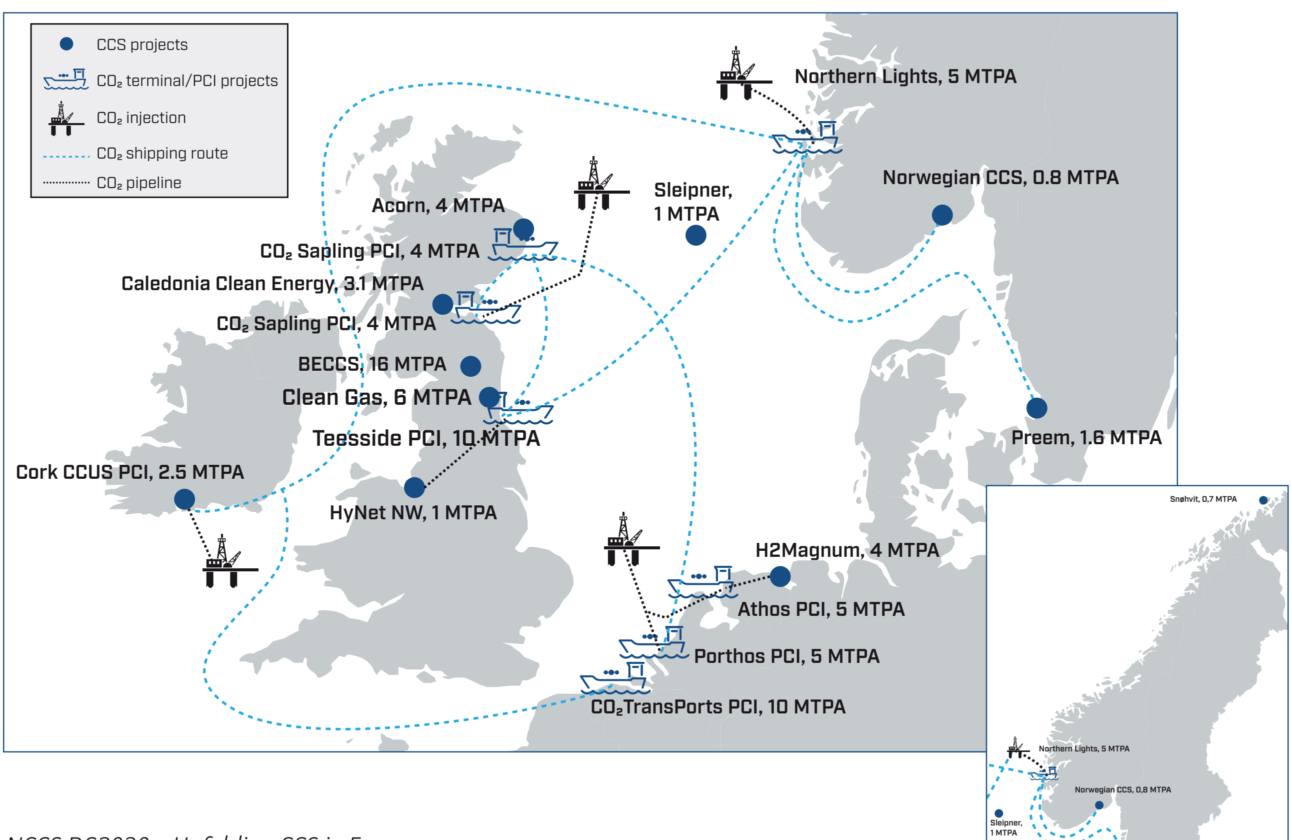
DC2030 - Unfolding CCS in Europe incorporates European CCS projects implemented, under construction and those planned to be in operation within 2030. It includes industry sources, power generation, natural gas processing and hydrogen production. A combination of ship and pipeline transport of CO_2 to aquifers and depleted gas fields ensures flexibility. Capacity is 15-20 Mt/year.

DC2050 - Storing Europe's CO_2, comprises captured CO_2 from many sources in Europe and transport via a pipeline network to Norwegian storage sites in the North Sea. Several major storage sites are foreseen, some with an opportunity for EOR, with a storage capacity of ~100 Mt/year by 2050.

TCCS-11

Because of the Longship announcement, Norway is now under the international CCS spotlight more than ever before. In June 2021, NCCS, SINTEF and NTNU invites the world of CCS professionals, scientists and students to the 11th Trondheim CCS Conference. Known as TCCS-11, the event usually attracts more than 400 CCS experts and world-leading speakers to present, discuss and debate the very latest research successes and challenges all along the CCS value chain.

Following the success of the NCCS webinar series in October, TCCS-11 will be a fully digital event, removing barriers for people to attend from all over the world, including the biggest ever student attendance. You can find out more information about TCCS-11 at www.tccs.no.



NCCS DC2030 – Unfolding CCS in Europe.

New initiatives

NCCS management also monitors initiatives that may affect the centre in the future, including:

- The unfolding of EU Green Deal and Norway's Green Platform
- ECCSEL infrastructure investments and applications for further development
- H2020 applications, ACT projects, Horizon Europe
- Potential new KSP projects in the coming years

Beyond NCCS

Knowing that CO_2-neutrality by 2050 will require more than 1 billion tons/year of CO_2 storage capacity in Europe, we cannot lean back and rely on the Longship project alone. We need more CO_2 storage capacity, and CCS as a viable measure for other industries including metal and waste-to-energy. CCS is also crucial in carbon dioxide removal as hundreds of tons of CO_2 will have to be removed from the atmosphere to reach climate neutrality by 2050.

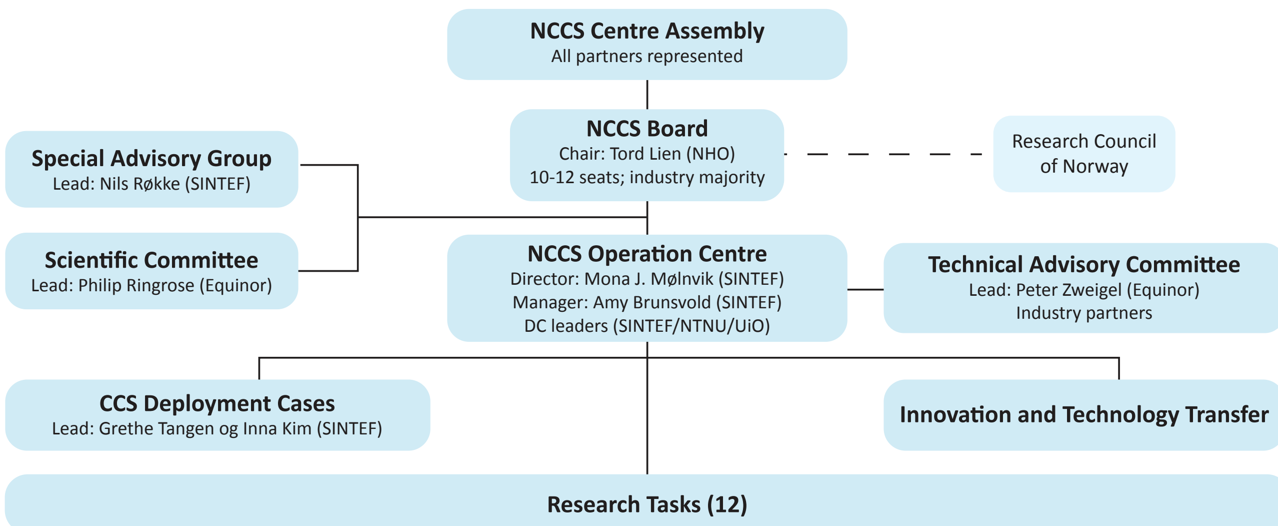
We still have a role in increasing the understanding of the potential value of, and role of hydrogen from reformed natural gas in combination with CCS. Further, compact CCS has been raised as a potential technology for offshore CO_2 emissions reductions that we cannot handle by electrification.

Full CCS deployment will not be reached by 2024, and the ambition is that NCCS will continue the operation beyond this. This will be secured by the strong industry involvement, public funding and the research partners contributions.

Previous TCCS conferences attracted a global audience. TCCS-11 will be held online and should be the biggest and best yet.

ORGANISATION

Organisational Structure



Partners

RESEARCH PARTNERS

British Geological Survey

Norges Geotekniske Institutt

Norwegian University of Science and Technology

Ruhr – Universität Bochum

SINTEF
SINTEF Energy Research
SINTEF Industry

TNO

Technische Universität Munchen

The University Centre in Svalbard

University of Zürich

University of Oslo

The University of Western Australia

INDUSTRY AND VENDOR PARTNERS

Equinor

Gassco

Shell Global Solutions International B.V.

TOTAL

Norsk Olje og Gass

Aker Clean Carbon

Ansaldo

CoorsTek

Quad Geometrics

Larvik Shipping

Krohne

NORCEM

Oslo Kommune, gjenvinningsetaten

Lundin Norway

Vår Energi

Baker Hughes

Allton

Stratum Reservoir

Wintershall DEA

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. As part of its work the SC conducted a review of the 12 tasks in the NCCS in June 2019, and then fed the assessment back to the Centre.

In 2020, The SC selected joint winners of the annual NCCS best paper award. You can read more about the winners including an interview with the lead author of one paper later in this report.

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 to the work done in NCCS has been three-fold:

- Key contributor in the yearly 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, particular 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 in NCCS. In 2020, we reviewed achievements so far and discuss strategic input to the shaping of the last half of the lifetime of this FME. New industry partners have joined NCCS, and it will be useful to include their ideas.

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.

Cooperation between partners

”Task families”

An industry led centre is dependent on effective arenas and processes for cooperation with industry partners. An important and highly successful measure was the establishment of ”task families”. The task families include specialists from industry and research actors with interest in the topics addressed. Through workshops, digital meetings, and webinars, all partners can contribute to technical discussions and influence the ambitions for next year's work program. NCCS includes a number of industry companies and all are active contributors in one or more task families.

Consortium Days

The prime event in the NCCS calendar is the annual Consortium Days staged in fall. Here several representatives from all partners meet to review and discuss this year's results. Due to travel restrictions, the 2020 Consortium Days were held online with a fantastic attendance of 130. The event combined a mix of pitches from the tasks, extended presentations in plenum, posters, and breakout sessions to go even deeper into the technical results.

Webinars

From the beginning of NCCS, webinars have proved an effective tool to convey and discuss results from research activities. During the societal restrictions of 2020, the NCCS consortium made extensive use of digital communication in general and webinars in particular for both internal and external purposes. The lack of travel saved time and made the sharing of information among partners much more efficient. The webinar format also allowed partners to attend more events than if they had been physical, increasing information exchange throughout the consortium. Following this success, the use of webinars will be considered for all future events as a replacement for or complement to a physical gathering.

Pictures from the NCCS Consortium Days 2019.

RESEARCH PLAN

With an eye on 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 continues to do so today.

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 during the Deployment Case Gate Reviews, will set the direction for what is required to advance technologies to a higher Technology Readiness Level (TRL).

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

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

THE VALUE OF INNOVATION IN NCCS

Throughout the life of NCCS so far, each research task has documented, developed and mapped innovations.

IMPACT OF **INNOVATIONS**

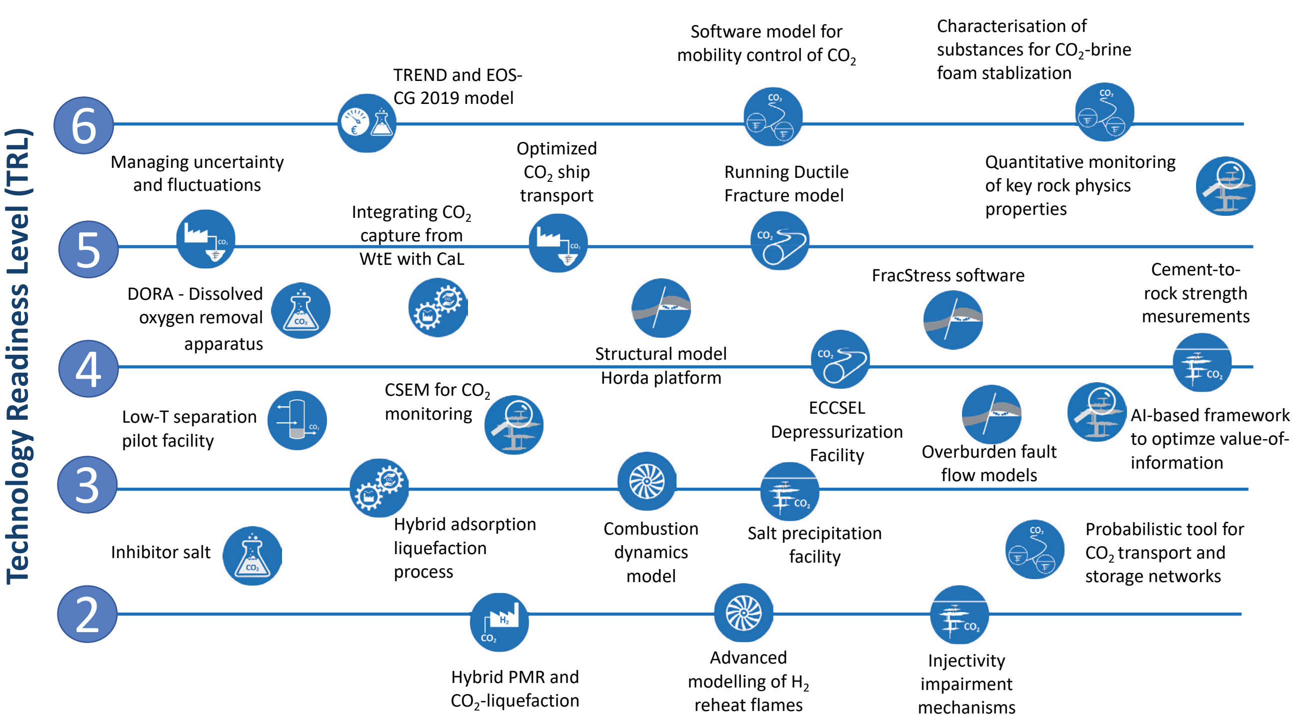
Innovations in NCCS

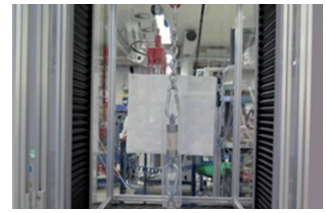
Innovation may be defined as a product, a technology, a component, a process, a model, a concept, an experimental facility, or a service that is new or significantly improved with respect to properties, technical specifications, or ease of use.

Maximising impact from our research is an important task for NCCS. In the NCCS Impact Study, we have evaluated the 12 research tasks and assessed the potential impact of the research and innovation given that the research is successful. In this context, impact can be measured along several axes. Examples include reduced emissions, economic impact (increased value creation, saved costs), improved decision making, saved energy, and industrial potential.

Expected impact from innovations in NCCS

Building on the methodology in the impact study conducted for the Research Council[1] and the 2019 NCCS impact study[2], NCCS has (in 2020) selected eight innovations and assessed the potential impact of the research. The innovations cover the whole range of topics along the CCS chain, including CO_2 capture, CO_2





Task 1
Models for identifying optimal conditions for ship transport of CO_2

Main impact:
Showing potential reductions in CAPEX and OPEX future projects with lower pressure-based transport

Task 3
Low emission H_2 production using novel membrane technology

Main impact:
Reduced H_2 production cost and reduced energy consumption

Task 7
Model enabling qualification of NG pipelines for CO_2 transportation

Main impact:
Avoided costs and CO_2 emissions due to re-qualification of existing NG pipelines to CO_2 transport

Task 10
Innovative laboratory testing of cement to rock bonding

Main impact:
Reduced well construction costs, maintenance costs and CO_2 footprint due to less conservative models for cement integrity

NCCS Impact study spring 2020

transport, CO_2 storage and CCS value chain. As before the innovations mainly fall under four categories: 1) new technology, 2) models and calculation tools, 3) new methods, and 4) new standards and guidelines.

The NCCS deployment cases serve as basis for the quantitative illustration of impact made for each innovation to indicate the order of magnitude of the potential gains. Below the innovations are presented.

Task 1: Models for identifying optimal conditions for transport of CO_2 via ship

- **The challenge**

CO_2 shipping is expected to play an important role in early CCS development, for "small" capacities, and/ or "long" distance transport. Over the last few years, questions on optimal transport conditions (temperature and pressure) have been raised. The four liquid CO_2 tankers operated today by Larvik Shipping are rated for medium pressure transport, 16-21 bar and around -30°C. Although the density of liquid CO_2 decreases, and the cost of storage tank increases, with increasing pressure, the cost of liquefaction is higher for the lower transport pressure.[3] 15 bar is currently considered the best option for the Norwegian full-scale project, based on maturity and safety. However, work in Task 1 has shown that in the future, lower pressure-based transport could be a better solution due to its potentially lower cost.

- **The innovation (TRL 5)**

Identification of optimal conditions (pressure, temperature) for transport of CO_2 by ship that would lead to significant reduction in the costs of CO_2 liquefaction and transport. The transport conditions of interest are especially the low-pressure option (7 bar) and the medium-pressure option (15 bar).

- **Potential impact**

Base case for illustration: A possible case within DC2030 is transport of 5MTPA CO_2 from Netherlands to Norway (1000km distance to Northern Lights).

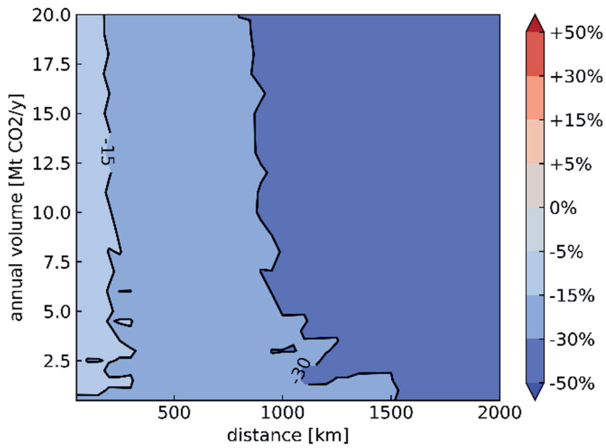
1 https://www.regjeringen.no/contentassets/816c63dcb0ea49768ec03cd64828af5a/effekter_av_energiforskningen.pdf

2 https://blog.sintef.com/sintefenergy/ccs/the-impact-of-nccs-research-innovations/

3 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761762/BEIS_Shipping_CO2.pdf

The NCCS work demonstrates that enabling 7 bar instead of 15 bar based shipping can significantly lower costs (figure):

– **Investment** could be reduced nearly by 50%.
– Reduction in **operating cost** of **15%**.
– Overall liquefaction and shipping cost would be reduced by **30%**.



CO_2 conditioning and transport cost reduction achievable by 7 bar ship option compared to the 15 bar ship option (color code indicates cost reduction)

Task 3: Low emission H_2 production using novel membrane technology

- **The challenge**

Clean hydrogen will be a key in the energy transition, enabling low emission power and industry processes. Protonic Membrane Reformer (PMR) is a breakthrough technology for hydrogen production with integrated carbon capture at competitive efficiency and cost. To enable implementation of the technology at large scale, it is necessary to improve on the most critical material performance and stability issues of the membrane and seals.

- **The innovation (TRL 5-6)**

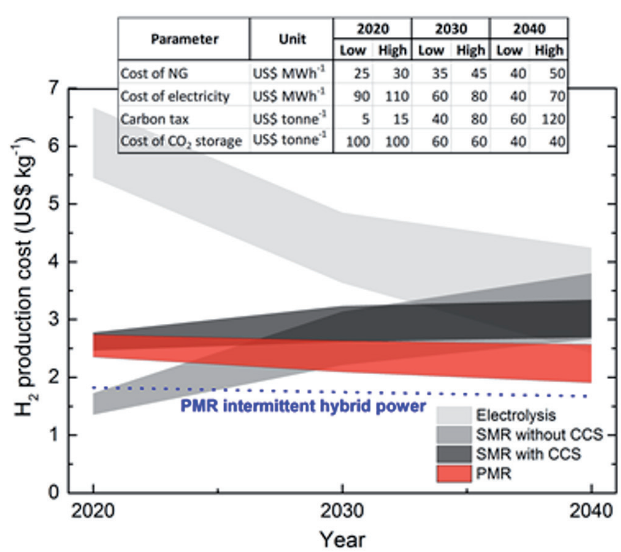
Advancing core membrane technology for hydrogen production by Steam Methane Reforming (SMR) with integrated CO_2 separation, based on electrochemical membrane technology developed by CoorsTek Membrane Science AS. The work focuses on individual cells compatible with modular engineering units up to 0.5 kg H_2/day.

- **Potential impact**

The membrane technology for H_2 production contributes to cost reductions, reduced emissions and improved safety. It also represents an opportunity for industrialisation of a new capture technology.

Base case illustration: By 2030, successful implementation of PMR technology for H_2 production is anticipated, e.g. methanol production at Tjeldbergodden, approx. 16 tonne/h (140 kton/year) H_2.

– H_2 production cost (figure): PMR - \$2.5/kg vs conventional SMR with CCS - \$3/kg H_2, or \$0.5 lower OPEX per tonne hydrogen produced (**17% reduction**), resulting in **OPEX** saving \$70M per year.



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

Simulated H_2 production costs for PMR compared to conventional SMR and water electrolysis. Source: CoorsTek

– 770 k tonne CO_2 per year is separated in situ at high pressure, enabling additional cost saving on CO_2 compression.

Task 7: Model enabling qualification of natural gas pipelines for CO_2 transportation

- **The challenge**

CCS deployment requires a pipeline network for CO_2 transportation. Some natural gas (NG) pipelines are scheduled for decommissioning. Re-use of the NG pipelines for CO_2 transport requires qualification. One of the issues that need consideration is fracture propagation control, i.e., that a crack does not develop into a long, running ductile fracture (RDF). Existing engineering tools (Battelle two-curve method, BTCM) are not developed for CO_2 or modern steels.

- **The innovation (TRL 5)**

The SINTEF coupled FE-CFD model for assessment or running-ductile fracture (RDF) can significantly contribute, among other methods and measures, to re-qualifying existing NG pipelines for CO_2 transportation (figure).

The model is flexible and has a wider range of use than existing tools and would be expected to approve more reuse cases. It could lead to reduction of safety margins and hence reduced costs. It could contribute to a larger operational window.

The FE-CFD model can be used to develop a simpler-to-use RDF engineering tool.

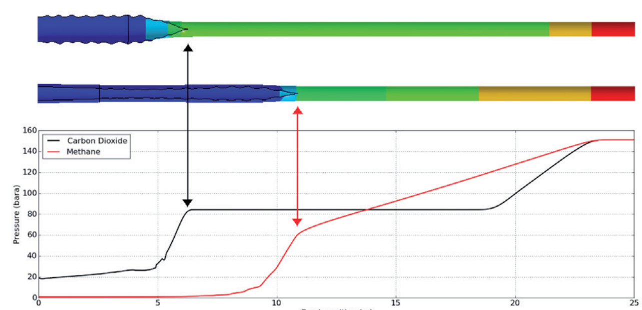
- **Potential impact**

Reduced uncertainties in the design of new pipelines and re-qualification of existing ones improves safety, lower the costs and accelerates deployment of CCS.

Illustrative example: 2.5 Mt/y CO_2 transported using a re-qualified pipeline 200 km (offshore), assumptions relevant for DC2030.

Avoided costs and CO_2 emissions due-to re-qualification of existing natural gas pipeline to transportation of CO_2:

– **Avoided investment cost** according to Sepra et al (2011)[4] for a 200 km 12" offshore pipeline: 1.18 MEUR/km*200 km = **EUR 236m**
– **Avoided CO_2 emissions** by not having to produce and install the pipeline, calculated using iCCS: 460 tonnes/km*200 km = **92k tonnes**



Example calculation showing that CO_2 gives a higher load on the opening pipe flaps compared to methane.

Task 10: Innovative laboratory testing of cement to rock bonding

- **The challenge**

Satisfactory sealing of the abandoned wells is mandatory and may limit the total injection volume or even disqualify a storage site, if not proven. Existing well construction and sealing methods rely on Portland cement with additives or alternate materials, which

4 https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/technical-and-economic-characteristics-co2-transmission-pipeline-infrastructure

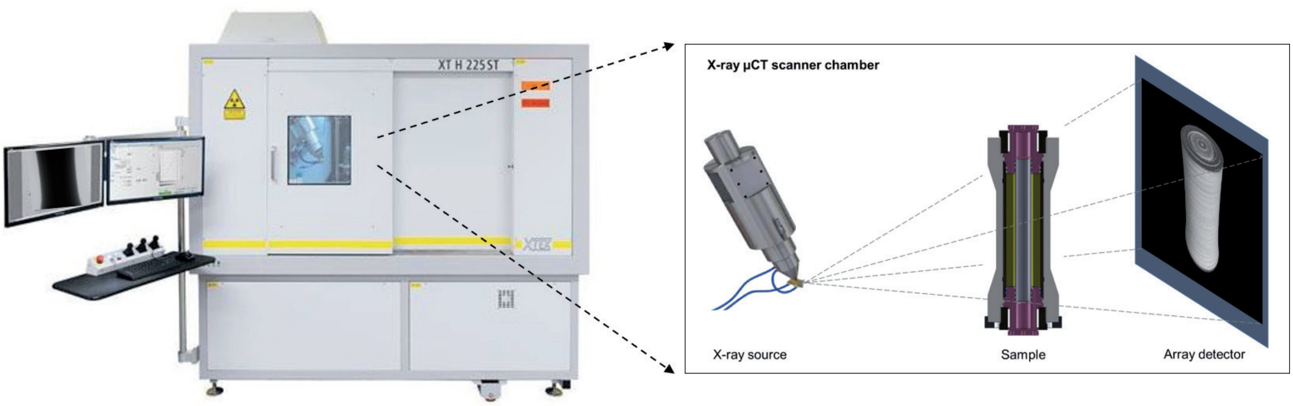
are difficult to qualify and test. On average, primary cementing services constitute around 5% of well cost. Secondary cementing can result in an incremental increase of up to 20% of well cost (www.scmdaleel.com).

- **The innovation (TRL 6)**

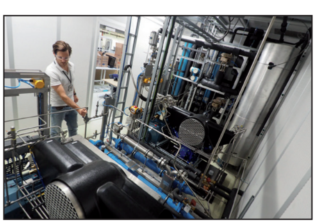
The testing method, developed in the laboratory, addresses several aspects needed to fully assess how a cement or other sealing material will perform at realistic down-hole conditions by performing thorough testing of the basic mechanical parameters needed for modelling purposes at field-relevant conditions.

- **Potential impact**

Less conservative models for cement integrity will reduce construction and maintenance costs and reduce demand for materials, and by this also reduce

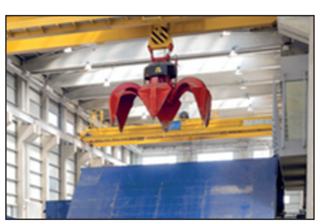


The ECCSEL well integrity research infrastructure. This mini-wellbore simulator is used for in-situ investigation of cement integrity under CT imaging. Sketch by A. Ghaderi.



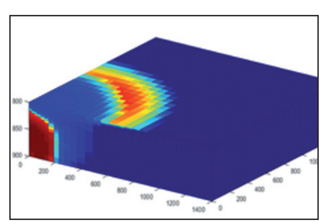
Task 4
Enabling lower CO_2 pressure in liquid storage and transport tanks.

