ANNUAL REPORT 2015

CLIMIT 10 Years

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You can read and learn more about CLIMIT's work at **future.climit.no/en**

THE CLIMIT PROGRAMME

CLIMIT IS THE NORWEGIAN NATIONAL PROGRAMME FOR RESEARCH, DEVELOPMENT AND DEMONSTRATION OF TECHNOLOGIES FOR CARBON CAPTURE AND STORAGE (CCS). THE PROGRAMME COVERS THE RESEARCH COUNCIL OF NORWAY'S SUPPORT PROGRAMME FOR RESEARCH AND DEVELOPMENT (R&D PART) AND GASSNOVA'S SUPPORT FOR DEVELOPMENT AND DEMONSTRATION (THE DEMO PART).

CLIMIT´S VISION

ACCELERATE COMMERCIALISATION OF CCS THROUGH FINANCIAL STIMULATION OF RESEARCH DEVELOPMENT AND DEMONSTRATION OF CCS TECHNOLOGY.

Publisher: CLIMIT programme, for its 10th anniversary **Editorial staff:** Liv Lønne Dille, Svein Staal Eggen, Åse Slagtern and Thelma Bergheim **Photos:** Geir Mogen, Sverre Jarild, Styrk Fjærtoft Trondsen, CO_2 Technology Centre Mongstad, SINTEF, HyNor and iStock **Illustrations:** Headspin
Editorial consulting and text: Fete typer **Design:** Fete typer **Printing:** Erik Tanche Nilssen AS

A SIGNIFICANT CONTRIBUTOR

Both the Paris Agreement and UN's Intergovernmental Panel on Climate Change emphasise that carbon capture and storage (CCS) is an essential technology in order for the world to achieve the two-degree target. While many developments are taking place within renewable energy sources, there is little doubt that fossil fuels will also be a part of the energy mix for several decades to come. Many industrial processes also result in substantial CO_2 emissions. It is therefore crucial to capture, transport and store large volumes of CO_2 from power plants and industry in upcoming years.

Ten years after the establishment of the CLIMIT programme in Norway, we can safely say that there have been technological advances within CCS. We can also be proud that Norway has already influenced technology development, and continues to do so, and that our work is recognised on the international stage.

First generation technology for capture, transport and storage of CO_2 is now in place, and the first plant is operational in Canada. CLIMIT views this development in a 10-20-year perspective, and we must continue the research efforts to develop second and third generation technology that will be even cheaper, more efficient and environmentally friendly than current technology. CLIMIT will take part in this development. There has been several important changes since the previous programme plan was adopted in 2013, and international cooperation will play a bigger role. This is why CLIMIT's programme board asked the secretariat to prepare a new programme plan for CLIMIT, starting in 2017.

The oil and gas activities in the North Sea have provided us with extensive expertise within geology, subsea technology and offshore operations. It also provides us with access to large subsea reservoirs that may be suited for storage of vast volumes of CO_2 as they are eventually depleted.

Perhaps this will be the answer to how to carry out "the Green Transition" in Norway? Using our experience from the oil and gas activities, and our knowledge about CCS, to create new green jobs. By offering climate-neutral Norwegian gas, and capture, transport and safe storage of CO_2, we can be part of the solution to the climate challenge – not just for Norway, but for all of Europe.

Hans Roar Sørheim
Programme board chair

INTERNATIONAL COOPERATION PLAYS A BIGGER ROLE

> Hans Jörg Fell, head of the CLIMIT secretariat

Norway is a leader within research on capture, transport and storage of CO_2.

> Through ECCSEL, European researchers can borrow equipment across national borders.

The climate challenge is global, which is why international cooperation to find solutions makes good sense. CLIMIT has made Norway an attractive partner and supports Norwegian researchers in a number of international CCS projects.

CLIMIT cooperates both bilaterally and in larger international networks. The largest current international project is undoubtedly ACT (Accelerating CCS Technology) where Norway has led the way for eight other countries to apply for support from the European Commission for an ERA-NET Cofund within CCS. This is a scheme under the EU's Horizon 2020 framework programme, where the Commission can grant additional support when multiple countries cooperate on joint announcements.

The application was approved, which means that nine countries are in the process of preparing a joint announcement totalling almost EUR 41 million. Nearly one-third of the funds come from the Commission, the rest is from the applicant nations. CLIMIT and Norway alone contributed EUR 6 million, which is a substantial contribution. The project funds will be announced in the summer of 2016, and projects that are closely related to industry are expected to be highly prioritised. This is a major research effort that will also provide European industry with the opportunity to test CCS technology.

SHARING EQUIPMENT Equipment represents a significant cost in technological research, and it is therefore highly beneficial if institutions can borrow from each other. ECCSEL, a European project headed by SINTEF to finance infrastructure and equipment, coordinates equipment procurement, so resources can be used with maximum efficiency. The Research Council of Norway granted NOK 200 million to the ECCSEL project, which provides CLIMIT researchers with access to important infrastructure. Going forward, it will be vital that projects supported by CLIMIT can benefit from the infrastructure developed through ECCSEL.

DRILLING WITH THE BRITS In 2015, Norwegian and British players joined forces on an application to the IODP (International Ocean Drilling Project) for support to carry out shallow drilling operations in the North Sea. The goal of the project is to learn more about the top 1000 metres of sediment in the North Sea Basin with regard to sealing of Utsira-type CO_2 storage sites. IODP is an international collaboration for scientific drilling operations on continental shelves around the world. Norway is a member, and drilling operations take place using drill ships or platforms. CLIMIT supported projects within CO_2 storage will greatly benefit from the data generated by this project.

NEW OPPORTUNITIES IN HORIZON 2020 Horizon 2020 is the European Commission's research and innovation programme, which includes excellent possibilities to apply for CCS projects. Through several years, Norwegian players have developed solid expertise through both CLIMIT and the Commission's programmes. We have found that Norwegian researchers are highly successful with applications for Horizon 2020 within CCS, and there are thus good synergies between the national and European research.

COOPERATING WITH THE US Research cooperation with the US and Canada is a proud tradition in Norway, and CLIMIT is no exception. Much is still at the planning stage, but CLIMIT awarded NOK 20 million in 2015 to research on CO_2-EOR (Enhanced Oil Recovery), a method for recovering more oil by injecting and storing CO_2. One of the preconditions for support was collaborating with players from the US or Canada, which hold leading positions within this technology. EOR could have a significant potential on the Norwegian shelf. One of the projects relates to development of a foam technology that will improve the EOR effect, while simplifying CO_2 storage. The University of Bergen is spearheading this project. SINTEF Petroleum also received support for a similar project, which will develop new methods for mobility control of CO_2 in connection with EOR.

EOR WITH THE NETHERLANDS CLIMIT has carried out a joint announcement with the Dutch CATO programme, with a budget of about NOK 11 million. The announcement presumed bilateral cooperation with industrial participation. The topical focus was projects within CO_2 transport, CO_2 storage and use of CO_2 for improved recovery of oil, gas or condensate. CLIMIT received two applications that were awarded support.

TEN YEARS OF TECHNOLOGICAL DEVELOPMENT

CLIMIT's long-standing work has significantly advanced CCS research and has made Norwegian research environments highly attractive partners for researchers in other countries. A decision has already been made to continue the programme for five more years until 2020.

