# $CO_2$

CAPTURE

TRANSPORT

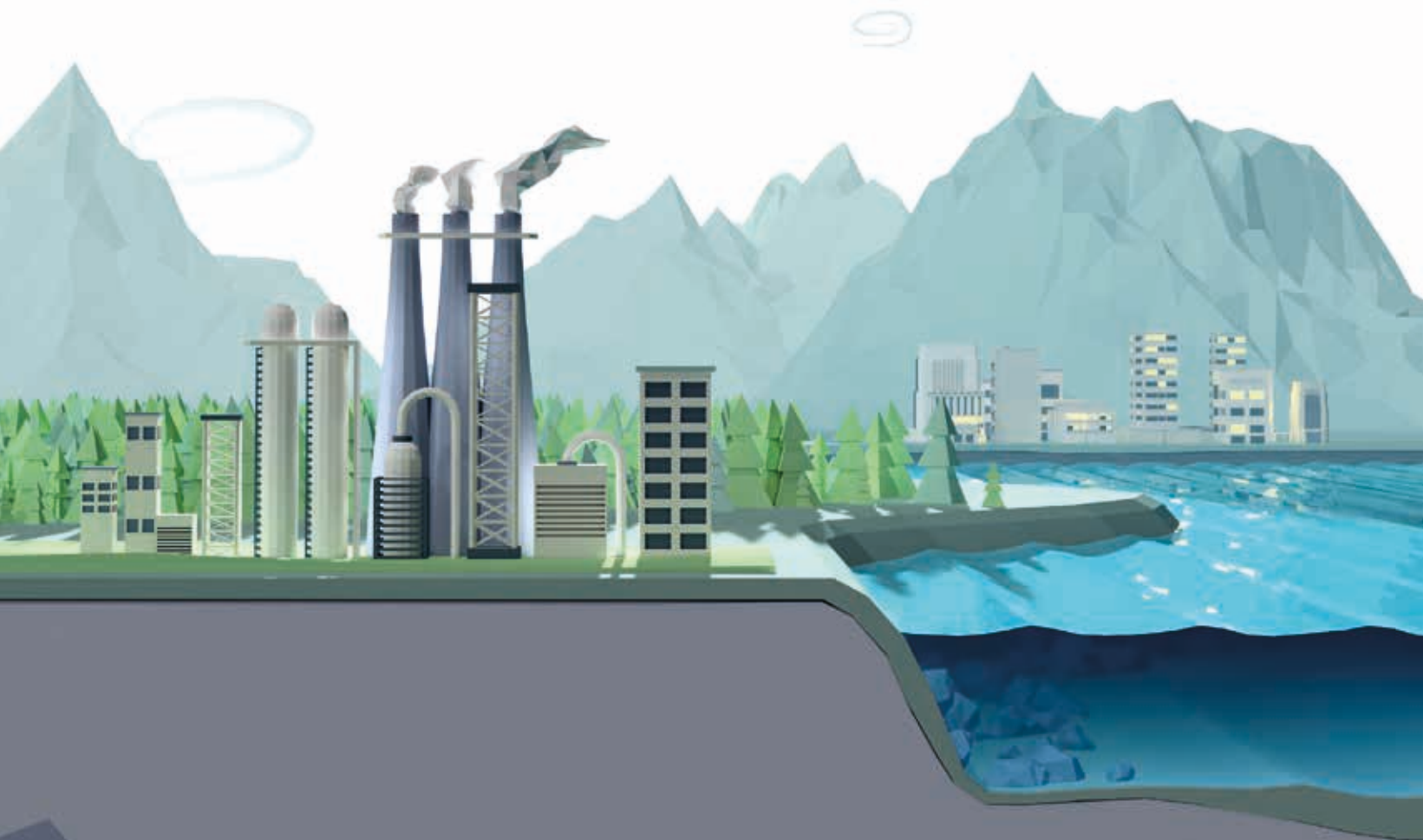
STORAGE

Tord Lien on international cooperation

Kristin Halvorsen: We need to take responsibility for emissions

Norcem wants carbon-neutral concrete

A magazine from the CLIMIT programme on CCS research



# Technology the world needs

In order to solve the climate crisis, we need to capture and store large volumes of $CO_2$. CLIMIT helps to develop this technology.