Main impact:
Lower net cost of CO_2 liquefaction and transport
Higher net capacity per cargo



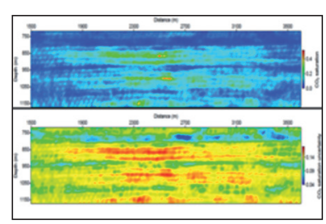
Task 6
Techno-economic investigation of Calcium Looping integration in Waste to Energy plants

Main impact:
Cost reduction and enabling Calcium Looping as competitive technology for negative emissions



Task 11
Improved CO_2 storage efficiency through mobility control

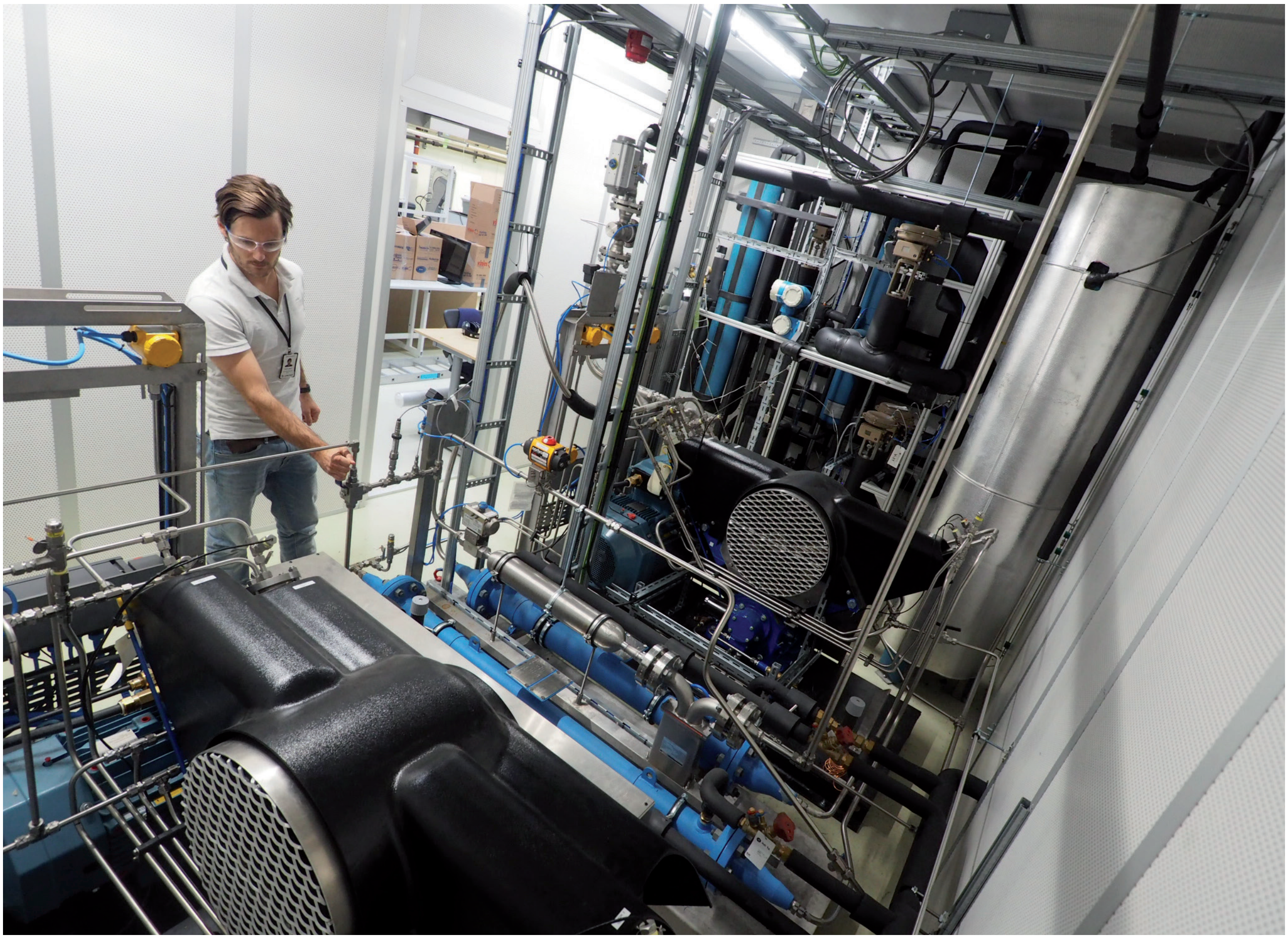
Main impact:
Mobility control even with moderate mobility reduction parameters, can significantly improve the storage efficiency



Task 12
A two-step Bayesian approach for quantitative CO_2 monitoring

Main impact:
Reduce monitoring costs, more predictable operation, improved safety, supporting communication with regulators and the public

NCCS Impact study fall 2020.



NCCS researcher David Berstad in the interior of small-industrial scale CO_2 liquefaction test facility.

the CO_2 footprint. Testing at field relevant conditions also increases confidence in CO_2 storage.

Base case for illustration: 15-20 Mt CO_2/yr is to be stored in NCCS DC-2030. The cost per tonne of Portland cement is around EUR 40/tonne. Additive pricing goes from EUR 80/tonne for gypsum to EUR 4,000/tonne for fluid loss additives. Cementing corresponds to between EUR 2-8m per well. Assuming average optimal injection rate of 0.2 – 1 Mt/y per well, with optimized placement, one would need up to 100 wells to reach the DC 2030 scenario, with cement costs reaching up to EUR 800m.

- **10 % less cement** per well would lead to an economy of up to **EUR 80m**.
- **Additional 10 % cost reduction** could be obtained by not having to use special cement additives.
- Plug and abandonment (P&A) needs for existing wells: 400 k€ per day * 30 days up = 12 M€ per well to plug (www.fourphase.com). Halving the required plug length compared to current regulation results in one day less per well, this sums up to between 40 to 1 200 M€ savings depending on number of wells, on top of the well construction cost reduction.

Task 4: Enabling lower CO_2 pressure in liquid storage and transport tanks.

- **The challenge**

There is a downward limit in terms of temperature and pressure in enabling lower pressure CO_2 transport, as the triple point for pure CO_2 is located at 5.18 bar(a) and -56.56 °C. The minimum liquid CO_2 pressure must prove to enable stable and safe operation in all joints of the CO_2 chain, hereunder: liquefaction, storage, transfer/bunkering, offloading, and more. Additionally, auxiliaries such as pressure safety valves must be reliable.

- **The innovation (TRL 6)**

Determination of the lowest pressure levels at which nearly pure CO_2 can be liquefied at stable and safe operation and experimental validation of all parts of the concept: liquefaction, liquid CO_2 transfer and minimum safe CO_2 pressure in liquid storage and transport tanks.

- **Potential impact**

Illustrative example: As shown by Task 1, low pressure CO_2 liquefaction for transport can lower the net cost of CO_2 liquefaction and transport and higher net capacity per cargo. Work in Task 4 provides experimental validation of the low-pressure liquefaction process and theoretical verification of the CO_2 storage and transport parts of the chain.

By using the results from Task 1[5], the potential cost savings that can be obtained by changing to a 7-bar transport pressure can be estimated. For a case in DC2025 similar to the Longship project, total cost savings of EUR 2.4m/year can be obtained. This calculation assumes cost savings of EUR 6/tonne for transport of 400,000 tons CO_2/yr, with a transport distance of 500 km. Transport at even lower pressure may lead to even lower transport costs.

Task 6: Techno-economic investigation of Calcium Looping integration in WtE plants

- **The challenge**

Waste to Energy (WtE) plants play an essential role today as advanced waste management facilities. They provide energy recovery and produce heat and/or power. However, they also result in CO_2 emissions from the combustion process of the MSW we generate. CCS from WtE can provide negative emissions due to the biogenic origin of a fraction of the MSW.

- **The innovation (TRL 4-5)**

Methodology and a tool for techno-economic assessment of the process integration of calcium looping technology in WtE plant, including evaluation of different heat integration options.

- **Potential impact**

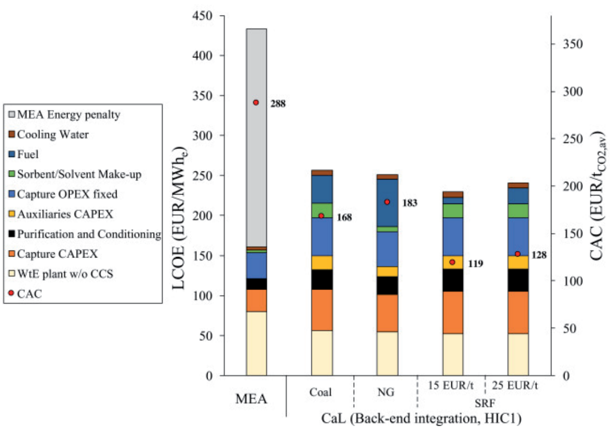
Calcium Looping (CaL) Integration in WtE plants can reduce costs, enhance energy efficiency, and offer a new business model for WtE industry as it will be competitive with other climate positive technologies, such as DAC and BECCS.

Base case for illustration: For a reference WtE plant of 60 MW similar to Klemetsrud (DC2025) with an electric power as a main product, assuming CaL back end integration NCCS analysis shows (figure):

– Estimated **47% reduction in levelized cost of energy** (LCOE) with respect to reference WtE with MEA.
– Over **30 % reduction in capture costs** (CAC) when using natural gas as auxiliary fuel in CaL calciner, in comparison to chemical absorption with MEA.

5 Techno-economic analyses of CO_2 liquefaction: Impact of product pressure and impurities, by Han Deng, Simon Roussanaly & Geir Skaugen, International Journal of Refrigeration, 103, 301-315.

– CAC of EUR 119-183/tonne$_{CO2,av}$ for WtE with CCS is competitive with expected cost of BECCS[6] (EUR 50-250/tonne$_{CO2,av}$) and DAC (currently EUR 600/tonne$_{CO2,av}$ estimated by scientific organizations[7] and at EUR 100-200/tonne$_{CO2,av}$ hypothetical future estimates advertised by technology providers[8]).



LCOE and CAC for the WtE plant with CO_2 Capture[9]

Task 11: Improving CO_2 storage efficiency through mobility control

- **The challenge**

The high mobility contrast between injected CO_2 and formation brine can lead to unstable displacement during storage operations. This causes early arrival of CO_2 at structural spill points, which limits the amount of CO_2 that can be stored. It can also make efficient use of pressure control wells difficult, which could either reduce storage capacity due to pressure constraints or due to early arrival of CO_2 at pressure control wells.

- **The innovation (TRL 4-5)**

Methodology and tools for efficient CO_2 mobility control for storage operations, including:

– Characterisation of CO_2/brine foam behaviour in laboratory experiments at reservoir conditions
– Development of a CO_2-foam module for MRST
– Modelling of behaviour and effect on storage efficiency at field scale

- **Potential impact**

Application of CO_2 mobility control has been simulated at field scale for an idealised five-spot injection/production well pattern. The **storage efficiency can be more than doubled** even with moderate mobility reduction parameters.

Illustrative example, scaled to 50 million tonnes CO_2 (DC2030): In one simulated case breakthrough of CO_2 at pressure control wells is delayed from 13.6 to 26.4 years when 0.3 wt% surfactant is added to the CO_2 during the first four years. Averaged over 26 years this represents about 0.5 kg surfactant per tonne of CO_2 injected.

If a well costs 50 million USD, twice as many wells are needed without mobility control and surfactant acquisition and handling costs 2 USD/kg, total cost of storage is 1.83 USD lower per tonne CO_2 when mobility control is used. At an exchange rate of ~10 NOK/USD this would mean that **910 MNOK can be saved for 50 million tonnes CO_2 stored.**

Task 12: A two-step Bayesian approach for quantitative CO_2 monitoring

- **The challenge**

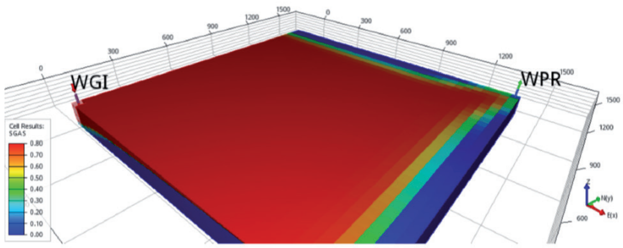
CO_2 monitoring is a regulatory requirement and an essential tool for predictable operation and safe CO_2 storage. While conventional monitoring focus mainly on determining the location and extent of the CO_2

6 https://www.sciencedirect.com/science/article/pii/S0306261916319043?via%3Dihub

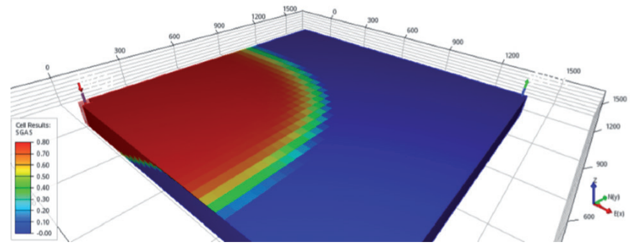
7 https://www.aps.org/policy/reports/assessments/upload/dac2011.pdf

8 https://climeworks.com/

9 Haaf M. et al. 2020. CO_2 Capture from waste-to-energy plants: Techno-economic assessment of novel integration concepts of calcium looping technology. Resources, Conservation & Recycling. (2020) 162, 104973. https://doi.org/10.1016/j.resconrec.2020.104973



CO_2 injection without mobility control



CO_2 injection with mobility control

plume, a more quantitative monitoring approach is useful for detailed conformance (agreement between observations and predictions) assessment and reliable operational decision making. A quantitative approach could also be used during the characterization phase to give more accurate assessment of storage capacity.

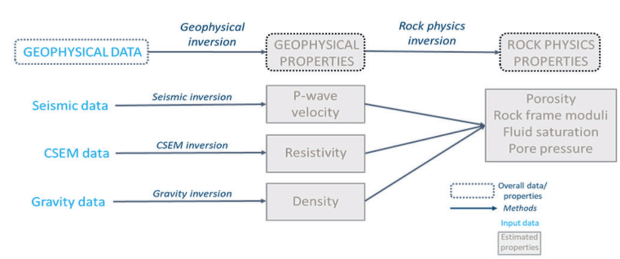
- **The innovation (TRL 5-6)**

The Bayesian Rock Physics Inversion method developed and investigated in NCCS, in collaboration with the Pre-ACT project, is a two-step approach consisting of geophysical inversion followed by rock physics inversion with uncertainty propagation (see figure). The method allows quantification of the most relevant rock physics parameters including their uncertainties. It is, in particular, useful for discrimination between pressure and saturation changes in the reservoir. The method handles multiple types of geophysical input data and can take prior information (e.g. well logs or down-hole measurements) into account for reliable assessment of site performance.

- **Potential impact**

The two-step Bayesian approach for quantitative CO_2 monitoring contributes directly to more informed operational decisions, safer storage, and at the same time fewer costly interventions during CO_2 injection. In addition, the approach uses available data in an efficient way, which can help to reduce the need for frequent (costly) geophysical surveys. Any operator could profit from adapting such a workflow as part of their Measurement, Monitoring, and Verification (MMV) plans, for updates of their reservoir models, better forecasts, and improved decision making. The quantitative information, and especially the uncertainty assessments, may also be helpful for communication with other stakeholders and with the public.

Illustrative example: With more efficient use of acquired data, we assume that the interval between geophysical surveys can be increased by up to 25% and that every second or third survey can be sparser and more targeted. This could result in around **30% overall reduction of monitoring costs**. For a storage project of Sleipner to Aurora size (DC2025) and 20 geophysical surveys at NOK 100m per survey, this means a potential cost reduction of around **NOK 600m**. In addition, we foresee a reduction in risk of and costs related to unexpected events like temporary interruption of operation, unplanned well intervention, need for additional wells, or even early abandonment of the storage project.



Two-step workflow combining geophysical and rock physics inversion.

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, NCCS has eight spin-off projects associated to 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 2020.


CO_2

TASK 1

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

www.sintef.no/NCCST1

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 have been identified as a key opportunity to facilitate large-scale implementation of CCS and improve cost efficiency. While such cases could present opportunities for cost reduction compared to stand-alone implementation, significant efforts are required to identify the best clustering strategies. Indeed, multiple options on how to pool, capture and conditions these CO_2 emissions can be considered.

With this in mind, we developed a model for planning and evaluating strategies for pooling and capturing from an industrial cluster. The model allows us to assess the technical and cost characteristics of a clustering facility with an accuracy very close to the one of detailed evaluation. This model performs such an evaluation in a matter of seconds or minutes instead of days or weeks for detailed evaluations. As a result, comparison of multiple strategies (example: Figure 1) becomes a more manageable and accessible way to find the most cost-efficient strategy for implementation of CO_2 capture and conditioning from an industrial cluster. This model will be used in 2021 to identify the best CCS clustering strategy for an industrial cluster case study.

Developing a transport infrastructure for the Norwegian industry

In 2020, we investigated how a shipping infrastructure could roll out to transport CO_2 from Norwegian industry. CO_2 transport of small volumes, such as from individual industrial sites in Norway, is typically expensive. As part of this work, we evaluated how

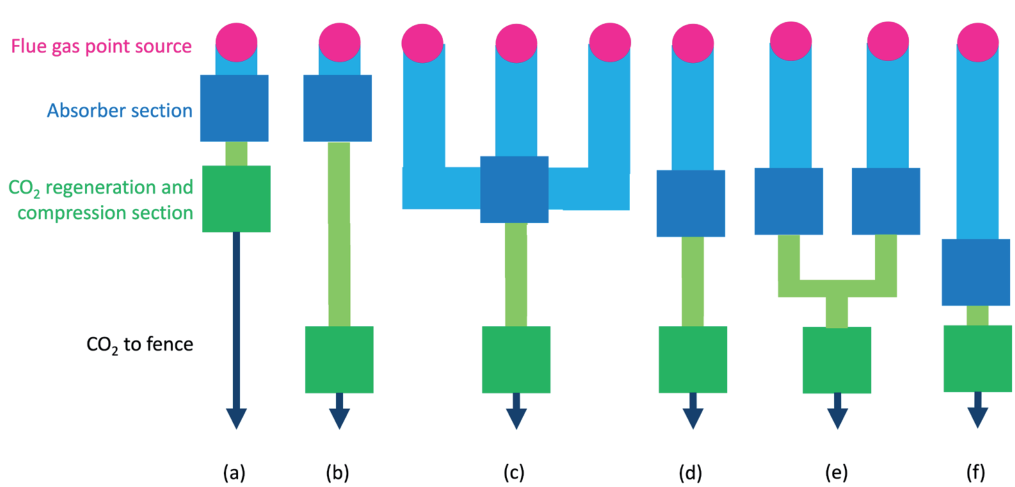


Illustration of different layout alternatives that could be considered in the case of an industrial cluster.

to best transport CO_2 from 22 industrial sources in central and southern Norway. Our results show the strong benefit of co-operation and coordination to reduce costs through shared infrastructure and ships. In addition, we also demonstrated that retrofitting a 15 bar shipping chain to 7 bar shipping, once the 7 bar shipping technology would become available, was not a cost attractive solution. This new knowledge will lead to journal publication in 2021.

Incentivising low-carbon product

Incentivising low-carbon product through public procurement is a new strategy put forward to support the development of low-carbon solution. For example, the Norwegian state and local authorities purchase goods, services and works to the sum of over NOK 550 billion every year, and the resulting carbon footprint corresponds to 14% of all Norwegian carbon emissions. As a result, public procurement can help the public sector reduce its carbon footprint, and also assist in the development of markets for low carbon products. In 2020, we investigated what legal constraints could arise from this strategy. We identified the two most important constraints that must be met. Firstly, the low-carbon product specification requirement cannot have the effect of disproportionately restricting competition. Secondly, these requirements must be formulated in a way that does not have the effect of further restricting the competition (for example, specific methods of emission reduction can't be set). The ability to set such requirements could be key to enable high enough demand to facilitate implementation of CCS from industry (cement, iron and steel, etc.).

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 operational- and investment cost by indicating amines with higher stability and developing technologies to control and monitor solvent stability. Higher stability of solvent means reduced cost, reduced emissions, improved lifetime of both material and solvent, improved safety for employees and reduced environmental impact.

www.sintef.no/NCCST2

Task leader:
Solrun Johanne Vevelstad

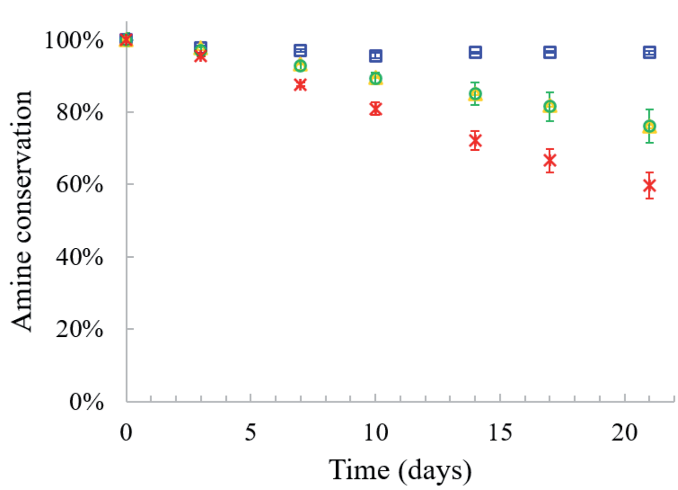
Solvent technology – environmental issues **(Task 2)**

Solvent management by using degradation mitigation technologies

As solvent degradation leads to increased capture cost and environmental issues, we study several different mitigation technologies. For example, **a dissolved oxygen removal apparatus (DORA)** was successfully tested at TRL-level 6 at PlantOne in Rotterdam in 2020. Typically, the concentrations of degradation compounds increase with increasing pilot-hours. However, with DORA in use, stable concentrations of degradation compounds were seen. Our preliminary assessment shows that DORA is an economically viable solution for controlling the degradation of CO_2 capture solvents in a large-scale plant and could be applied independently or combined with a reclaimer unit, as part of the plant solvent management strategy.

The **proof-of-principle of in-situ iron removal** was also achieved in 2020. As iron is believed to have an essenti-al role in accelerating solvents' degradation, removing it could significantly reduce solvent loss.

Finally, in 2020 we identified a salt that leads to significant inhibition of oxidative degradation of MEA-solvent when added in small concentrations (~2wt%). Several salts did show increased chemical stability of aqueous MEA under oxidative degradation. The addition of the best performing salt into MEA-solvent did not reduce the solvent's absorption capacity, nor did it increase the solvent viscosity or changed the thermal degradation behaviour. The results suggest that adding a small concentration of specific salt into MEA-solvent can reduce oxidative



Amine conservation (%) as a function of time (days) for oxidative degradation experiments without (red markers - basecase) and with various salts added (yellow, green, blue).

degradation without deranging neither CO_2 solubility nor its mass transfer rates. This is excellent news. In 2020, the idea was taken from TRL0 to TRL3. The results will be shared with the CO_2 capture community in a gold-open access journal publication.

In 2021, the work will continue, and the technology will be taken to higher TRL-levels. We will run a campaign in the circulative solvent degradation rig to understand how the salt behaves in a circulative, temperature swing process. After that, we are ready to take the salt-concept to a pilot scale.

Understanding of solvent degradation

In spring 2020, we also studied the degradation of 40wt% MEA in the circulative degradation rig, mimicking the capture plant by exposing the solvent for both low and high temperatures. The campaign focused on the effect of desorber temperature, NOx, and iron concentration on the formation of different degradation compounds. Additionally, it was also investigated if absorber sump stripping with N_2 could reduce degradation. We discovered that desorber temperature and NOx have a significant effect on the formation of certain degradation compounds.

The work on testing the chemical stability of 18 amines in the presence of oxygen and CO_2 at 60 °C was finished in 2020. The objective was to find structural features of amines that are more stable than MEA. It was discovered that steric effects play a large role in stabilizing the amines under oxidative conditions, and carbamate formation plays a vital part in the degradation pathway of some solvents. Results will be shared in an open-access publication to be submitted in 2021.

Metal ions and especially iron (Fe) have a catalytic effect on solvent degradation so the solubility of iron in the amine solvent is a topic of interest. We studied the solubility of Fe in 30wt% MEA both with and without CO_2 using a 3^2-factorial design. The results show that temperature and CO_2 concentration did not significantly affect the iron solubility, which was in the range of 178-200 mg/l. However, there were indications that the solubility decreases when CO_2 is added to the solvents and increased at higher temperatures.

Finally, the availability and the challenges of creating an overview of the learnings and outcomes of different pilot campaigns focusing on solvent degradation and amine emissions led to a review paper. Currently under review, the paper focuses on pilot plant testing of amine solvents for post-combustion CO_2 capture. It aims to summarise the lessons learned in different pilot campaigns and give recommendations on how solvent stability and emissions can be monitored and assessed.

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 utilizes electrical energy as input, which becomes an increasing advantage in the transition towards renewable and intermittent energy. The goal in Task 3 is to identify and improve the core technology in the PMR: single-tube membranes (6 cm tubular membrane, 1 cm diameter) that are compatible with modular single engineering units (SEU) up to 0.5 kg H_2/day. The work in NCCS is aligned with a Gassnova demo project (PROTONIC) on a semi-integrated PMR prototype and digital-twin at TRL 5 (Phase I) and TRL 6 (Phase II).

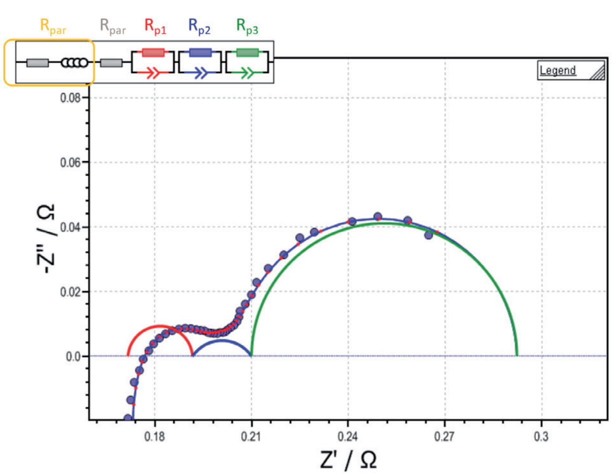
www.sintef.no/NCCST3

Task leader:
Jonathan Polfus

Low emission H_2 production **(Task 3)**

Detailed electrical characterization of PMR membranes

In order to further understand the electrical and electrochemical properties of the PMR membranes, detailed electrical characterization was performed on single-tube membranes supplied by CoorsTek, as a function of steam pressure (0.05-5 bar) and temperature (600-800°C). Using impedance spectroscopy, ohmic and electrode polarization resistances could be extracted, which serve as basis for further improvement of performance of the membranes.



Electrical impedance spectra of a PMR membrane showing how the various contributions to the resistance can be extracted when fitting the data to an equivalent circuit model: ohmic (R_{ohm}), parasitic (R_{par}) and polarization resistances (R_{p1-3}).

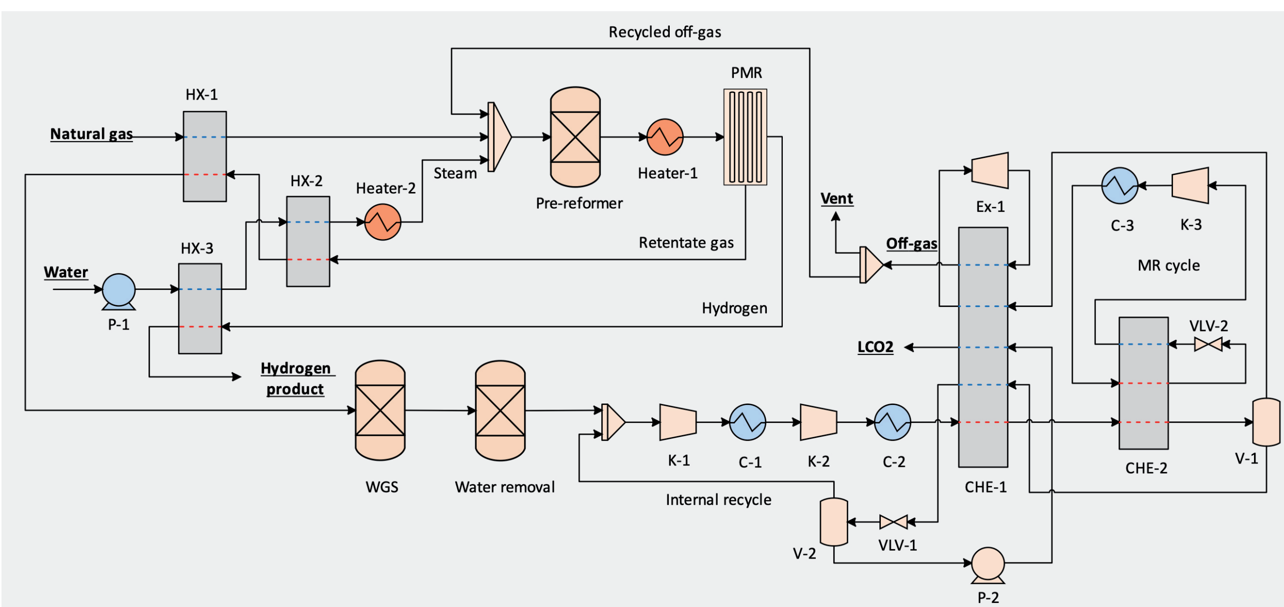
Chemical and electrochemical degradation studies

Further experimental work in NCCS will focus on investigating potential chemical and electrochemical degradation of the PMR materials in relevant atmospheres as well as impurities in the natural gas such as H_2S. The work so far has been to prepare different types of samples required for the chemical and electrochemical degradation experiments, and to make a test matrix including the relevant post-characterization methods. These have been chosen to address hypothesis regarding the degradation mechanism based on previous experimental and computational work.

