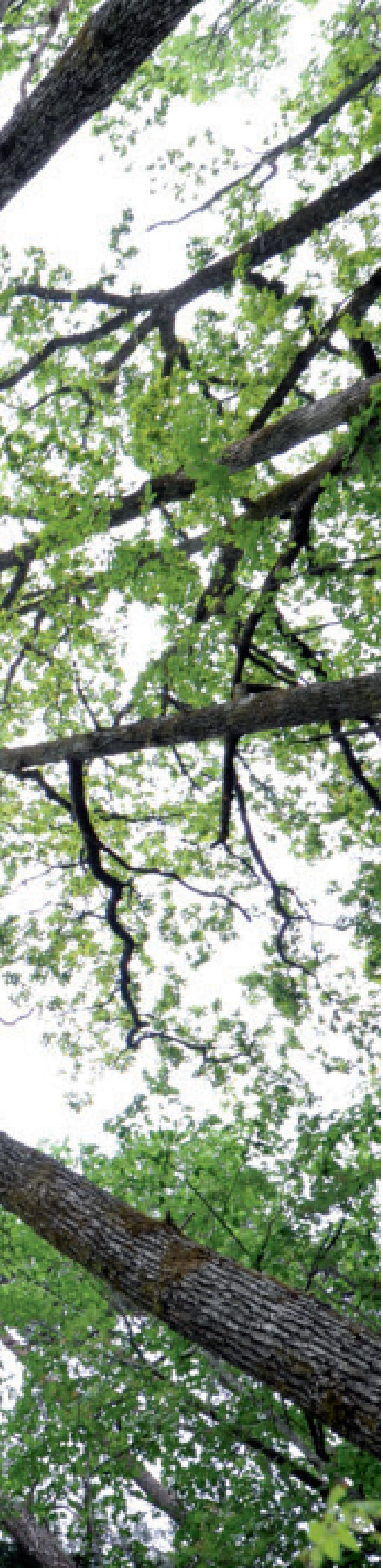
CLIMIT 2018

SUMMARY

THE NATIONAL PROGRAMME for research, development and demonstration of CO_2 Capture, Transport and Storage (CCS)



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CLIMIT'S PRIMARY OBJECTIVE is to contribute to the development of technology and CCS solutions by supporting the development of knowledge, expertise, technology and solutions that can make important contributions to cost reductions and broad international deployment, as well the exploitation of national advantages and the development of new technology and service concepts with commercial and international potential. The programme is a collaborative partnership between Gassnova and the Research Council of Norway. CLIMIT encompasses the Research Council of Norway's support scheme for research and development (the R&D part) and Gassnova's support for development and demonstration (the Demo part). Gassnova has the overall responsibility and manages the programme secretariat.

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PREFACE

CO_2-HANDLING IS NOW A REALISTIC OPPORTUNITY

Carbon capture has become a strategic tool. Industrial companies consider the new technology as an opportunity to bolster their position in a green market.

IN 2005, CLIMIT WAS founded on a mission to stimulate research and innovation in the field of carbon management. CLIMIT was established as an instrument to develop the technology all the way from basic research to piloting and demonstration.

– Since then, there has been a rapid development. Today, the technology is ready to be deployed. This is the reason why industrial companies have become more engaged. And CLIMIT has been a driving force in creating this innovation chain.

INDUSTRIAL EMISSIONS

We are experiencing a turn in the climate debate. Until recently, the effort has been directed towards developing green energy sources that can replace fossil fuels. However, sun and wind can only reduce the emissions, not remove CO_2 from industrial processes.

Energy accounts for 25 percent of the greenhouse gases, while the industry emits 20 percent. This is why the production of materials that society needs – such as cement, steel, aluminium, etc. – now receives more attention.

A new trend is that companies themselves are asking for technology that cuts emissions. They want to make products with smaller carbon footprints. Through a strategic, long-term focus on green products, an industrial company can strengthen its global market position.

– Carbon Capture and Storage (CCS) is the only technology that can reduce CO_2 emissions to the atmosphere, by putting the CO_2 back where it came from, says Vinje.

Extensive work lies behind the development of the technology. Thousands of thoughts have spawned concrete results.

BROAD COOPERATION

– CLIMIT emphazises the applicability of research. When we receive applications for funding, we also evaluate whether the researchers include a plan delineating how their research can generate business. Moreover, CLIMIT requires that researchers obtain financing from the industry, says Vinje.

Close cooperation between research and industry is one of the reasons why the technology is now mature and ready for implementation. Industrial competence is injected into the research process, and a significant share of the research revolves around identifying cost-effective solutions. Most of the projects covered in this report, represent a synergy between researchers and end-users of technology.

– Research projects funded by CLIMIT, have contributed with insight and knowledge that will be decisive in the realization of Norway's first full-scale CCS project, now under development, says Vinje.

TOWARDS FULLSCALE INFRASTRUCTURE

Construction of a fullscale plant for capture, transport and storage of CO_2 will represent a turning point both for the research community and the industry.

– When we put the technology to use, we will acquire important experience and insight. And this will speed up the innovation cycle, says Arvid Nøttvedt, Program Board Director of CLIMIT.

A fullscale CCS plant will open up for completely new opportunities. The project includes an infrastructure for the entire value chain. Thus, the industry can focus on the capture of carbon – because transport and storage have already been taken care of.

Furthermore, an infrastructure will acommodate for more flexible solutions. Companies can catch parts of the emissions, which are fed into the transport system. This is less demanding, both in terms of technology and economics. Concepts for

CLIMIT Programme Board. Second row from the left: Arvid Nøttvedt, Hans Jørgen Vinje and Kaare Helle. Front row from left: Hildegunn Blindheim, Hanne Lerche Raadal,Sveinung Hagen, Lars Petter Maltby, Eystein Leren, Marie Bysveen and Eva Halland. Photo: Sverre Christian Jarild

partial capture makes it possible to take out smaller amounts of CO_2 from more locations, and simultaneously achieve significant reductions in total emissions.

The Norwegian fullscale CCS project has also garnered attention outside the country. One example is Preem, which is one of the largest emittors of CO_2 in Sweden due to its many refineries. In cooperation with Aker Solutions, SINTEF, Chalmers and Equinor, Preem has received funding from CLIMIT and the Swedish Energy Agency. In a project that will run for three years, the CCS technology of Aker Solutions will be tested out on the refinery in Lysekil, Sweden, and the possibilities for a connection to the Norwegian fullscale project will be evaluated.

– It is indeed positive that the planned fullscale infrastructure opens up for expansion at a future date. This will make it possible to test a scaled construction of a CCS value chain, says Nøttvedt.

ACROSS BORDERS

Norway is one of the leading nations when it comes to competence on carbon capture.

– Consequently, we consider it important to share our knowledge in this field with central players internationally, says Vinje.

CLIMIT is an active contributor to the international research organization ERA-NET ACT. The program counts members from 11 countries, in Europe as well as the US. Both research institutions and process industry companies participate. An array of significant projects are developed under the auspices of ACT. ■

CAPTURE

INDUSTRIAL COOPERATION

In the northern county of Nordland, industrial companies have joined forces to reduce CO_2 emissions.

Mo Industrial Cluster in Rana is where the industrial companies are looking into CO_2 management. Photo: MIP

MO INDUSTRIAL PARK has set ambitious goals for their business development. The process industry in Nordland is amongst the greenest in the world, and now the industrial park intends to take the sector one step further.

About a quarter of the global greenhouse gas emissions stems from the process industry. To mitigate the carbon footprint of the production processes, cost effective solutions are needed to ensure realistic possibilities for implementation of capture technologies in the process industry.