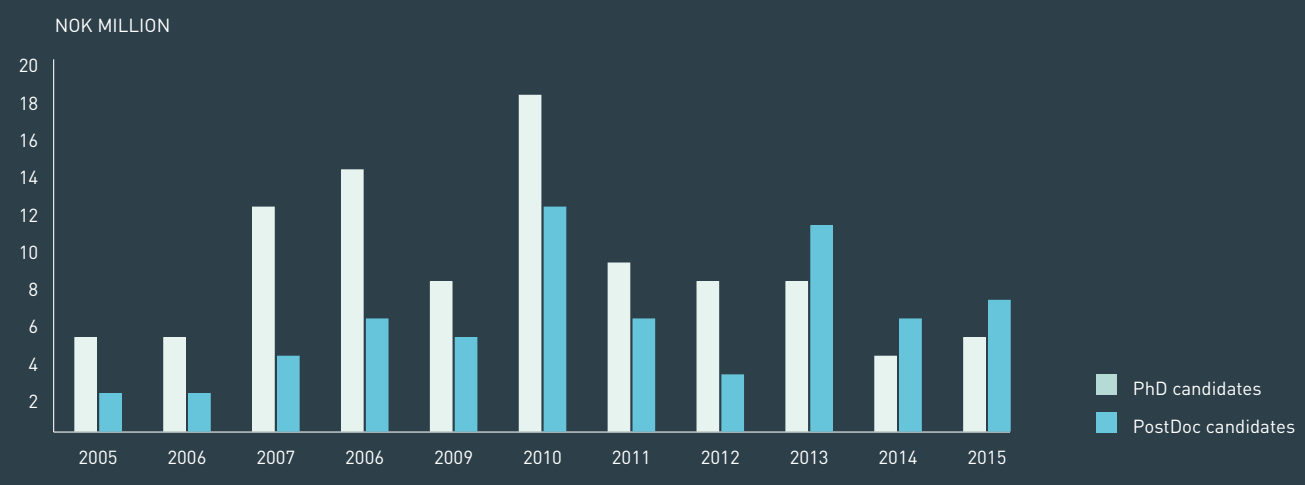
CLIMIT was started based on an acknowledgement that capture, transport and storage had to be part of the solution to the global climate changes. However, the CCS technologies were too expensive and ineffective for commercial application. CLIMIT's goal has been to help close this technology gap.

Over its first 10 years, CLIMIT has not only significantly advanced the research, but has also contributed to developing substantial expertise in Norway, in both research environments and among industry partners. The close and long-term cooperation between research and industry is one of CLIMIT's most valued advantages, and is vital for getting the technology out of the lab and into the real world.

EVALUATION This impression of CLIMIT's significance is emphasised in the evaluation conducted by the Swedish company Faugert & Co of the demonstration part in 2015. The evaluation concludes that CLIMIT Demo has contributed to developing new CCS concepts and created room for ideas that would otherwise not have occurred (evaluation is discussed in more detail on page 12).

10-YEAR ANNIVERSARY CLIMIT celebrated its 10-year anniversary in multiple ways. An insert in Teknisk Ukeblad (technical journal) summarised many of the results achieved, and also pointed out the challenges ahead. The insert contained an interview with Minister of Petroleum and Energy Tord Lien, who said:

NUMBER OF DOCTORAL AND POST-DOCTORAL FELLOWSHIPS – 2005–2015



54 MILLION TONNES

Norway's total CO_2 emissions were approx. 54 million tonnes last year.

70 BILLION TONNES

the volume of CO_2 we believe can be stored on the Norwegian shelf.

82 PER CENT

Today, 82 per cent of all energy we consume comes from fossil fuels.

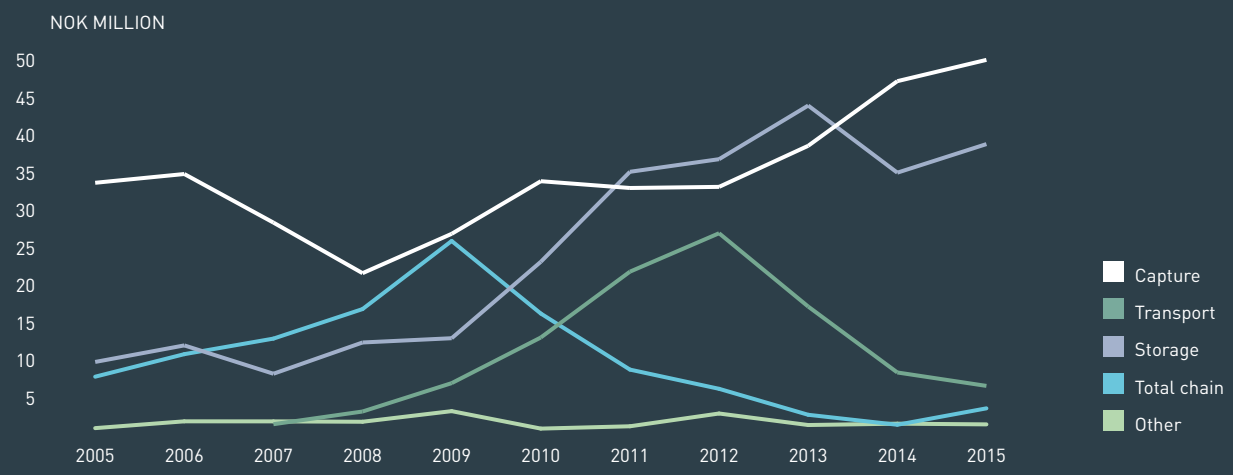
> Minister of Petroleum and Energy Tord Lien

"Through CLIMIT and other programmes, we have developed world-leading research environments, and Norway's climate of close cooperation between institutes, industry and the authorities is quite unique".

A web portal was also made (future.climit.no) to promote and share information about CLIMIT, how CLIMIT can contribute to addressing the global climate issues and to highlight project results. The portal contains several videos and interviews with representatives from the CCS environment.

CLIMIT SUMMIT The researcher conference CLIMIT Summit was organised for the fourth time in 2015, with more than 230 participants, 39 technical presentations and 80

CLIMIT R&D: DISTRIBUTION OF FUNDS BY AREA – 2005–2015



200 MILLION NOK

is what CLIMIT spends on research each year.

300 PROJECTS

More than 300 projects have been carried out over the past 10 years.

117 DOCTORATES

have been completed through CLIMIT.

posters. The conference, which was also part of the 10-year anniversary celebration, has become an important meeting place for researchers, industry and authorities nationally and internationally. CLIMIT has also organised multiple workshops with researchers and the industry to discuss how existing knowledge, expertise and equipment can best be utilised in the future. CLIMIT researchers have participated in, and held presentations at, a multitude of conferences both in Norway and abroad.

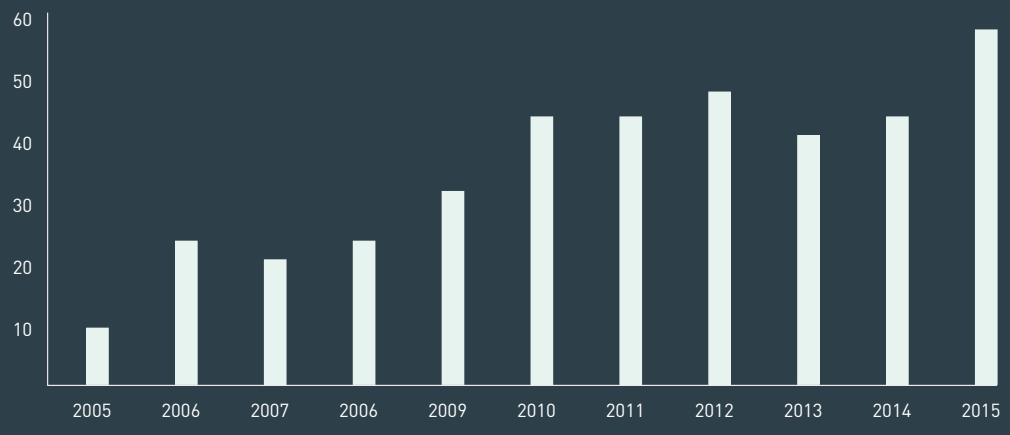
WHAT IS THE CHALLENGE FOR CCS RESEARCH?

Development and innovation of new CCS technology is necessary, but clear goals must be identified so that the research supports development of upcoming pilot and demonstration projects. Furthermore, exchange of knowledge and international cooperation are essential for driving technology development onwards.

Within *transport*, research that helps develop better practice standards is needed. There is also a need to further examine challenges with regard to material selection and corrosion.

There is a vast potential for *storage* of CO_2 in the subsurface on the shelf. We must develop better models and technology in this area that can be used to plan development and operation of storage sites in detail. There is also a need for improved and more efficient methods for monitoring CO_2 storage sites.