Hybrid PMR and CO_2 liquefaction process

A hybrid process comprising PMR technology and CO_2 liquefaction is being developed in the MACH-2 KSP spin-off project. By exploiting the advantages of both technologies and applying them in their preferred window of operation, significant cost and efficiency gains are expected. In optimizing the process, the configuration of the hybrid process was varied with respect to the type of liquefaction process for CO_2 capture and the treatment methods of the residual gas from the low-temperature process. The latter is critical for optimal design of the hybrid system with a high H_2 recovery rate as the PMR retentate gas may contain considerable amounts of hydrogen and CO if the PMR is not operated at high conversion. The detailed process flow diagram of the hybrid process with the liquefaction system is illustrated below. In the selected hybrid process, a mixed refrigerant liquefaction system is used for the carbon capture part, and a water gas shift reactor for the retentate gas is included to reduce the CO content in the feed and achieve a high CO_2 capture rate and high H_2 recovery rate by recycling the residual gas. Based on the performance analysis of the hybrid process, the configuration of the liquefaction process will be further modified to minimize the overall cost of the system. The heat recovery method of the warm hydrogen product and retentate gas from the PMR will also be further developed in the MACH-2 project to improve the energy efficiency of the hybrid system for hydrogen production with low carbon footprint.

In 2020, results originating from the MACH-2 project were presented at the 30th European Virtual Symposium on Computer Aided Process Engineering (ESCAPE-30) in September, and during the NCCS-organized webinar in October. A scientific article detailing the low temperature process was published in the Elsevier journal Computer Aided Chemical Engineering.



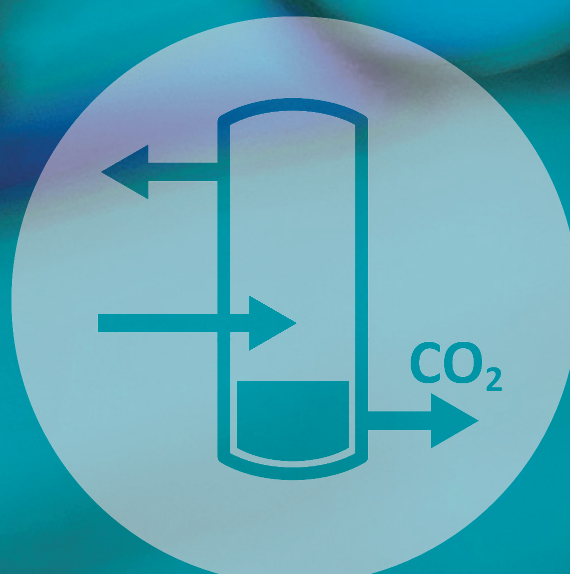
Detailed process flow diagram of hybrid PMR and CO_2-liquefaction process with off-gas recycle and WGS reactor after PMR.

TASK 4

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

www.sintef.no/NCCST4

Task leader:
David Berstad



CO_2 capture and transport conditioning through liquefaction **(Task 4)**

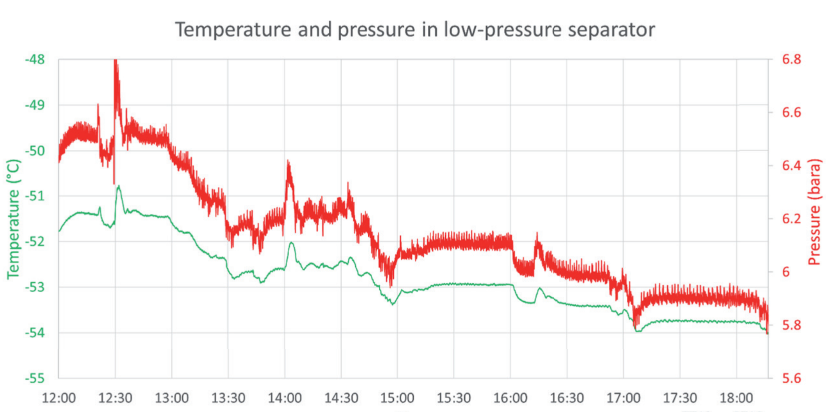
In 2020, low-pressure liquefaction experiments have been conducted in the Cold Carbon Capture Pilot (CCCP) experimental facility. Four experiments using a CO_2/N_2 mixture with 97 % CO_2 as feed gas, and one experimental series using pure CO_2 (99.992 %), have been performed. In the CO_2/N_2 mixture experiments, the final separation pressure was gradually lowered until the liquid outlet from the second separator was clogged by solid CO_2. In the experiments with pure CO_2, liquid CO_2 was produced for an extended period at pressures from 6.5 bar(a) down to 5.4 bar(a). The graph below shows the stepwise reduction in pressure in the final separator for part of the CO_2 liquefaction experiment. The scale of experiments is around 3.6 – 6.0 tonnes CO_2 per day or approximately 150 - 250 kg per hour.

The goal of the experiments is to demonstrate the feasible pressures at which liquid CO_2 can be produced and the practical limit with respect to solid CO_2 formation. The experiments will increase the confidence in low-pressure liquid CO_2 transport chains.

A lower CO_2 transport pressure has several benefits (e.g. increased liquid CO_2 density, possibility to use larger and lighter tanks, better ship hull utilization) that can reduce the transport costs significantly.

In the MACH2 spinoff project, the CCCP rig will be used to investigate syngas/retentate separation in hydrogen production. The required upgrades of the experimental facility to enable these experiments, which will include flammable and poisonous components, have been completed, and a new risk assessment of the rig have been approved. The planned MACH2 experiments will be the first proof-of-concept for efficient CO_2 separation and purification from H2-selective membrane retentate gas mixtures and will serve to pave the way for further development towards an integrated membrane/ low-temperature pilot.

A review of required modifications and cost estimates for upgrading the rig to enable experiments with small concentrations of water in the feed gas mixture in the liquefaction rig have also been conducted.



Pressure and temperature in the final separation stage for liquefaction of pure CO_2

TASK 5

Task 5 pertains to combustion in gas turbine engines for power generation that represents the enabling step required to complete the CCS value chain from the Norwegian Continental Shelf and throughout Europe. 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 emerging from the different CCS routes. Ultimately, the Task aims to assess the overall impact of these fuel mixtures on combustion system stability, thermodynamic cycle efficiency and pollutants emissions in the exhaust gas.

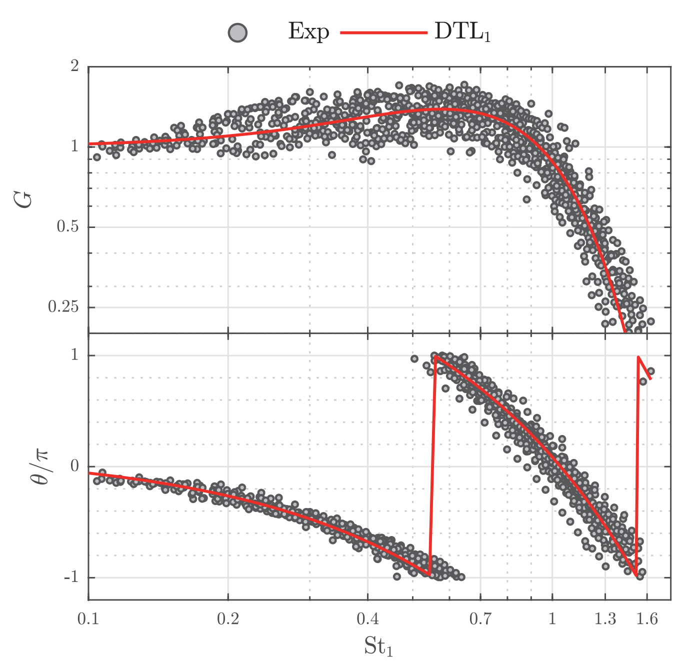
www.sintef.no/NCCST5

Task leader:
Andrea Gruber

Gas turbines
(Task 5)

Combustion of hydrogen (from the pre-combustion capture route) in state-of-the-art gas turbine combustion systems has been the main focus of the research activities in Task 5. Enabling the near-future clean and efficient hydrogen-firing of gas turbines creates the attractive possibility of a very convenient value-chain synergy. This combines and optimizes power generation based on hydrogen feedstocks obtained via natural gas reforming with CCS and via water electrolysis, powered by Renewable Energy Sources (RES) in periods of excess production.

In 2020, through advanced numerical modelling (DNS), we have made considerable progress in our fundamental understanding of the characteristics of hydrogen combustion at “reheat” conditions. The “reheat” combustion scheme is implemented in Ansaldo’s state-of-the-art commercial heavy-duty gas turbines and represents the most promising technology to achieve stable, clean and efficient hydrogen-firing of H-class gas turbines (the largest and most efficient engines). In parallel with the numerical modelling activity, experimental investigations have



FTFs (symbols) and DTL model (solid line) illustrating the good agreement between experimental measurements and analytical predictions [REF].

focused on the effects of increasing hydrogen content in the fuel mixture on the stability of a model, lab-scale combustor. In the framework of the NCCS-sponsored KPN “Reheat2H2”, the necessary preparations and preliminary activities including analytical modelling, numerical simulation tool and lab setup have been completed during 2020. The research work itself is set to start in 2021.

There were two main achievements during 2020:

Firstly, the unsteady spontaneous ignition process that takes place in hydrogen flames at reheat conditions has been fully characterized with the help of DNS calculations. The conditions (reactants’ temperature, pressure and composition) that lead to a self-excited instability of the flame are charted for a range of relevant flame temperatures and pressure levels to derive a simple relation that is able to predict the time scale of the instability.

Secondly, based on experimental measurements, features of flame transfer function (FTF) have been characterized for turbulent, non-swirled, bluff body stabilized “M” flames for different hydrogen and methane blends, including pure hydrogen flames. A developed model separately considers the impulse response of acoustic velocity fluctuations and vortex shedding and is interpreted as a distribution of time lags between velocity fluctuations and the unsteady heat release rate. This novel distributed time lag (DTL) model is shown to capture all the features of the FTFs, as shown in figure 1.

These new fundamental insights are key to assessing and improving the robustness of gas turbine combustors operating on increasing fractions of hydrogen in the fuel mixture and will speed up combustor development by OEMs.

TASK 6

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

www.sintef.no/NCCST6

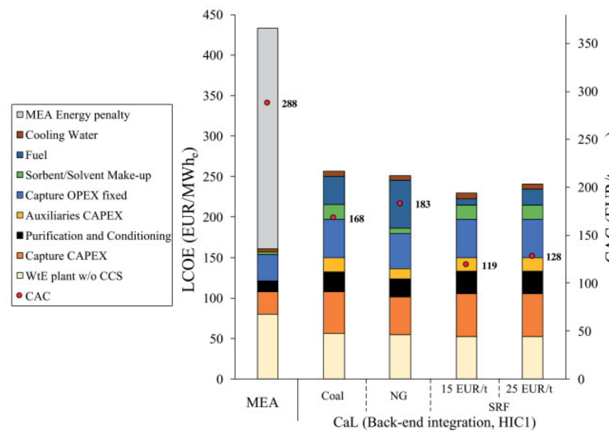
Task leader:
Marie Bysveen

CO_2 capture process integration **(Task 6)**

The Norwegian and European process industry sees CCS as one of the key technologies to lower or even eliminate their CO_2 emissions. At EU level, the perception of CCS has moved from "something that could be used if" to "a needed tool for jobs and climate change mitigation". An extension of the Longship project must include CCS from industrial sectors in Norway and the EU. This year's activity involved the establishment of a dialog with process industry in Norway and Europe by organizing and hosting work-shops and an Innovation Sprint in collaboration with other projects. In addition, two webinars hosted by NCCS were held around this topic:

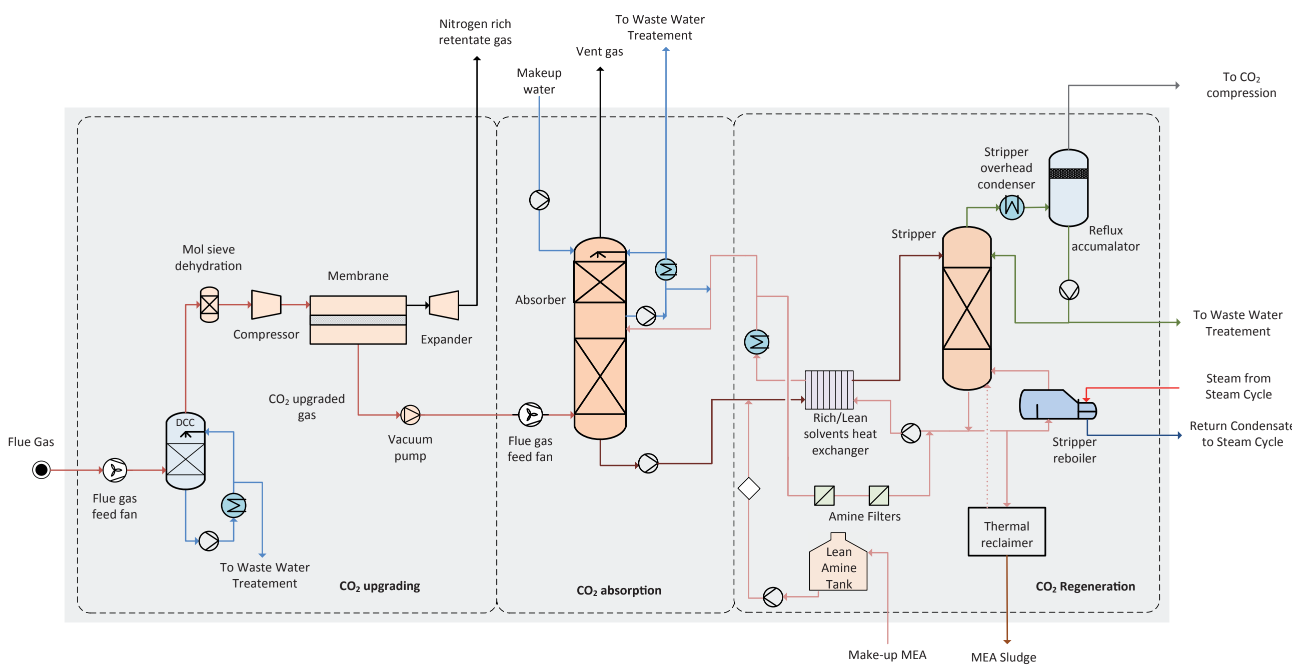
- Aligning European CCUS funding and R&I strategies, by Dr. Marie Bysbeen
- Potential and challenges for CO_2 capture integration in process industries, by Dr. Rubén M. Montañés

Waste-to-Energy (WtE) plants play an essential role today as advanced waste management facilities. They provide energy recovery and produce heat and/or power. However, they also result in CO_2 emissions from the combustion process of the MSW we generate. CCS from WtE can provide negative emissions due to the biogenic origin of a fraction of the MSW. A key activity in R&D is the integration of new generation capture technologies for reduced cost of capture. Calcium Looping is a high potential next generation capture technology currently at Technology Readiness Level 6 (TRL6). Task 6 conducted systematic Calcium Looping Integration in WtE Plants and a techno-economic assessment. We discovered a potential for 30% reduced total cost of capture with respect to baseline mature technology using amines. This could potentially help CCS implementation in WtE towards 2030 and 2050. In addition, a potential new business case and role for WtE plants with CCS in sustainable cities: since Waste to Energy plants could provide negative emissions. The results of the work were published in 2020 in collaboration with TU Darmstad.



LCOE and CAC for the WtE plant with CO_2 Capture.

Hybrid CO_2 capture technologies can significantly reduce the cost of capture by integrating technologies that are best-in-class within a subset of the overall expected operating range. This year we explored the potential of membrane chemical absorption technologies. We improved and updated our process models for membranes and chemical absorption using solvents. We studied how modular CO_2 enrichment membrane process for standardised absorption processes because it has potential reductions in capture cost compared to end-of-pipe CO_2 capture with chemical absorption. The membrane module enables to have a standardise absorption process by producing a permeate product with a fixed CO_2 purity. This hybrid system was able to achieve significant savings in the capital cost of the absorption process. Nevertheless, the large increase in electricity consumption and the capital cost of the membrane module dilutes the cost savings from the standardisation, resulting in a larger CO_2 avoided cost of the hybrid system compared to the standalone absorption process. The potential of the membrane assisted absorption process can be improved by proper selection of membrane characteristics and operating conditions, which will require thorough cost optimisation of the hybrid system.



Membrane-absorption hybrid system layout.

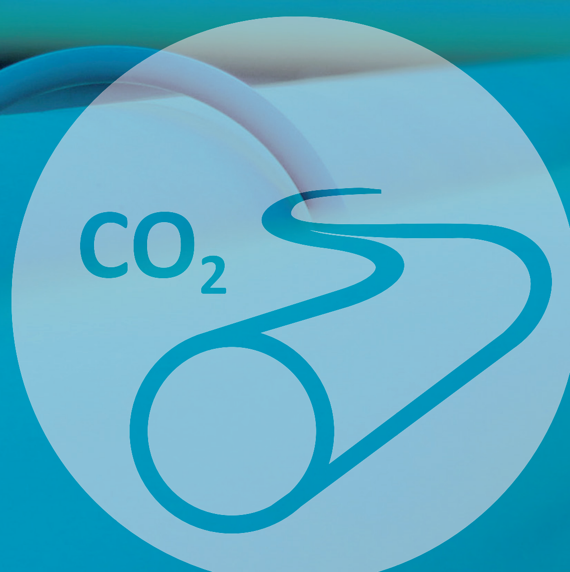
REF. Haaf M. et al. 2020. CO2 Capture from waste-to-energy plants: Techno-economic assessment of novel integration concepts of calcium looping technology. Resources, Conservation & Recycling. (2020) 162, 104973. https://doi.org/10.1016/j.resconrec.2020.104973

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 investigation on running-ductile fractures in CO_2 pipelines, ship transport, and impurities and non-equilibrium flow of CO_2.

www.sintef.no/NCCST7

Task leader:
Svend Tollak Munkejord



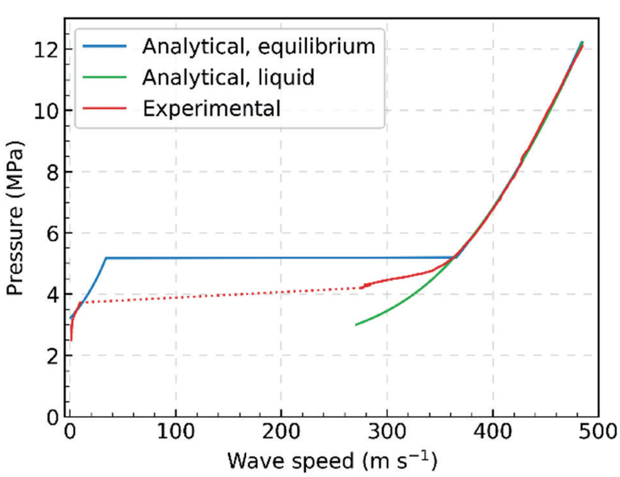
CO_2 transport (Task 7)

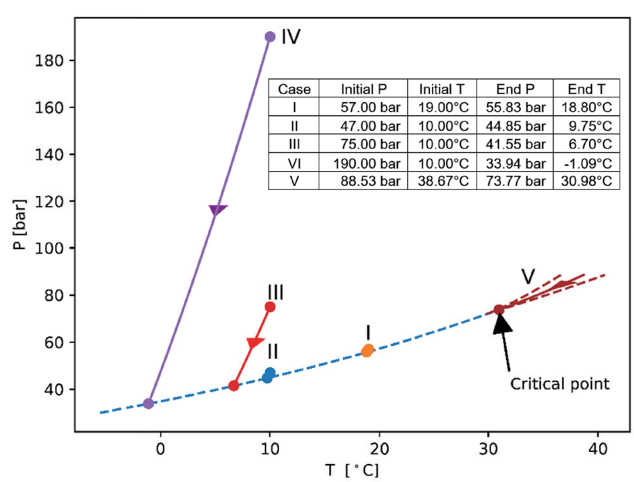
Understanding CO_2 depressurization in pipes

Depressurization of CO_2 in pipes in one of the keys to obtain the quantitative models that are needed by engineers to design efficient and safe CO_2-transportation systems, and to devise how to best operate them. In 2020, the first results from the ECCSEL depressurization facility were published in the form of a journal article and dataset. They yielded new insight into the pressure and temperature development as a pipe filled with CO_2 is emptied through a full-bore opening. In particular, these experiments are the first of their kind published with dense and accurate temperature measurements. The experiments also showed that the first instants of depressurization are out of equilibrium (see figure). This has implications on assessment methods for running-ductile fracture – one of the design criteria for pipelines transporting highly pressurized and compressible fluids.

Model to predict running-ductile fracture in CO_2 pipelines

SINTEF's coupled fluid-structure (FE-CFD) model to predict running-ductile fracture (RDF) in CO_2 pipelines was further developed, both with respect to thermo-dynamics (implementation of accurate equations of





Left: Decompression wave speeds for different pressure levels – comparison between experimental data (red) and calculations (blue and green). The graph shows that the experiments give a lower 'plateau pressure' than what is obtained by assuming full equilibrium.

Right: Calculated pressure and temperature during decompression of CO_2 from different initial states. The graph shows that (for dense-phase CO_2) a higher initial pressure gives a lower saturation pressure and hence lower driving forces for RDF.

state for CO_2-rich mixtures) and material mechanics (how to accurately calculate the steel behaviour and the crack propagation). We are testing these improvements by comparing to published data from full-scale tests. The work is in progress and will be published next year. This year, our work on fracture propagation control for the Northern Lights project was published at the IPC 2020 conference, jointly with Equinor. One result from that work is shown below, namely, an illustration of the perhaps non-intuitive effect that a higher operating pressure is less severe with respect to running-ductile fracture.

Educating the next generation of CCS scientists

This year, we co-supervised a master's candidate at the Physics Department at NTNU on the topic of accurate numerical methods for two-phase flow in pipes or channels with abruptly varying cross sections. This candidate was then employed to pursue her PhD in NCCS on the topic of depressurization of CO_2 in pipes. A second PhD was also employed this year, on the topic of fracture mechanics related to fracture-propagation control in pipes. Both candidates are supervised jointly between SINTEF and NTNU.

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)**

CO_2 that is captured, transported and stored is not considered emitted according to the ETS directive, and so will not require the purchase of emission allowances. This is a major business driver for CCS, but it is a condition that the stored CO_2 mass flow is traceably metered within defined uncertainty limits. So far, no technology has been qualified for the conditions, composition, and flow rates relevant for CCS.

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. The ImpreCCS project produces data on viscosity, density, and thermal conductivity and develop property models which will be applied in reservoir modeling.

The ImpreCCS KPN 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 2020

Fiscal metering

The properties of CO_2 under transport are pressurized liquids, which set them apart 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 also has large sound attenuation. There is hence a need for a facility to test flow meter technologies under realistic conditions, which also could enable calibration and hence traceability of fiscal flow meters. In 2020, Task 8 has this contributed to a design basis for a fiscal metering test loop for CO_2, prepared for industrially relevant flow rates. This work will be the basis for developing a business plan for such a flow loop in 2021.

In addition, the industrially relevant technologies for density measurements associated with flow measurements have been evaluated. Density of the fluid transported is needed for fiscal metering for all flow meter technologies that do not measure the mass flow directly.

In 2020, Baker Hughes joined NCCS as a partner and as an active participant in Task 8. KROHNE has been an active partner in task 8 from the beginning of NCCS. The active participation of these leading flow meter suppliers, as well as experts from the end-user associated with e.g. Northern Lights, is indispensable.

Measurement of fluid properties

There are very little data available on viscosity and thermal conductivity for CCS relevant mixtures, especially in the liquid phase. Hence, estimates on laminar flow, e.g. in reservoirs, or heat transfer, in CCS processes are very crude. To alleviate this situation, both thermal conductivity of liquid CO_2 mixed with nitrogen and methane, as well as viscosity of gaseous and supercritical CO_2 mixed with hydrogen have been measured in the ImpreCCS project. In 2021, it is the aim to proceed with measurements of viscosity using a new ECCSEL facility of SINTEF Energy Research

Further, phase equilibria have been measured for the binary system of CO_2+SO_2 in Task 8. Although SO_2 is an important impurity from many processes producing CO_2, most of the data on this binary system are more than 100 years old with 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 exchange of personnel within NCCS.

Thermodynamic modeling

Task 8 partner RUB has over the last decade developed a reference equation of state, EOS-CG. It is available through the thermodynamic tool TREND, but its routines are also expected to be used ahead in the thermodynamics of commercial process simulation tools, making it possible to improve the accuracy of their predictions. EOS-CG is continuously developed by adding new components and improving existing models. In 2020, ammonia was added to EOS-CG. Some of the components that so far have not been included in EOS-CG will react chemically with other components, greatly affecting the thermodynamic properties. Hence, a framework has been made for including reactive mixtures in EOS-CG, which will be demonstrated for mixtures of CO_2 and the solvent MEA in 2021.

Measurements of phase equilibria using the ECCSEL CO_2Mix facility of SINTEF Energy Research

Impact and innovations

- A new release of the thermodynamic tool TREND with the latest models has been made available for the partners of NCCS. 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 developed.

- A design basis for a test loop for fiscal metering has been completed. The test loop includes innovative processes, and realized, it will enable 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.

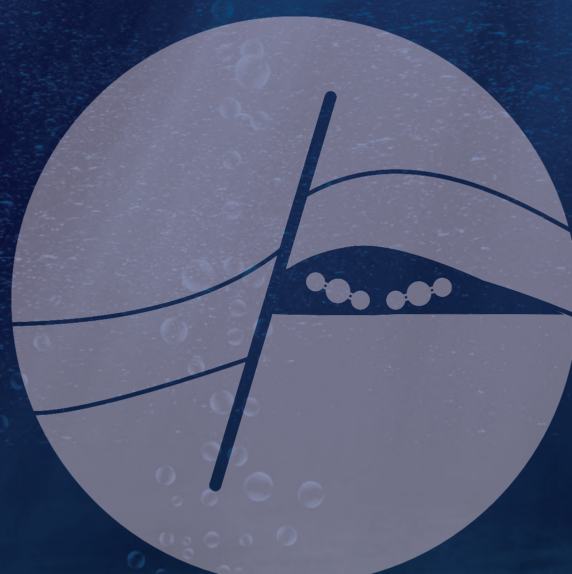
[1] Regulation (EU) 2018/2066 of 19 December 2018. http://data.europa.eu/eli/reg_impl/2018/2066/oj

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 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



Structual derisiking
(Task 9)

An improved workflow for quantification of fault leakage risk during CO_2 injection in saline aquifers is an important contribution for identification and qualification of additional storage volume in the Horda Platform area, where the Northern Lights project currently develops the Aurora site for CO_2 injection.

New datasets released from Eos well drilled in Aurora site have resulted in improved geological models for the area. Close collaboration between Northern Lights, NCCS and the University of Oslo on reservoir characterisation, building on existing sedimentological models as a basis for reservoir simulations, has improved the confidence in the storage capacity for the Johansen Formation.

Screening of fault stability in the Horda Platform area showed that the local stress regime around the fault as well as the internal strength of the fault zone is highly important for the determination of fault slip stability. To address these findings in more detail, we have initiated laboratory testing to better understand the deformation processes in shale dominated units and the development of faults in these units. The ongoing test programs provide new data on frictional strength comparing intact Draupne shale material properties and synthetic mixtures of fault gouge (Intact material that is crushed down).

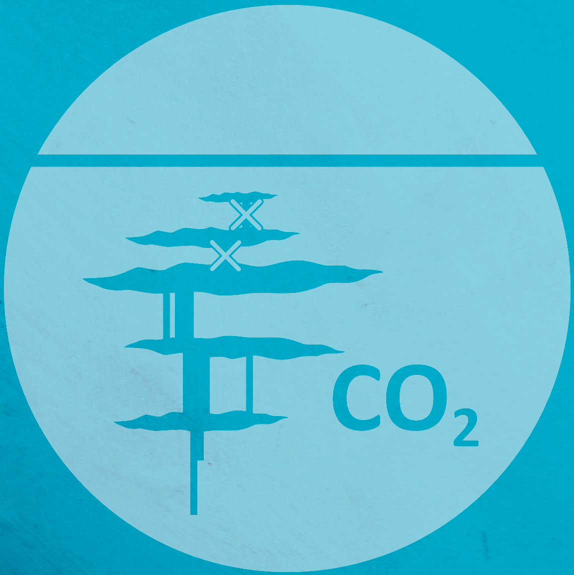
Results provide systematic frictional properties with clay content and will provide new and valuable input for modelling fault slip stability in the overburden of the CO_2 storage reservoirs.