PROACTIVE INDUSTRY

– In the project CO_2 Hub Nordland, the industrial park collaborates with

industrial players in the county to do a CO_2 management study in the region. We have received funding from CLIMIT, and SINTEF is coordinating the project, says Jan Gabor, market director of Mo Industrial Park.

The goal is to catch more than 1.2 million tonnes CO_2 annually.

The project maps the emission points of the partners in Nordland, in addition to NorFraKalk further south inVerdal. These companies account for most of the emissions in Nordland. Different capture technologies will be evaluated during the project. Increased energy-efficiency will be decisive to cut emissions, and utilization of excess heat from existing industry is very interesting in this context.

The companies cooperate closely to ensure the transfer of competence on process improvements, for example closed smelter ovens in the metals industry, and utilization of excess heat to produce vapor to be used as energy source for CO_2 removal.

FOCUS ON POSSIBILITIES

– We are also looking into how we can create concepts for a circular economy. Can we use CO_2 as an input factor for other types of industry? Currently, we are working on two interesting projects – the production of methanol and proteins for the aquaculture sector, says Gabor.

An important part of the project revolves around developing infrastructure for transport and storage. The CO_2 that is captured by the industrial companies in Nordland, will according to the current plans be fed into the planned Northern Lights infrastructure. In addition, the CO_2 Hub Nordland engages in close dialoge with Fortum, at Klemetsrud, and Norcem, in Breivik – the leading carbon capture projects in Norway.

One goal is to ensure that the findings are made available for the entire Norwegian industry – and hopefully contribute to industry in Norway and abroad being able to slash emissions.

PRACTICAL SOLUTIONS

– Success hinges on realistic, cost-effective solutions. Therefore, we put a lot of effort in creating a solid basis for investment decisions.

Mo Industrial Park works closely with the companies to ensure robust cost estimations and pre-studies.

– There is an expectation that the Norwegian government will assume a central role in promoting CCS. But we depend on attractive investment solutions to achieve this cooperation, says Gabor. ■

JAN GABOR
Mo Industripark

Project:
CO_2 Hub Nordland.
Towards zero emissions in the process industry

Project owner:
Mo Industrial Park

Project period:
2018-2020

Total budget:
9.8 MNOK

Support from CLIMIT:
6.4 MNOK

Partners:
Alcoa Mosjøen, Elkem, Celsa Armeringsstål, Ferroglobe Mangan Norge, SMA Minerals, Norcem Kjøpsvik, NorFraKalk, SINTEF and Oil and Gas Cluster Helgeland.

CAPTURE

REMOVAL OF CO_2 FROM INDUSTRIAL EMISSIONS

New technology cuts emissions of chemicals that mitigate CO_2 in combustion processes.

KARL A. HOFF
SINTEF

Project:
Monitoring and reduction of aerosol-related solvent emissions in Post Combustion CO_2 capture (AeroSolve)

Project owner:
SINTEF Industry

Porsjektperiode:
2017-2019

Total budget:
45 MNOK

Support from CLIMIT:
22.5 MNOK

Partners:
NTNU, TCM, TNO, Engie, Uniper, ROAD Maasvlakte CCS (until March 2018)

INDUSTRIAL COMBUSTION PROCESSES – at cement factories, steel mills and waste incineration plants, for example – produce flue gas with significant concentrations of CO_2. Chemical absorption is the usual technology to take out the CO_2.

CO_2 is led into an absorption tower, where the gas reacts with amine solvent that is directed into a desorber. Under altered pressure and temperature conditions, the amine releases the CO_2, and the cleaned gas continues through the process.

SMALL DROPLETS

However, in several applications of amine technology, very small droplets are created in the absorber reactor. These droplets, which are called aerosols, are so tiny that they can't be captured by traditional equipment.

– Aerosols are formed when particles and trace substances in the flue gas react with amine. However, earlier versions of the technology often generated emissions that exceeded the limits, says Karl A. Hoff, project manager at SINTEF.

Thus, the objective has been to produce more generic knowledge about the formation of aerosols, so that the industry can adapt the technology and ensure that emissions remain at levels far below the limits.

COMPREHENSIVE SCOPE

NTNU has covered the entire span from deep theoretical approaches at molecular level to design of cleansing technologies for a range of industrial processes. The researchers have devised mathematical models that describe how the arerosols develop and grow.

At SINTEF, the researchers have been engaged in laboratory tests. In Trondheim, the institute operates a pilot plant where dust, catalysator particles and sulphuric acid in flue gas are introduced. The researchers can observe the formation of drops and mist.

Technology Centre Mongstad (TCM) has also tested equipment for measurement and reduction of discharge. In particular, TCM has focused on pre-treatment of the gas. If particles and drops of sulphuric acid can be removed before the gas streams into the absorber, it is possible to prevent the formation of aerosols and mist.

NEW INSIGHT

– Scientifically, this has been an exciting project. For instance, we have acquired a new understanding of what happens when aerosols are formed.

Technology Centre Mongstad (TCM) has tested equipment for measuring and reducing emissions as part of the aerosol project. Photo: Helge Hansen

Like how amine builds a droplet with a diameter of perhaps only a few nanometers – and how the droplet grows, explains Hoff.

The merging of theory and operational experience has been central.

– When we combined the models with tests at TCM and SINTEF's laboratory, for example, we experienced several surprises related to the mechanistic aspects. We now possess a deeper understanding about the different phenomena, and have gained a more holistic perspective.

In order to obtain funding from CLIMIT, the projects must make the research results available for the industry, research community and technology suppliers.

– Our goal has been to push the technology envelope and contribute to the realization of safe and robust fullscale CCS plants, says Hoff.

In this project, SINTEF has worked together with partners NTNU, TCM, Engie, Uniper and TNO. ■

CAPTURE

COST-EFFECTIVE SOLUTIONS FOR THE PROCESS INDUSTRY

If carbon capture shall become a reality, reduction of costs is a critical success factor.

RAGNHILD SKAGESTAD
SINTEF

Project:
Cost reductions for CO_2 capture in the process industry (CO2stCap)

Project owner:
SINTEF

Project period:
August 2015 – December 2019

Total budget:
25 MNOK

Støtte fra CLIMIT Demo:
14.5 MNOK

Partners:
Chalmers, University of South-Eastern Norway, Norcem, Elkem, Global CCS Institute, Swerim AS, Rise Bioeconomy, SSAB, AGA Gas and IEAGHG

EMISSIONS FROM THE process industry constitute a significant part of the global total. The iron and steel industry alone, for example, accounts for seven percent of global emissions.

– To reach the 2 degree goal of the Paris agreement, we have to find pragmatic solutions that the process industry can deploy rapidly, says project manager Ragnhild Skagestad of SINTEF.

When it comes to installing CCS technologies, costs are the main challenge. Today, it would be difficult for most companies to implement processes that catch the full emissions of CO_2.

PARTIAL CAPTURE

In 2015, at the outset of the CO_2stCAP project, partial capture was a rather new concept. There are often several emitting points of CO_2 at a plant. Capturing some of them may be less costly than others. If a portion of the CO_2 is captured on many plants, instead of concentrating the efforts on one, the same amount is captured, but at a far lower cost.

The CO_2st CAP project has evaluated different categories of process industry. The researchers have analyzed processes in a SSAB steel mill, a Norcem cement factory, a REC solar cell plant and a generic paper mill

– We want to take advantage of the opportunities already existing. Surplus heat, for example, can be used to produce vapor. In combination with amine technology, the vapor is used to extract CO_2 in the capture plants, says Skagestad.