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

## 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.

CLIMIT 10 Years


**Publisher:** CLIMIT programme, for its 10th anniversary
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# This is why we need CLIMIT

*In connection with CLIMIT's 10th anniversary, we are pleased to present a portion of the programme's diversity in in this magazine.*

Climate change is a global challenge that must be met with a variety of measures. In order to prevent the global average temperature from increasing by more than two degrees, greenhouse gas emissions must be drastically reduced. We need to switch to more sustainable production and consumption, and we must use more renewable energy. The problem is that this is not enough, and progress is too slow.

The global population is increasing; general welfare and energy demand are rising. The green transition is coming, but it takes time. Fossil energy sources will still be important for several decades, with many key industries emitting greenhouse gases. This is exactly why technology for capture, transport and storage of $CO_2$ is so crucial. We will simply not be able to achieve the two-degree target without utilising this technology.

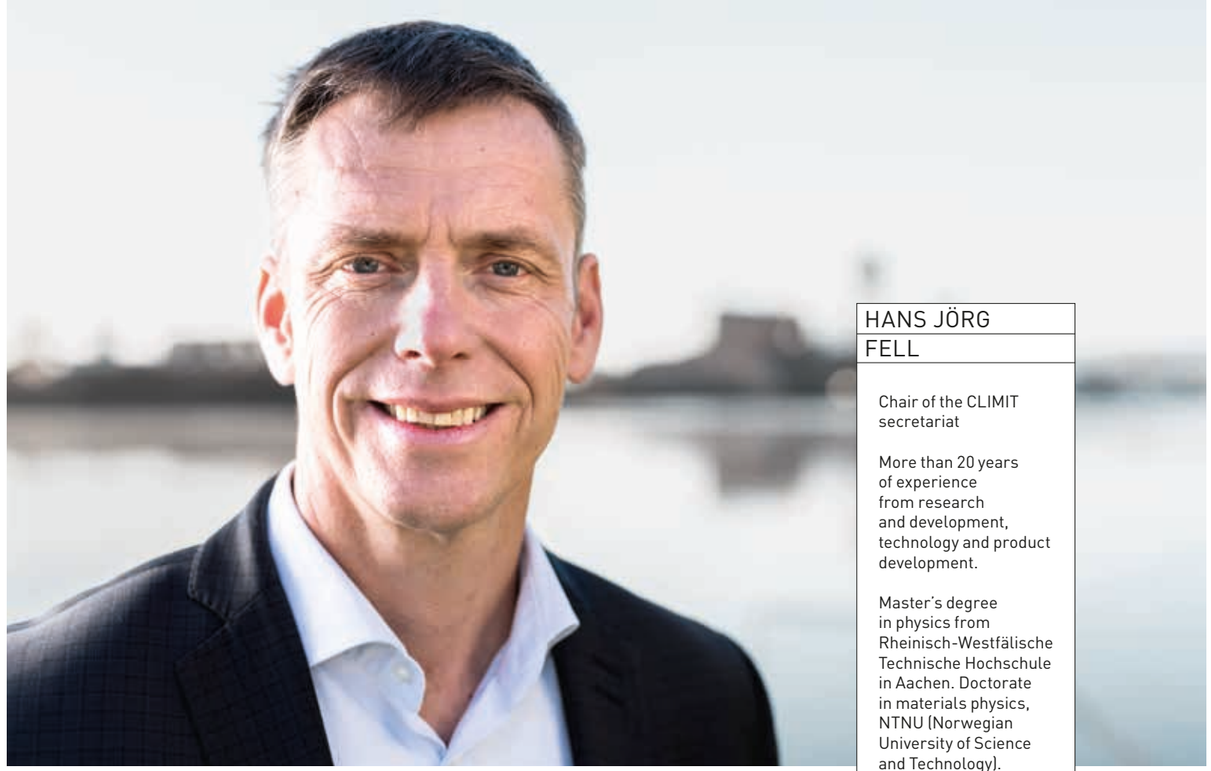
CLIMIT is one of Norway's most important contributions towards solving the climate challenges. Over the past ten years, we have invested significantly in the development of knowledge and high-level expertise. This has taken us to the forefront of international research, and made us a key player. Norway, with its continental shelf, is well positioned to handle storage of large volumes of $CO_2$. We have the best preconditions for assuming a leading role within capture, transport and storage of $CO_2$.