TASK 10

By ensuring containment of CO_2 in the storage reservoir, we can optimize storage capacity and maximize the number of suitable reservoirs. These goals can only be achieved by addressing remaining research gaps identified in the near-well area (well integrity, CO_2 injectivity) and at reservoir borders with the caprock (especially faults). Task 10 therefore 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 in considering new storage sites.

www.sintef.no/NCCST10

Task leader:
Pierre Rolf Cerasi

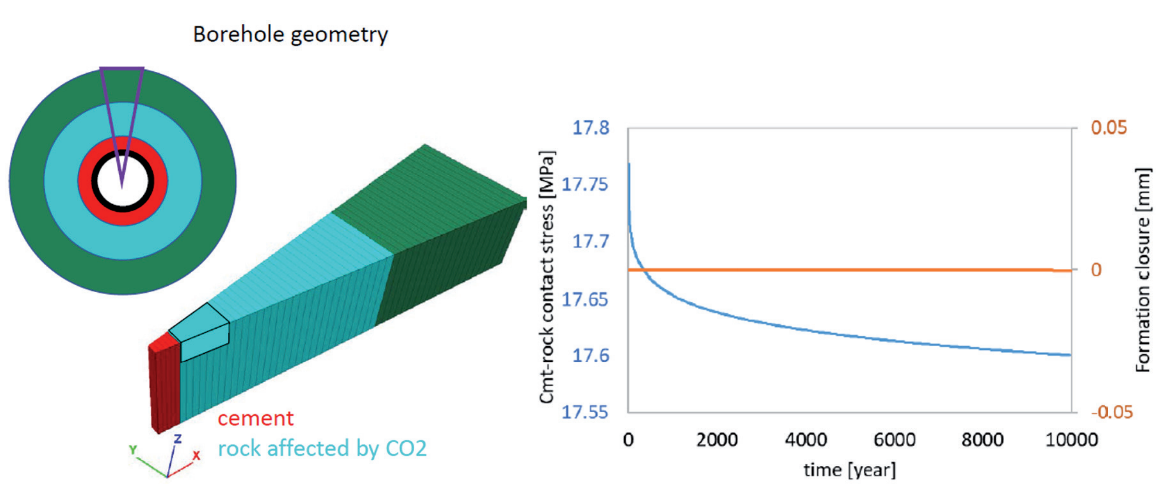


CO_2 storage site containment (Task 10)

The report on the well integrity survey (Atlas of Well Integrity) was completed in 2020. The number of teleconferences with our partners across the Atlantic, Lawrence Livermore National Laboratory in California and the National Energy and Technology Laboratory in Pennsylvania, doubled as the reporting deadline approached. The learnings from the approximately 30 replies from operators in charge of CO_2 injection wells all around the world were compared to published scientific literature. We have planned a joint USA-Norway workshop in 2021, where we will present the results and discuss the prioritisation of remaining research gaps.

Confident from the benchmarking of previous fault reactivation and hysteresis work using two different computer codes, we tackled shale creep modelling as a way to self-heal micro-annuli potentially developing between well cement sheath and surrounding caprock. A finite element simulation was set up where we looked at the competition between fluid pressure pushing apart the crack faces and shale creeping back in place through constant stress creep.

In our model, a behaviour law for the shale was derived from laboratory measurements done on small Draupne shale samples, exposed to different fluids including brine and super-critical CO_2. Thus, our model extrapolates from the time-dependent stiffness uncovered in the fluid exposure tests to predict rock deformation up to 10 000 years after injection. The interesting results show a cross-over point from fracture closure to remaining open, depending on stress conditions and fluid pressure.



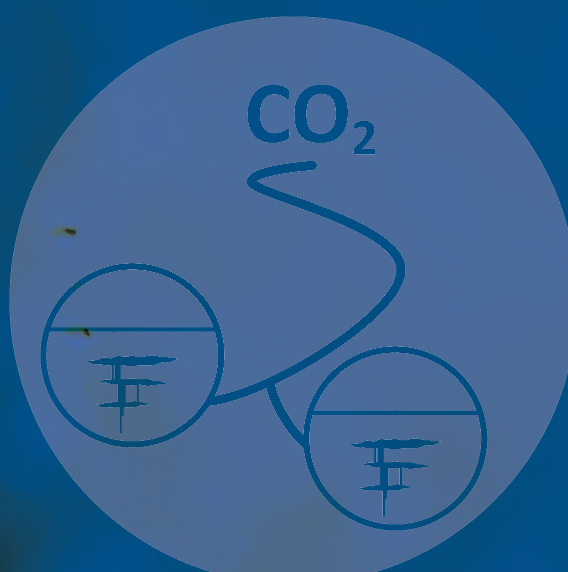
Computer model investigating creep of caprock shale exposed to CO_2 towards a well's cement sheath. In the case presented here, the contact stress between cement and caprock relaxes with time and the crack closes.

TASK 11

Task 11 develops technologies for optimal utilisation of available storage space, and for efficient utilisation of CO_2 for enhanced oil recovery (CO_2-EOR). Investment both in characterisation of a storage site and in the development of 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)**

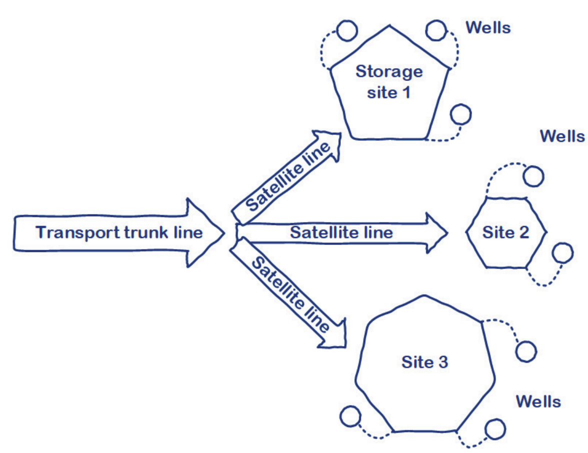
Work in Task 11 in 2020 has led to the submission of three journal manuscripts.

Laboratory testing of commercial surfactants for CO_2-brine foam stabilisation has demonstrated significant differences between the surfactant systems in the way the surfactant concentration influences the foam strength. Loss of strength as the concentration is reduced can be gradual or it can be sudden as the concentration falls below a given threshold. This concentration dependence of foam strength is important for the performance of CO_2 mobility control in field application and should therefore be investigated further to provide guidance on the most promising surfactants.

Earlier work in Task 11 has demonstrated that CO_2 mobility control, if successfully applied at field scale, can give significantly increased storage efficiency (the fraction of pore space that is occupied by stored CO_2). This year, we have extended this work with an economic analysis. The economic model includes cost of surfactant purchase and handling, which could be a significant fraction of the total expenses for the storage operation. The benefit of increased storage efficiency could still outweigh the increased costs and give a reduced total cost per tonne of CO_2 stored. Our work shows that this is most likely to occur if the surfactant can be dissolved in the injected CO_2 and if the surfactant preferentially dissolved in the CO_2 over the formation brine. In the most beneficial cases the saving in storage cost is more than € 1 per tonne of CO_2 injected.

While CCS chains in the current pilot and demonstration phases are mostly connecting a single source to a single sink, CCS chains in the later large-scale deployment phases (DC 2030 and DC 2050) could also connect several CO_2 capture facilities to larger transport and storage networks. The transport and storage networks must be developed in such a way that CO_2 supplied by the capture facilities always can be received and stored. The network design has to account for any geological uncertainty remaining after the storage site characterisation and development phases.

In the third manuscript we describe a probabilistic tool for studies of such networks, and apply it to a synthetic case for a CO_2 storage hub development on the Norwegian Continental Shelf. The paper also discusses how possible designs for a pipeline network supplying CO_2 to the storage hub can have different response curves to a random injection well failure. This emphasises the need for flexibility both in the internal transport pipelines in the storage hub and in the injection system.



Generic illustration of a transport and storage network for a CO_2 storage hub with several sites.

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 for 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 which will enable safe operation in compliance with laws and regulations in the most cost-efficient manner.

This is achieved by research on five topics:

- methods for assessment of cost vs value-of-information for geophysical data
- ways of extracting all available information from acquired geophysical data
- strategies for comparing/combining prior reservoir modelling to geophysical observations
- unconventional data acquisition technology and survey layouts
- use of advanced data analytics to handle big data in geophysical monitoring

www.sintef.no/NCCST12

Task leader:
Jon Peder Eliasson

Cost-effective monitoring technology **(Task 12)**

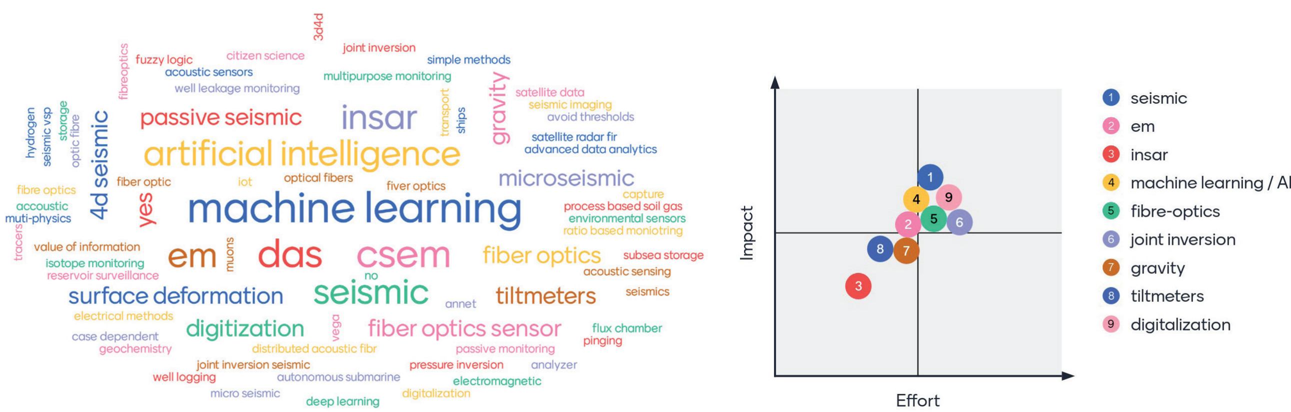
In 2020, an effort has been made to disseminate important recent results from the CO_2 monitoring task of the NCCS centre. The Bayesian Rock Physics Inversion technique (completed and demonstrated in 2019) and its application to Sleipner data was thoroughly described in a paper ("Combined geophysical and rock physics workflow for quantitative CO_2 monitoring") for the International Journal of Greenhouse Gas Control (IJGGC) that was accepted for publication at the end of the year. Similarly, another IJGGC paper, "Assessing the value of seismic monitoring of CO_2 storage using simulations and statistical analysis", summarizing previous work on a value-of-information assessment workflow was accepted for publication at the very end of the year.

At the beginning of the year, four abstracts were also sent to the GHGT conference, which was unfortunately delayed until 2021. All abstracts were accepted and draft papers have been written related to each of these topics. One of the papers describes the current status of work done on combining monitoring data and reservoir simulations of CO_2 storage sites for improved understanding of a storage site. The method, based on a flexible modelling framework in the open source Matlab Reservoir Simulation Toolbox (MRST), allows optimization of CO_2 storage modelling to any combination of observed monitoring data. It has been applied to the new, layered, Sleipner benchmark model, which was optimised to fit plume outlines, gravity monitoring data and CO_2 saturations inferred from joint full waveform and rock physics inversion with promising results.

Another GHGT draft paper describes how SINTEF's optAVO method can be used to map the extent of the CO_2 plume and provide an estimate for seismic parameters for a synthetic Sleipner case. Using the results (a P-wave model) of the optAVO as an initial model for Full Waveform Inversion (FWI) was seen to significantly improve the final FWI results.

The two other GHGT draft papers focused on monitoring at Smeaheia; one about application of a workflow for baseline quantitative characterisation using synthetic and real data from Smeaheia and one about a feasibility study on marine CSEM monitoring of CO_2 flow along the Vette Fault. This latter study is the first of its kind as the only previous evidence of the efficiency of CSEM for detection of CO_2 flow through faults/fractures was made through a laboratory test. The work has resulted in knowledge about how the CSEM data may interact with CO_2 flow through the Vette Fault. In addition, issues for which the CSEM technique should be improved have been identified.

Two successful webinars were carried out in 2020, both with a focus on more novel and so far unconventional technologies for CO_2 monitoring. The spring webinar summarized work done within the task related to "A machine learning based monitoring framework for CO_2 storage". The approach is based on integration of reservoir modelling, geophysical monitoring, and decision-making theory, and it was shown that a neural network can be trained to optimize geophysical data acquisition in terms of its value for verification of site performance. This is a first step towards a novel AI-based technique to support the decision-making process related to cost-efficient MMV. The autumn webinar, with nearly 230 registered, had a more general look at "Safe and cost-efficient CO_2 storage: Emerging monitoring technologies" with an overview of what we

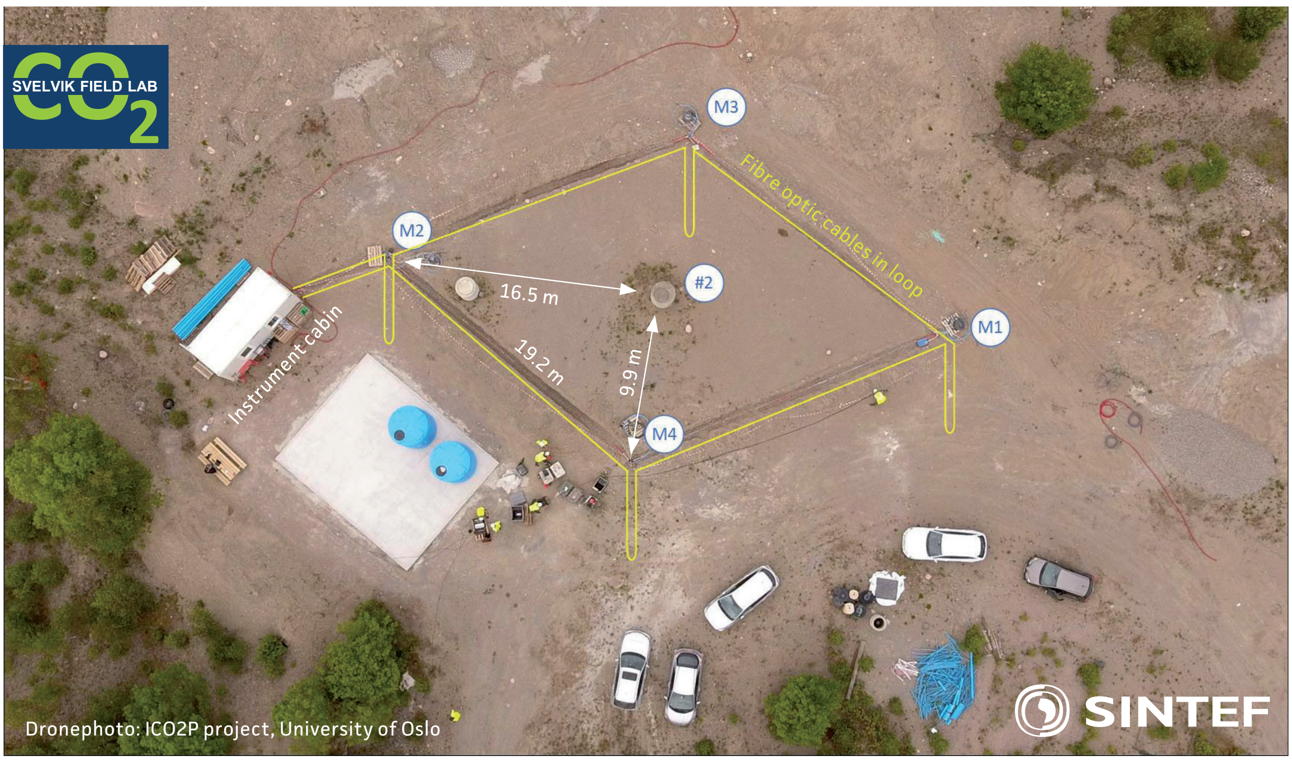


Word cloud summarizing webinar particpants answers to "What are the most promising emerging technologies for CO_2 monitoring". (right) Boston square matrix showing webinar participants answers to "Estimate potential impact of technology when deployed and the research effort needed to get there".

see as promising future techniques. An informal survey on the view of the participants was also carried out.

In addition to this survey of emerging technologies, two smaller studies were carried out in 2020 to investigate the potential of using ECCSEL infrastructure in future work within the monitoring task. The first investigated the possibility and usefulness of performing measurements of elastic and electric parameters at controlled laboratory and test site conditions in order to explore the physics and the interrelationships of these parameters as functions of saturation, pressure and temperature. Such measurements will contribute to calibrating rock physics models and would consequently result in more reliable interpretation of monitoring data. Several potential research tasks were suggested. Similarly, a study of potential research efforts on development and testing of fibre-optic (DAS/DTS/DSS) technology was carried out. This emerging monitoring technology is still not properly explored for CO_2 monitoring purposes.

The recently upgraded Svelvik CO_2 Field Lab has several monitoring wells instrumented with various types of optical fibres and offers great possibilities for such studies. A number of potential research tasks and spin-off projects have been suggested for the next few years in NCCS.



Aerial view of the Svelvik CO_2 Field Lab with injection (#2) and monitoring wells (M1-M4) marked. The loops with fibre optic cables (several different commercial and research types) are shown yellow with "tongues" indicating how the cables also go down into the wells.

SPIN-OFF PROJECTS

New spin-off project

An eighth spin-off project from NCCS was approved in December 2020 and will start in 2021.

NEW

CCShip (MAROFF)

CCS from Ships: Develop cost-effective solutions for CCS from ships, as well as understand when CCS can be a more attractive technology than alternative solutions to reduce CO_2 emissions from ships. Project partners: SINTEF Energy, SINTEF Ocean, NTNU, UiO, SNU, NCCS, Klaveness, Wärtsilä, Calix.

Impact of CO_2 impurities and additives in CCS (IMPRECCS)

The primary objective 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
Duration: 4 years – Start: 2018
PM: Sigurd W. Løvseth, SINTEF Energy Research

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

POREPAC will obtain 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
Duration: 4 years – Start: 2018
PM: Malin Torsæter, SINTEF Industry

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

The MACH-2 project will 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
Duration: 3 years – Start: 2019
PM: Thijs Peters, SINTEF Industry

Quantification of fault-related leakage risk (FRISK)

The main goal 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 TOTAL.
Duration: 3 years – Start: 2019
PM: Elin Skurtveit, NGI

Tophole monitoring of permanently plugged wells

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 Solution will have an active role in the project.
Funding: Petromaks2
Duration: 4 years – Start: 2019
PM: Cathrine Ringstad, SINTEF Industry

Accelerating CSEM technology for efficient and quantitative CO_2 monitoring (EM4CO_2)

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, NGI, UiO, University of Southampton and collaboration with several other international research institutions on the open-source CSEM software. EMGS will be an advisor in the project and will host the PhD for parts of the employment.
Funding: CLIMIT
Duration: 3 years – Start: 2019
PM: Anouar Romdhane, SINTEF Industry

Towards clean and stable hydrogen reheat combustion in gas turbines (Reheat2H2)

The primary objective 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 will work closely with Ansaldo Energia Switzerland.
Funding: EnergyX
Duration: 4 years – Start 2019
PM: Jonas Moeck, NTNU

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.

Dr. Nils Røkke (Chair of the NCCS Special Advisory Group and the Centre Assembly) is the current Chair of the European Energy Research Alliance (EERA). With 175 research centre and university members from 27 countries, EERA's objective is to build on national and EU research initiatives and to be the cornerstone in the European Strategic Energy Technology Plan. The CCS Joint Programme under the EERA (EERA 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. Dr. Marie Bysveen has held the coordinator role in JP-CCS since 2015.

Since 2010, Dr. Nils A. 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.

NCCS Mobility Program

Researcher mobility can be a catalyst for innovation, networking, knowledge sharing, and dissemination between research institutions and partners that cannot be done as efficiently remotely. NCCS launched a dedicated mobility program to facilitate these activities.

NCCS has awarded many mobility grants, the results of which have been shared in blog posts. Unfortunately, global travel restrictions put a hold on mobility programs in 2020, but hopes are high that this can be re-started in 2021 and beyond. In the meantime, work on joint papers has taken place in various parts of the centre.

Horizon 2020 - ongoing projects:

- Pre-ACT - Pressure control and conformance management for safe and Efficient CO_2 storage - Accelerating CCS technologies. Partners: SINTEF, NORSAR, BGS, PML, GFZ, TNO, Equinor, Total, Shell, TAQA. [Task 11].
- ALIGN-CCUS - Accelerating low-carbon industrial growth through CCUS. Partners: Asahi Kasei Europe, Bellona, British Geological Survey, CO_2 Club Association, ECN, FEV, Forschungszentrum Jülich, GeoEcoMar, Heriot-Watt Univ., IFE, Imperial College London, Leiden Univ., Mitsubishi Hitachi Power Systems Europe, Norcem, NTNU, NUSPA, PicOil, RWE

Power, RWTH Aachen Univ., Scottish Enterprise, SINTEF, TAQA Energy, TCM, Tees Valley Combined Authority, TNO, UK Pilot-scale Advanced Capture Technology Facilities-PACT, Univ. of Edinburgh, Univ. of Groningen, and Yara. [Task 11].
- Elegancy – Enabling a low-carbon economy via hydrogen and CCS. Partners: SINTEF, BGS, PSI, TNO, Swerea MEFOS, ETH Zurich, Imperial College London, Ruhr Universität Bochum, Utrecht University, UiO, Aker Solutions, Gassco, Equinor, INEOS, Climeworks, Open Grid Europe, Uniper, Gerg, Scottish Enterprise, Sustainable Decisions, First Climate, TOTAL. [Task 7, Task 1].

Horizon 2020 – applications granted:

ACCSESS – Providing access to cost-efficient, replicable, safe, and flexible CCUS. Partners: StoraEnso AB, HeidelbergCement AG, Fortum Oslo Varme AS, Saipem, Compact Carbon Capture, Neustark AG, Linde GmbH, Humboldt Wedag GmbH, Equinor Energy AS (also representing Northern Lights), Total S.A., Technology Centre Mongstad, Eidgenoessische Technische Hochschule Zuerich, VDZ Technology gGmbH, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung e.V., Chalmers Tekniska Hoegskola AB, Heriot-Watt University. Application granted December 2020 [Task 1, Task 6, Task 8].

Strategic cooperation with other countries (2017-2020):

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 [Task 1].

China

An application was sent for the bilateral program for energy research Norway-China, including phase equilibria measurements. Title: Technology and demonstration of combined cooling, heating and power based on photo- voltaic-solar thermal-energy storage-heat pump composite system – ECOCHINO [Task 8].

South-Africa

INTPART application titled "CO2EduNet – The Norway – United States – South Africa Network for Research based CCS Education" was developed as a cooperation with South-Africa in 2019. Partners were: University of Oslo, NTNU, SINTEF, The NETL lead Carbon Capture Simulation for Industry Impact consortium (CCSI2): Carnegie Mellon University, SACCCS/University of Pretoria. The application was not granted [Task 9].

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 Jaisree Iyer from Lawrence Livermore and Greg Lackey from National Energy Technology Laboratory about the Well Integrity Atlas. LLNL is partner in NCCS and NETL has obtained additional funding from Department of Energy [Task 10].
- Cooperation with Lawrence Livermore National Labs on monitoring of well integrity (via TOPHOLE) [Task 12].

Other countries:

- The new approach for design of CCS value chains under uncertainties is used in a cooperation with a PhD candidate from Technische Universität Darmstadt (Germany), [Task 1].
- PhD candidate from NTNU has, via the NCCS mobility program, spent one month at TNO (Netherlands) working with oxygen solubility [Task 2].
- Cooperation with TU Munich (Germany) under the KPN project "Reheat2H2". TUM contributes with a unique experimental setup [Task 5].
- NCCS was host for PhD student from TU Darmstadt (Germany). Cooperation on integration of energy recovery plant with CaL for CO_2 capture. The student stayed at SINTEF from March to June 2019, and the cooperation continued throughout the year producing a joint publication (submitted for publishing) [Task 6].
- A Postdoc from University of Zürich (Switzerland) working on development of highly accurate numerical methods for multiphase flow of CO_2, had a research period at SINTEF. The cooperation aimed at integrating the CO_2 thermodynamic into the method [Task 7].
- We have an extensive cooperation with Ruhr Univ. Bochum (Germany). This is related to a CO_2-N_2-CH_4 paper for publishing and other development activities [Task 8].
- A PhD candidate from University of Western Australia (Australia) stayed at SINTEF for the period August to December [Task 8].
- Cooperation with the Mont Terri laboratory (Switzerland) and Herriot Watt University in Edinburgh (Scotland) is established under the FRISK KPN project. 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) under EM4CO_2 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

NCCS announced joint winners of the Best NCCS Paper award for 2019. We speak to one of the award winners to find out more about what it takes to produce award-winning research.

The NCCS Best Paper award aims to highlight world-leading research in carbon capture, transport and storage technologies from the NCCS research centre.

The award winner is chosen by the NCCS Scientific Committee. Chair Philip Ringrose congratulated both winners: "All six shortlisted papers have clear potential to make an impact in their field of application. However, these two were clear front-runners, as they demonstrated both research insights and potential value for broader application."

The Winning Papers
Chosen in 2020, the two winning papers for the NCCS Best Paper 2019 award were:

Techno-economic analyses of CO_2 liquefaction: Impact of product pressure and impurities
By Han Deng, Simon Roussanaly & Geir Skaugen, published in the International Journal of Refrigeration, 103, 301-315.

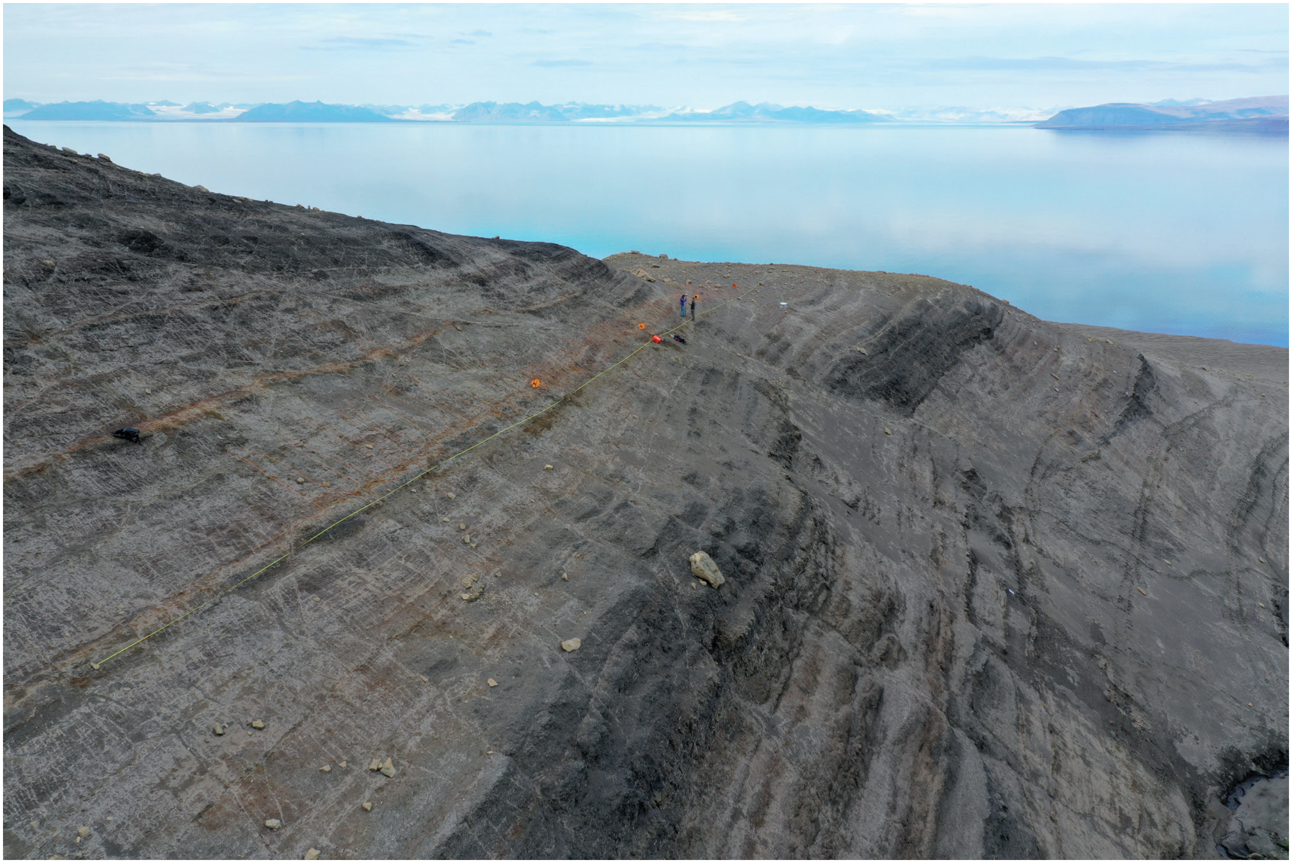
Demonstrating the potential of CO_2 hydrate self-sealing in Svalbard, Arctic Norway
By Stian Almenningen, Peter Betlem, Arif Hussain, Srikumar Roy, Kim Senger & Geir Ersland, published in the International Journal of Greenhouse Gas Control, 89, 1-8.