– Most of the plants don't have sufficient energy available to capture all the CO_2. Therefore, we scale down the capture facility. For example, it is possible to take out fifty percent of the emissions, at significantly lower costs. And then it may be easier to get started.

REALISTIC CONCEPTS

Moreover, CO_2stCAP has concluded that in some cases, coal can be replaced by biomass.

– If we capture CO_2 from biomass, we can in theory achieve negative emissions. In the real world, however, some CO_2 will always be released. Still, adapting the processes to biomass will result in a significant reduction of emissions.

The researchers have identified the factors that drive costs down.

– Many ideas may seem promising

The cement industry accounts for 8 percent of global CO2 emissions. The Norcem cement plant in Breivik is a possible capture location for the fullscale project. Photo: Norcem

on the drawing table. But how cost-effective will these concepts be, if we scale them up to an industrial plant?

COOPERATION WITH INDUSTRY

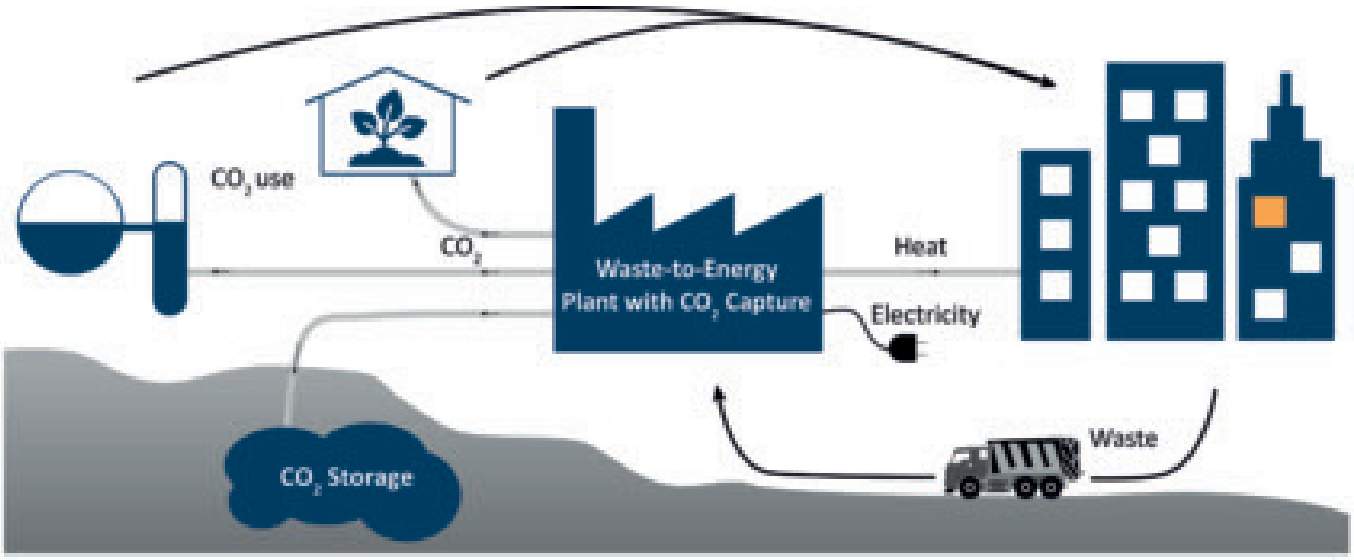
The researchers have worked closely with the industry.

– To propel the technology forward, we need the connection between research and operational knowledge. In workshops with people from the industry, we have discussed a wide range of process improvements and new concepts. ■

CAPTURE

REDUCED EMISSION IN COMBUSTION PROCESSES

Oxy-fuel technology represents an important contribution to better manage CO_2 in industry.



MORE THAN 80 PERCENT of all energy consumed globally, is produced from fossil fuels. The traditional combustion process is central in power generation, production of cement and metals, and waste incineration, among others.

Since the early 2000s, Norwegian researchers have worked extensively with oxy-fuel combustion technology to remove CO_2 from exhaust gas. Several of these projects have received funding from CLIMIT.

OXY-FUEL FOR THE INDUSTRY

– Since Norway is a significant producer of natural gas, we have directed our focus towards this fuel. But we have also developed oxy-fuel technologies for industrial applications, says Mario Ditaranto, project manager at SINTEF.

The oxygen that is used to burn a fuel comes from the air. However, only 21 percent of the air contains oxygen,

the rest is nitrogen. And the nitrogen just "passes through" the combustion process without contributing to the reactions that release heat. Still, the nitrogen ends up in the exhaust gas.

When CO_2 is produced in the combustion, it is difficult to separate CO_2 from the nitrogen. So an alternative concept for catching CO_2, must entail avoiding nitrogen in the exhaust gas.

Combustion with pure oxygen instead of air, generate only CO_2 and vapor. These are two natural exhaust gases that are easy to separate – if the water is condensed, the result is a clean flow of CO_2.

ADAPTED COMBUSTION PROCESSES

But oxy-fuel combustion also presents new challenges. This is a relatively new field of expertise, and there is limited experience with a mixture of oxygen and CO_2.

– When we burn pure oxygen, for example, the temperature is high. In addition to flame temperature, there are changes in flame dynamics, heat transfer, and contaminations. At SINTEF, we have modified the burners, and other infrastructure, to fit a new combustion process that is very different from the traditional process, explains Ditaranto.

A lot of work has been put into conducting experiments. SINTEF has built an infrastructure to test oxy-fuel combustion under high pressure, at a realistic scale. The research is to a large degree directed towards the practical application of the technology, adapting the oxy-fuel technology to specific fuels.

LOWER COSTS

– In one project, we are building a demonstration plant, financed by the Research Council of Norway. This constitutes a part of the European CCS infrastructure-network ECCSEL. We are modifying a gas turbine so that it can produce electricity from natural gas in oxy-fuel mode. Simultaneously, CO_2 is captured. And this is not merely an experiment in the laboratory, but a demonstration of the technology in a pilot micro-plant connected to the electrical network in Trondheim.

Another project that CLIMIT is supporting, is CAPEWASTE, where the researchers are investigating how oxy-fuel combustion technology can be used in waste-to-energy plants. More than fifty percent of the carbon content in waste stems from biomass. This opens for 'carbon negative' emissions, which entails removing CO_2 from the atmosphere. According to the International Panel on Climate Change (IPCC), this is necessary if the goals for reduction of climate gases are to be reached.

– The oxy-fuel process requires less energy for the capture part of the process. This means that it becomes cheaper to catch CO_2. And this is a requirement for the broad implementation of the technology in the industry, says Ditaranto. ■

MARIO DITARANTO
SINTEF Energi

Project:
Enabling Bio CO_2-Capture technology in the waste-to-energy sector (CAPEWASTE)

Project owner:
Oslo Kommune Energi-gjenvinningsetaten (EGE)