NUMBER OF CLIMIT PROJECTS – 2005–2015



CLIMIT's PROGRAMME BOARD

Not present when the photo was taken: Cato Christiansen and Per Aagaard.

4 Anita Utseth

6 Sveinung Hagen

3 Hans Jörg Fell (Head of the secretariat)

8 Per Reidar Ørke

2 Marie Bysveen

9 Eva Halland

5 Mette Vågnes Eriksen

1 Karen Lyng Anthonsen

7 Hans Roar Sørheim (Chair of the Programme board)

TOWARDS NEXT GENERATION TECHNOLOGY

BASIC RESEARCH

The CLIMIT research has provided extensive new knowledge about capture, transport and storage of CO_2, and ready-to-use technology. At the same time, much of CLIMIT R&D's research work is focussed on next generation CCS technology.

The R&D aspect of CLIMIT, which is headed by the Research Council of Norway, currently comprises about 50 ongoing research projects. Some are just starting out, others are nearly complete.

"We announce funding for projects amounting to NOK 80–90 million each year, and the applications are of high quality, which means that we have to turn down a lot of good projects," says Aage Stangeland, special adviser in the Research Council of Norway.

LONG-TERM KNOWLEDGE DEVELOPMENT Ever since the CLIMIT programme started 10 years ago, researchers have worked to develop and improve existing CCS technology, both to make it more efficient and to reduce the costs of utilising it. The largest single effort has been SOLVit, a project that has further developed amine technology to capture CO_2 from flue gas in a cooperation between research environments and industry. The project is now completed, and the technology is ready for use in a full-scale plant.

"While research will continue to improve the amine technology, much of the basic research effort is targeting next generation capture technologies – technologies that may first be used in about 20 to 30 years," says special adviser Åse Slagtern, who also works with CCS in the Research Council of Norway.

"This could be new membrane technologies, use of different solid absorbents or third generation solvent technologies, all technologies that will likely be less energy-intensive, cheaper and more environmentally friendly than the amine technologies in the long term."

MAJOR AND BROAD CAMPAIGN In addition to researching the capture methods of the future, there are also challenges related to transport and storage of CO_2 which require more knowledge.

"Within transport, one of the challenges entails understanding how CO_2 mixed with various contaminants, and under varying pressures and temperatures, affects tanks and pipelines. Corrosion is the biggest challenge facing transport," says Åse Slagtern.

Capture and transport cannot do much without a suitable, safe and accessible storage site.

"We have experience from storage in sandstone formations on Sleipner and Snøhvit, but researchers need far more data to develop their models and simulators to cover a broad spectrum

of various geologies. We have strong mathematics research groups in Norway that work on modelling, but they cannot keep on working with the same data forever. It is therefore important to establish real storage projects on a pilot scale.

MONITORING TECHNOLOGY Despite the fact that CO_2 can be stored safely and securely, there is a certain scepticism regarding extensive storage of CO_2, and fear of what may happen if it leaks out. Aage Stangeland believes this fear is mostly unfounded, but that it still needs to be taken seriously.

Thanks to the CLIMIT programme, a number of solid Norwegian knowledge environments have been developed, which makes Norwegian researchers attractive partners for foreign research environments.

"Researchers believe it is completely safe to store CO_2 underneath the seabed, but we need to be able to document that it will remain safely stored," he says. "There is agreement that monitoring CO_2 storage sites is important, so we can take action if something should happen. CLIMIT is therefore prioritising research on various methods for monitoring storage sites. One example is a new technology for micro seismic monitoring of reservoirs, which could result in efficient and reasonable monitoring. This has been tested at the Longyearbyen CO_2 lab, among other places.

Researchers are also working on more efficient well plugging methods, a further development of technology from the oil and gas industry.

"There is a difference between sealing an empty oil well and a chock-full CO_2 store," says Stangeland. "CO_2 is highly corrosive on cement. We therefore need to develop resistant cement mixtures and other materials that can be used for plugging."

SOLID KNOWLEDGE GROUPS The research within CLIMIT is spread across institutes and universities all over Norway. The research groups at SINTEF/NTNU represent a substantial share. Research groups at the Institute for Energy Technology (IFE), the University of Oslo and Bergen, NTNU and NORSAR are also well represented.

"Thanks to the CLIMIT programme, several solid Norwegian knowledge groups have been developed, which makes Norwegian researchers attractive partners for foreign research groups," says Åse Slagtern. This becomes very evident at international researcher conferences.

"At the most recent Greenhouse Gas Control Technologies conference (GHGT), the most important researcher conference in the field, a substantial share of the presentations were Norwegian. This says a lot about our position, despite being a small country."

WHAT DOES THE FUTURE LOOK LIKE? CLIMIT has developed strong research groups, and it is therefore necessary to maintain our research efforts in upcoming years. It is important to take the knowledge we have acquired in to use.

"We have developed a lot of expertise, and good CCS research groups. When we start larger scale projects, new challenges will pop up, and it will be good to know that we have the knowledge to meet these challenges," says Stangeland. At the same time, he also believes it is important for the research that large-scale CCS projects are realised as soon as possible.

"In 10 or 15 years we may have technology that is much cheaper than our current options, but we will not achieve second and third generation technology until the first generationis fully tested. In order to progress we need that experience," says Aage Stangeland.

CLIMIT DEMO ACCELERATES CCS

An external evaluation reveals that CLIMIT Demo contributes to development of new concepts and improvement of processes and products that would otherwise not have been realised. CLIMIT Demo has reduced the costs and risk associated with CCS.

The consulting firm Faugert & Co has reviewed the activity in CLIMIT Demo during the period from 2011–2013.

The evaluation report is on the whole positive with regard to the CLIMIT programme.

"We are pleased that one of the conclusions is that CLIMIT has a clear additionality, which means that the programme supports projects that would otherwise never have been realised. The positive feedback in the evaluation report corresponds with my experience when meeting people abroad. The CLIMIT programme and the Norwegian CCS effort enjoy high international regard," says Hans Jörg Fell.

The demonstration part of the programme creates room for ideas that would not otherwise have been possible to develop and has contributed to triggering new CCS concepts.

However, the programme has been unable to accelerate commercialisation of CCS. This is primarily because commercialisation is governed by factors which the programme cannot control, and which the programme can only influence to a limited extent.

The report also points out challenges and opportunities for improvement. The evaluation report encourages CLIMIT to stimulate more applicants to ensure high quality and innovation in the programme.

A condensed version of the evaluation report has been published on climit.no

> From the poster exhibit during CLIMIT Summit.

CLIMIT DEMO CAN BE EXTENDED UNTIL 2020

The EFTA Surveillance Authority, ESA, approved an extension of the CLIMIT Demo support scheme until 2020.

ESA initially approved the CLIMIT Demo support scheme in 2005 for a ten-year period. However, technological challenges have created a need for additional research and development before CCS technology can be utilised commercially. Norwegian authorities therefore wanted to extend the programme. ESA has determined that continued public support is necessary to further develop the technology, and that CLIMIT Demo complies with the state aid guidelines.

After ESA approved the Norwegian scheme for industry support through CLIMIT Demo, new regulations for CLIMIT Demo entered into force on 1 December 2015.

"The most important change is that the Ministry of Petroleum and Energy removed the requirement for applicants to be established in Norway and formally registered in a register of business enterprises, or the corresponding in Norway. However, projects supported through CLIMIT Demo are still required to generate value creation in Norway," says legal adviser in CLIMIT Svein Mofossbakke.

In order to receive support from CLIMIT Demo, the planned project must satisfy a number of requirements stipulated in the regulations. The project must also contribute towards realisation of the goals listed in CLIMIT's Programme Plan. If these criteria are met, the Programme Board will decide whether to approve the application based on a technical assessment.

CLIMIT Demo will grant financial support for development and demonstration of CCS technologies that contribute to:

- Development of knowledge, expertise, technology and solutions that can make important contributions towards cost reductions and widespread international application of CCS.
- Utilisation of national advantages and development of new technology and service concepts with a commercial and international potential.