A look inside award-winning research
To find out more about the work behind award-winning papers, we spoke to one of the co-authors of the second paper, Peter Betlem.

Peter Betlem, UiO/UNIS

Peter is a PhD candidate in (Arctic) Geology at the University Centre in Svalbard (UNIS) and University of Oslo (UiO). He investigates the multi-physical detection limit of fluid flow through caprock sequences for carbon capture and storage purposes, supplementing proven and traditional workflows with experimental techniques and modern technologies. He has previously written about characterising and storing samples from Svalbard using digital drill core models.

What was the topic of the paper?
The potential self-sealing properties of CO_2 hydrate are demonstrated at realistic reservoir conditions using samples from the Longyearbyen CO_2 Lab in Svalbard, Arctic Norway. The work demonstrates the potential of CO_2 hydrate formation as a secondary seal in settings with favourable CO_2 hydrate formation conditions in or above the reservoir. The results indicate that the self-sealing nature of CO_2 hydrate should be considered while characterizing carbon sequestration reservoirs in both marine and permafrost-affected settings, and



EM acquisition of the faulted cap rock shales of the Longyearbyen CO_2 Lab in Svalbard

may provide an important contribution to storage safety assessments.

Tell us about the research behind the paper?

The work relied heavily on strong collaboration between industry (e.g., Equinor, UNIS CO_2 Lab) and academia in Norway and Ireland for the characterization of drill core samples acquired during drilling at the Longyearbyen CO_2 Lab drill site and further experimental studies of CO_2 hydrate formation in drilled cores.

Suitable drill cores at different intervals were selected from the drill core facility in Longyearbyen, and subsequently sent to University College Dublin to determine core plug properties through petrography and scanning electron microscope. Another set of drilled cores were sent to the University of Bergen, where researchers performed the CO_2 hydrate experiments equipped with magnetic resonance imaging instruments at Equinor.

Beforehand, CO_2 hydrate stability was predicted based on local wireline logging data and integrated knowledge obtained from a previous study on natural gas hydrate potential onshore central Spitsbergen. Controlled pressure and CO_2 injection tests subsequently led to the formation of hydrate plugs, which were verified through cross-plug resistivity measurements, when thermobaric conditions were favourable.

Does this research and paper provide a foundation for further work?

Carbon capture and storage is the only viable technology for substantial emission cuts and net atmospheric CO_2 reduction needed to achieve the goals of the Paris Agreement. We think hydrates hold a lot of potential for this technology, as a better understanding of hydrate self-sealing may open up additional CCS possibilities that were until recently disregarded on hydrate risk grounds.

Both Ireland and Norway are currently pushing for more research to be done in the field of methane and CO_2 hydrates. As a matter of fact, we recently submitted a proposal to the Norwegian Research Council for a more in-depth study into the gas hydrate sealing mechanisms and integrity thereof in geological formations, and we hope to apply our findings in a much larger setting.

Complementary research proposals with a focus on CO_2 hydrates and CCS are being submitted in Ireland to the Science Foundation Ireland, Sustainable Energy Authority of Ireland and the EU Commission.

Are you pleased to win the award?

Of course! It is great to see that CO_2 hydrate isn't just an academic niche, but has support from industry and the wider CCS community alike. It is definitely a great motivation to conduct further related research.

Other NCCS awards

Professor Hanna Knuutila from NTNU's Department of Chemical Engineering was named as 2020's Best Teacher at the Faculty of Natural Sciences awards day. Hanna supervises several NCCS-funded PhD candidates in solvent technologies. Congratulations to Hanna on her award, which highlights the quality of education made possible by NCCS.

The digital ceremony was streamed live and featured a talk from Dr. Richard Miller, professor at Olin College and visiting professor at MiT.

The award speech was as follows: "Hanna is a dedicated lecturer and strongly engaged in the education of students. She is constantly exploring new pedagogical tools with the aim of improving teaching, stimulating students' learning through student-active methods, and contributing to increased understanding and competence among students. Her efforts to introduce active learning methods and to share her own and other teachers experiences with this is an inspiration to others and a contribution to improved teaching in the faculty as a whole. The students appreciate Hanna's genuine wish for them to learn, and her abilities to adjust the teaching based on her needs and feedback. Congratulations Hanna!"

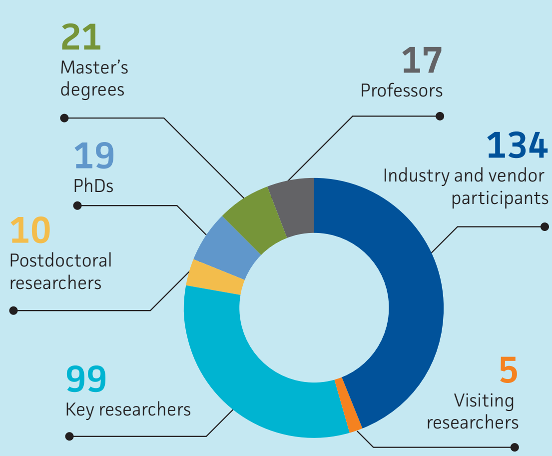
EDUCATION & **RECRUITMENT**

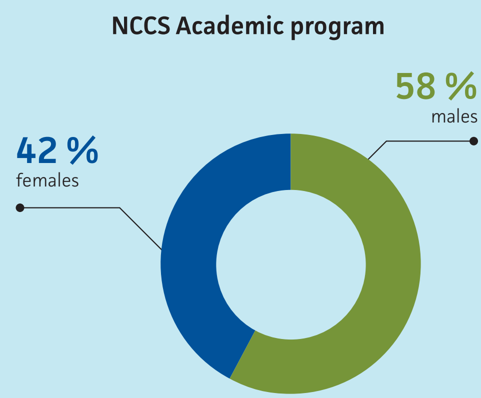
One of the most important tasks in NCCS is to train master and doctoral students and post-doctoral fellows in CCS research so they are willing and able to transfer this knowledge in future work, whether they work in industry or as researchers.

Hanna Knuutila from NTNU's Department of Chemical Engineering was named as 2020's Best Teacher at the Faculty of Natural Sciences awards day. Hanna supervises several NCCS-funded PhD candidates in solvent technologies.

Sigmund Størset, Innovation and Technology Transfer leader from 2016-2019, is now a Senior Marked Advisor at ENOVA SF.

Tobias Neumann will receive a double PhD degree from Ruhr University in Germany (supervised by Professor Roland Span) and from NTNU in Norway (supervised by Professor Jana Jakobsen). This exemplifies a special case of international collaboration and education within NCCS.





PhD Students working in NCCS in 2020

Name	Affiliation	Funding	Gender	Nationality	Period
Dongchan Kim	UWA	International	M	Korea	08/2019 -04/2020
Vanja Buvik	NTNU	NCCS	F	Norway	10/2017 -10/2021
Lucas Braakhuis	NTNU	NCCS	M	Netherlands	10/2019 -10/2022
Jonathon Osmond	UIO	NCCS	M	USA	10/2017 -09/2021
Vegard Bjerketvedt	NTNU	NCCS	M	Norway	11/2017 -04/2021
Eirik Æsøy	NTNU	NCCS	M	Norway	03/2018 -03/2022
Tobias Neumann	RUB/NTNU	NCCS	M	Germany	01/2017 -12/2021
Bahereh Khosravi	NTNU	NCCS	F	Iran	12/2018 -11/2021
Camilla L. Würtzen	UIO	NCCS	F	Denmark	10/2018 -09/2021
Peter Betlem	UNIS	NCCS	M	Netherlands	03/2019 -03/2023
Magnus Soldal	NTNU	NCCS	M	Norway	06/2019 -07/2022
Marcin Duda	NTNU	NCCS	M	Poland	01/2018 -02/2021
Anne-Sophie Sur	NTNU	NCCS	F	Germany	01/2020-01/2023
Tarik Yahou	NTNU	NCCS	M	Algeria	10/2020-10/2023
Alexandra M. Log	NTNU	NCCS	F	Norway	08/2020-08/2023
Olaf Lehn Tranås	NTNU	NCCS	M	Norway	09/2020-08/2023
Heidi S. Egeland	UIO	NCCS	F	Norway	11/2020-11/2024
Mohammad Masoudi	UIO	KSP POREPAC	M	Iran	09/2018-08/2021
Seyed E. Hosseini	NTNU	KSP TOPHOLE	M	Iran	02/2020-02/2023
Hanbo Chen	UIO	KSP EM4CO2	M	China	09/2020-09/2023

Postdocs working in NCCS in 2020

Name	Affiliation	Funding	Gender	Nationality	Period
Mark Mulrooney	UIO	NCCS	M	Ireland	09/2017 - 09/2021
Ozgu Turgut	NTNU	NCCS	F	Turkey	11/2017 - 11/2020
Viktor Weber	UIO	NCCS	M	Hungary	08/2018 - 08/2021
Jose Aguilar	NTNU	NCCS	M	Mexico	08/2018 - 07/2020
Emma Michie Haines	UIO	KSP FRISK	F	UK	02/2020 - 01/2023
Donghoi Kim	NTNU	KSP MACH-2	M	South Korea	07/2019 - 07/2020
Zhongxuan Liu	NTNU	KSP MACH-2	F	China	06/2020 - 06/2021

Related PhD thesis completed on projects in the centre so far (not funded by NCCS)

Name	Affiliation	Gender	Advisor	Thesis title
Mats Rongved	NTNU	M	Rune Holt	Hydraulic fracturing for enhanced geothermal systems
Dongchan Kim	UWA	M	Eric May	Working on measurements of thermal conductivity

NCCS funds PhD students at NTNU in Trondheim and the University of Oslo, among other institutes.

COMMUNICATION

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

Against a background of the ongoing global pandemic, communication played an even more vital role in 2020. Digital tools have been utilised since the beginning of NCCS, but they proved much more important in 2020 as physical events were impossible for much of the year.

The communications plan was adapted to include digital meetings where appropriate, and a major webinar series in October to replace the lack of physical events NCCS members could attend. A new NCCS LinkedIn page is helping to replace the loss of networking at physical events.

The approach to communication in NCCS

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

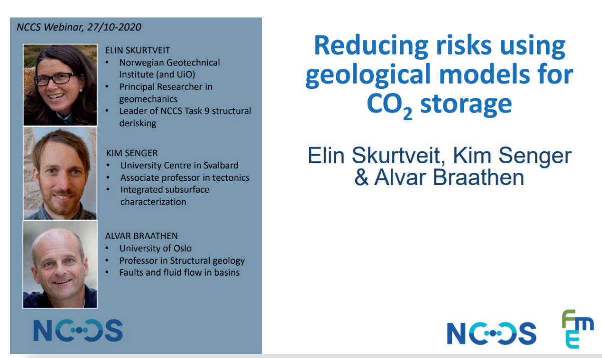
Led by SINTEF, the communications plan encourages participation from all centre partners. The main platform for communicating results to the outside world is the website www.nccs.no, where all open results are published.

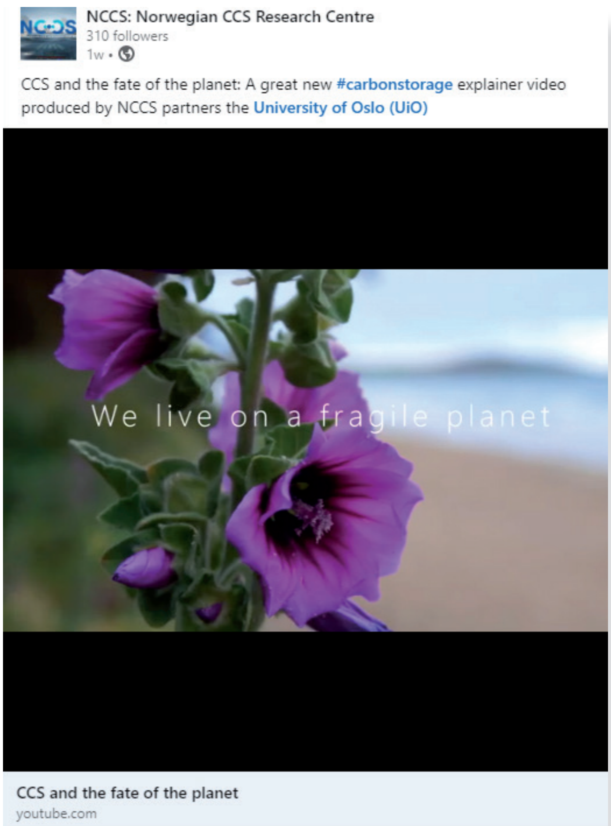
During 2020, SINTEF was recognised by the CHARGE Energy Awards for its strategic approach to branding and communications, of which the strategy and plan developed and implemented for NCCS played a part.

Webinars and video

From a communications perspective, the October webinar series was the undoubted highlight of the year. A total of 1300 people participated in 18 webinars, amplifying NCCS project results to far greater numbers within the target groups specified in the communications plan. Webinars allow much wider participation by removing time and cost barriers, so they will be utilised more in the remaining years of NCCS. The webinars also served to increase the size of the NCCS email newsletter list and social following, both of which will boost dissemination and communication efforts over the years to come.

During 2020, the University of Oslo produced two videos showcasing some of their CCS work in education and communication. These were shared across all NCCS channels with good engagement.



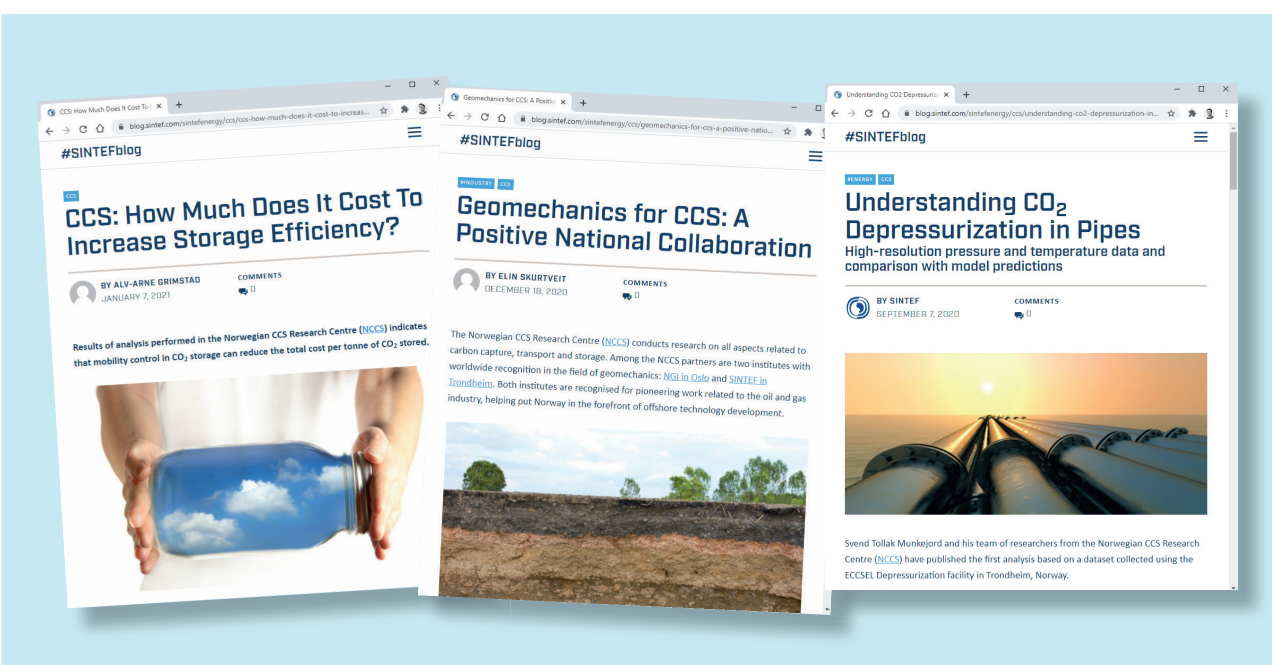


Website, blogs & newsletters

The NCCS website received 3,587 pageviews in 2020 and was updated as required throughout the year. The new-look online annual report for 2019 was well received, providing an easier, more visually appealing way of exploring NCCS research. The template will be used for future annual reports.

NCCS 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.

In 2020, NCCS researchers published 21 blog posts on the SINTEF blog, which are included on the NCCS website and shared widely on both NCCS and SINTEF social channels. The best-performing blog post was the republished NCCS memo "The Safety of CO_2 Storage" that received more than 1,000 pageviews.



In 2020, we continued to send regular newsletters. An update to the NCCS website and all blog posts made it much easier for readers to join the newsletter.

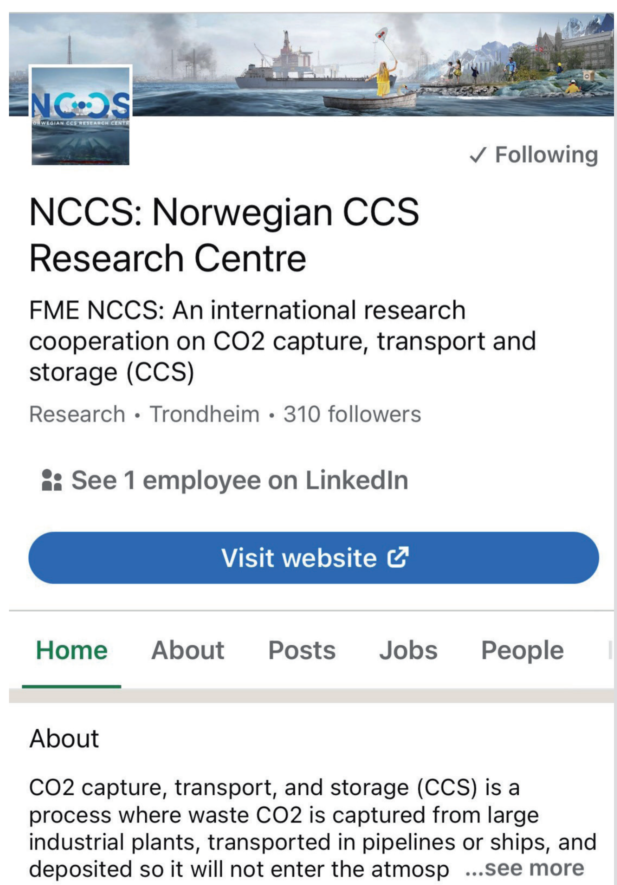
Social media

With the lack of physical events during 2020, the NCCS board identified the need to facilitate networking in other ways. Given the platform's focus on professional networking, an NCCS LinkedIn page was created. Within the first two months, the page amassed 300 followers including students and professionals from companies working in the CCS field, both inside and outside the NCCS consortium. With good engagement rates, LinkedIn should prove to be an important tool for NCCS communication in the years to come.

Follow NCCS on LinkedIn:
https://www.linkedin.com/company/nccs-norway/

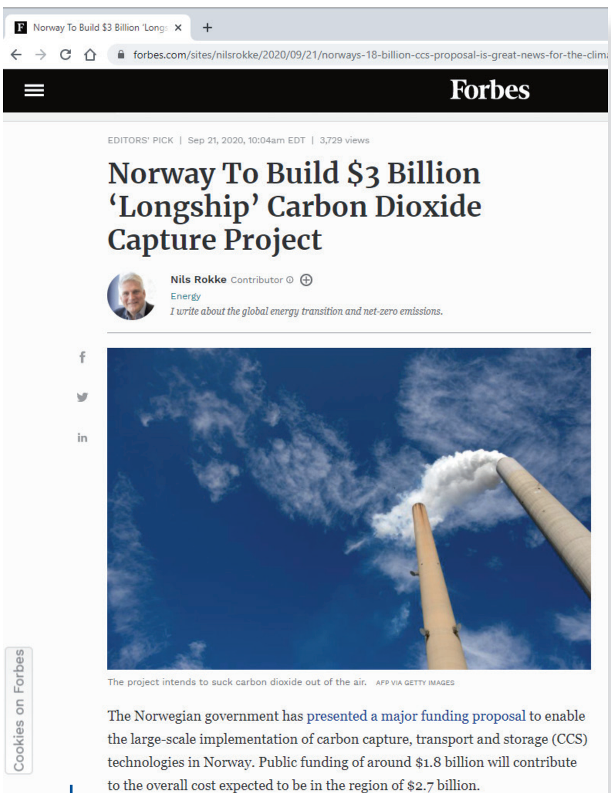
Twitter continues to be an important platform. The 30 NCCS tweets were seen more than 45,000 times, according to Twitter's built-in analytics. The number of followers at the end of 2020 stood at 700, an increase of 173 in the past 12 months.

Follow NCCS on Twitter:
https://twitter.com/NCCS_FME



Media and visibility

The announcement of Longship gave NCCS a unique opportunity to gain high-profile coverage in international media. The NCCS communications team reacted quickly to offer experts for interview and quotations on stories related to Longship and CCS in general.


Norway To Build $3 Billion 'Longs

forbes.com/sites/nilsrokke/2020/09/21/norways-18-billion-ccs-proposal-is-great-news-for-the-clima

Forbes

EDITORS' PICK | Sep 21, 2020, 10:04am EDT | 3,729 views

Norway To Build $3 Billion 'Longship' Carbon Dioxide Capture Project

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

The project intends to suck carbon dioxide out of the air. AFP VIA GETTY IMAGES

The Norwegian government has presented a major funding proposal to enable the large-scale implementation of carbon capture, transport and storage (CCS) technologies in Norway. Public funding of around $1.8 billion will contribute to the overall cost expected to be in the region of $2.7 billion.

Cookies on Forbes

For the last four years, the Norwegian CCS Research Center (NCCS) has been working to address barriers to full-scale implementation that have been identified within pilot projects.

As a result of this work, NCCS spokespeople were quoted in Addresseavisen, Teknisk Ukeblad, Dagens Næringsliv and Energy Voice. SINTEF's VP Sustainability Nils Røkke mentioned the importance of ongoing NCCS research in his Forbes.com column about the launch of Longship. He was also quoted as a CCS expert in Reuters and Politico, among other outlets.

NCCS Centre Director Mona Mølnvik was featured in a video about CCS research made by Trondheim municipality's "Teknologihovedstaden" (Technology Capital) project at www.teknologihovedstaden.no. The video has been viewed 16,500 times since publication in August 2020.

Centre manager Amy Brunsvold appeared on the podcast 'The Life in Norway Show' to discuss CCS in general, NCCS in particular, and the experience of living and working in Norway. Released in October 2020, the episode was downloaded 1,975 times, a number that is expected to increase over time.

TCCS-11

The 11th edition of the Trondheim CCS Conference (TCCS-11) is planned for June 2021. NCCS has provided communications support to the planning team to create interest in the event well in advance of registration opening.

APPENDIX

NCCS publications registered in cristin

Peer Reviewed Journal Publications

Search criteria: From: 2016 *sub-category:* Academic article *sub-category:* Academic literature review *sub-category:* Short communication *All publishing channels*

1. **Aditya, Konduri; Gruber, Andrea; Xu, Chao; Lu, Tianfeng F.; Krisman, Alex; Bothien, Mirko R.; Chen, Jacqueline H.** Direct numerical simulation of flame stabilization assisted by autoignition in a reheat gas turbine combustor. *Proceedings of the Combustion Institute* 2019 ;Volume 37.(2) p. 2635-2642. ENERGISINT
2. **Almenningen, Stian; Betlem, Peter; Hussain, Arif; Roy, Srikumar; Senger, Kim; Ersland, Geir.** Demonstrating the potential of CO2 hydrate self-sealing in Svalbard, Arctic Norway. *International Journal of Greenhouse Gas Control* 2019 ;Volume 89. p. 1-8. UiB UNIS
3. **Anantharaman, Rahul; Roussanaly, Simon; Ditaranto, Mario.** Feasibility of Selective Exhaust Gas Recycle Process for Membrane-based CO2 Capture from Natural Gas Combined Cycles – Showstoppers and Alternative Process Configurations. *SSRN* 2019. ENERGISINT
4. **Betlem, Peter; Birchall, Thomas; Ogata, Kei; Park, Joonsang; Skurtveit, Elin; Senger, Kim.** Digital Drill Core Models: Structure-from-Motion as a Tool for the Characterisation, Orientation, and Digital Archiving of Drill Core Samples. *Remote Sensing* 2020 ;Volume 12.(2) p. - NGI UiO UNIS
5. **Birchall, Thomas; Senger, Kim; Hornum, Mikkel Toft; Olaussen, Snorre; Braathen, Alvar.** Underpressure in the northern Barents shelf: Causes and implications for hydrocarbon exploration. *American Association of Petroleum Geologists Bulletin* 2020 ;Volume 104.(11) p. 2267-2295. UiO UNIS
6. **Braathen, Alvar; Petrie, Elisabeth; Nystuen, Tonje; Sundal, Anja; Skurtveit, Elin; Zuchuat, Valentin; Gutierrez, Marte; Midtkandal, Ivar.** Interaction of deformation bands and fractures during progressive strain in monocline - San Rafael Swell, Central Utah, USA. *Journal of Structural Geology* 2020 ;Volume 141. p. - NGI UiO
7. **Brunsvold, Amy; Tangen, Grethe; Størset, Sigmund Østtveit; Dawson, James; Braathen, Alvar; Steenstrup-Duch, Anne; Aarlien, Rune; Mølnvik, Mona J.** The Norwegian CCS Research Centre (NCCS): facilitating industry-driven innovation for fast-track CCS deployment. *Clean Energy* 2020 ;Volume 4.(2) p. 158-168. ENERGISINT NTNU SINTEF UiO
8. **Buvik, Vanja; Bernhardsen, Ida; Figueiredo, Roberta V.; Vevelstad, Solrun Johanne; Goetheer, Earl L.V.; van Os, peter; Knuutila, Hanna K.** Measurement and prediction of oxygen solubility in post-combustion CO2 capture solvents. *International Journal of Greenhouse Gas Control* 2020 p. - NTNU SINTEF
9. **Deng, Han; Roussanaly, Simon; Skaugen, Geir.** Techno-economic analyses of CO2 liquefaction: Impact of product pressure and impurities. *International journal of refrigeration* 2019 ;Volume 103. p. 301-315. ENERGISINT
10. **Dupuy, Bastien; Romdhane, Anouar; Eliasson, Peder; Querendez, Etor; Yan, Hong; Torres Caceres, Veronica Alejandra; Ghaderi, Amir.** Quantitative seismic characterisation of CO2 at the Sleipner storage site, North Sea. *Interpretation* 2017 ;Volume 5.(4) p. SS23-SS42. NTNU SINTEF
11. **Dupuy, Bastien; Torres Caceres, Veronica Alejandra; Romdhane, Mohamed Anouar; Ghaderi, Amir.** Norwegian large-scale CO2 storage project (Smeaheia): baseline geophysical models. *SSRN* 2019. SINTEF
12. **Fan, Changyu; Braathen, Alvar.** Flow of brine and oil along reverse faults in the northwestern Sichuan Basin, China. *American Association of Petroleum Geologists Bulletin* 2019 ;Volume 103.(5) p. 1153-1177. UiO
13. Fan, Changyu; **Braathen, Alvar; Wang, Zhenliang; Zhang, Xiaoqiang; Chen, Suiying; Feng, Nana; Wang, Aiguo; Huang, Lei.** Flow pathway and evolution of water and oil along reverse faults in the northwestern Sichuan Basin, China. *American Association of Petroleum Geologists Bulletin* 2019 ;Volume 103.(5) p. 1153-1177. UiO
14. **Fu, Chao; Roussanaly, Simon; Jordal, Aina Benedikte Kristin; Anantharaman, Rahul.** Techno-Economic Analyses of the CaO/CaCO3 Post-Combustion CO2 Capture From NGCC Power Plants. *Frontiers in Chemical Engineering* 2021. ENERGISINT