Project period:
2018-2021

Total budget:
12.35 MNOK

Support from CLIMIT:
8 MNOK

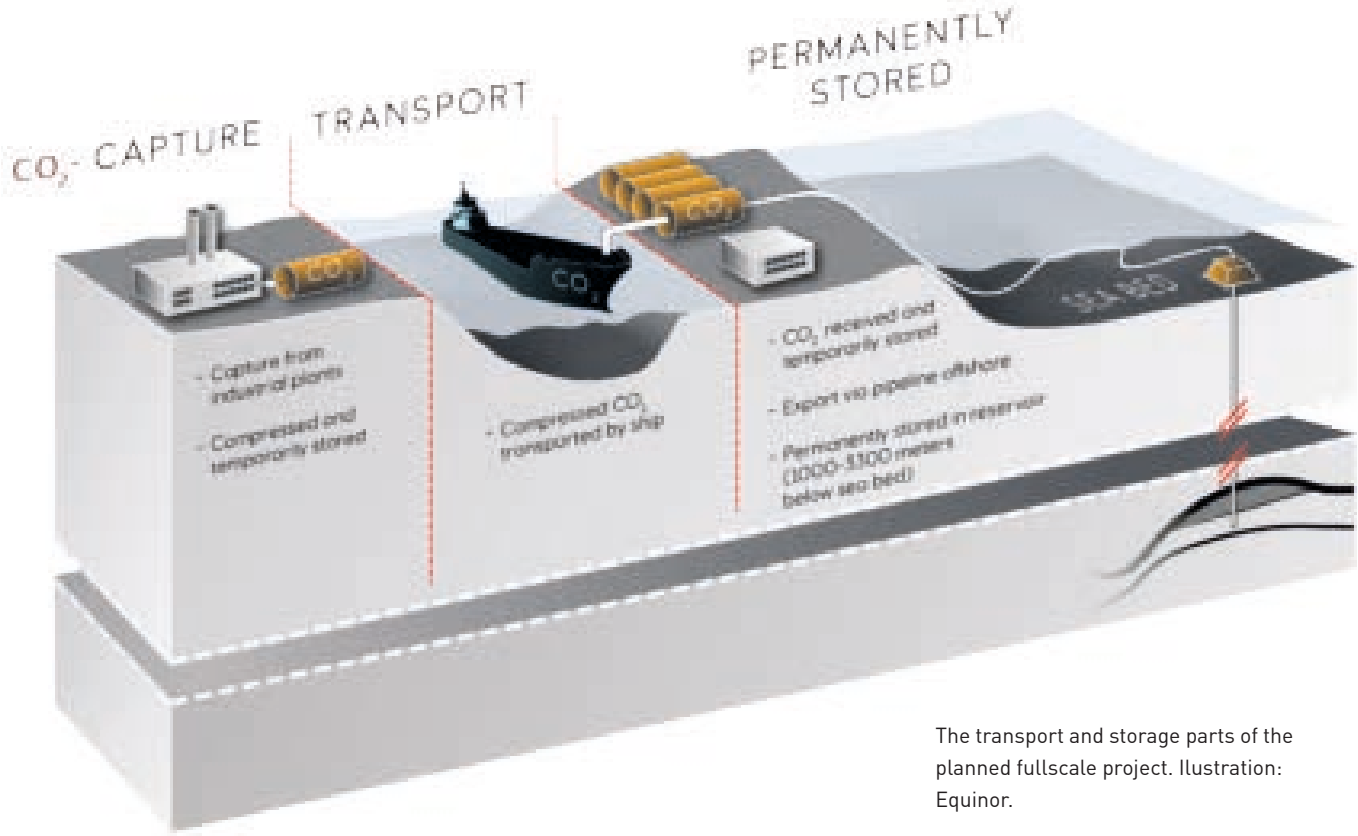
Partners:
Energigjenvinningsetaten (EGE), SINTEF Energi, AGA, Norwegian Environment Agency

TRANSPORT

MORE KNOWLEDGE ABOUT CO_2-TRANSPORT

New software will assist engineers in designing safer, more reliable and cost effective CO_2 transport systems.

EQUINOR OPERATES THE Sleipner gas field in the North Sea. The raw gas from Sleipner contains more CO_2 than allowed by the export gas specification. A tax on CO_2 emissions from oil&gas production on the Norwegian continental shelf made it more economical for Equinor to separate the CO_2 from the raw gas and reinject it into a saline reservoir than to vent the CO_2 to the atmosphere. Since 1996 Equinor has injected about a million tons of CO_2 per year from the Sleipner field. Since 2009 Equinor does the same for the gas from the Snøhvit field in the Barents sea, only in this case the CO_2 rich raw gas is piped to shore for separation of the CO_2 at the gas processing plant on



The transport and storage parts of the planned fullscale project. Ilustration: Equinor.

Melkøya. The CO_2 stream is then transported offshore again through a 110 km pipeline for injection in a geological formation.

The experience of CO_2 transport from Sleipner and Snøhvit is a good start, but Equinor still needs to develop tools to predict the behavior of CO_2 in different flow conditions.

SAFE TRANSPORT

– We consider the transport of CO_2 as very safe. But even though we have experience from Snøhvit and Sleipner, we are now focusing on strengthening our knowledge base, says project manager Zhilin Yang of Equinor.

The objective of the CO_2FACT project is to develop and validate software to simulate CO_2 flows through pipelines and injection wells.

Usually, CO_2 is transported in liquid phase or high pressure super critical phase. The physics are well understood and the models robust. However, there is a small risk that other substances, such as water, can enter the CO_2-stream and change its properties. Currently, we have limited experience with multiphase CO_2 flows.

PRECISE MODELS

– We will conduct experimental studies at the Institute for Energy Technology (IFE) to obtain data on how the properties of CO_2–streams changes with impurities in the stream. These data will be used to develop and validate simulation software for CO_2 transport in existing commercial flow assurance software for oil&gas, explains Yang.

– If pressure falls in the pipeline, the temperature of the CO_2, for example, can fall rapidly. Then there is a risk that CO_2 and water forms hydrates, which may cause problems by obstructing pipeline flow, explains Yang.

The researchers have also investigated the physical processes in the injection well.

– We know that water can penetrate the well and cause corrosion. CO_2 can react with water and form acid, which can damage the cement in the wells.

APPLIED KNOWLEDGE

The software developed by the project can contribute towards designing safer, more reliable and more cost-effective CO_2 transport systems.

– Carbon capture is costly, and a critical success factor will be to reduce costs in all parts of the value chain, says Yang.

The results of the project are shared with the other partners in the project – Total, Gassco, Schlumberger and LedaFlow – and will be utilized in support of the Northern Lights Project, which covers infrastructure for transport and storage in the Norwegian full scale demonstration project. ■

ZHILIN YANG
Equinor

Project:
CO_2 flow assurance for Cost effective transport (CO_2FACT)

Project owner:
Equinor

Project period:
Nov. 2018- March 2021

Total budget:
17.8 MNOK

Support from CLIMIT:
8.9 MNOK

Partners:
Total E&P Norge, Gassco, Schlumberger, LedaFlow Technologies

TRANSPORT

SAFE PIPELINES FOR CO_2 TRANSPORT

DNV GL and EPCRC have conducted two full scale tests of running fractures in CO_2 pipelines.

The requirements for the transport of CO_2 are different from those of hydrocarbons. This project updates the design codes for CO_2 pipelines.

THE OBJECTIVE OF the CO_2 SafeArrest project is to develop guidelines for design of safe and cost optimal pipelines for CO_2 transport.

CO_2SafeArrest is a collaboration project between DNV GL and Australian Energy Pipelines Cooperative Research Centre (EPCRC). The project is funded by CLIMIT and the Australian government. The purpose of the project is to develop design guidelines to avoid running fractures in CO_2 pipelines, and to develop simulation models of the dispersion of the CO_2 plume from the pipeline crack.

PREVENT RUNNING FRACTURES

Running fractures can happen in case an existing weakness in the pipeline material causes the pipeline to crack under pressure or if the pipeline is damaged by accident. The pipeline must be strong enough to prevent a crack from initiating a running fracture while reducing the cost impact of excessive margins in pipeline strength.

– The estimation methodology for design of natural gas pipelines cannot be transferred directly to pipelines transporting CO_2. One goal of this project has been to adapt the design equations in order to create safer pipelines, says Bente Helen Leinum, project manager at DNV GL.