MEMBRANE THAT MIMICS HUMAN LUNGS

PROJECT

> May-Britt Hägg at NTNU has developed a capture technology that mimics human lungs.

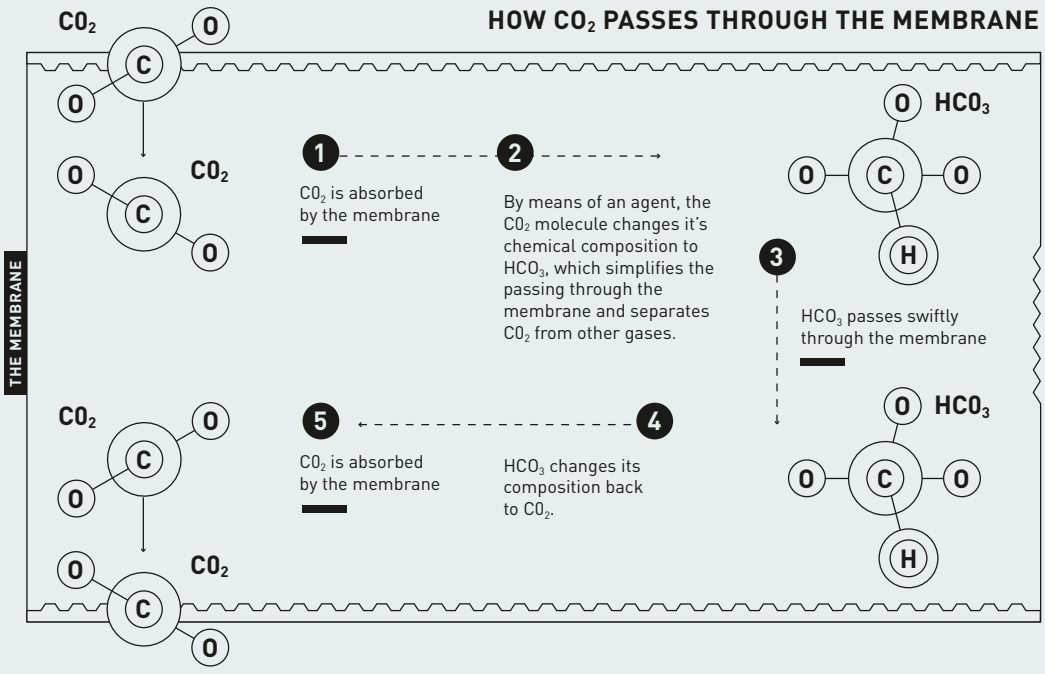
FACTS

Project owner: NTNU

Project period: 2013–2016

Financing: NOK 6.1 million

Partners: Sintef Materials and Chemistry (Trondheim), Air Products & Chemicals, Inc. (US) Statoil Petroleum AS (Norway), Alberta Innovates – Energy and Environment Solutions (Canada), DNV GL (Netherlands)



> By means of an amine group the CO_2 is separated from the exhaust gas as it passes through the membrane. Water is a prerequisite for this process to be successful, but water is present in all exhaust gas.

The air we inhale mainly consists of nitrogen and oxygen, but what we exhale is actually almost pure CO_2 and water. May-Britt Hägg, Professor at NTNU, has developed a membrane that mimics how our lungs separate CO_2.

The use of amine-based solvents to capture CO_2 from flue gas is the technology that has come the farthest so far, and is closest to commercial application. The method is efficient, but both space and energy-intensive. Development of other types of technology is therefore also in progress, including use of membranes. One such technology is May-Britt Hägg's "lung mimic".

"The lungs contain an enzyme – carbonic anhydrase – which 'captures' and removes CO_2, and this process is very quick. The membrane we developed mimics this process," says Hägg. The membrane provides a very environmentally friendly method for separating CO_2 from flue gas. It requires considerably less energy than the solvent technology, and is very fast.

ENERGY EFFICIENT Using membranes to clean gas is nothing new. It has been done since the late-1980s, but high pressure was used back then to push the gas through the membrane, which was highly energy-intensive. The innovation in May-Britt's technology is that the gas separation takes place using a chemical carrier in the actual membrane. The membrane is made from a material similar to plastic (polyvinylamine), where an amine group attaches to the polymer chain. This amine group is the CO_2 carrier. "In the same way as carbonic anhydrase transports CO_2 in our lungs when we breathe, this amine will function as a transport molecule that takes CO_2 with it through the membrane," explains Hägg. The method requires the presence of water, but this is no problem for flue gas, which often contains considerable volumes of water vapour.

READY FOR PRODUCTION After many years of research, including support from CLIMIT, the membrane is now ready for production and application. The technology has been tested at coal power plants in Portugal, at Norcem's cement plant in Brevik, and at SINTEF's CO_2 lab at Tiller outside Trondheim. It is particularly effective at cleaning flue gases from coal power plants. According to Hägg, the membrane can remove almost 90 per cent of the CO_2 from the flue gas. Hägg and NTNU have now entered into cooperation with the American company Air Products, a major membrane producer. The company also has a department in Kristiansand, where the membrane will be produced.

BIG POSSIBILITIES May-Britt Hägg believes the membrane has a significant potential and several areas of application. It can be used to clean nearly all types of flue gas, but is still somewhat sensitive to high temperature and pressure. Work is ongoing to make the membrane more resistant to pressure strain, and if we are successful, it could be used e.g. to separate CO_2 from natural gas. As we know, the flue gas is delivered at atmospheric pressure, and CO_2 is 'pulled through'.

"We are seeing interest in the technology from all over the world," says Hägg. "I believe we could make some Norwegian industrial history here, with a lot of jobs – not least in Kristiansand.

CAPTURE TECHNOLOGY READY FOR THE MARKET

PROJECT

FACTS

Project owner: Aker Solutions

Project period: 2008–2016

Financing: NOK 332 million

Partners: Sintef Materials and Chemistry (Trondheim), NTNU (Trondheim) EON (UK), Scottish Power (UK), Statkraft (Norway) and EnBW (Germany)

> Aker Solutions' mobile test unit.

More than seven years of research and testing through the SOLVit programme lie behind Aker Solution's technology for carbon capture from flue gas. They are ready for the market as soon as power plants and industry have to face more stringent climate requirements.

"We realised back in 2005 that carbon capture would be necessary to meet the climate challenges. As a technology company with extensive knowledge from the oil and gas industry, we thought we might have something to contribute," says Oscar Graff, technical director in Aker Solutions.

He was there when the company started evaluating existing carbon capture technologies, and concluded that cleaning flue gas using amine solvents held the most promise.

"We had the most expertise within this technology, but we also had the most faith in this method," says Graff. "It's a flexible and robust technology, and one we assumed would be the most useful over the first few decades. History has shown that we made the right decision."

CRUCIAL TESTING Aker Solutions established the subsidiary Aker Clean Carbon in 2007, and shortly after entered into a research collaboration with SINTEF and NTNU. Together, they applied for funding from CLIMIT in 2008. This became the start of the SOLVit research programme, which has developed and improved solvents that can bind and release CO_2 over more than seven years. SOLVit is the largest ever single project in CLIMIT's ten-year history.

"It was crucial that we had the best research partners, and we found them in Trondheim. We also wanted a test facility that we could use to test real, industrial flue gases," says Graff. "We knew that research results and laboratory testing were not enough. We had to test the technology in real situations and gain operational experience through long-term testing. This is why we built our mobile capture test unit (MTU), which has been tested at a coal power plant in Alabama in the US, at Mongstad and most recently at Norcem's cement plant in Brevik.

SINTEF's CO_2 lab at Tiller outside Trondheim also received contributions from SOLVit. The laboratory is a fully functioning small-scale cleaning plant, which has been essential for testing the properties of the various solvents in a controlled setting. →

→ "We have tested about 90 different solvents here. Our intention was to find the best and most cost-efficient mixtures," says Graff. The mobile test unit has been used to test the solvents on real flue gas from cement production, coal and gas power plants, as well as refinery gas.

IMPORTANT INDUSTRIAL PARTNERS In addition to having good research partners, Aker Solutions has highly valued key industry partners on their team.