15. **Gant, Francesco; Gruber, Andrea; Bothien, Mirko R.** Development and validation study of a 1D analytical model for the response of reheat flames to entropy waves. *Combustion and Flame* 2020 ;Volume 222. p. 305-316. ENERGISINT NTNU
16. **Grimstvedt, Andreas Magnar; Wiig, Merete; Einbu, Aslak; Vevelstad, Solrun Johanne.** Multi-component analysis of monethanolamine solvent samples by FTIR. *International Journal of Greenhouse Gas Control* 2019 ;Volume 83. p. 293-307. SINTEF
17. **Gruber, Andrea; Richardson, Edward S.; Aditya, Konduri; Chen, Jacqueline H.** Direct numerical simulations of premixed and stratified flame propagation in turbulent channel flow. *Physical Review Fluids* 2018 ;Volume 3.(11). ENERGISINT NTNU
18. **Haaf, Martin; Anantharaman, Rahul; Roussanaly, Simon; Ströhle, Jochen; Epple, Bernd.** CO2 capture from waste-to-energy plants: Techno-economic assessment of novel integration concepts of calcium looping techno-logy. *Resources, Conservation and Recycling* 2020 ;Volume 162. ENERGISINT
19. **Hennings, Peter H.; Lund Snee, Jens-Erik; Osmond, Johnathon Lee; DeShon, Heather R.; Dommisse, Robin; Horne, Elizabeth; Lemons, Casee; Zoback, Mark D.** Injection-induced seismicity and fault-slip potential in the Fort Worth Basin, Texas. *Bulletin of The Seismological Society of America (BSSA)* 2019 ;Volume 109.(5) p. 1615-1634. UiO
20. **Horne, Elizabeth A.; Hennings, Peter H.; Osmond, Johnathon L.; DeShon, Heather R.** Structural characterization of potentially seismogenic faults in the Fort Worth Basin. *Interpretation* 2020 ;Volume 8.(2) p. T323-T347. UiO
21. **Jiang, Yuanjie; del Alamo Serrano, Gonzalo; Gruber, Andrea; Bothien, Mirko R.; Seshadri, Kalyanasundaram; Williams, Forman Arthur.** A skeletal mechanism for prediction of ignition delay times and laminar premixed flame velocities of hydrogen-methane mixtures under gas turbine conditions. *International Journal of Hydrogen Energy* 2019 ;Volume 44.(33) p. 18573-18585. ENERGISINT
22. **Koevoets, Maayke Jacqueline; Hammer, Øyvind; Olaussen, Snorre; Senger, Kim; Smelror, Morten.** Integrating subsurface and outcrop data of the Middle Jurassic to Lower Cretaceous Agardhfjellet Formation in central Spitsbergen. *Norwegian Journal of Geology* 2018 ;Volume 98.(4) p. - NGU UiO UNIS
23. **Lavrov, Alexandre; Torsæter, Malin.** All microannuli are not created equal: Role of uncertainty and stochastic properties in well leakage prediction. *International Journal of Greenhouse Gas Control* 2018 ;Volume 79. p. 323-328. SINTEF
24. **Li, Zuoan; Polfus, Jonathan Marc; Xing, Wen; Denonville, Christelle; Fontaine, Marie-Laure; Bredesen, Rune.** Factors Limiting the Apparent Hydrogen Flux in Asymmetric Tubular Cercer Membranes Based on La27W3.5Mo1.5O55.5−δ and La0.87Sr0.13CrO3−δ. Membranes 2019 ;Volume 9.(126). SINTEF
25. **Lubrano-Lavadera, Paul Louis Francois; Senger, Kim; Lecomte, Isabelle; Mulrooney, Mark Joseph; Kühn, Daniela.** Seismic modelling of metre-scale normal faults at a reservoir-cap rock interface in Central Spitsbergen, Svalbard: implications for CO2 storage. *Norwegian Journal of Geology* 2019 ;Volume 99.(2) p. 329-347. NORSAR UiB UiO UNIS
26. **Løvseth, Sigurd Weidemann; Westman, Snorre Foss; Austegard, Anders; Stang, Hans Georg Jacob.** Need and Measurements of Accurate Thermodynamic Data for CCS. *SSRN* 2019. ENERGISINT
27. **Mulrooney, Mark Joseph; Larsen, Leif; Van Stappen, Jeroen; Rismyhr, Bjarte; Senger, Kim; Braathen, Alvar; Olaussen, Snorre; Mørk, Mai Britt Engeness; Ogata, Kei; Cnudde, Veerle.** Fluid flow properties of the Wilhelmøya Subgroup, a potential unconventional CO2 storage unit in central Spitsbergen. *Norwegian Journal of Geology* 2018 ;Volume 99.(4) p. 85-116. NTNU UiB UiO UIS UNIS
28. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Skurtveit, Elin; Faleide, Jan Inge; Braathen, Alvar.** Structural analysis of the Smeaheia fault block, a potential CO2 storage site, northern Horda Platform, North Sea. *Marine and Petroleum Geology* 2020 ;Volume 121. p. - NGI UiO
29. **Munkejord, Svend Tollak; Austegard, Anders; Deng, Han; Hammer, Morten; Stang, Hans Georg Jacob; Løvseth, Sigurd Weidemann.** Depressurization of CO2 in a pipe:High-resolution pressure and temperature data and comparison with model predictions. *Energy 2020* ;Volume 211. ENERGISINT
30. **Mølnvik, Mona J.; Brunsvold, Amy; Tangen, Grethe; Henriksen, Partow Pakdel; Munkejord, Svend Tollak; Jakobsen, Jana Poplsteinova.** The Norwegian CCS Resear-ch Centre: Industry-Driven Innovation for Fast-Track Ccs Deployment. *SSRN* 2019. ENERGISINT NTNU SINTEF
31. **Møyner, Olav; Nilsen, Halvor Møll.** Multiresolution coupled vertical equilibrium model for fast flexible simulation of CO2 storage. *Computational Geosciences* 2018 p. 1-20. NTNU SINTEF

32. **Neumann, Tobias; Thol, Monika; Bell, Ian H.; Lemmon, Eric W.; Span, Roland.** Fundamental thermodynamic models for mixtures containing ammonia. *Fluid Phase Equilibria* 2020 ;Volume 511. p. - NTNU
33. **Ohm, Sverre Ekrene; Larsen, Leif; Olaussen, Snorre; Senger, Kim; Birchall, Thomas; Demchuk, Thomas; Hodson, Andrew; Johansen, Ingar; Titlestad, Geir Ove; Karlsen, Dag Arild; Braathen, Alvar.** Discovery of shale gas in organic-rich Jurassic successions, Adventdalen, Central Spitsbergen, Norway. *Norwegian Journal of Geology* 2019 ;Volume 99.(2) p. 349-376
IFE UiO UIS UNIS
34. **Olaussen, Snorre; Senger, Kim; Braathen, Alvar; Grundvåg, Sten-Andreas; Mørk, Atle.** You learn as long as you drill; research synthesis from the Longyearbyen CO2 Laboratory, Svalbard, Norway. *Norwegian Journal of Geology* 2019 ;Volume 99.(2) p. 157-188. NTNU UiO UiT UNIS
35. **Osmond, Johnathon Lee; Meckel, Timothy A.** Enhancing trap and fault seal analyses by integrating observations from HR3D seismic data with well logs and conventional 3D seismic data, Texas inner shelf. *Geological Society Special Publication* 2019 p. - UiO
36. **Ottøy, Sindre; Neumann, Tobias; Stang, Hans Georg Jacob; Jakobsen, Jana Poplsteinova; Austegard, Anders; Løvseth, Sigurd Weidemann.** Thermodynamics of the carbon dioxide plus nitrogen plus methane (CO2 + N2 + CH4) system: Measurements of vapor-liquid equilibrium data at temperatures from 223 to 298 K and verification of EOS-CG-2019 equation of state. *Fluid Phase Equilibria* 2019 ;Volume 509. ENERGISINT NTNU
37. **Polfus, Jonathan M.; Yang, Jing; Yildiz, Bilge.** Interplay between H2O and CO2 coadsorption and space-charge on Y-doped BaZrO3 surfaces. Journal of Materials Chemistry A 2018 ;Volume 6. p. 24823-24830. SINTEF
38. **Polfus, Jonathan M.; Yildiz, Bilge; Tuller, Harry; Bredesen, Rune.** Adsorption of CO2 and Facile Carbonate Formation on BaZrO3 Surfaces. *Journal of Physical Chemistry C* 2018 ;Volume 122.(1) p. 307-314. SINTEF
39. **Ringrose, Philip; Meckel, T A.** Maturing global CO2 storage resources on offshore continental margins to achieve 2DS emissions reductions. *Scientific Reports* 2019 ;Volume 9.(1) p. 1-10. NTNU
40. **Rismyhr, Bjarte; Bjærke, Tor; Olaussen, Snorre; Mulrooney, Mark Joseph; Senger, Kim.** Facies, palynostratigraphy and sequence stratigraphy of the Wilhelmøya Subgroup (Upper Triassic–Middle Jurassic) in western central Spitsbergen, Svalbard. *Norwegian Journal of Geology* 2018 ;Volume 99.(4) p. 35-64. UiB UiO UNIS
41. **Romdhane, Mohamed Anouar; Eliasson, Peder.** Optimised Geophysical Survey Design for CO2 Monitoring – A Synthetic Study. *SSRN* 2019. SINTEF
42. **Roussanaly, Simon.** Calculating CO2 avoidance costs of Carbon Capture and Storage from industry. *Carbon Management* 2019 ;Volume 10.(1) p. 105-112. ENERGISINT
43. **Roussanaly, Simon; Anantharaman, Rahul; Fu, Chao.** Low-Carbon Footprint Hydrogen Production from Natural Gas: a Techno-Economic Analysis of Carbon Capture and Storage from Steam-Methane Reforming. *Chemical Engineering Transactions* 2020 ;Volume 81. p. 1015-1020 ENERGISINT
44. **Roussanaly, Simon; Anantharaman, Rahul; Lindqvist, Karl Erik Artur; Hagen, Brede Andre Larsen.** A new approach to the identification of high-potential materials for cost-efficient membrane-based post-combustion CO2 capture. *Sustainable Energy & Fuels* 2018 ;Volume 2.(6) p. 1225-1243. ENERGISINT NTNU
45. **Roussanaly, Simon; Ouassou, Jabir Ali; Anantharaman, Rahul; Haaf, Martin.** Impact of uncertainties on the design and cost of CCS from a waste-to-energy plant. *Frontiers in Energy Research* 2020. ENERGISINT
46. **Sazinas, Rokas; Sunding, Martin Fleissner; Thøgersen, Annett; Sakaguchi, Isao; Norby, Truls Eivind; Grande, Tor; Polfus, Jonathan M.** Surface reactivity and cation non-stoichiometry in BaZr1-xYxO3-δ (x=0-0.2) exposed to CO2 at elevated temperature. *Journal of Materials Chemistry* A 2019 ;Volume 7.(8) p. 3848-3856. NTNU SINTEF UiO
47. **Skonseng Bjerketvedt, Vegard; Tomasgard, Asgeir; Roussanaly, Simon.** Optimal design and cost of ship-based CO2 transport under uncertainties and fluctuations. *International Journal of Greenhouse Gas Control* 2020 ;Volume 103. ENERGISINT NTNU
48. **Skurtveit, Elin; Sundal, Anja; Bjørnarå, Tore Ingvald; Soldal, Magnus; Sauvin, Guillaume; Zuchuat, Valentin; Midtkandal, Ivar; Braathen, Alvar.** Experimental investigation of natural fracture stiffness and flow properties in a faulted CO2 bypass system (Utah, USA). *Journal of Geophysical Research (JGR):* Solid Earth 2020 ;Volume 125.(7) p. - NGI UiO
49. **Størset, Sigmund Østtveit; Tangen, Grethe; Berstad, David Olsson; Eliasson, Peder; Hoff, Karl Anders; Langørgen, Øyvind; Munkejord, Svend Tollak; Roussanaly, Simon; Torsæter, Malin.** Profiting from CCS innovations: A study to measure potential value creation from CCS research and development. *International Journal of Greenhouse Gas Control* 2019 ;Volume 83. p. 208-215. ENERGISINT SINTEF

50. **Subraveti, Gokul Sai; Roussanaly, Simon; Anantharaman, Rahul; Riboldi, Luca; Rajendran, Arvind.** Techno-economic Assessment of Optimised Vacuum Swing Adsorption for Post-Combustion CO2 capture from Steam-Methane Reformer Flue Gas. *Separation and Purification Technology* 2020 ;Volume 256. ENERGISINT
51. **Torsæter, Malin; Cerasi, Pierre.** Geological and geomechanical factors impacting loss of near-well permeability during CO2 injection. *International Journal of Greenhouse Gas Control* 2018 ;Volume 76. p. 193-199. SINTEF
52. **Westman, Snorre Foss; Austegard, Anders; Stang, Hans Georg Jacob; Løvseth, Sigurd Weidemann.** Vapor-liquid equilibrium data for the carbon dioxide and carbon monoxide (CO2 + CO) system at the temperatures 253, 273, 283 and 298 K and pressures up to 13 MPa. *Fluid Phase Equilibria* 2018 ;Volume 473. p. 37-49. ENERGISINT
53. **Yan, Hong; Dupuy, Bastien; Romdhane, Mohamed Anouar; Arntsen, Børge.** CO2 saturation estimates at Sleipner (North Sea) from seismic tomography and rock physics inversion. *Geophysical Prospecting* 2018 ;Volume 67.(4) p. 1055-1071. NTNU SINTEF
54. **Æsøy, Eirik; Aguilar, Jose; Wiseman, Samuel; Bothien, Mirko R.; Worth, Nicholas; Dawson, James.** Scaling and prediction of transfer functions in lean premixed H2/CH4-flames. *Combustion and Flame* 2020 ;Volume 215. p. 269-282. NTNU

Presentations

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

1. **Anantharaman, Rahul.** Benchmarking MEA performance – concentration, scale and practicalities. NCCS Consortium Days 2019; 2019-10-22 - 2019-10-23. ENERGISINT
2. **Anell, Ingrid Margareta.** NCCS – Education, mobility, student engagement and visions for the future. NCCS Consortium Days; 2019-10-22 - 2019-10-23. UiO
3. **Anell, Ingrid Margareta; Backer, Dag; Sundal, Anja; Torvanger, Asbjørn; Meisingset, Egil; Rørvik, Kari-Lise; Øye, Olav.** Feasibility of CO2 storage as a climate mitigation measure in Norway. Outside the BoCCS - CCS Seminar series; 2019-03-13 - 2019-03-13. UiO CICERO
4. **Anell, Ingrid Margareta; Banet, Catherine; Weber, Viktor; Vold, Sofie Fogstad; Riseng, Cathrine; Seglem, Heidi; Svendsen Skriung, Camilla.** The role of law in CCS deployment – Regulatory incentives to enable carbon capture and storage (CCS) in Norway. Outside the BoCCS - CCS Seminar series; 2019-11-14 - 2019-11-14. UiO
5. **Anell, Ingrid Margareta; Mulrooney, Mark Joseph.** Combatting Climate Change: An introduction to geological storage of CO2. 3rd international OHG conference: "Make our Planet Great Again"; 2020-02-13. UiO
6. **Austegard, Anders; Deng, Han; Hammer, Morten; Løvseth, Sigurd Weidemann; Munkejord, Svend Tollak; Stang, Hans Georg Jacob.** A new experimental facility for decompression of CO2 and CO2-rich mixtures. 10th Trondheim CCS Conference, TCCS-10; 2019-06-17 - 2019-06-19. ENERGISINT
7. **Banet, Catherine.** Bioenergy with carbon capture and storage (Bio-CCS): moving from carbon neutrality to carbon negativity as a legal requirement. Colloque INGILAW «Tempête sur la planète: penser le droit et les politiques de l'ingénierie climatique et environnementale à l'heure de l'anthropocène»; 2018-10-11 - 2018-10-12. UiO
8. **Banet, Catherine.** "Public support to carbon capture and storage (CCS) under EU state aid rules.". Climate emergency: the role of law in CCS deployment: Regulatory incentives to enable carbon capture and storage (CCS) in Norway and Europe.; 2019-11-14 - 2019-11-14. UiO
9. **Banet, Catherine.** Public support to carbon capture and storage (CCS) under EU state aid rules. NCCS Consortium Days; 2019-10-22 - 2019-10-23. UiO
10. **Banet, Catherine.** Regulating re-use and repurposing of installations for CCS and energy system integration. Energy Transition Week; 2020-04-27 - 2020-04-27. UiO
11. **Banet, Catherine.** Regulating the re-use and re-purposing of oil and gas installations for CCS in the context of decommissioning. NCCS Webinar; 2020-05-05 - 2020-05-05. UiO
12. **Banet, Catherine.** Regulating the re-use and repurposing of oil and gas installations in the context of decommissioning. Webinar; 2020-05-07 - 2020-05-07. UiO
13. **Banet, Catherine.** Rør- og sjøtransport av CO2. Juridiske hindringer for å gjennomføre fullskala CO2-håndtering. Teknas CO2 konferanse 2019; 2019-01-17 - 2019-01-17. UiO
14. **Barrabino, Albert; Bergmo, Per Eirik Strand; Grimstad, Alv-Arne; Holt, Torleif.** Mobility control of CO2 during aquifer storage. 10th Trondheim Conference on Carbon Capture, Transport and Storage (TCCS-10); 2019-06-17 - 2019-06-19. SINTEF
15. **Berntsen, Andreas Nicolas.** Ensuring CO2 well integrity. CLIMIT Summit; 2019-02-26 - 2019-02-27. SINTEF
16. **Betlem, Peter.** Svalbard 2020 in overview: from field campaign to what lies ahead. NCCS Consortium Days 2020; 2020-11-04 - 2020-11-05. UNIS

17. **Betlem, Peter; Birchall, Thomas; Mosočiová, Tereza; Sartell, Anna Marie Rose; Senger, Kim.** From seismic-scale outcrop to hand sample: streamlining SfM photogrammetry processing in the geosciences. ARCEx Annual Conference 2020; 2020-10-19 - 2020-10-22. UNIS
18. **Betlem, Peter; Rabbel, Ole; Lecomte, Isabelle; Senger, Kim.** Seismic Modelling of Virtual Outcrops: Application of Rock Physics Beyond the Borehole. Fifth EAGE Workshop on Rock Physics; 2020-02-10 - 2020-02-12. UiB UiO UNIS
19. **Betlem, Peter; Senger, Kim.** Svalbox: an interactive digital portal to Svalbard's geoscientific data. Online conference on remote sensing in Svalbard - 4-5 June 2020; 2020-06-04 - 2020-06-05. UNIS
20. **Bjerkevedt, Vegard; Roussanaly, Simon; Tomasgard, Asgeir.** Design of a shipping supply chain under operational uncertainties. NCCS Consortium day; 2019-10-22 - 2019-10-23. ENERGISINT NTNU
21. **Bjerkevedt, Vegard; Tomasgard, Asgeir; Roussanaly, Simon.** Capacity Investments and Operational Uncertainty. TCCS-10 conference; 2019-06-17 - 2019-06-19. ENERGISINT NTNU
22. **Bouquet, Grégory.** TOPHOLE kick-off meeting: smart sensor systems. TOPHOLE kick-off meeting; 2019-10-21 - 2019-10-21. SINTEF
23. **Bouquet, Grégory.** Tophole project meeting: sensor evaluation for gas leakage detection. Tophole summer meeting; 2020-08-26 - 2020-08-26. SINTEF
24. **Bouquet, Grégory.** TopHole: sensor evaluation for gas leakage detection. Tophole annual meeting; 2020-11-03 - 2020-11-03. SINTEF
25. **Braathen, Alvar; Mulrooney, Mark Joseph; Osmond, Johnathon L.** Fault studies - challenges and applications. UiO Department of Geosciences Seminar; 2018-02-28 - 2018-02-28. UiO
26. **Braathen, Alvar; Senger, Kim; Skurtveit, Elin.** Reducing risks using geological models for CO2 storage. NCCS Webinar; 2020-10-27 - 2020-10-27. NGI UiO UNIS
27. **Brunsvold, Amy.** CCS in Norway: The Norwegian Full-Scale CCS Project and the Norwegian CCS Research Centre. US Department of Energy Regional CO2 Sequestration Partnership; 2017-06-06. ENERGISINT
28. **Brunsvold, Amy.** NCCS, activities, plans, and collaboration. CO2lagringsforum; 2018-11-20. ENERGISINT
29. **Brunsvold, Amy.** NCCS: Collaboration with the United States. US Norway Bilateral Meeting on CCS; 2018-05-02 - 2018-05-03. ENERGISINT
30. **Brunsvold, Amy.** NCCS: The Norwegian CCS Research Centre. UiO: Energy Forum 2019; 2019-11-27 - 2019-11-28. ENERGISINT
31. **Brunsvold, Amy.** Norway Singapore Webinar Series 2020: The Norwegian CCS Research Centre. Norway Singapore Webinar Series 2020; 2020-05-29 - 2020-05-29. ENERGISINT
32. **Brunsvold, Amy.** Norwegian CCS Research Centre: Examples of collaborations with the United States. US-Norway Collaboration on CCS/CCUS; 2017-08-28 - 2017-08-29. ENERGISINT
33. **Brunsvold, Amy.** Scientific Achievements in NCCS. NCCS Consortium Days 2020; 2020-11-04 - 2020-11-05. ENERGISINT
34. **Brunsvold, Amy.** The Norwegian CCS Research Centre. Norwegian Oil and Gas; 2018-02-09. ENERGISINT
35. **Brunsvold, Amy.** The Norwegian CCS Research Centre: Overcoming barriers to CCS deployment through industry-driven Research and Innovation. NCCS Webinar Series 2020; 2020-10-01 - 2020-10-01. ENERGISINT
36. **Brunsvold, Amy.** Welcome to the IEAGHGCCS Summer School: This is NCCS. IEAGHG; 2018-06-24. ENERGISINT
37. **Brunsvold, Amy.** Why CCS in Norway?. "Forum for Climate & Environment, Network for air emissions (all operating companies on the NCS represented)"; 2017-11-16. ENERGISINT
38. **Brunsvold, Amy; Mølnvik, Mona J.** Norwegian CCS Research Centre - Industry-driven innovation for fast-track CCS deployment. UKCCS Spring Biannual Meeting, CCS In the UK: Delivering for the Future; 2017-04-11 - 2017-04-12. ENERGISINT
39. **Brunsvold, Amy; Tangen, Grethe; Størset, Sigmund Østtveit; Dawson, James; Braathen, Alvar; Aarlien, Rune; Steenstrup, Anne; Mølnvik, Mona J.** The Norwegian CCS Research Centre (NCCS): Facilitating industry-driven innovation for fast-track CCS deployment. GHGT-14; 2018-10-22 - 2018-10-25. ENERGISINT NTNU SINTEF UiO
40. **Buvik, Vanja; Knuutila, Hanna K.** Oxygen solubility in selected amine solvents. NCCS Webinar; 2018-11-21. NTNU
41. **Buvik, Vanja; Knuutila, Hanna K.** Review of oxidative degradation of 30 wt. % MEA in pilot campaigns. University of Texas 4th Conference on Carbon Capture and Storage UTCCS-4; 2018-01-30 - 2018-01-31. NTNU
42. **Buvik, Vanja; Vevelstad, Solrun Johanne; Knuutila, Hanna K.** Comparison of oxidative and biodegradability of aqueous amine solvents for CO2 capture. TCCS-10; 2019-06-17 - 2019-06-19. NTNU SINTEF
43. **Buvik, Vanja; Vevelstad, Solrun Johanne; Knuutila, Hanna K.** Oxidative and biological degradability of aqueous amine solvents for CO2 capture. University of Texas 5th Conference on Carbon Capture and Storage, UTCCS-5; 2020-01-28 - 2020-01-29. NTNU SINTEF

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45. **Carlton, Brian; Skurtveit, Elin; Atakan, Kuvvet; Kaynia, Amir M.** Probabilistic Seismic Hazard Analysis of a CO2 Storage Prospect Using the NGA East Ground Motion Models. SECED 2019 Conference: Earthquake risk and engineering towards a resilient world; 2019-09-09 - 2019-09-10. NGI NTNU UiB UiO
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47. **Cerasi, Pierre; Lavrov, Alexandre; Torsæter, Malin; Ytrehus, Jan David; Taheri, Amir.** Enhancing CO2 well integrity by improving primary cement jobs. GHGT-14; 2018-10-23. NTNU SINTEF
48. **Cerasi, Pierre; Stroisz, Anna Magdalena.** Laboratory testing of cement-rock bonding strength for improved well integrity. Interpore 2018; 2018-05-13 - 2018-05-17. SINTEF
49. **Choi, Jung Chan; Skurtveit, Elin; Grande, Lars.** Deep Neural Network Based Prediction of Leak-Off Pressure in Offshore Norway. Offshore Technology Conference (OTC 2019); 2019-05-06 - 2019-05-09. NGI
50. **Choi, Jung Chan; Skurtveit, Elin; Grande, Lars.** Prediction of leak-off pressure in Norwegian offshore using NPD factpages and deep neural network. International Symposium on Energy Geotechnics (SEG) 2018; 2018-09-25 - 2018-09-28. NGI
51. **Choi, Jung Chan; Skurtveit, Elin; Grande, Lars; Park, Joonsang.** Effect of CO2 injection-induced stress rotation in overburden on the fault stability and induced seismicity: Numerical investigation. TCCS-10. The 10th Trondheim Conference on Carbon Capture, Transport and Storage; 2019-06-17 - 2019-06-19. NGI
52. **Deng, Han; Roussanaly, Simon; Skaugen, Geir.** Toward the identification of optimal conditions for transport of CO2 by ship: Part I - CO2 liquefaction. 14th Greenhouse Gas Technology Conference (GHGT-14); 2018-10-21 - 2018-10-25. ENERGISINT
53. **Duda, Marcin.** Top Seal Undrained Pore Pressure Response - Sensitivity to Skempton's A. Fault & Top Seals; 2019-09-08 - 2019-09-12. NTNU
54. **Dumoulin, Stephane; Gruben, Gaute; Hammer, Morten; Munkejord, Svend Tollak.** Simulation of a full-scale fracture propagation test. 10th Trondheim CCS Conference, TCCS-10; 2019-06-17 - 2019-06-19. ENERGISINT SINTEF
55. **Dupuy, Bastien.** Spin-off project TOPHOLE - Pitch NCCS consortium days. NCCS consortium days; 2019-10-21 - 2019-10-22. SINTEF
56. **Dupuy, Bastien.** TOPHOLE annual meeting: Introduction and project status. Tophole annual meeting; 2020-11-03 - 2020-11-03. SINTEF
57. **Dupuy, Bastien.** TOPHOLE kick-off meeting: project overview. TOPHOLE kick-off meeting; 2019-10-21 - 2019-10-21. SINTEF
58. **Dupuy, Bastien.** Tophole project meeting: project overview and status. Tophole summer meeting; 2020-08-26 - 2020-08-26. SINTEF
59. **Dupuy, Bastien; Romdhane, Anouar; Bouquet, Grégory; Zonetti, Simone.** Tophole project status. NCCS task 12 Spring meeting; 2020-05-25 - 2020-05-25. SINTEF
60. **Dupuy, Bastien; Romdhane, Anouar; Eliasson, Peder; Yan, Hong; Torres Caceres, Veronica Alejandra; Querendez, Etor; Ghaderi, Amir.** Carbon dioxide saturation estimates at Sleipner using seismic imaging and rock physics inversion. EAGE/SEG research workshop: geophysical monitoring of CO2 injection - CCS and CO2-EOR; 2017-08-28 - 2017-08-31. NTNU SINTEF
61. **Dupuy, Bastien; Romdhane, Anouar; Park, Joonsang.** Rock physics inversion from CSEM and seismic data. EM4CO2 annual meeting; 2020-11-03 - 2020-11-03. NGI SINTEF
62. **Dupuy, Bastien; Romdhane, Mohamed Anouar; Eliasson, Peder.** Quantitative monitoring and uncertainties during multiphysics inversion. SEG Postconvention Workshop 11: Long term monitoring of CO2 geosequestration: continuous surveillance and quantitative interpretation; 2019-09-19 - 2019-09-19. SINTEF
63. **Egeland, Heidi Sydnes.** CCS under the EU ETS: legal consequences of different transport options. NCCS Consortium day; 2019-10-22 - 2019-10-23. UiO
64. **Emmel, Benjamin.** TOPHOLE - Troll field evaluation for P&A. Tophole annual meeting; 2020-11-03 - 2020-11-03. SINTEF
65. **Faleide, Thea Sveva; Midtkandal, Ivar; Planke, Sverre; Corseri, Romain; Faleide, Jan Inge; Nystuen, Johan Petter; Anell, Ingrid Margareta; Braathen, Alvar.** High-resolution seismic imaging and modelling of structural and stratigraphical features in the SW Barents Sea. American Association of Petroleum Geologists 2019 Annual & Exhibition; 2019-05-19 - 2019-05-22. UiO
66. **Fjelde, Ingebret; Omekeh, Aruoture Voke; Guo, Ying.** Permeability reduction by salt precipitation. NCCS Consortium Days; 2019-10-22 - 2019-10-23. NORCE UIS
67. **Fu, Chao; Roussanaly, Simon; Gardarsdottir, Stefania Osk; Anantharaman, Rahul.** Energy and cost performances baseline for post-combustion capture using MEA. NCCS Consortium Days 2019; 2019-10-22 - 2019-10-23. ENERGISINT