FULL SCALE TESTS IN THE UK

The full scale tests, which were run at DNV GL's test centre in Spadeadam in the UK, produced experimental data used to develop guidelines for pipeline design and models of CO_2 plume dispersion in the environment surrounding the test site.

The pipelines used in the tests were made up of sections of pipes with different toughness and yield strengths increasing from the middle of the pipelines towards the ends. An explosive charge in the middle of the test pipeline initiated a crack and fracture that begun running towards the ends before being stopped (or arrested) in a later section with the required strength.

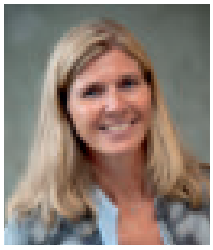
High velocity cameras filmed crack propagation which was measured at 150 m/s.

DNV GL has used the project's results to adjusted their guidelines for CO_2 pipeline material properties.

NEW DESIGN CODES

– These will be codified in an updated version of DNV GL's recommended practice (RP) F104 'Design and operation of carbon dioxide pipelines' – and made available for everyone, says Sigbjørn Røneid, project engineer and responsible for the update of DNV GL RP-F104.

– To avoid excessive costs, operators need to design pipelines that are not too conservative. The industry is constantly focusing on maintaining a robust project economy in the production and installation of pipelines. To that end, the update of the design codes is an important tool, says Leinum. ■



BENTE LEINUM
DNV GL

Project:
Improving the safety and efficiency of CO_2 pipelines by developing and validating predictive models for CO_2 pipeline design (CO_2SafeArrest)

Project owner:
DNV GL and EPCRC

Project period:
2016 to 2019

Total budget:
40 MNOK

Support from CLIMIT:
20 MNOK

Partners:
DNV GL and Energy Pipelines Cooperative Research Centre (EPCRC)

STORAGE

MARINE MONITORING OF CO_2 STORAGE

The researchers investigate how a CO_2 leak may be detected if it should reach the seabed.

ANN ELISABETH ALBRIGHT BLOMBERG
NGI

Project:
Acoustic and chemical technologies for environmental monitoring of geological CO_2 storage (ACT4Storage)

Project owner:
Norwegian Geotechnical Institute (NGI)

Project period:
2018-2019

Total budget:
17 MNOK

Support from CLIMIT:
11 MNOK

Partners:
Equinor, Total, Kongsberg Maritime, Franatech GmbH, NIVA, NORCE, University of Oslo, University of Bergen and FFI

ACT4STORAGE FOCUSES ON technologies for monitoring the marine environment, in other words the seabed and water column.

– Before injecting CO_2 into a geological reservoir, careful investigations are conducted to ensure that the risk of leakage is small. Still, it is important to monitor the injected plume as well as the marine environment, in order to verify and document that there are no indications of leakage, says project manager Ann Elisabeth Albright Blomberg at the Norwegian Geotechnical Institute (NGI).

DIFFERENT SCENARIOS

It is difficult to know what a leakage will look like if it should reach the water column. Depending on the water depth, it is likely that CO_2 bubbles will appear, in addition to increased concentrations of dissolved CO_2. Another potential early sign of leakage may be that liquids – or pore fluids – are pushed through the sediments and into the water column due to increased pressure.

The researchers believe that these fluids will have a different geochemistry than the rest of the water – including different pH, oxygen content, salt concentration, etc. It is likely that pore fluids from sediments will appear before the gas, and may indicate that something is happening further down in the reservoir. Thus, one goal has been to map which technologies can detect such movements, and to understand how to combine information from different sensors for more robust monitoring.

OPTIMAL SENSORS

In NIVA's laboratories at Solbergstrand, the researchers have tested how different sensors respond to different leakage scenarios. Big tanks are filled with sea water and CO_2 is added. The natural seasonal variations are simulated. Response time is a central parameter. How fast can a sensor detect a discrepancy?

The sensors were also tested in a more realistic 'near-shore' environment, in the sea outside Horten, in order to understand how the sensors function when they are exposed to external factors such as sea currents, background noise from boats, marine growth on the sensors, etc.

– We conducted a controlled CO_2 release experiment a few hundred meters from shore. We found it very useful to look at dissolved CO_2 together with oxygen and pH, in order to detect small amounts

Sensors were tested in a nearshore environment in the sea outside Horten in near Oslo. Photo: NGI

of released CO_2. This may avoid false alarms caused by natural variability, says Albright Blomberg.

REALISTIC TESTS

A new round of nearshore tests were conducted in May 2019, where the researchers used autonomous underwater vehicles. These vehicles can investigate both the seabed and the water column over extensive distances.

The project also includes an offshore expedition. Together with the University of Bergen, the researchers will travel on the research vessel *G.O. Sars* to outside the island of Jan Mayen. A range of technologies will be used to study hydrothermal activity – subsea volcanos that emit CO_2 – in order to observe a leakage in the real world.

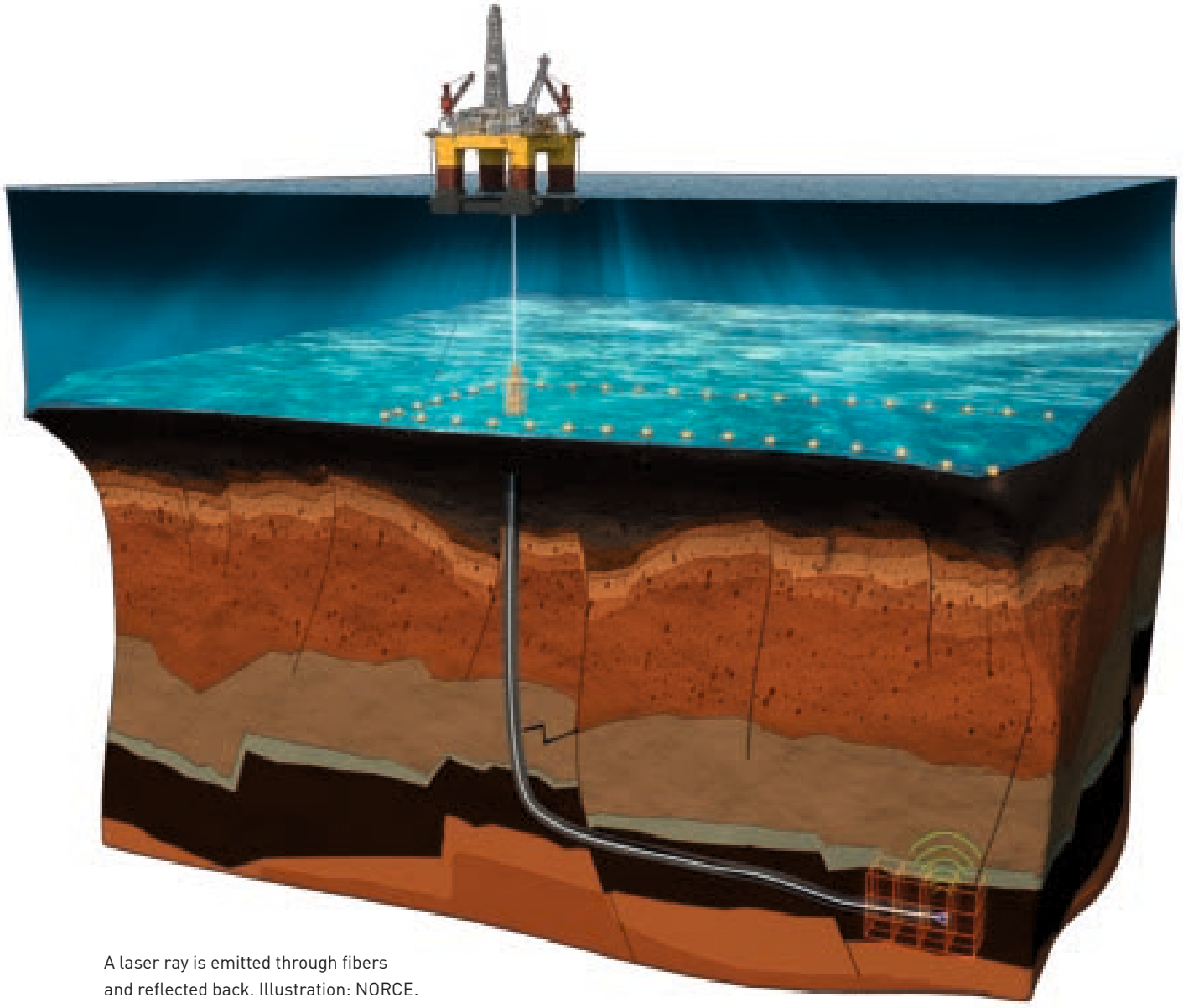
The project, which consists of partners NGI, NORCE, University of Oslo, University of Bergen, Norwegian Defence Research Establishment (FFI), Kongsberg Maritime, Franatech, Total, Equinor, has generated huge amounts of data, and comprehensive work is going on interpreting and analyzing the data.