CLIMIT will continue to work on research and development in cooperation with the Research Council of Norway, and on pilot infrastructure together with Gassnova. This will yield even better and more competitive technologies, but it will not solve what is currently the biggest obstacle: Implementing this technology.

The first step to get started is on a full-scale pilot plant, which is part of the Government's plan by 2020. This will provide important experience for the time ahead. At the same time, policy work is needed to put commercial framework conditions into place, making it profitable to capture and store carbon. This concerns pricing emissions, introducing and reinforcing carbon tax. Norway cannot introduce this alone, but we can assume a leading role in the work for optimal international agreements and rules.

We know this is possible. The world has done it before, for example when dealing with the chlorofluorocarbons that destroyed the ozone layer, or sulphur emissions that acidified soil, forests and water. We have not yet reached a similar international agreement on carbon emissions, but we must. Because it is urgent.

**Hans Roar Sørheim**
Chair of the CLIMIT´s programme board



HANS JÖRG FELL

Chair of the CLIMIT secretariat

More than 20 years of experience from research and development, technology and product development.

Master's degree in physics from Rheinisch-Westfälische Technische Hochschule in Aachen. Doctorate in materials physics, NTNU (Norwegian University of Science and Technology).

Gassnova from 2013.

# Norway leading the way

**When CLIMIT started 10 years ago, the goal was to promote better and more sustainable technology for capture, transport and storage of $CO_2$. We have come a long way towards this goal. The technology is now basically ready for use.**

Hans Jörg Fell, Chair of the CLIMIT secretariat  Styrk Fjærtoft Trondsen

During its first ten years, CLIMIT not only advanced the research by several increments, but also contributed to developing a substantial expertise base in Norway, both in research communities and among industry partners. The close and long-term cooperation between research and industry is one of CLIMIT's unique features, and an important factor in bringing the technology out of the laboratory and into the real world. Thanks to CLIMIT, Norwegian research communities have also become highly attractive as partners for researchers in other countries.

Climate change is global and we need to find worldwide solutions. Even though reduced emissions and the transition to renewable energy are essential, development is too slow for this alone to enable us to reach the two-degree target. CCS is therefore not only a transitional technology to a carbon-free future, but a vital part of the solution to the climate problems in the near future.

Norway is a small country in the world of research. We cannot be experts in every field, but we can do our part and participate in the international research cooperation. The first 10 years have been hugely successful. The programme board will now discuss how CLIMIT can best manage knowledge and research funds in the years to come. Though research and technology are not the only answers to the climate problems, they must undoubtedly be a part of the solution.

> *We cannot be experts in every field, but we can do our part.*

The Government is now considering the possibility of a full-scale project to test the entire chain from capture and transport to storage. Such a demonstration would show that not only is CCS necessary, but also practically feasible. This acknowledgement will help create a market for $CO_2$, and thus also the technology that will handle it. Norway must be prepared. ✱



# How the technology works

**In order to avoid catastrophic climate changes, the UN Climate Panel believes that the earth's average temperature cannot increase by more than two degrees Celsius compared with the pre-industrial age.**

Morten Ryen  Headspin

Such a goal presumes severe reductions in greenhouse gas emissions, and this will not be easy. The world will be dependent on energy from coal, oil and gas for several decades to come. There are also major $CO_2$ emissions from process industries such as cement and steel. In order to limit emissions from these sources, technology to capture, transport and store $CO_2$ is crucial.

Norway is a pioneer when it comes to CCS research, and technology that is ready to use exists today.

**CARBON CAPTURE** Carbon capture involves by separating $CO_2$ from other gases that are part of industrial emissions or power generation (exhaust gases). There are different technologies for capturing $CO_2$. Some are already mature and ready for use; others will require more research and development. Technologies to capture $CO_2$ are often split into three main groups:

- **Post-combustion – separation of exhaust gas**. This method uses chemical that absorb $CO_2$ when they are exposed to exhaust gas. This method makes it possible to capture approx. 80-90 per cent of all $CO_2$ in the exhaust gas.
- **Separation of $CO_2$ before combustion.** Hydrocarbons are split into $CO_2$ and hydrogen before the actual power generation starts. The hydrogen gas is used for combustion, while $CO_2$ is captured.
- **Combustion in a pure oxygen atmosphere.** Fossil fuel is combusted in a pure oxygen atmosphere. The exhaust will then only consist of $CO_2$ and water vapour. When the gas is cooled, the water vapour will turn into water and the remaining gas will be pure $CO_2$ gas.