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69. **Ghaderi, Amir.** Tophole project meeting: experimental ideas and plans. Tophole summer meeting; 2020-08-26 - 2020-08-26. NTNU
70. **Grimstad, Alv-Arne.** CO2 mobility control - modelling of CO2 foam core flooding experiments. NCCS Webinar; 2020-04-16 - 2020-04-16. SINTEF
71. **Grimstad, Alv-Arne; Bergmo, Per Eirik Strand; Nilsen, Halvor Møll; Klemetsdal, Øystein.** CO2 storage with mobility control. GHGT-14; 2018-10-21 - 2018-10-25 NTNU SINTEF
72. **Grimstad, Alv-Arne; Loeve, Daniel.** Probabilistic tool for design of transport and storage networks: Built-in flexibility to handle geological uncertainty. NCCS Consortium Days 2020; 2020-11-04 - 2020-11-05. SINTEF
73. **Grimstvedt, Andreas Magnar.** Multi-component Analysis of amine solvent by FTIR and PLS. Webinar; 2019-09-25 - 2019-09-25. SINTEF
74. **Grimstvedt, Andreas Magnar.** Solvent technology – environmental issues. Consortium dager NCCS; 2018-12-05 - 2018-12-06. SINTEF
75. **Grimstvedt, Andreas Magnar; van os, peter; Goether, Earl; Monteiro, Juliana Garcia Moretz-Sohn; Knuutila, Hanna K; Vevelstad, Solrun Johanne.** Solvent Technology - environmental issues. Consortium dager NCCS; 2017-03-16 - 2017-03-17. SINTEF NTNU
76. **Grimstvedt, Andreas Magnar; Vevelstad, Solrun Johanne.** Evaluation of MEA data from different lab set-ups. Webinar; 2019-09-25 - 2019-09-25. SINTEF
77. **Grimstvedt, Andreas Magnar; Vevelstad, Solrun Johanne.** Solvent degradation testing in post combustion CO2 capture. The importance of fundamental knowledge and test strategies. Webinar; 2020-10-29 - 2020-10-29. SINTEF
78. **Gruben, Gaute; Macdonald, Kenneth Alasdair; Munkejord, Svend Tollak; Skarsvåg, Hans Langva; Dumoulin, Stephane.** Pipeline fracture control concepts for Norwegian offshore carbon capture and storage. 15th International Pipeline Conference, IPC2020; 2020-09-28 - 2020-09-30. ENERGISINT SINTEF UIS
79. **Haaf, Martin; Anantharaman, Rahul; Roussanaly, Simon; Ströhle, Jochen; Epple, Bernd.** CO2 Capture from Waste to Energy Plants: Techno-Economic Assessment of Novel Integration Concepts of Calcium Looping Technology. TCCS-10 The 10th Trondheim Conference on CO2 Capture, Transport and Storage; 2019-06-17 - 2019-06-19. ENERGISINT
80. **Haaf, Martin; Anantharaman, Rahul; Roussanaly, Simon; Ströhle, Jochen; Epple, Bernd.** CO2 capture from WtE plants using CaL process. NCCS Consortium Days 2019; 2019-10-22 - 2019-10-23. ENERGISINT
81. **Herrig, Stefan; Bell, Ian H.; Neumann, Tobias; Span, Roland.** An extended fundamental equation of state for thermodynamic properties of mixtures relevant for CCS-applications. Twentieth symposium on thermophysical properties; 2018-06-24 - 2018-06-29. NTNU
82. Holden, Nora; Osmond, Johnathon L.; Mulrooney, Mark Joseph; Sundal, Anja; Skurtveit, Elin. Structural characterization of the Aurora prospect, a potential CO2 storage site in the northern North Sea. NGF Vinterkonferansen; 2021-01-06 - 2021-01-08. UiO
83. **Horne, Elizabeth; Hennings, Peter H.; Osmond, Johnathon L.** Characteristics of Potentially Seismogenic Faults in the Greater Fort Worth Basin. AAPG Annual Convention and Exhibition; 2019-05-19 - 2019-05-22. UiO
84. **Hosseini, Ehsan; Dupuy, Bastien; Romdhane, Anouar; Arntsen, Børge.** Artificial intelligence for well integrity monitoring using geophysical data: preliminary results and plans . Tophole annual meeting; 2020-11-03 - 2020-11-03. SINTEF NTNU
85. **Kim, Donghoi; Mocholí Montañés, Rubén; Anantharaman, Rahul; Roussanaly, Simon.** Potential of membrane assisted absorption process in carbon capture. NCCS Norwegian CCS Research Centre - Consortium Days 2020; 2020-11-04 - 2020-11-05. ENERGISINT
86. **Klemetsdal, Øystein Strengehagen; Møyner, Olav; Nilsen, Halvor Møll; Lie, Knut-Andreas.** How to use recent developments of the MATLAB Reservoir Simulation Toolbox for fast prototyping of complex fluid models. NCCS Webinarserie; 2020-10-06 - 2020-10-06. SINTEF NTNU
87. **Knuutila, Hanna K.** Solvent-Technology - environmental aspects. Consortium dager NCCS; 2019-10-22 - 2019-10-23. NTNU
88. **Leon, Elias H.; Osmond, Johnathon L.; Mulrooney, Mark Joseph; Braathen, Alvar.** Distribution and spatial statistics of pockmarks in Quaternary sediments above the Smeaheia CO2 storage area. NGF Vinterkonferansen; 2019-01-07 - 2019-01-09. UiO
89. **Løvseth, Sigurd Weidemann.** More accurate fluid properties enable reductions of CCS costs and risks. NCCS Webinar; 2020-10-20 - 2020-10-20. ENERGISINT
90. **Løvseth, Sigurd Weidemann; Austegard, Anders; Stang, Hans Georg Jacob; Westman, Snorre Foss.** Accurate Phase

Equilibrium Measurements for CCS Using an Analytical Method. Twentieth symposium on thermophysical properties; 2018-06-24 - 2018-06-29. ENERGISINT

91. **Løvseth, Sigurd Weidemann; Westman, Snorre Foss; Austegard, Anders; Stang, Hans Georg Jacob.** Need and Measurements of Accurate Thermodynamic Data for CCS. 14th Greenhouse Gas Control Technologies Conference (GHGT-14); 2018-10-21 - 2018-10-26. ENERGISINT
92. **Mulrooney, Mark Joseph.** Fault affects on Reservoirs: Case Studies from the Norwegian continental shelf. Geology and Geophysics Seminar; 2018-02-28 - 2018-02-28. UiO
93. **Mulrooney, Mark Joseph.** HIGH-RESOLUTION FAULT MODEL:VETTE FAULT SEGMENTS AND INTRA-BLOCK SUBSIDIARY FAULTS. NCCS-Northern Lights project meeting; 2018-02-14. UiO
94. **Mulrooney, Mark Joseph.** Sites of hard linkage and critically stressed faults. NCCS-Northern Lights project meeting; 2018-06-12 - 2018-06-12. UiO
95. **Mulrooney, Mark Joseph.** Structural analysis of Smeaheia and NCCS updates. NCCS inhouse mini-siminar; 2019-05-29 - 2019-05-29. UiO
96. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Leon, Elias H.; Braathen, Alvar.** A reduced capacity Smeaheia prospect – Structural risks associated with an Alpha-only storage scenario. The 10th Trondheim Conference on CO2 Capture, Transport and Storage; 2019-06-17 - 2019-06-19. UiO
97. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Skurtveit, Elin; Braathen, Alvar.** Fault stability of seismic-scale normal faults: Implications for CO2 storage on the northern Horda Platform. The 34th Nordic Geological Winter Meeting; 2020-01-08 - 2020-01-10 NGI UiO
98. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Skurtveit, Elin; Braathen, Alvar.** Horda Platform: New Learnings. NCCS Consortium Days 2019; 2019-10-22 - 2019-10-23. UiO
99. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Skurtveit, Elin; Braathen, Alvar.** HordaPlatform: New Learnings 2020. NCCS Consortium Days; 2020-11-04 - 2020-11-05. UiO
100. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Skurtveit, Elin; Braathen, Alvar.** Smeaheia – structural uncertainty. NCCS Task 9 Workshop; 2019-02-12 - 2019-02-13. UiO
101. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Skurtveit, Elin; Braathen, Alvar.** Smeaheia case study – first assessments: Sites of structural complexity and gaps in the geological knowledge. NCCS fault de-risking workshop; 2017-11-01 - 2017-11-02. UiO
102. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Skurtveit, Elin; Braathen, Alvar.** Structural observations from The Smeaheia Prospect: Sites of structural complexity and gaps in the geological knowledge. NCCS Task 9 Fault De-Risking Workshop; 2017-11-01 - 2020-11-02. UiO
103. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Skurtveit, Elin; Faleide, Jan Inge; Braathen, Alvar.** Structural analysis of the Smeaheia fault block, a potential CO2 storage site, northern Horda Platform. Vinterkonferansen 2021; 2021-01-06 - 2021-01-08. UiO
104. **Mulrooney, Mark Joseph; Osmond, Johnathon L.; Skurtveit, Elin; Faleide, Jan Inge; Braathen, Alvar.** Summary of manuscript: Structural analysis of the Smeaheia fault block, a potential CO2 storage site, northern Horda Platform, North Sea. NCCS-FRISK status meeting; 2020-04-21. UiO
105. **Mulrooney, Mark Joseph; Osmond, Johnathon Lee; Skurtveit, Elin; Wu, Long; Braathen, Alvar.** Smeaheia, A Potential Northern North Sea CO2 Storage Site: Structural Description And De-Risking Strategies. Fifth CO2 Geological Storage Workshop; 2018-11-21 - 2018-11-23. NGI UiO
106. **Munkejord, Svend Tollak.** CO2 Transport by pipeline. IEAGHG Summer School; 2018-06-25 - 2018-06-29 ENERGISINT
107. **Munkejord, Svend Tollak; Hammer, Morten; Aursand, Peder; Aursand, Eskil; Morin, Alexandre; Gjennestad, Magnus Aashammer; Gruber, Andrea; Lervåg, Karl Yngve; Ervik, Åsmund; Lund, Halvor; Nordhagen, Håkon Ottar; Dumoulin, Stephane.** Pipeline transport of CO2: Mechanistic modelling of dynamics related to safety and operation. IEAGHG Modelling and Risk Management Network Meeting; 2017-12-19 - 2018-06-22. ENERGISINT SINTEF
108. **Mølnvik, Mona J.** Aatte aars forskning på CCS – dette er hva vi fikk til Resultater fra forskningssenteret FME BIGCCS og planer for FME NCCS. Tekna CO2 - konferansen 2017 - Hvorfor er CCS viktig for Norge?; 2017-01-11 - 2017-01-11. ENERGISINT
109. **Mølnvik, Mona J.** Arendalsuka: CCS frokost. Arendalsuka: CCS frokost; 2017-08-15. ENERGISINT
110. **Mølnvik, Mona J.** CCS - innovasjoner og implementasjon i full skala. TEKNA CO2-konferansen 2018; 2018-01-17 - 2018-01-17. ENERGISINT
111. **Mølnvik, Mona J.** CCS ON INDUSTRIAL SOURCES – "THE NEXT FRONTIER FOR GHG REDUCTIONS" Full-scale

implementation and the role of research. Global CCS Symposium; 2017-10-03 - 2017-10-05. ENERGISINT

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113. **Mølnvik, Mona J.** FME NCCS – hvordan nye teknologier åpner muligheter for Norsk sokkel. VISTA Seminar; 2016-11-14. ENERGISINT
114. **Mølnvik, Mona J.** Industrielle muligheter og arbeidsplasser ved storskala CO2-håndtering i Norge. Arendalsuka; 2018-08-13 - 2018-08-15. ENERGISINT
115. **Mølnvik, Mona J.** NCCS - Norweigen CCS Research Centre - Industry-Driven Innovation for Fast-Track CCS Deployment. GHGT-14; 2018-11-21 - 2018-11-25 ENERGISINT
116. **Mølnvik, Mona J.** NCCS relatert til det norske fullskalaprosjektet. OED; 2017-11-30. ENERGISINT
117. **Mølnvik, Mona J.** Norwegian CCS Research Centre - Official opening of Centre. Norwegian CCS Research Centre Kick-off; 2016-11-04. ENERGISINT
118. **Mølnvik, Mona J.; Brunsvold, Amy.** FME Norwegian CCS Research Centre: Consortium Days 2017. Consortium Days 2017; 2017-11-28 - 2017-11-29. ENERGISINT
119. **Mølnvik, Mona J.; Brunsvold, Amy.** Norwegian CCS Research Centre: Industry-led innovation for fast-track CCS deployment. CLIMIT Summit; 2017-03-07 - 2017-03-07. ENERGISINT
120. **Møyner, Olav; Nilsen, Halvor Møll.** Multiresolution Coupled Compositional Vertical Equilibrium Model for Fast Flexible Simulation of CO2 Storage. Interpore 10th Annual Meeting and Jubilee; 2018-05-14 - 2018-05-17 SINTEF
121. **nakken, lise; Løvlie, Karoline; Mulrooney, Mark Joseph; Senger, Kim; Schaaf, Niklas; Skurtveit, Elin.** Fracture characterization of the Agardhfjellet Formation in central Spitsbergen: insights from drill core and outcrop data. The 34th Nordic Geological Winter Meeting; 2020-01-08 - 2020-01-10. NGI UiO UNIS
122. **Neumann, Tobias; Herrig, Stefan; Span, Roland.** A New Fundamental Equation of State for the Binary Mixture of Carbon Dioxide and Argon. Twentieth symposium on thermophysical properties; 2018-06-24 - 2018-06-29 NTNU
123. **Neumann, Tobias; Thol, Monika; Bell, Ian H.; Lemmon, Eric W.; Span, Roland.** Helmholtz-energy equations of state for CCS-relevant binary mixtures containing ammonia. ATCP 2019: The 12th Asian Thermophysical Properties Conference 2019; 2019-10-02 - 2019-10-06 NTNU
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125. **Opedal, Nils van der Tuuk; Cerasi, Pierre; Vrålstad, Torbjørn.** CEMENT BOND STRENGTH MEASUREMENTS. ASME 2019 38th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2019; 2019-06-09 - 2019-06-14. SINTEF
126. **Osmond, Johnathon L.** Addressing across-fault and top seal potential for CCS in Viking Group sandstones of the Horda Platform. NCCS Webinar; 2019-10-09 - 2019-10-09 UiO
127. **Osmond, Johnathon L.** Addressing top and across-fault juxtaposition seal potential for CCS in Viking Group sandstones of the Horda Platform. UiO Department of Geosciences Basement Talk; 2019-11-01 - 2019-11-01 UiO
128. **Osmond, Johnathon L.** Characterization of overburden faults and features above the Alpha CO2 storage prospect, Smeaheia area, northern North Sea. UiO Department of Geosciences Basement Talk; 2018-01-22 - 2018-01-22. UiO
129. **Osmond, Johnathon L.** Characterization of overburden faults and features above the Alpha CO2 storage prospect, Smeaheia area, northern North Sea. NCCS Task 9 Update Meeting; 2018-02-14 - 2018-02-14. UiO
130. **Osmond, Johnathon L.** Current perspectives on structural derisking the Smeaheia area for full-scale geological CO2 storage. NCCS Fault Derisking Workshop; 2019-02-12 - 2019-02-13. UiO
131. **Osmond, Johnathon L.** Helping build the seismic network for Texas and a 3D structural model for the Fort Worth Basin as a backbone for induced seismicity research. UiO Department of Geosciences Basement Talk; 2019-01-25 - 2019-01-25. UiO
132. **Osmond, Johnathon L.** PhD progress update. NCCS Task 9 and FRISK Status Meeting; 2020-04-21 - 2020-04-21. UiO
133. **Osmond, Johnathon L.; Holden, Nora; Leon, Elias H.; Mulrooney, Mark Joseph; Skurtveit, Elin; Faleide, Jan Inge; Braathen, Alvar.** Top and lateral seal characterizations for CO2 storage in Jurassic saline aquifers of the Horda Platform. CGG Academia Day; 2021-01-12 - 2021-01-12 UiO
134. **Osmond, Johnathon L.; Holden, Nora; Mulrooney, Mark Joseph; Skurtveit, Elin; Faleide, Jan Inge; Braathen, Alvar.** Ongoing top and lateral seal characterizations for CO2 storage in the Horda Platform. UiO Department of

Geosciences Basement Talk; 2020-12-02 - 2020-12-02 NGI UiO
135. **Osmond, Johnathon L.; Leon, Elias H.; Mulrooney, Mark Joseph; Braathen, Alvar.** Quaternary pockmark distributions informed by 3D seismic interpretation above the Horda Platform, northern North Sea. Nordic Geological Winter Meeting; 2020-01-08 - 2020-01-10 UiO
136. **Osmond, Johnathon L.; Leon, Elias H.; Mulrooney, Mark Joseph; Braathen, Alvar.** Stacked Quaternary pockmark distributions above the Horda Platform, northern North Sea. UiO Department of Geosciences Basement Talk; 2020-04-16 - 2020-04-16. UiO
137. **Osmond, Johnathon L.; Leon, Elias H.; Mulrooney, Mark Joseph; Braathen, Alvar.** Stacked Quaternary pockmark distributions above the Horda Platform, northern North Sea. NCCS Outreach Meeting with UiB; 2020-08-13 - 2020-08-13. UiO
138. **Osmond, Johnathon L.; Meckel, Timothy A.** Trap and seal geohistory informed from integrated overburden interpretation, Texas inner shelf. Nordic Geological Winter Meeting; 2020-01-08 - 2020-01-10. UiO
139. **Osmond, Johnathon L.; Mulrooney, Mark Joseph.** First-pass modeling of the faults displacing the Sognefjord Formation within the Alpha CO2 storage prospect and Vette relay ramp areas / Interpretation of overburden horizons and faults, Smeaheia, northern North Sea. NCCS Task 9 Update Meeting; 2018-06-12 - 2018-06-12. UiO
140. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** Addressing across-fault and top seal potential for CCS in Viking Group sandstones of the Horda Platform. NCCS Consortium Days; 2019-10-22 - 2019-10-23. NGI UiO
141. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** Analogous Juxtaposition of Mixed Lithologies Against a Siliciclastic Hydrocarbon Reservoir and Proposed CO2 Storage Formation in the Norwegian North Sea. AAPG Annual Convention and Exhibition; 2019-05-19 - 2019-05-22. NGI UiO
142. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** Arrangement of top and across-fault seal intervals within the Horda Platform: implications towards CCS in Viking Group sandstones. Nordic Geological Winter Meeting; 2020-01-08 - 2020-01-10. NGI UiO
143. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** Comparison between two Late Jurassic CO2 storage prospects with respect to structural derisking, Smeaheia area, Norwegian North Sea. NGF Vinterkonferansen; 2019-01-07 - 2019-01-09 NGI UiO
144. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** Distribution of faulted Mesozoic and Tertiary seals for CCS in the Horda Platform, northern North Sea. 82nd EAGE Annual Conference & Exhibition Workshop; 2020-12-08 - 2020-12-08. NGI UiO
145. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** First-pass 3D geologic interpretation and structural modeling of the Alpha CO2 storage prospect in the Smeaheia area, Norwegian North Sea. NFiP Annual PhD Seminar; 2018-11-16 - 2018-11-16. UiO
146. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** Potential top and lateral seals for supplemental CO2 storage in Dunlin Group sandstones of the Tusse fault block, northern North Sea. Tectonic Studies Group Annual Meeting; 2021-01-05 - 2021-01-08. UiO
147. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** Top and lateral seal assessment for CCS in Dunlin Group sandstones within the Tusse fault block, Horda Platform. NGF Vinterkonferansen; 2021-01-06 - 2021-01-08. UiO
148. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** Top and lateral seal variation along the Horda Platform, northern North Sea: implications towards CO2 storage in Viking Gp sandstones. 21st Annual Houston Geoscience Student Expo; 2020-10-09 - 2020-10-09. NGI UiO
149. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Braathen, Alvar.** 3D geologic framework and structural derisking of two offshore CO2 storage prospects in the Smeaheia area, Norwegian North Sea. CLIMIT PhD and Postdoc Seminar; 2019-01-18 - 2019-01-18. NGI UiO
150. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Faleide, Jan Inge; Braathen, Alvar.** Horda Platform geology and CCS research discussion. NCCS Outreach Meeting with Equinor ASA; 2020-09-22 - 2020-09-22. NGI UiO
151. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Faleide, Jan Inge; Braathen, Alvar.** Horda Platform geology and CCS research discussion. NCCS Outreach Meeting with SINTEF; 2020-02-11 - 2020-02-11. NGI UiO
152. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Faleide, Jan Inge; Braathen, Alvar.** Horda Platform geology and CCS research discussion.

NCCS Outreach Meeting with NPD; 2020-09-09 - 2020-09-09. NGI UiO

153. **Osmond, Johnathon L.; Mulrooney, Mark Joseph; Skurtveit, Elin; Faleide, Jan Inge; Braathen, Alvar.** Ongoing top and lateral seal characterizations for CO2 storage in the Horda Platform. Norwegian CCS Research Centre Consortium Days; 2020-11-04 - 2020-11-05. NGI UiO
154. **Ottøy, Sindre; Stang, Hans Georg Jacob; Neumann, Tobias; Løvseth, Sigurd Weidemann; Jakobsen, Jana Poplsteinova.** VLE Measurements and Verification of a state-of-the-art Helmholtz Energy Equation of State for the Ternary Mixture of CO2-N2-CH4. TCCS-10, Trondheim CCS Conference; 2019-06-17 - 2019-06-19. ENERGISINT NTNU
155. **Peters, Thijs.** Membrane-assisted CO2 capture through liquefaction for clean H2 production. NCCS Consortium Days 2019; 2019-10-22 - 2019-10-23. SINTEF
156. **Polfus, Jonathan M.; Yang, Jing; Tuller, Harry; Yildiz, Bilge; Bredesen, Rune.** Coadsorption of H2O and CO2 on BaZrO3-based proton-conducting electrolytes. International Conference on Inorganic Membranes; 2018-06-18 - 2018-06-22. SINTEF
157. **Polfus, Jonathan M.; Yang, Jing; Tuller, Harry; Yildiz, Bilge; Bredesen, Rune.** Interplay between H2O/CO2 coadsorption and space-charge on Y-doped BaZrO3 surfaces. Workshop on Ion conducting ceramic electrochemical devices: how interfaces and surfaces affect performance and lifetime; 2018-04-19 - 2018-04-20. SINTEF
158. **Raynaud, Xavier; Ahmed, Elyes.** Development of Simulation Tools for Near-Well Injectivity. NCCS Webinar; 2020-04-02 - 2020-04-02. SINTEF
159. **Raynaud, Xavier; McNeece, Colin.** Newton strategies for simulations of implicit coupled transport and chemistry. Advances in simulation of reactive flow and transport in porous media; 2019-12-02 - 2019-12-02. NTNU
160. **Raynaud, Xavier; Nilsen, Halvor Møll; Hesse, Marc; McNeece, Colin.** Robust chemical solver for fully-implicit simulations. European Conference on the Mathematics of Oil Recovery; 2018-09-03 - 2018-09-06. NTNU SINTEF
161. **Riboldi, Luca; Anantharaman, Rahul.** Exploring the potential of PSA-Liquefaction process for post-combustion CO2 capture. NCCS Consortium Days 2019; 2019-10-22 - 2019-10-23. ENERGISINT NTNU
162. **Riboldi, Luca; Anantharaman, Rahul.** On the potential of a hybrid PSA-liquefaction process for post-combustion CO2 capture. PCCC-5 5TH POST COMBUSTION CAPTURE CONFERENCE; 2019-09-17 - 2019-09-19 ENERGISINT NTNU
163. **Romdhane, Anouar; Dupuy, Bastien.** TOPHOLE kick-off meeting: SINTEF seismic and EM modelling tools. TOPHOLE kick-off meeting; 2019-10-21 - 2019-10-21. SINTEF
164. **Romdhane, Mohamed Anouar.** Tophole project meeting: EM and seismic modelling status. Tophole summer meeting; 2020-08-26 - 2020-08-26. SINTEF
165. **Rongved, Mats; Bauer, Andreas; Lavrov, Alexandre; Larsen, Idar; Lothe, Ane Elisabet; Cerasi, Pierre.** Along-fault permeability modelling with modified discrete element method(MDEM). CO2Geonet Open Forum; 2018-04-23 - 2018-04-25. NTNU SINTEF
166. **Rongved, Mats; Delbar, Anthony; Cerasi, Pierre; Bauer, Andreas.** Modelling leakage risk along a fault using modified discrete elements. GHGT-14; 2018-10-22 - 2018-10-25. NTNU SINTEF
167. **Roussanaly, Simon; Anantharaman, Rahul; Ouassou, Jabir Ali; Bjerkevedt, Vegard; Tomasgard, Asgeir.** Pitch NCCS Task 1: Design of CCS chain under uncertainties and fluctuations. NCCS Consortium day; 2019-10-22 - 2019-10-23. ENERGISINT NTNU
168. **Roussanaly, Simon; Deng, Han; Skaugen, Geir.** Toward the identification of optimal conditions for transport of CO2 by ship. NCCS Consortium day; 2019-10-22 - 2019-10-23 ENERGISINT
169. **Roussanaly, Simon; Deng, Han; Skaugen, Geir.** Toward the identification of optimal conditions for transport of CO2 by ship. TCCS-10 conference; 2019-06-17 - 2019-06-19 ENERGISINT
170. **Roussanaly, Simon; Ouassou, Jabir Ali; Anantharaman, Rahul.** Design of post-combustion CCS from a waste-to-energy plant under uncertainties and fluctuations. PCCC-5 conference; 2019-09-17 - 2019-09-19. ENERGISINT NTNU
171. **Roussanaly, Simon; Ouassou, Jabir Ali; Anantharaman, Rahul.** Design of post-combustion CCS from a waste-to-energy plant under uncertainties and fluctuations. NCCS Consortium day; 2019-10-22 - 2019-10-23. ENERGISINT NTNU
172. **Roussanaly, Simon; rahul, anantharaman; chao, fu; Arvind, Rajendran; Sai Gokul, subraveti; luca, riboldi.** Low-Carbon Footprint Hydrogen Production from Natural Gas:A Techno-Economic Analysis of Carbon Capture and Storage from Steam-Methane Reforming. 23rd PRES Conference; 2020-08-17 - 2020-08-21. ENERGISINT
173. **Sai Gokul, subraveti; Roussanaly, Simon; rahul, anantharaman; luca, riboldi; Arvind, Rajendran.** Technoeconomic assessment of optimized adsorption processes for post-combustion CO2 capture in hydrogen plants. AiCHE; 2020-11-16 - 2020-11-21. ENERGISINT