– Through ACT4storage, we hope to contribute with new insights into how to make best use of available technology for reliable and robust marine environmental monitoring for CCS, says Albright Blomberg. ■

STORAGE

SAFE STORAGE OF CO_2 REQUIRES MONITORING

Optical fibres that detect microseismic movements, lower the costs of monitoring the stored CO_2.



A laser ray is emitted through fibers and reflected back. Illustration: NORCE.

EVERY OTHER YEAR, a ship sets out for the Sleipner field, where CO_2 has been stored since 1996, in order to conduct seismic investigations. The purpose is to ensure that the CO_2 is located where it should be in the reservoir. An effective, but costly, inspection round.

Thus, a consortium lead by NORCE aimed to develop a cost-effective system for continuous monitoring.

ACCESSIBLE KNOWLEDGE

– Even though the risk of significant leakage from geological structures is considered small, there are strict safety regulations for central storage of CO_2 in the North Sea, and safety must be extensively documented, says project manager Kirsti Midttømme of NORCE.

For several years, fiber optic cables have been employed in the oil and gas industry to detect microseismic movements. However, the technology was developed by commercial enterprises and is therefore proprietary. Researchers and end users have not enjoyed access to the knowledge. But now, research institutions have started to build their own systems.

– At NORCE, we have a group of optical specialists with extensive experience in fiber optics. We have drawn on this competence to develop the system, says Midttømme.

EARLY WARNING

The aim of the project has been to create a monitoring system that detects CO_2-leakages as early as possible. Central components are fibers and processing methods that generate high quality signals.

A laser pulse is emitted through the fibers, and reflected back. Changes in the environment will impact the reflection of the light. The system is capable of monitoring a continuous distance of 50 km, every day of the year.

One leakage scenario describes increased pressure in the reservoir, causing the rock to break up. A network of fibers detects the sounds created by the fracturing rock.

The system can also be used actively. A sound signal is emitted into the ground and reflected. The shape of the signal is determined by whether the ground contains water or gas. Through fractures, gas may seep into the sediments above the CO_2 storage and accumulate in gas pockets. Since gas has different properties than water, it is easy to detect. The system then gives a warning that a leakage might be about to happen.

BROAD PARTICIPATION

The system has great benefits.

– A fiber occupies little space in an injection or observation well, where it detects microseismic activity, and fibers are relatively cheap, says Midttømme.

NORCE works closely with other high competence environments in this project. There are many ways to process data, and both NTNU and NORSAR have contributed with expertise on the interpretation and processing of data. OCTIO has participated with expertise on monitoring. Equinor is also a partner.

The project has attracted attention abroad. In Indonesia, the hydrocarbon blend being extracted contains a high level of CO_2. For that reason, an Indonesian university has chosen to participate as a partner in this project. With funding from the World Bank, Indonesia is planning to establish the country's first CO_2 storage plant. ■

KIRSTI MIDTTØMME
NORCE

Project:
Distributed seismic monitoring for geological storage of CO_2 (DEMODAS)

Project owner:
NORCE

Project period:
June 2016 – May 2019

Total budget:
12.5 MNOK

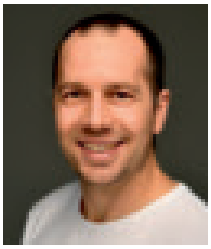
Support from CLIMIT:
10 MNOK

Partners:
NORSAR, Norwegian University of Science and Technology (NTNU), OCTIO, Equinor, CMC Research Institute, (Canada), Institut Teknologi Bandung (ITB), Indonesia, Kyoto University, Japan

STORAGE

FROM LAB TO WELL

The POREPAC project aims to develop knowledge for safe and efficient injection of CO_2 into the reservoir.



ANDREAS BERNTSEN
SINTEF

Project:
Prevent loss of near-well permeability in CO_2 injection wells (POREPAC)

Project owner:
SINTEF AS

Project period:
2018-2021

Total budget:
11.4 MNOK

Support from CLIMIT:
8.9 MNOK

Partners:
University of Oslo, NORCE, Lawrence Livermore National Laboratory, Equinor, Total, Shell, and Gassco

CO_2 OCCURS NATURALLY in geological structures in several locations around the world, where it has remained in place for millions of years. CO_2 storage is now considered safe, but injection and storage is not without its challenges.

AVOIDING CLOGGING

On the Norwegian continental shelf, Equinor has acquired comprehensive experience from injecting CO_2 into formations at Sleipner and Snøhvit. But in some instances, as for example at Snøhvit, the pores in the near wellbore area have been clogged, probably by salt precipitation. Consequently, the operator could not fill the entire Tubåen formation.

The objective of the POREPAC project is to expand our knowledge about what occurs in porous rock formations during injection.

– There are several mechanisms that can lead to clogging. Stress, fluid pressure, temperature and flow can cause different scenarios such as salt precipitation, the formation of wax and hydrates, and the transport of crushed rock around the well, explains Andreas Berntsen, researcher and acting project manager at SINTEF.

FROM LABORATORY TO REALITY

Research has been done and is ongoing in this field, both in Norway and abroad. But one of the big challenges is that the laboratory conditions are not always close to those in the field.

– We want to fill the gap between field studies and small scale experiments. In SINTEF's laboratories, we scale down the injection well. CO_2 is injected through a 20 cm rock specimen with a cylindrical hole in the middle, under varying conditions, says Berntsen.

In the laboratory, researchers can isolate physical and chemical mechanisms. Many variables are kept constant, while one variable is changed. In this way, a deeper understanding of various processes can be developed.

– We also run the risk of over-simplification. We can, for example, saturate a rock specimen with salt water, and then let CO_2 stream through. But a well on the continental shelf will be subject to an array of physical conditions, differing fluid pressure and complex patterns of stresses. The temperatures may also be high – sometimes up to 80 degrees C. Hence, it is important to be aware of the interactions between these factors.

Small scale wells are tested under realistic pressure and temperature conditions with specialized equipment. Photo: SINTEF.

PRACTICAL USER VALUE

A central goal of the project has been to see clogging mechanisms in a realistic, operational context. The knowledge will be used by the operators for better planning and execution of CO_2 injection.