> *Norway is a leader in research on capture, transport and storage of $CO_2$.*

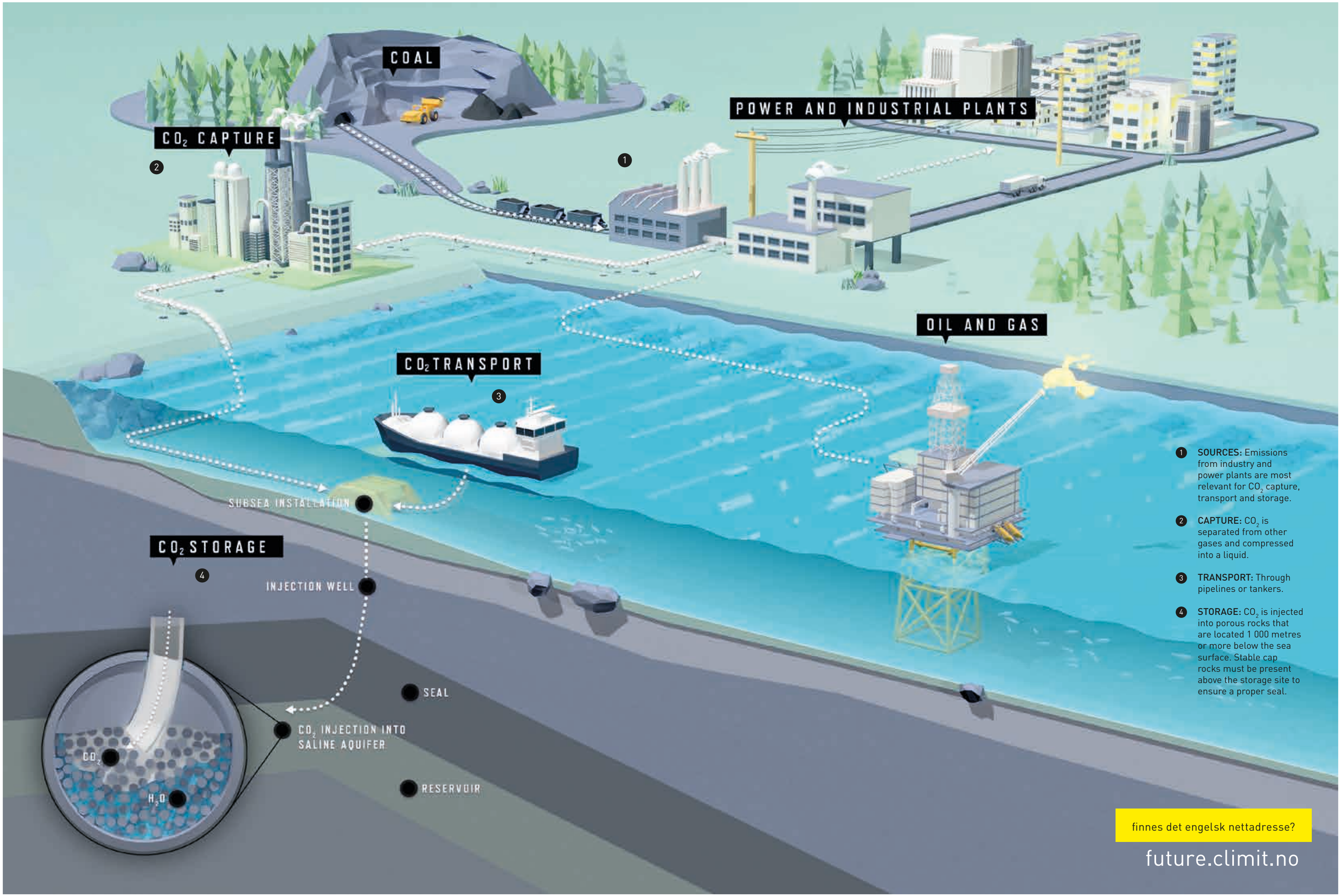
**TRANSPORT** When the $CO_2$ gas is separated and "captured", it is compressed into a liquid-like state. It can then be transported further under pressure, either via pipelines, in trucks or sea tankers to a location that is suited for permanent storage. $CO_2$ together with water has a highly corrosive effect on many metals, which is why research on transport comprises finding materials that can withstand $CO_2$. Currently, $CO_2$ transport by ship is probably the most relevant option, and is already done by Yara for sale to the food industry, among others. In the longer term, pipelines from shore to disposal sites on the Norwegian shelf may become relevant.