174. **Skurtveit, Elin; Bjørnarå, Tore Ingvald; Bohloli, Bahman; Soldal, Magnus; Eidsvig, Unni; Gasda, Sarah; Keilegavlen, Eirik; Torabi, Anita; Braathen, Alvar.** Dynamic changes in fault permeability – How can experimental work provide support for fault seal integrity?. Nordic Geological Winter Meeting 2020; 2020-01-08 - 2020-01-10 NGI NORCE UiB UiO
175. **Skurtveit, Elin; Bjørnarå, Tore Ingvald; Bohloli, Bahman; Soldal, Magnus; Eidsvig, Unni; Gasda, Sarah; Keilegavlen, Eirik; Torabi, Anita; Braathen, Alvar; Sandve, Tor Harald.** Dynamic changes in fault permeability How can experimental work provide support for fault seal integrity?. 4th International Workshop on Offshore Geologic CO2 Storage; 2020-02-11 - 2020-02-12 NGI NORCE UiB UiO
176. **Skurtveit, Elin; Bjørnarå, Tore Ingvald; Wu, Long.** Maturing Smeaheia and the need for along fault flow risking. NCCS Consortium days 2020; 2020-11-04 - 2020-11-05. NGI UiO
177. **Skurtveit, Elin; Choi, Jung Chan; Mulrooney, Mark; Osmond, Johnathon Lee; Braathen, Alvar.** 3D fault integrity screening for Smeaheia CO2 injection site. GHGT-14. International Conference on Greenhouse Gas Control Technologies; 2018-10-21 - 2018-10-26. NGI UiO
178. **Skurtveit, Elin; Choi, Jung Chan; Osmond, Johnathon Lee; Mulrooney, Mark Joseph; Braathen, Alvar.** 3D fault integrity screening for Smeaheia CO2 injection site. NCCS Webinar (results from task 9, Structural derisking); 2018-10-17 - 2018-10-17. NGI UiO
179. **Skurtveit, Elin; Mulrooney, Mark; Osmond, Johnathon Lee; Choi, Jung Chan; Braathen, Alvar.** Structural derisking for Smeaheia - Improved fault characterization workflow. 3rd International Workshop on Offshore Geologic CO2 Storage May 3 - 4, 2018. Research Council of Norway Oslo, Norway; 2018-05-03 - 2018-05-04. NGI UiO
180. **Soldal, Magnus; Skurtveit, Elin; Bohloli, Bahman; Wilkinson, Heidi; Choi, Jung Chan; Griffiths, Luke; Smith, Halvard**. Experimental and analytical assessment of Draupne shale seal integrity for CO2 storage sites. DECOVALEX 2019 Symposium on Coupled Processes in Radioactive Waste Disposal and Subsurface Engineering Applications; 2019-11-04 - 2019-11-05. NGI UiO
181. **Stroisz, Anna Magdalena; Gawel, Kamila; Bjørge, Ruben; Cerasi, Pierre.** Tensile strength of cement to shale interface. 53rd US Rock Mechanics/Geomechanics Symposium; 2019-06-23 - 2019-06-26. SINTEF
182. **Størset, Sigmund Østtveit; Tangen, Grethe.** Profiting from CCS innovations: A study to measure potential value creation from CCS research and development. GHGT 14; 2018-10-22 - 2018-10-25. ENERGISINT SINTEF
183. **Taghipour, Ali.** TOPHOLE kick-off meeting: drilling and wells. TOPHOLE kick-off meeting; 2019-10-21 - 2019-10-21. SINTEF
184. **Todorovic, Jelena; Raphaug, Martin Hagen; Øia, Thomas; Grimstad, Alv-Arne; Cerasi, Pierre.** The effect of brine supply on CO2 injectivity impairment due to salt precipitation. GHGT-14; 2018-10-22 - 2018-10-25. SINTEF
185. **Torsæter, Malin.** CCS in Norway and research in FME NCCS. UiO CCS course; 2018-06-05 - 2018-06-05. SINTEF
186. **Torsæter, Malin.** CO2 Well Integrity Challenges and Relevant New Technology/materials. CCS Miniseminar for OD og PTIL; 2018-08-30. SINTEF
187. **Torsæter, Malin.** Effect of Intermittent CO2 injection on Well Integrity and Injectivity. IEAGHG-EERC Modelling and Risk Management Network Meeting 2018; 2018-06-18 - 2018-06-22. SINTEF
188. **Torsæter, Malin.** FME NCCS som plattform for CCS FoU porteføljeutvikling. Møte i CLIMIT Programstyre; 2018-10-17. SINTEF
189. **Torsæter, Malin.** New technology for handling legacy well integrity issues. 3rd International Workshop on Offsohre Geologic CO2 storage; 2018-05-03 - 2018-05-04 SINTEF
190. **Torsæter, Malin.** R&D COLLABORATION PROJECTS ON WELL INTEGRITY. US-Norway collaboration on CCS/CCUS; 2018-05-02 - 2018-05-02. SINTEF
191. **Torsæter, Malin.** Safe length of cement Barriers in CO2 wells. NCCS Consortium Days; 2017-11-28 - 2017-11-29 SINTEF
192. **Torsæter, Malin.** Update from Mission Innovation. NCCS Consortium Days; 2017-11-28 - 2017-11-29. SINTEF
193. **Torsæter, Malin.** WELLBORE INTEGRITY. IEAGHG Summer School; 2018-06-24 - 2018-06-29. SINTEF
194. **Torsæter, Malin; Opedal, Nils van der Tuuk; Todorovic, Jelena; Lavrov, Alexandre.** The importance of drilling-induced damage for well integrity. NCCS Consortium Days; 2017-11-28 - 2017-11-29. SINTEF
195. **Vevelstad, Solrun Johanne; Grimstvedt, Andreas Magnar.** Lessons Learned Solvent Stability. Webinar; 2018-10-17 - 2019-10-17. SINTEF
196. **Vevelstad, Solrun Johanne; Grimstvedt, Andreas Magnar.** MEA degradation. Consortium dagene NCCS; 2019-10-22 - 2019-10-23. SINTEF
197. **Vevelstad, Solrun Johanne; Grimstvedt, Andreas Magnar; Kim, Inna; Knuutila, Hanna K.** Systematic work on solvent deradation - importance and challenges. Consortium dager; 2017-03-16 - 2017-03-17. SINTEF NTNU

198. **Weber, Viktor.** Liability regulation for CCS storage sites in Norway - A potential model for EU Member States. Energy Transitions 2020; 2020-02-27 - 2020-02-28. UiO
199. **Weber, Viktor.** The harmonisation or unification of interpretation - A case study of European cabon capture and storage. Harmonisation in Environmental and Energy Law; 2019-03-28 - 2019-03-29. UiO
200. **Weber, Viktor.** The legal framework of CO2 shipping for CCS in Norwegian waters. 2019 NCCS Consortium; 2019-10-23. UiO
201. **Weber, Viktor.** The liability aspects of CCS – Storage and shipping. Outside the BoCCS seminar; 2019-11-14. UiO
202. **Weber, Viktor.** The liability aspects of CCS – Storage and shipping. UiO:Energy Forum 2019; 2019-11-28. UiO
203. **Würtzen, Camilla Louise; Nystuen, Johan Petter; Müller, Reidar; Faleide, J. I.; Midtkandal, Ivar.** Basin Fill Dynamics of the Triassic Alluvial Succession on the Horda Platform, Northern North Sea. 34th Nordic Geological Winter Meeting; 2020-01-10. UiO
204. **Zonetti, Simone.** EM modelling for well detection and monitoring. Tophole annual meeting; 2020-11-03 - 2020-11-03. SINTEF
205. **Zonetti, Simone.** Tophole project meeting: electro-magnetic simulations with COMSOL Multiphysics. Tophole summer meeting; 2020-08-26 - 2020-08-26. SINTEF

Peer Reviewed Papers

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

1. **Banet, Catherine.** Regulating the Reuse and Repurposing of Oil and Gas Installations in the Context of Decommissioning: Creating Incentives and Enabling Energy System Integration. I: *The Regulation of Decommissioning, Abandonment and Reuse Initiatives in the Oil and Gas Industry: From Obligation to Opportunities*. Wolters Kluwer 2020 ISBN 9789403506937. p. 205-227. UiO
2. **Dupuy, Bastien; Romdhane, Anouar; Eliasson, Peder; Yan, Hong; Torres Caceres, Veronica Alejandra; Querendez, Etor; Ghaderi, Amir.** Carbon Dioxide Saturation Estimates at Sleipner Using Seismic Imaging and Rock Physics Inversion. I: *EAGE/SEG Research Workshop 2017 on Geophysical Monitoring of CO2 Injection: CCS and CO2-EOR*. European Association of Geoscientists and Engineers 2017 ISBN 9781510850781. p. 122-126. NTNU SINTEF
3. **Gruben, Gaute; Dumoulin, Stephane; Nordhagen, Håkon Ottar; Hammer, Morten; Munkejord, Svend Tollak.** Calibration of Pipeline Steel Model for Computational Running Ductile Fracture Assessment. I: *The 29th International Ocean and Polar Engineering Conference*. International Society of Offshore & Polar Engineers 2019 ISBN 978-1-880653-85-2. ENERGISINT SINTEF
4. **Gruben, Gaute; Dumoulin, Stephane; Nordhagen, Håkon Ottar; Hammer, Morten; Munkejord, Svend Tollak.** Simulation of a Full-Scale CO2 Fracture Propagation Test. I: *2018 12th International Pipeline Conference - IPC2018*. ASME Press 2018 ISBN 978-0-7918-5188-3. p. - ENERGISINT SINTEF
5. **Gruben, Gaute; Macdonald, Kenneth Alasdair; Munkejord, Svend Tollak; Skarsvåg, Hans Langva; Dumoulin, Stephane.** Pipeline fracture control concepts for Norwegian offshore carbon capture and storage. I: *Proceedings of the 2020 13th international pipeline conference : Volume 3: Operations monitoring and maintenance : Materials and joining : Virtual Online. September 28–30, 2020.* The American Society of Mechanical Engineers (ASME) 2020 ISBN 9780791884461. p. - ENERGISINT SINTEF UIS
6. **Gruber, Andrea.** Direct numerical simulation: Present and future role in fundamental and applied combustion research. I: *AIAA Scitech 2019 Forum*. American Institute of Aeronautics and Astronautics (AIAA) 2019 ISBN 978-1-62410-578-4. ENERGISINT NTNU
7. **Kim, Donghoi; Berstad, David Olsson; Anantharaman, Rahul; Straus, Julian; Peters, Thijs; Gundersen, Truls.** Low Temperature Applications for CO2 Capture in Hydrogen Production. I: *Proceedings of the 30th European Symposium on Computer Aided Process Engineering.* Elsevier 2020 ISBN 9780128233771. p. 445-450. ENERGISINT NTNU SINTEF
8. **Stroisz, Anna Magdalena; Gawel, Kamila; Bjørge, Ruben; Cerasi, Pierre.** Tensile strength of cement to shale interface. I: *Proceeding of 53th US Rock Mechanics / Geomechanics Symposium.* American Rock Mechanics Association (ARMA) 2019 ISBN 978-1-5108-9406-8. p. - SINTEF
9. **Subagjo, Isa Adi; Dupuy, Bastien; Park, Joonsang; Romdhane, Mohamed Anouar; Querendez, Etor; Stovas, Alexey.** Joint Rock Physics Inversion of Seismic and Electromagnetic Data for CO2 Monitoring at Sleipner. I: *Proceedings 24th European Meeting of Environmental and Engineering Geophysics.* European Association of Geoscientists and Engineers (EAGE) 2018 ISBN 9789462822634. p. - NGI NTNU SINTEF

Multimedia products

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

1. **Anell, Ingrid Margareta.** CO2 Storage Demonstration. YouTube 2020. UiO
2. **Berstad, David Olsson.** Low Temperature rig. SINTEF Energi 2019. ENERGISINT
3. **Brunsvold, Amy.** IEAGHG International CCS Summer School - NCCS. SINTEF Energi 2018. ENERGISINT
4. **Munkejord, Svend Tollak.** Trykkavlastning av CO2. SINTEF Energi 2019. ENERGISINT
5. **Mølnvik, Mona J.** Effektstudien NCCS. SINTEF Energi 2019 ENERGISINT
6. **Mølnvik, Mona J.** IEAGHG International CCS Summer School - Luis Vargas-avila. SINTEF Energi 2018 ENERGISINT
7. **Mølnvik, Mona J.** IEAGHG International Summer School - Tim Dixon. SINTEF Energi 2018. ENERGISINT
8. **Mølnvik, Mona J.** Kloden har feber. SINTEF Energi 2019 ENERGISINT
9. **Mølnvik, Mona J.** Mona jager klima-djevelen. Teknologihovedstaden Trondheim Youtube 2020 ENERGISINT
10. **Mølnvik, Mona J.** NCCS Annual Report 2017. SINTEF Energi 2018. ENERGISINT
11. **Mølnvik, Mona J.** NCCS annual report 2018. SINTEF Energi 2019. ENERGISINT
12. **Mølnvik, Mona J.** NCCS Annual report 2019. SINTEF Energi 2020. ENERGISINT
13. **Mølnvik, Mona J.** NCCS at GHGT-14: Nobody can do CCS on their own. SINTEF Energi 2018. ENERGISINT
14. **Mølnvik, Mona J.** Realising CCS - NCCS. SINTEF Energi 2019. ENERGISINT
15. **Mølnvik, Mona J.** Summary: IEAGHG International CCS Summer School 2018. SINTEF Energi 2018. ENERGISINT
16. **Mølnvik, Mona J.** TCCS Keynot 7, Mona Mølnvik. SINTEF Energi - TCCS-10 2019. ENERGISINT
17. **Mølnvik, Mona J.** What is CCS and what are the final steps to deploying it globally?. SINTEF Energi 2019. ENERGISINT
18. **Røkke, Nils Anders.** Annonsørinnhold: Kan gass og hydrogen være en del av klimaløsningen?. enerWe 2019 ENERGISINT
19. **Røkke, Nils Anders.** #arendalsuka: Slik kan Norge bli Europas batteri. SINTEF Energi 2018. ENERGISINT
20. **Røkke, Nils Anders.** #CCS - Kan gass og hydrogen være en del av klimaløsningen?. enerWe 2019. ENERGISINT
21. **Røkke, Nils Anders.** CCS fra hot til not til hot igjen. SINTEF Energi Facebook 2017. ENERGISINT
22. **Røkke, Nils Anders.** COP24 - Nils Røkke John Podesta Fredric Hauge. SINTEF Energi Facebook 2018 ENERGISINT
23. **Røkke, Nils Anders.** CO2 lager - kommentar fra Nils Røkke. SINTEF Energi 2020. ENERGISINT
24. **Røkke, Nils Anders.** Derfor er CO2-lagring en sikker løsning. SINTEF Energi AS 2020. ENERGISINT
25. **Røkke, Nils Anders.** How CO2 Can Help The Climate. SINTEF Energi 2020. ENERGISINT
26. **Røkke, Nils Anders.** Langskip - Bærekraftsdirektør Nils Røkke kommenterer. SINTEF Energi 2020. ENERGISINT
27. **Røkke, Nils Anders.** Nils Røkke GHGT-14. SINTEF Energi 2018. ENERGISINT
28. **Røkke, Nils Anders.** Reaching climate goals is a social responsibility. SINTEF Energi 2019. ENERGISINT
29. **Røkke, Nils Anders.** SINTEF and NTNU CCS Award. SINTEF Energi 2019. ENERGISINT
30. **Røkke, Nils Anders.** Talking Hydrogen at the Heart of Europe. SINTEF Energi 2020. ENERGISINT
31. **Røkke, Nils Anders.** TCCS Welcome - Nils Røkke. SINTEF Energi - TCCS-10 2019. ENERGISINT
32. **Røkke, Nils Anders.** TCCS-10: Nobody can reach climate goals on their own. SINTEF Energi 2019. ENERGISINT
33. **Størset, Sigmund Østtveit.** SINTEF sommerforsker 2018: Elise Otnes. SINTEF Energi 2018. ENERGISINT
34. **Størset, Sigmund Østtveit.** TCCS Pitch 1 - Sigmun Størset. SINTEF Energi - TCCS-10 2019. ENERGISINT

Op-eds

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

1. **Gruben, Gaute; Nordhagen, Håkon Ottar; Munkejord, Svend Tollak.** Slik tøyles CO2 i rør. *Dagens næringsliv* 2018 ENERGISINT SINTEF
2. **Mølnvik, Mona J.** Det store skiftet kommer. *Klassekampen* 2019. ENERGISINT
3. **Mølnvik, Mona J.** Hva gjør vi med klimakrisen etter koronakrisen?. *Aftenposten (morgenutg. : trykt utg.)* 2020 ENERGISINT
4. **Nekså, Petter; Berstad, David Olsson; Størset, Sigmund Østtveit.** Fossil lhjelp til grønt skifte. *Dagens næringsliv* 2018. ENERGISINT
5. **Røkke, Nils Anders.** EU Green Investment Classification Is Necessary But Needs Improvement. *Forbes* 2020 ENERGISINT

6. **Røkke, Nils Anders.** Hydrogen av naturgass kan sikre Europa ren energi og Norge inntekter. *Teknisk Ukeblad* 2019. ENERGISINT
7. **Røkke, Nils Anders.** Kan bli en stor næring for Norge. *Dagbladet* 2019. ENERGISINT
8. **Røkke, Nils Anders.** La CO2-jegerne gjøre gassen utslippsfri. *Klassekampen* 2019. ENERGISINT
9. **Røkke, Nils Anders.** Må få på plass CO2 håndtering. *Dagens næringsliv* 2018. ENERGISINT
10. **Røkke, Nils Anders.** Norway To Build $3 Billion 'Longship' Carbon Dioxide Capture Project. *Forbes* 2020 ENERGISINT
11. **Røkke, Nils Anders.** Norwegian scientist: 'No way' of reaching climate neutrality without hydrogen. *EurActiv* 2019. ENERGISINT
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Financial statement

Costs	NOK
Personnel and indirect costs	22 528 987
Purchased R&D services	43 241 620
Other operational costs	2 829 234
Total costs	68 599 841

Funding	NOK
Own Funding	6 051 725
Other public funding	10 705 947
Other private funding	24 763 837
International unding	2 078 332
RCN funding	25 000 000
Total Funding	68 599 841

Personnel

Master degrees

Name	Sex M/F	Topic	Task	Year
Avinash S.R. Subramanian	M	Reducing Energy Consumption in the Production of Hydrogen from Natural Gas	6	2017
Hong Yan	F	Rock physics inversion for CO2 characterization at Sleipner	12	2017
Isabella Stellwag	F	Testing of Oxygen Removal technology	2	2017
Niklas Hunka	M	Description of accurate viscosity setup for CCS	8	2017
Veronica Alejandra Torres Caceres	F	Seismic Wave Attenuation in Partially Saturated Sandstone and AVO Analysis for Carbon Dioxide Quantification at Sleipner	12	2017
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
Morten Heide Feiring	M	Legal aspects of CO2 storage	1	2018
Robin David Kifle	M	Geophysical data sensitivity in Smeaheia field	12	2018
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
Heidi Sydnes Egeland	F	CCS under the EU ETS: Legal consequences of the CO2 shipping option	1	2019
Jens Kolnes	M	Reconstruction of the uplift and subsidence history of Smeaheia, a proposed CO2 injection and storage site	9	2019
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
Scott Bunting	M	Value of information analysis in the context of leakage detection in CO2 storage	12	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
Sindre Ottøy	M	Investigation of CO2-N2-CH4 mixture: VLE measurements and analysis of Helmholtz energy-based EOS	8	2019

Name	Sex M/F	Topic	Task	Year
Tonje Laukvik	F	Quantification of nitrogen loss in oxidative degradation experimants using total nitrogen analyser	2	2019
Ådne Bjerkeli	M	A detailed structural analysis of the Øygarden Fault and footwall bock. Implications for CCS in the Smeaheia prospect	9	2019
Helge Nipen	M	Tectonostratigraphic study in the triassic, Smeaheia	9	2020
Karoline Helene Løvlie	F	A structural analysis of the upper Agardhfjellet Formation aiming to understand the cap rock properties for CO2-sequestration purposes	9	2020
Lise Nakken	F	A caprock integrity evaluation of the lower Agarhdfjellet Formation for CO2 sequestration purposes	9	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
Shajahat Ahmed	M	Structural analysis of Horda Platform and Stord Basin in the Norwegian North Sea using Machine Learning method	9	2020
Scott Adam Smith	M	Effects of fractures on seismic velocities in fault zones	12	2020
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

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)
Mats Rongved	KPN project	Norwegian	08/2015 - 03/2018	M	Hydraulic fracturing for enhanced geothermal systems	10	
Mohammad Masoudi	KPN Porepac	Iran	09/2018-08/2021	M	Modeling nucleation reactions	10	
Seyed Ehsan Hosseini	KPN TOP-HOLE	Iran	02/2020-02/2023	M	Innovative geophysical and AI approaches to monitor plugged and abandoned wells	12	
Hanbo Chen	KPN EM4CO2	China	09/2020-09/2023	M	Accelerating CSEM technology for efficient and quantitative CO2 monitoring	12	

PhD students with financial support from the Centre budget

Name	Nationality	Period	Sex M/F	Topic	Task	Completetd (X)
Stefan Herrig	German	06/2017 - 07/2018	M	New Helmholtz-energy models for pure fluids and CCS-relevant mixtures	8	X
Johnathon Osmond	USA	10/2017 - 09/2021	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	
Vegard Bjerketvedt	Norway	11/2017-04/2021	M	Optimisation of CO2 transport value chain	1	

Name	Nationality	Period	Sex M/F	Topic	Task	Completetd (X)
Peter Betlem	Dutch	03/2019-03/2023	M	Geological and geophysical analysis of overburden for CO2 storage sites	9	
Magnus Soldal	Norway	06/2019-07/2022	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	
Eirik Æsøy	Norway	03/2018 - 03/2022	M	Gas turbine combustion instabilities for H2/CH4 blends	5	
Lucas Braakhuis	Netherlands	10/2019-10/2022	M	Solvent degradation - environmental aspects	2	
Marcin Duda	Poland	01/2018-02/2021	M	Overburden pore pressure changes due to fluid injection	10	
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	
Bahereh Khosravi	Iran	12/2018-11/2021	F	Viscosity and density measurements of CO2 and CO2-rich mixtures at conditions relevant for CCS	8	
Camilla Louise Würtzen	Denmark	10/2018-09/2021	F	Tectonostratigraphic analysis of CO2 storage reservoirs in the Upper Triassic alluvial Lunde Formation in the Smeaheia area, Norwegian North Sea	9	
Olaf Lehn Tranås	Norway	09/2020-08/2023	M	Energy carrier integration, sector coupling and carbon capture and storage. Modeling low carbon	1	
Tarik Yahou	Algerie	10/2020-10/2023	M	Combustion dynamics in hydrogen rich combustion	5	
Vanja Buvik	Norway	10/2017-10/2021	F	Amine structure relationship to degradation and corrosion	2	
Tobias Neumann	Germany	01/2017-12/2021	M	Improved description of minor components relevant for the transport of CO2-rich mixtures including	8	

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	"201907-202004 (100%) 05/2020-07/2020 (20%)"	M	Modeling of hybrid processes (H2 production and CO2 liquefaction)	3	
Emma Michie Haines	UK	202002-202301??	F	Structural geology	9	
Zhongxuan Liu	China	06/2020-06/2021	F	Modeling of hybrid processes (H2 production and CO2 liquefaction)	3	

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	
Mark Mulrooney	Irland	09/2017 - 09/2021	M	Structural analysis and geomodel for fault modelling	9	
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	
Viktor Weber	Hungary	08/2018- 08/2021	M	Legal aspects of CO_2 transport and storage with a focus on liabilities	1	
Barbara Re	Switzerland	01/2018- 12/2019	F	Large-scale transient behaviour of CO_2-transport pipelines	7	x
Jose Aguilar	Mexican	08/2018- 07/2020	M	Gas turbine combustion instabilities for H_2/CH_4 blends	5	

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
Simon Roussanaly	SINTEF Energy Research	CO_2 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	CO_2 capture process integration and design	1
Luca Riboldi	SINTEF Energy Research	CO_2 capture process integration and design	1
Asgeir Tomasgard	NTNU	Industrial economics	1
Ozgu Turgut	NTNU	Industrial economics	1
Vegard Bjerketvedt	NTNU	Industrial economics	1
Ruud Egging	NTNU	Industrial economics	1
Olaf Lehn Tranås	NTNU	Industrial economics	1
Catherine Banet	UiO	Legal	1
Viktor Weber	UiO	Legal	1
Heidi Sydnes Egeland	UiO	Legal	1
Sai Gokul Subraveti	University of Alberta	Adsorption-based capture	1
Arvind Rajendran	University of Alberta	Adsorption-based capture	1
Solrun Johanne Vevelstad	SINTEF Industry	Post combustion CO_2 capture	2
Andreas Grimstvedt	SINTEF Industry	Post combustion CO_2 capture	2
Merete Wiig	SINTEF Industry	Post combustion CO_2 capture	2
Inna Kim	SINTEF Industry	Post combustion CO_2 capture	2

Name	Institution	Main research area	Task
Aslak Einbu	SINTEF Industry	Post combustion CO2 capture	2
Geir Haugen	SINTEF Industry	Post combustion CO2 capture	2
Hanna Knuutila	NTNU	Post combustion CO2 capture	2
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
Jonathan Polfus	SINTEF Industry	Ceramic membranes	3
Laure Guironnet	SINTEF Industry	Ceramic membranes	3
Elena Stefan	SINTEF Industry	Ceramic membranes	3
Einar Vøllestad	SINTEF Industry	Ceramic membranes	3
Vidar Skjervold	SINTEF Energy Research	Membrane modelling	3
Luca Riboldi	SINTEF Energy Research	Membrane modelling	3
Harald Malerød-Fjeld	CoorsTek Membrane Sciences	Ceramic Membranes	3
David Berstad	SINTEF Energy Research	CO2 liquefaction	4
Stian Trædal	SINTEF Energy Research	CO2 liquefaction	4
Jacob Stang	SINTEF Energy Research	CO2 liquefaction	4
Andrea Gruber	SINTEF	Numerical modelling of reactive flows	5
Gonzalo del Alamo	SINTEF	Chemical kinetics modelling	5
James R Dawson	NTNU	Experimental combustion dynamics	5
Nicholas Worth	NTNU	Experimental combustion dynamics	5
Rubén M. Montañés	SINTEF Energy Research	CO2 Capture Process modelling and inte-gration	6
Rahul Anantharaman	SINTEF Energy Research	CO2 capture process integration and design	6
Donghoi Kim	SINTEF Energy Research	Process Modeling	6
Chao Fu	SINTEF Energy Research	Process modelling and integration	6
Vidar Skjervold	SINTEF Energy Research	Process modelling	6
Kristin Jordal	SINTEF Energy Research	CO2 capture process integration and design	6
Svend Tollak Munkejord	SINTEF Energy Research	CO2 transport	7
Stéphane Dumoulin	SINTEF Industry	CO2 transport	7
Gaute Gruben	SINTEF Industry	CO2 transport	7
Morten Hammer	SINTEF Energy Research	CO2 transport	7
Han Deng	SINTEF Energy Research	CO2 transport	7
Sigurd Weidemann Løvseth	SINTEF Energy Research	CO2 Thermodynamics / Fiscal metering	8
Snorre Foss Westman	SINTEF Energy Research	CO2 Thermodynamics	8
Jacob Stang	SINTEF Energy Research	CO2 Thermodynamics / Fiscal metering	8
Han Deng	SINTEF Energy Research	CO2 Fiscal metering	8
Roland Span	Ruhr Universität-Bochum	CO2 Thermodynamics	8
Stefan Herrig	Ruhr Universität-Bochum	CO2 Thermodynamics	8
Tobias Neumann	Ruhr Universität-Bochum	CO2 Thermodynamics	8

Name	Institution	Main research area	Task
Edward Jukes	Krohne Ltd	CO2 Fiscal metering	8
Alvar Braathen	UiO	Structural geology	9
Elin Skurtveit	NGI/UiO	Structural geology	9
Jung Chan Choi	NGI	Geomechanics	9
Bahman Bohloli	NGI	Rock mechanics	9
Jan Inge Faleide	UiO	Geophysics	9
Nazmul Haag Mondol	UiO	Rock physics	9
Ivar Midtkandal	UiO	Geology	9
Ingrid Anell	UiO	Geology	9
Anja Sundal	UiO	Geology	9
Kim Senger	UNIS	Structural geology	9
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
Christian Simon	SINTEF Industry	CO2 storage	11
Christian Bos	TNO	CO2 storage	11
Filp Neele	TNO	CO2 storage	11
Daniel Loeve	TNO	CO2 Storage	11
Øystein Klemetsdal	SINTEF Digital	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
Cathrine Ringstad	SINTEF Industry	CO2 monitoring	12
Odd Andersen	SINTEF Digital	CO2 monitoring	12
Francesca Watson	SINTEF Digital (Heriot Watt)	CO2 monitoring	12
Joonsang Park	NGI	CO2 monitoring	12
Guillaume Sauvin	NGI	CO2 monitoring	12
Jim White	BGS	CO2 monitoring	12
Hayley Vosper	BGS	CO2 monitoring	12
Gareth Williams	BGS	CO2 monitoring	12
Ola Eiken	Quad Geometrics	CO2 monitoring	12

Name	Institution	Main research area	Task
Jan Petter Morten	EMGS	CO2 monitoring	12
Astrid Kornberg Bjørke	EMGS	CO2 monitoring	12
Halvor Møll Nilsen	SINTEF Digital	CO2 monitoring	11, 12
Anders Austegard	SINTEF Energy Research	CO2 Thermodynamics / Fiscal metering / transport	7 & 8
Pierre Cerasi	SINTEF Industry	Geomechanics, leakage de-risking	9, 10
Tore Ingvald Bjørnarå	NGI	Flow modelling	9/FRISK
Sigmund Ø. Størset	SINTEF Energy Research	CO2 capture and process integration, innovation management	ITT
Grethe Tangen	SINTEF Industry	CO2 storage	ITT
Jon Magne Johansen	SINTEF Energy Research	Innovation management	ITT

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NCCS is a Centre for Environment-friendly Energy Research (FME). The objective of the FME-scheme is to establish time-limited research centres which conduct concentrated, focused and long-term research of high international calibre.

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