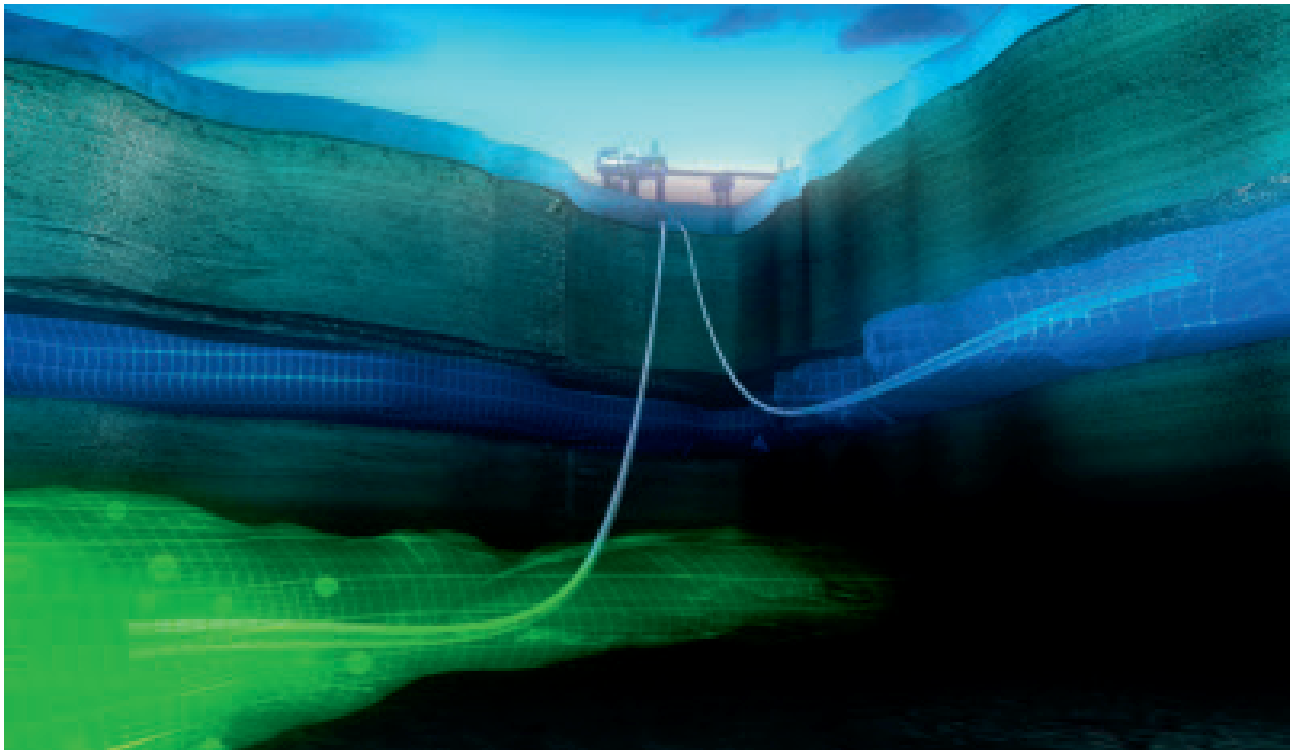
– We have collaborated closely with our industrial partners Equinor, Gassco, Total and Shell, through the Norwegian CCS Centre. The partnership has ensured that the researchers are well steeped in the concrete, operational challenges they meet on the shelf – and down in the wells. This has great significance for which scenarios we are testing in our laboratory, says Berntsen.

SINTEF has worked closely with NORCE, the University of Oslo, and Lawrence Livermore National Laboratory in the US, who are all partners in the project. ■

STORAGE

SAFELY SEALED WELLS

Wellcem has developed resins that hinder leakages of CO_2 in injection wells.



The Wellcem project investigates what it takes to avoid leakages in a well. This is an illustration of the Sleipner field. Ill: Equinor.

HOW CAN LEAKAGES IN wells be avoided? In many ways, CO_2 represents a new field of expertise. In this project, Wellcem has conducted a range of test scenarios to expand the knowledge base.

When CO_2 is dissolved in water, a light acid is created. Under certain conditions, this acid may cause cracking in the cement in the wells.

FLEXIBLE SOLUTIONS

– Together with our research partner, NORCE, we have tested different formulations for resins, to find the optimal chemical compositions for most cracking geometries. We have also developed more environmentally-friendly resin alternatives, says CEO Jonny Haugen of Wellcem.

The material can be adapted to a specific well. Wellcem creates solutions that harden at defined temperatures. The hardening process is calibrated to the temperature of the cracking area, and other variables such as time. The company has also developed a very runny resin solution, which penetrates minute cracks.

– Leakage can lead to different pressure levels in the well. This represents a risk, and the production well must be closed. The most serious scenario is loss of circulation and well control during drilling. This can cause blowout – or other problems can arise. The plugging solution we have developed, makes for safer wells, explains Haugen.

NUMEROUS EXPERIMENTS

In cooperation with Wellcem, the researchers have invested many hours in the laboratory. Cement cores with artificial cracks were treated with different resin types, and the trials were conducted under the same pressure and temperature conditions that exist in a typical well. The researchers measured the flows of both super critical CO_2 and CO_2-saltwater, and could ascertain that the resin was intact after the trials.

– We have conducted several experiments to validate the effect of the product. There are strict requirements to the documentation of new technology, and we must demonstrate that the resin represents a safe and reliable plugging solution.

NEW BUSINESS OPPORTUNITIES

Wellcem sees interesting business opportunities in preventing or staunching leakage of CO_2 in wells.

– As carbon capture is implemented, it will become more important to have long term seals in the wells. Our company will be strongly positioned in this market. We can see the inception of such a market on the Norwegian Continental Shelf, and to an even larger extent in the US. In Europe, there is a widespread preoccupation about CO_2 leakages. Still, it is quite possible that it will be considered more important to find concrete solutions to the threat of climate change. In this scenario, a product that creates safer wells, will add distinct value.

Wellcem contributes with fifty percent of the project costs, while CLIMIT covers the other half. ■

JONNY HAUGEN
Wellcem

Project:
Resin-based solution for sealing leaks in CO_2 wells

Project Owner:
Wellcem

Project Period
Jan. 2016 – March 2020

Total Budget:
10 MNOK

Suppport from CLIMIT:
5 MNOK

Partner:
NORCE

KEY FIGURES 2018

There was a great deal of interest in applying for funding from CLIMIT in 2018, and at the end of the year a total of 43 new projects received NOK 201.5 million in support. A growing number of research projects are continuing as demonstration projects.

DEMONSTRATION PROJECTS

CLIMIT-Demo had 102 active projects with a total allocated support of NOK 473 million in 2018. Twentyfour new projects were awarded support.

In addition, support was awarded to conceptual studies, smaller studies and information initiatives. Overall, conditional allocations totaled approximately NOK 145 million in 2018. A total of 32 projects were completed in 2018.

RESEARCH PROJECTS

In 2018, CLIMIT R&D had 64 active projects that received a total of NOK 109 million in support during the year. A total of 480 million in support has been budgeted for these projects over several years.

In 2018, support was granted to seven major projects, including two research projects, three competence building projects for the business sector and two innovation projects in the business sector.

In addition, support was also provided for several smaller projects, including network projects, events and mobility grants.