"The fact that an external player wants to participate is a good indicator that we are on the right track. In SOLVit we had key industry partners such as Statkraft, Scottish Power and E.ON," says Graff.

"The support from CLIMIT was obviously essential. Without this, we would not have achieved the results we did. It would also be significantly more difficult to entice industry partners without the public research support through CLIMIT.

GOOD RESULTS After about 45,000 hours of operation in six different pilot plants, and about 10,000 special analyses in SINTEF's lab, SOLVit has generated a comprehensive knowledge basis.

"The result being that we can now provide efficient solvents that require much less energy, with very low degradation and minimal emissions," says Graff. He believes that Norway, overall, has come far within research and development of carbon capture, but that commercial plants are a necessity in order for the industry to keep developing.

"We believe that our technology can be used to clean emissions from industry and power plants, and to clean natural gas, and can be used for EOR (enhanced oil recovery). We also have expertise along the entire value chain," says Graff. "What we need now is the framework conditions that will make it profitable to start using the technology. The day it costs more to emit carbon than to capture it, we are in business."

> Oscar Graff in Aker Solutions believes that the support from CLIMIT has been essential in enabling them to make such progress.

STABILISATION OF FLY ASH

PROJECT

The project 245051 NOAH AS "Utilisation of CO_2 in waste gas from the cement industry to stabilise fly ash from combustion of household waste" was completed in December 2015. The project started in January 2015, with a budget of NOK 8.4 million and 45 per cent support from CLIMIT.

Fly ash is considered hazardous waste because it contains small volumes of heavy metals. The ash must be treated (stabilised) before it can be disposed of so the heavy metals do not leak out. NOAH currently processes about 300,000 tonnes of fly ash every year, which is disposed of on Langøya. NOAH has worked since 2012 to develop a new process to stabilise fly ash with gas containing CO_2. The process was tested in a pilot plant at Norcem in Brevik where flue gas from the cement plant was used to stabilise the fly ash. The flue gas is what is used to stabilize the ash, not CO_2 gas that is captured from the flue gas. CO_2 absorption was about 75 kg per tonne of dry fly ash. The project captured about five tonnes of CO_2 in stabilised fly ash that is stored on Langøya. Test results were good and NOAH wants to continue investing in development and commercialisation of the process.

NOAH estimates a future volume of 500,000 tonnes of fly ash per year. This will allow them to capture about 40,000 tonnes of CO_2 per year. This corresponds to the emission of 15,000 passenger cars yearly. NOAH's goal is for the process to be ready for operation in 2020 without investment or operational support from the government.

FACTS

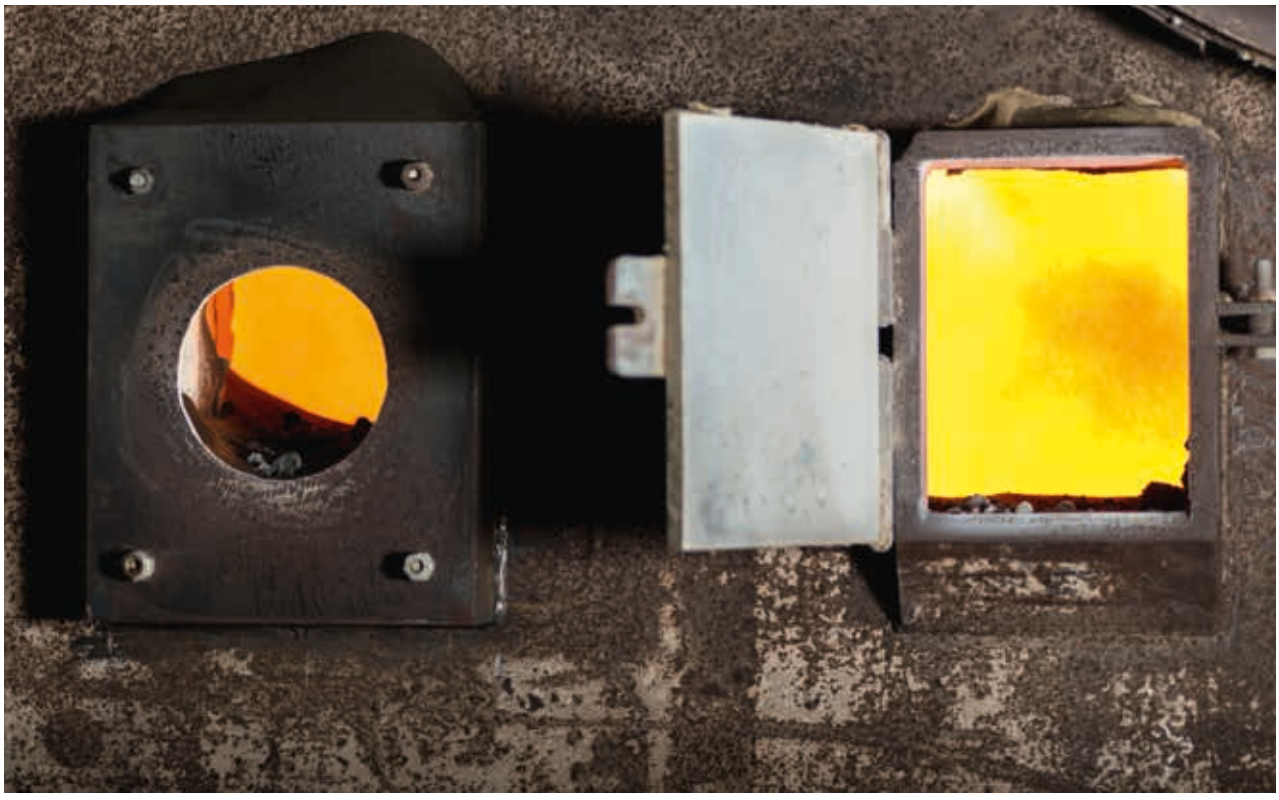
Project owner: NOAH AS

Project period: 2015

Financing: NOK 8.4 million

Partners: Norcem

> Experiments have shown that the ash can be stabilised with flue gas and bind CO_2 at the same time.



CLIMATE-NEUTRAL GAS POWER PLANT THAT PRODUCES HYDROGEN

PROJECT

FACTS

Project owner: ZEGPower AS

Project period: 2013–2016

Financing: NOK 6.1 million

> Bjørg Andresen in ZEGPower wants to produce hydrogen from natural gas while simultaneously capturing CO_2 from the gas

Akershus Energipark outside Lillestrøm is home to a unique small gas power plant in the middle of a field. Unlike other gas power plants, it produces hydrogen in addition to power, and it separates CO_2 in the process.

> Ruter is already using hydrogen buses in Oslo.

BioZEG is a pilot plant owned and operated by ZEGPower, a company born from research at the Institute of Energy Technology (IFE) at Kjeller and Christian Michelsens Research in Bergen. ZEG stands for "Zero Emission Gas power", and is a technology for production of hydrogen and power with integrated CO_2 capture.

EFFICIENT ENERGY The pilot plant uses biogas that is converted into CO_2 and hydrogen in a reformer. Some of the hydrogen goes to a fuel cell that produces power for the grid, but most of the hydrogen can go to Hynor's filling station for hydrogen cars in the same building. Excess heat from the fuel cell is used in the reformer process, which allows the plant to achieve high thermal efficiency.

"With BioZEG, we produce both power and hydrogen, which results in return of 70 per cent of the energy in the biogas, including separation of CO_2. This is very good," says Bjørg Andresen, general manager in ZEG Power.

CLIMATE-NEUTRAL Hydrogen and fuel cells can, over time, replace fossil fuels in the transportation sector, as well as other sectors. Toyota is one of the companies investing in hydrogen and fuel cells. The company recently launched its first mass-produced car with a fuel cell in the European market.

"In practice, producing hydrogen from biogas or natural gas, while also cleaning CO_2, results in climate-neutral energy," says Andresen.

BioZEG produces a total of 50 kW today, but the company plans to gradually build larger plants in the future.

"Testing in a somewhat larger scale is a precondition for scaling up and commercialising the technology," says Andresen. "However, our experience with BioZEG is a good point of departure for the work we are doing now to design and plan a 400 kW plant."