**STORAGE** In order for $CO_2$ capture to make sense, we need to be certain that $CO_2$ is stored in a manner that ensures safe storage. In practice, this involves finding storage sites that are deep enough in the crust for the natural pressure to ensure the $CO_2$ remains liquid. Currently, the most relevant option is to inject $CO_2$ into geological formations located one kilometre or more below the ground. The geological formations suitable for $CO_2$ storage consist of porous layers that can "house" the $CO_2$, and one or more tight rock formations on top which act as a sort of sealing, preventing $CO_2$ from leaking out, so-called cap rocks. Depleted oil and gas fields represent a relevant alternative today. The reservoirs are ready for use, and have proven that they can contain oil and gas for millions of years. Why shouldn't they be able to contain $CO_2$ in the same way? ✱

CAPTURE

TRANSPORT

STORAGE


COAL
$CO_2$ CAPTURE
2
1
POWER AND INDUSTRIAL PLANTS
OIL AND GAS
$CO_2$ TRANSPORT
3
SUBSEA INSTALLATION
$CO_2$ STORAGE
4
INJECTION WELL
SEAL
$CO_2$ INJECTION INTO SALINE AQUIFER
$CO_2$
$H_2O$
RESERVOIR
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.
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future.climit.no

*Through programmes such as CLIMIT, we have developed cutting-edge international research communities.*

# Norway is part of the global movement

**Fossil fuel will continue to be important for several decades in the future, according to Minister of Petroleum and Energy Tord Lien. Norway must therefore cooperate with other countries to develop and utilise CCS technology.**

Morten Ryen  Styrk Fjærtoft Trondsen

On our way towards a low emission society, we must increase our efforts on renewable energy sources. Nevertheless, we will also need fossil energy sources for many, many decades to come. In addition, we will still have an industry that emits large volumes of greenhouse gases in a low emission society. If you produce solar cells, you need silica, and you cannot make silica without emitting $CO_2$," says Tord Lien. He believes technology for capture, transport and storage of $CO_2$ will become essential in this regard.

**NORWAY IN A LEAGUE OF ITS OWN** The Minister is restless during our interview on an early afternoon in November. He is heading for Riyadh in Saudi Arabia in just a few short hours to participate in an international ministerial on CCS and international cooperation. "Our efforts in research and technology development are an important reason why Norway participates in such forums. Through programmes such as CLIMIT, we have developed international cutting-edge research communities, and our close interaction between institutes, industry and the authorities in Norway is quite unique," says Lien. "This is something others could learn from."

**A TOUGHER QUOTA MARKET** The development of technology for capture, transport and storage of $CO_2$ has progressed far, but power producers and industrial companies so far have too few incentives to put it to use. "Today, emitting $CO_2$ is practically 'free of charge'. This must end. We need to establish a functioning quota market as soon as possible, so that using CCS technology becomes profitable," says Tord Lien. However, he does not think the market can do it alone. "I do not believe it is realistic to achieve a quota market by 2030 that by itself is tough enough to make capture profitable in a large scale," he says. "This will come eventually, but it will take time. In the meantime, authorities in various countries need to contribute, through regulations, subsidies or support schemes."

**INTERNATIONAL COOPERATION** According to the International Energy Agency, IEA, one-sixth of $CO_2$ cuts over the next 30 years must take place through capture, transport and storage of $CO_2$. We will not achieve the two-degree target without it. "In order to make the technology more efficient and profitable, we need cooperation both in Europe and with other countries. Thanks to CLIMIT, and a strong public investment in research and technology, Norway has a lot to bring to the table," says Lien. "International cooperation gives us increased access to resources, but also to the world's best researchers within this field. With their expertise, our research communities are highly relevant partners for researchers in Canada, the US and other countries that are paving the way in CCS research."