In 2018, NOK 57 million was allocated to new projects. The reason for the somewhat low amount is that ACT projects were allocated in 2017 and 2019, but not in 2018. ■

Active projects by sector (MNOK)

	2017		2018	
	R&D	Demo	R&D	Demo
Institute sector	63.9	40.0	77.4	46.9
Business sector	5.9	60.8	10.5	47.1
University and college sector	30.3	7.5	18.9	
Others	0.9	2.6	2.6	2.1

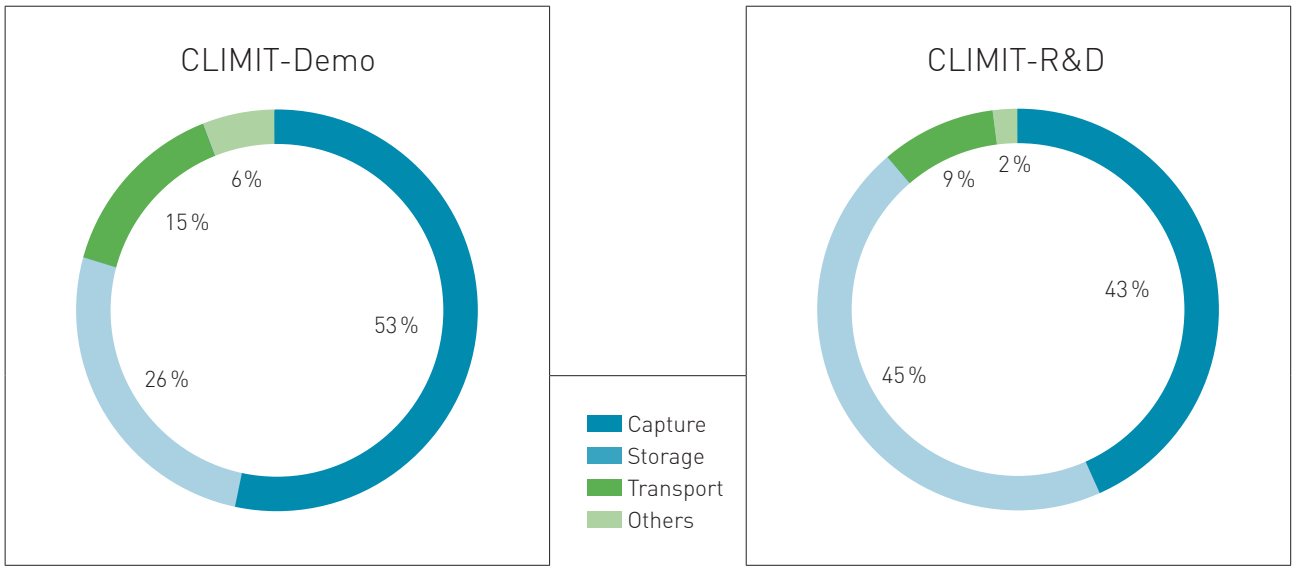
Active projects by application type (MNOK)

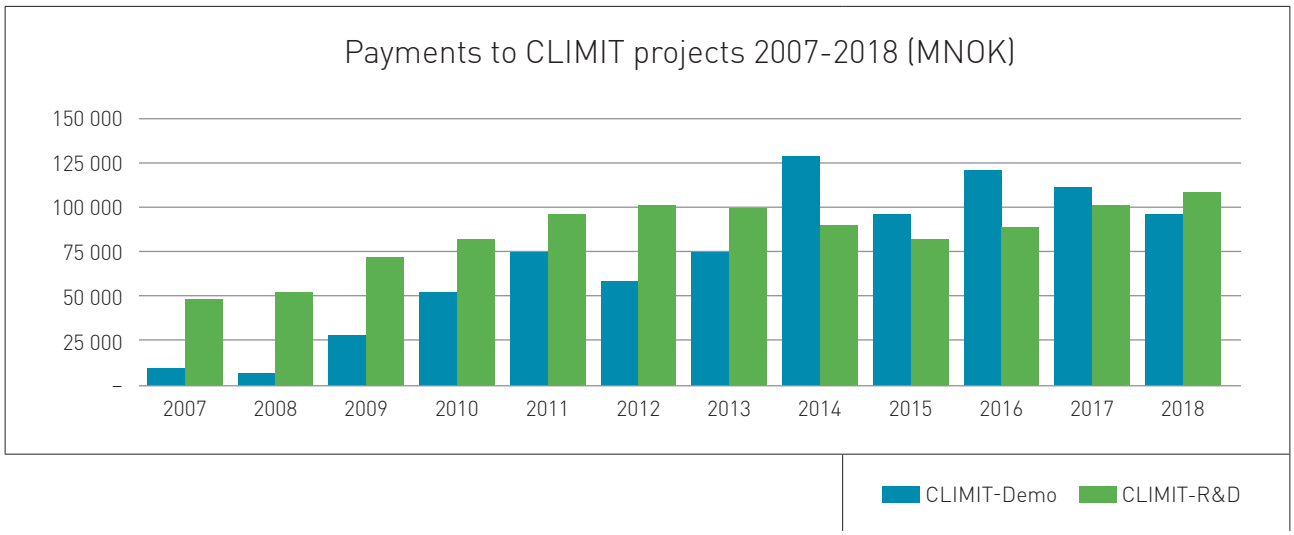
	2017		2018	
	R&D	Demo	R&D	Demo
Other support	11.1	1.5	16.6	0.2
Event support	1.1	1.2	0.6	0.8
Researcher projects	65.7		63.7	
Innovation projects in the business sector	5.9		11.2	
Competence projects for the business sector	17.2		17.3	
Personal foreign scholarships	0.1		0.1	
Demo projects		107.0		92.9
Idea, pre-studies		1.3		2.2

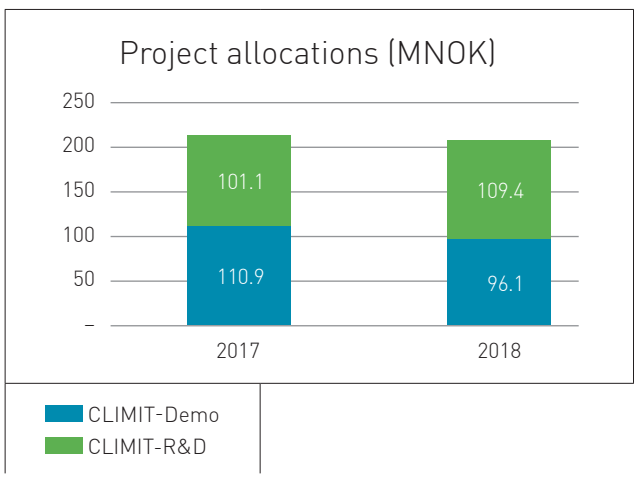
Income (MNOK)

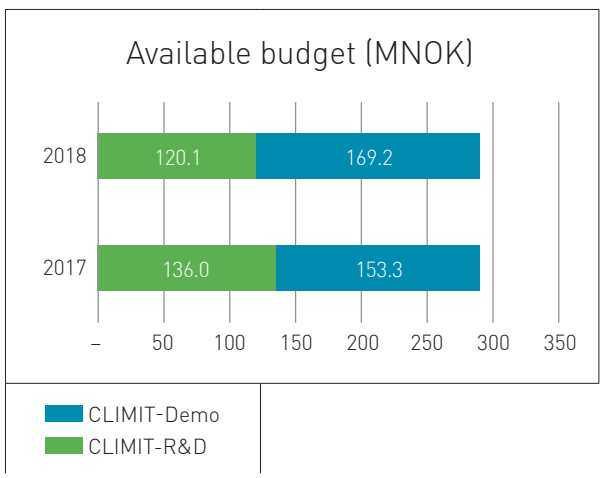
	2017		2018	
	R&D	Demo	R&D	Demo
Various	8.2		–0.1	
Ministry of Petroleum and Energy	105.0	94.2	92.1	90.0

Allocated projects









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