SUCCESSFUL STORAGE ATTEMPT ON SVALBARD

PROJECT

For eight years, researchers in the Longyearbyen CO_2 Lab on Svalbard have investigated whether it is possible to store CO_2 in the geological strata on the archipelago. The results could be useful on Svalbard – and many other places.

Longyearbyen CO_2 Lab was established in 2007, and the first holes in Adventsdalen were drilled using Store Norske's drilling rig in sandstone layers to investigate whether it was possible to store CO_2 here. The Svalbard community receives lighting and heating from a coal power plant, and the idea was electricity that cleaning of CO_2 from the power plant and local storage could make Svalbard CO_2-neutral. The goal was also for the CO_2 lab to function as a testing station to obtain knowledge and test technology for future storage in other locations as well.

"The project has shown that storage of CO_2 is fully possible on Svalbard, and we have gained knowledge that is relevant for storage in other parts of the world," says professor and project manager Snorre Olaussen.

"We have drilled a total of eight wells during the project, the deepest being about 1,000 metres. We tested the reservoir properties with water injection, to mimic liquid CO_2, conducted pressure readings, 'monitored' injection rates and tested the rock strength. We also examined how the strata behave using traditional 2D seismic and micro seismic. We cannot get much further now without using real CO_2."

PHASE 2 COMPLETED Phase 2 of the project, which was supported by CLIMIT, has been concluded, and all wells have been plugged.

"The process of plugging the wells became more complicated than predicted because we encountered gas, which made concluding the project considerably more costly than budgeted," says Olaussen.

"It's a complex reservoir with very tight rocks. The storage potential is mainly related to cracks in the sandstone layer. We still believe it is suitable for storage of the small volumes of CO_2 from the coal power plant on Svalbard, and there are good cap rocks over the reservoirs that will prevent the gas from seeping out," says Olaussen. The project has applied to the Norwegian Environment Agency for permission to conduct a test using CO_2 for final verification of the storage potential.

NEW POWER PLANT However, a completely new coal power plant with an integrated cleaning facility for CO_2 capture will need to be built in order to realise the vision of zero emissions on Svalbard.

"Building a power plant with the capture facility will naturally require an investment of billions, and new wells need to be drilled, as well as facilities that are dimensioned for injection of CO_2 into the subsurface," says Olaussen.

"The research has confirmed that it is possible, but it is obviously up to the politicians and whether they are willing to support it.

Even though such a power plant may not become a reality in the immediate future, the project has provided valuable knowledge regarding CO_2 storage that will be useful for other locations."

"We have some previous experience with storage of CO_2 in sandstone reservoirs, on Sleipner and Snøhvit among others, but knowledge from this project can be valuable for parts of the world where the rocks are a bit more difficult," says Olaussen.

FACTS

Project owner: The University Centre in Svalbard (UNIS)

Project period: 2007–2015

Financing: NOK 29.1 million

Partners: SÙCCESS Centre for Environment-friendly Energy Research (FME), UiO, UIB, NTNU, SINTEF, NGU, NGI, NORSAR, Store Norske Spitsbergen, Leonard Nilsen, Baker Hughes, Statoil, ConocoPhillips, Lundin and Statkraft

TESTING MEASUREMENT INSTRUMENTS IN FIELD PILOTS

Storage of CO_2 in disposal wells underneath the seabed will be very safe, and the risk of leaks is minimal. But just to be safe, the disposal wells will be monitored with sensitive metering instruments. Such instruments have been tested in field trials in a sand pit in Svelvik.

In a sand pit in Svelvik, researchers have drilled holes down to various depths, injected small volumes of CO_2 down into sand layers underneath the ground, so the gas slowly rises to the surface. The objective was to learn how different types of measurement instruments detect CO_2 leaks.

"In reality, CO_2 storage sites will be chosen based on how safe they are, with solid rock strata that form a lid over the disposal well. We still cannot fully exclude that leaks may occur under some conditions. It is therefore important to monitor the sites," says Maria Barrio, project manager for the CO_2 Field Lab.

SENSITIVE INSTRUMENTS Any leaks that do occur will be minor, so the instruments need to be highly sensitive. We conduct tests in the laboratory, but testing out in the field like in Svelvik provides more realistic results. The first feasibility studies including seismic and ground-penetrating radar were conducted in Svelvik as early as in 2009. The intention was to determine whether the area was suitable for injection and monitoring of CO_2 movements. Injection and monitoring wells were drilled from 2011 to 2013, and injections were made at depths of approx. 20–25 metres. Seismic, geo-chemical, electromagnetic and ecological surveys and aerometry were carried out to measure the movement of CO_2.

"We also planned to inject CO_2 at greater depths, but this turned out to be impossible due to deep clay layers that would have prevented CO_2 from leaking to the surface," says Maria Barrio.

The injections were stopped in 2013, and the time since has primarily been spent analysing the results from the field trials.

VALUABLE LESSONS Though the full scope of the project was not completed this time, extensive experience and insight were obtained from the trials conducted so far.

"All measurement methods were successful in detecting CO_2 gas, and we learned a lot about advantages and disadvantages of the various measurement tools," says Maria. Both stationary and mobile measurement instruments were used, which turned out to be important to uncover exactly where CO_2 leaked out through the subsurface.

"All of the knowledge from the field trial will be valuable when we eventually get started on full-scale storage," says Barrio.

FACTS

Project owner: SINTEF Petroleum AS

Project period: 2009–2015

Financing: NOK 51.7 million

Research partners: NGI, BRGM, BGS, Geosciences and Montpellier

Industry partners: Schlumberger Carbon Services, Imageau, WesternGeco and Bureau Veritas

> Svein Eggen (Gassnova) and Erik Lindeberg (SINTEF).

DOCTORATE SEMINAR:

– YOUNG RESEARCHERS SHOW US HOW IT'S DONE!

The doctorate seminar held in Trondheim in September showed that young doctorate and post-doctoral candidates have many interesting solutions for new and innovative CCS technologies.

CLIMIT's doctorate seminar has become a tradition. Every autumn, doctorate and post-doctoral candidates gather to present their results and learn from each other.

"CLIMIT sees the importance of organising these seminars and with the level of interest and activity we are seeing – we will continue to do this," says Aage Stangeland, initiator in the Research Council of Norway.

This year's seminar was organised in cooperation with the BIGCCS research centre, and CLIMIT doctorate seminar.

FORTY RESEARCHERS About 40 young researchers participated in the seminar, which started with visiting the pilot CCS plant at Tiller. This is a world-class laboratory for testing solvents for CO_2 capture after combustion. The laboratory has played an important role in qualifying CCS technologies and offers excellent research infrastructure for researchers who want to improve their CCS technologies.

"Showing the breadth within the research is possibilities for our upcoming researchers, of which Tiller is a great example. Meeting others and learning about the different areas of CCS research within the disciplines is important for the participants," says Åse Slagtern, Research Council of Norway.

KNOWLEDGE SHARING The main focus the second day of the seminar was on presentations from the young researchers. The goal was to ensure knowledge sharing and to create a networking platform. The presentations showed that the doctorate and post-doctoral candidates have arrived at some very interesting results. The presentations covered everything from innovations within membranes for CCS to new models for storing CO_2. All presentations, including the posters shown, proved that young researchers have achieved results that will be vital for our joint effort to commercialise cost-effective CCS technologies.

NEW KNOWLEDGE Three invited lecturers held presentations that were greatly appreciated by the participants. Nils Røkke from SINTEF presented an overview of the international CCS status, Christian Gutvik from NTNU Technology Transfer gave us an insight into how research results can be commercialised, and Malin Torsæter from SINTEF Petroleum gave an inspiring lecture on the challenges and opportunities that doctoral students may face at the start of their academic career. Evaluation forms completed by the participants showed that they received new and valuable knowledge about CCS and that the networking was very useful.

PROJECT

NEW BURNER COULD GENERATE COAL POWER WITH LOW CO_2 EMISSIONS

> Tore Hatlen, Senior Adviser in Gassnova

FACTS

Project owner: SINTEF Energi AS

Project period: 2012–2015

Financing: NOK 30 million

Partners: German Aerospace Center (DLR) Germany and Alstom Switzerland Ltd, Switzerland

An important piece of the puzzle is now in place for coal power with low CO_2 emissions. The BIGH2 CLIMIT project has developed a new type of gas turbine burner.

Coal is a reasonably priced and readily available energy source in many places throughout the world. The coal can be gasified, and the resulting syngas can be combusted in power plants. This process generates CO_2, which can be captured and stored, if desirable. Syngas contains significant hydrogen, and if this gas is combusted in conventional gas turbines, it will result in high emissions of environmentally harmful nitrogen oxides (NO_x). The objective of the project is to reduce NO_x emissions to an acceptable level when combusting hydrogen-rich gas in gas turbines, without affecting the efficiency of the process.

WORLD-CLASS RESEARCH The CLIMIT supported BIGH2 project is a collaboration between SINTEF, Alstom in Switzerland and the German Aerospace Center (DLR). The objective of the project was to develop a new burner concept.

"The project represents cutting-edge research. The goals were met, and this could benefit CCS globally," says senior adviser Tore Hatlen in Gassnova and CLIMIT.

Hydrogen-rich fuel generates excessive nitrogen oxide (NO_x) emissions when combusted in conventional gas turbines. If the hydrogen-rich gas is diluted with nitrogen or water vapour, the NO_x emissions can be reduced, but this will also reduce the efficiency. This creates a need for new gas turbine burners that can use hydrogen-rich gas with acceptable NO_x emissions, without affecting the thermal efficiency.

"An increase in efficiency of 2-4 percentage points is a lot, and could be the difference between whether or not a future project is realised. In this market, suppliers are competing down to the slightest decimal point when it comes to efficiency," says Hatlen.

LOW EMISSIONS The goal of the project was to develop a new burner concept for lean pre-mixed combustion of hydrogen-rich fuels in stationary gas turbines. More specifically, the goal was to develop a new burner for the first combustion chamber (high-pressure) in Alstom's GT24/26 gas turbine. The burner also had to withstand varying loads and be able to use natural gas as back-up fuel.

The project took a basis in several proposed burner designs from Alstom. SINTEF has conducted advanced numerical simulations to identify factors that affect the performance of the burner designs. Alstom and DLR have tested burner models in various scales. The results of the tests were sent back to SINTEF for calibration of the simulation models. This iterative process has led to the testing of one burner design in full scale.

The selected design had lower emission figures than current burners. The project has thus made considerable contributions towards maturing this low-NO_x burner for hydrogen-rich fuels.

MARKET OPPORTUNITIES However, more testing is required to assess the performance before the burner is released in the market. Load variations and stability evaluations must also be included here.

Assessments are currently underway to determine the best way to continue this project.

Hydrogen-fired gas turbines, with the new "BIGH2 burners", could become an important piece of a future energy system based on hydrogen, both as an energy carrier and energy storage when renewable sources produce more than the market consumes.

KEY FIGURES 2015

The CLIMIT programme awarded a total of about NOK 179 million in project funding in 2015. Overall, 57 new projects received funding, and one project received an additional grant.

Overall disbursements for CLIMIT Demo over the year constitute about NOK 96 million, which is NOK 33 million less than the record year of 2014. For R&D, about NOK 83 million was awarded, which is somewhat lower than in 2014.

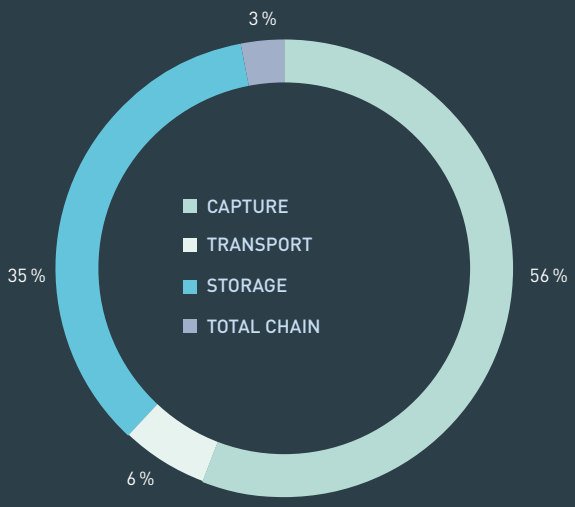
CLIMIT R&D received many applications in 2015, 51 overall, with a total application amount of NOK 464 million, which exceeded the available budget. Thirteen of the project applications were awarded support totalling about NOK 99 million. The applications received by CLIMIT were dominated by researcher projects. This reflects the challenge of motivating the industry to invest in technology development when there is no market for CCS.

It was an important year for CLIMIT Demo, as four major projects were concluded; the SOLVit programme, BIGH2, CO_2 lab Svalbard and Svelvik (all discussed in this annual report). This shows the capability to realise comprehensive and long-term projects in Norway with results that support the global CCS effort.

Internationally, CLIMIT has intensified its cooperation with both the US and the Netherlands, with a first ever announcement in both countries. This has resulted in exciting projects, with international cooperation as primary focus.

Diagrams 1 and 2 show the distribution by area (five by amount) for R&D and Demo, respectively. CLIMIT has a majority of capture projects in its 2015 portfolio. CLIMIT supports the ERA-NET Cofund effort, ACT. For this purpose, CLIMIT Demo has allocated 27 MNOK under TOTAL CHAIN. CLIMIT R&D has not allocated funds for this effort in 2015, but plans to provide an equivalent amount to support the project. Altogether, 10 partners from nine countries are participating; Norway, Germany, Switzerland, Romania, the Netherlands, the UK, Greece, Turkey and Spain. Gassnova and the Research Council of Norway are participating from Norway. The Research Council of Norway is the coordinator of the programme, which has an R&D budget of nearly EUR 43 million, of which about one-third comes from the EU. The national research support can only be awarded to respective national applicants. The entire budget is expected to be announced as a whole in 2016.

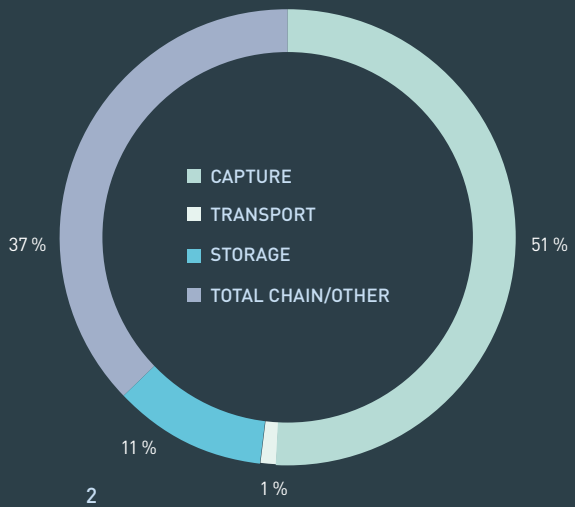
Since CLIMIT's beginnings in 2005, annual disbursements have trended upwards. The disbursements from CLIMIT R&D are somewhat below the peak year of 2012. And disbursements from CLIMIT Demo are somewhat lower than in the record year of 2014. Projects typically last from two to three years.



1

CLIMIT R&D: ALLOCATION PER AREA

ONGOING PROJECTS 2015, ALLOCATED



2

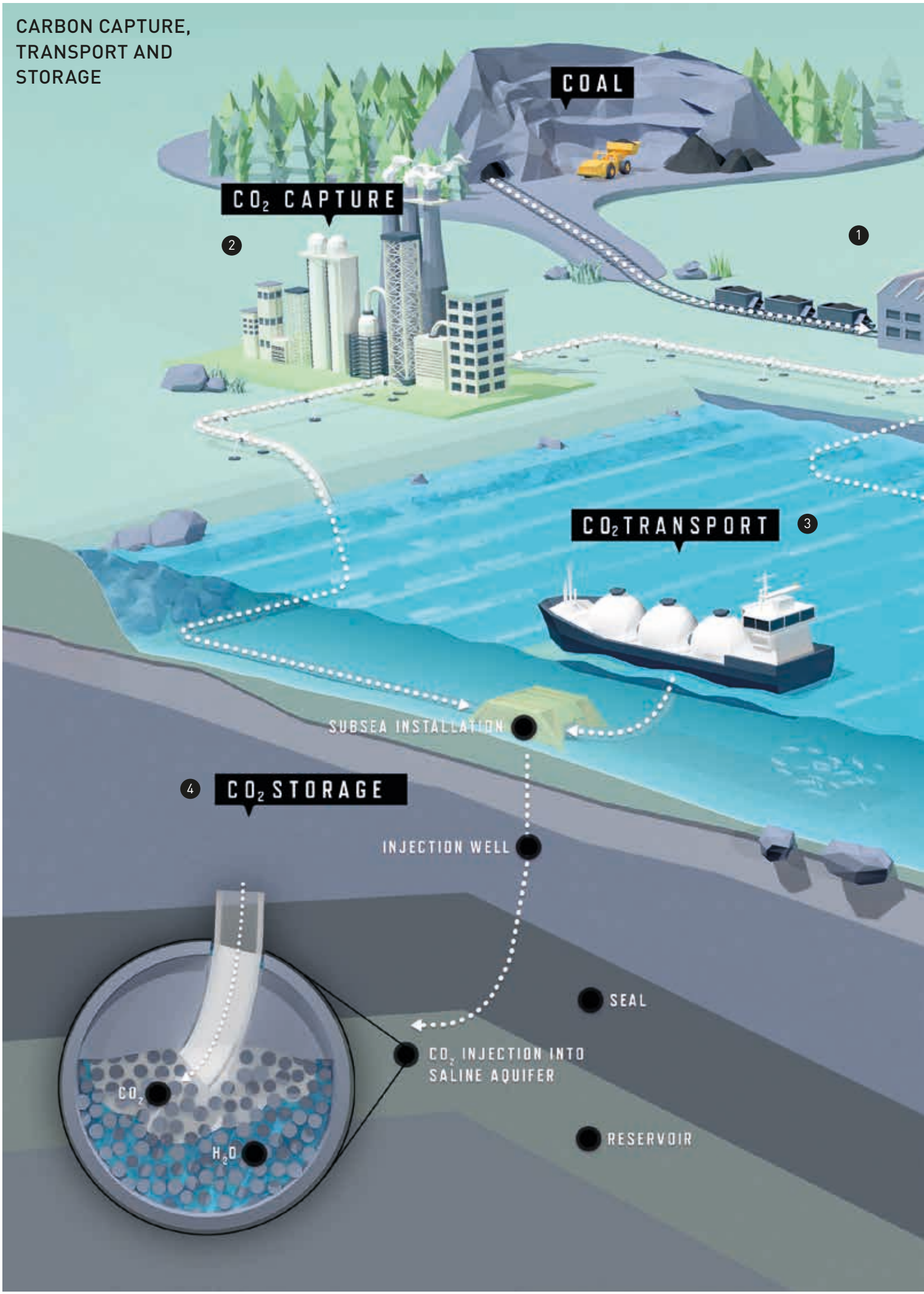
CLIMIT DEMO: ALLOCATION PER AREA

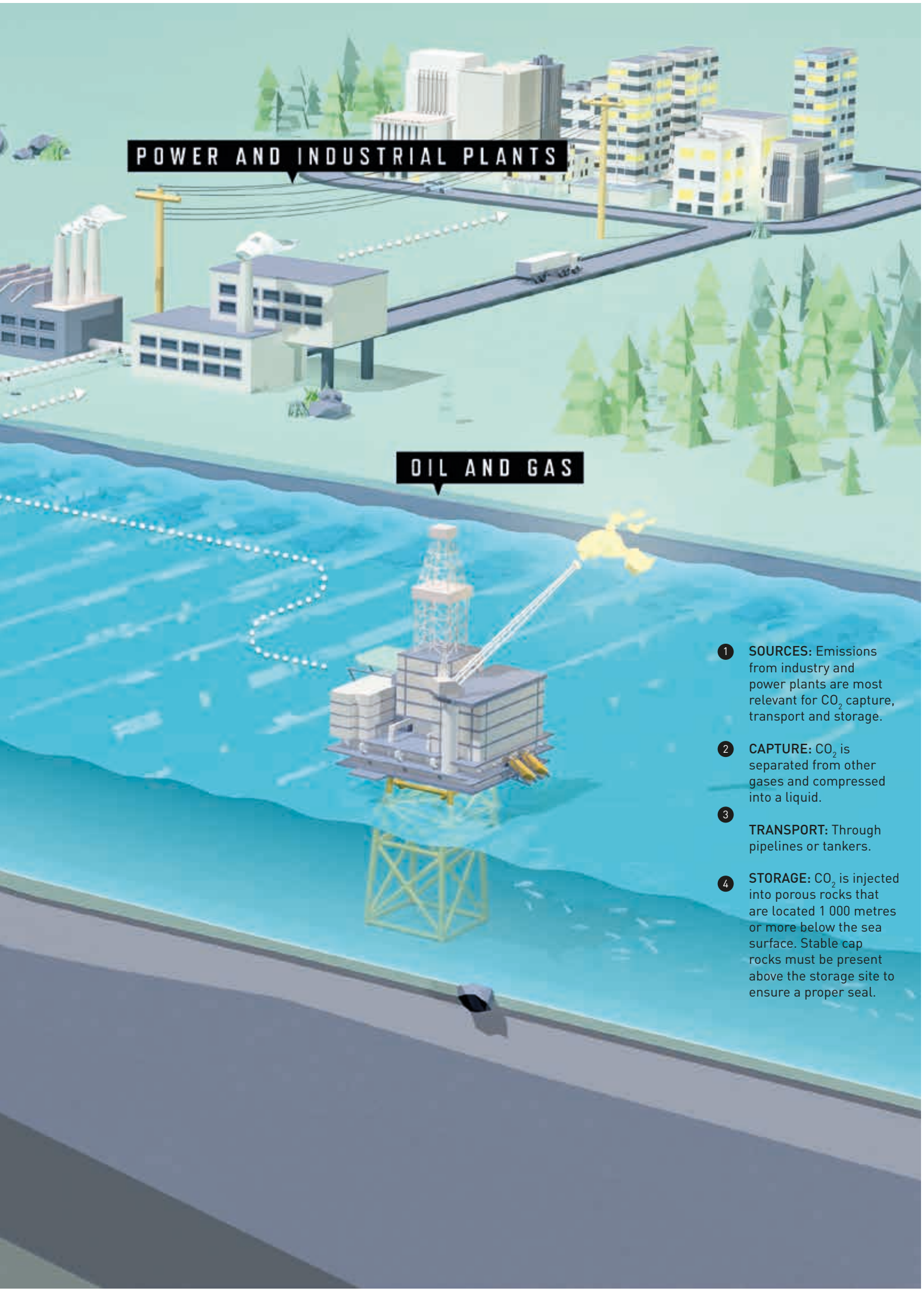
ONGOING PROJECTS 2015, ALLOCATED

3

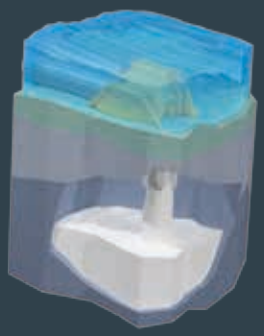
DISBURSEMENTS TO PROJECTS, R&D AND DEMO

CARBON CAPTURE, TRANSPORT AND STORAGE





1. **SOURCES:** Emissions from industry and power plants are most relevant for CO_2 capture, transport and storage.
2. **CAPTURE:** CO_2 is separated from other gases and compressed into a liquid.
3. **TRANSPORT:** Through pipelines or tankers.
4. **STORAGE:** CO_2 is injected into porous rocks that are located 1 000 metres or more below the sea surface. Stable cap rocks must be present above the storage site to ensure a proper seal.



CLIMIT 10 Years

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