**THE FULL-SCALE MODEL** Norwegian researchers believe it is time to test the entire chain from capture to storage in a full-scale project. Tord Lien agrees that this is necessary to verify whether the technology works in practice. "We already have the world's largest test centre for $CO_2$ capture at Mongstad, and there are also operational plants in the US and Canada as well. We will absolutely work towards a full-scale plant here in Norway too, but it will be challenging to achieve this by 2020. I also believe it is more important that we do this thoroughly, rather than quickly," he says. "This isn't the world championship. It's an international movement." ✱

TORD LIEN

**POSITION:** Minister of Petroleum and Energy (Progress Party)

**CV:** Former member of the Standing Committee on Energy and the Environment (2005–2009) and the Standing Committee on Education, Research and Church Affairs (2009–2013).

Cand. Phil with a major in history, minor in political science and international affairs.

# Wants to become the world's cleanest cement plant


> Aker Solutions' mobile test plant is modest compared with the plant in Brevik. A full-scale plant would take up considerably more space and require partial modification of the cement plant.

**Everyone who has visited Brevik in through Telemark county, is familiar with the large grey silos at Norcem's cement plant in Brevik. Large volumes of $CO_2$ are emitted from this plant every year. The company wants to do something about this.**

Morten Ryen  Styrk Fjærtoft Trondsen

The cement industry is responsible for about five per cent of global $CO_2$ emissions, and Norcem's cement plant in Brevik, in Telemark, is the largest single source in mainland Norway. The 800 000 tonnes that are emitted through these pipes each year, are equivalent to emissions from all vehicular transport in Norway in one month. Norcem wants to change this, for example by cutting emissions of $CO_2$ from the exhaust gas in Brevik by half. "We have a vision of zero emissions from our products in a lifecycle perspective," says Liv Margrethe Bjerge in Norcem. She has been Norcem's project manager for the project, where different technologies for $CO_2$ capture have been tested at the plant in Brevik. "We cannot achieve this by only removing $CO_2$ from the exhaust gas, it must be combined with measures that include energy-efficiency, $CO_2$-neutral fuel sources and changes in the production process," she says. Part of the equation also entails that finished concrete over time will bind substantial volumes of $CO_2$ through so-called carbonisation.

**UNAVOIDABLE EMISSIONS** Norcem´s target is ambitious, because it is currently impossible to produce cement without emitting vast volumes of $CO_2$. It is also difficult to imagine a world without cement, the most important ingredient of concrete, which is used for everything from roads, bridges and buildings to quay facilities and airports. "There are two $CO_2$ sources in the cement production," says Bjerge. "Two-thirds come from the limestone that is the raw material for cement production. Limestone contains about 60 per cent $CO_2$, which is released when the limestone is crushed and combusted. The last third of the emissions comes from fuel for the incinerators. Because cement production requires such high temperatures, it has been common to use coal for the incinerators. Norcem has worked for a long time to reduce emissions from its own plant, and made significant progress by switching to pellets and waste, which are $CO_2$-neutral. The company now wants to reduce emissions even further, by targeting the exhaust gas from the production. "Norcem initiated this project itself," says Bjerge. "It started by us mapping the knowledge status of known technology for $CO_2$ capture, to find out whether any of it could be used at our plant. We ended up with four technologies that we believed were promising for testing."

**SUCCESSFUL TESTING** The company applied to CLIMIT for funds to establish a test centre, and contacted researchers working with the CLIMIT programme through other projects at NTNU and the Telemark University College, respectively. The various capture technologies have been carefully tested with regard to both efficiency and costs over the past two years. "As far as I know, this is the only place in the world where the technologies are tested on real exhaust gas from cement production. It was important to us →


> OPTIMIST: Project manager Liv Bjerge is optimistic about the possibilities of a full-scale plant at the cement plant in Brevik.

**FACTS**

NORCEM

With support from CLIMIT, Norcem established a small-scale $CO_2$ capture test centre at the cement plant in Brevik.

The test centre studies various technologies for $CO_2$ capture and assesses their suitability for modern cement plants.

The project runs from May 2013 to March 2017.

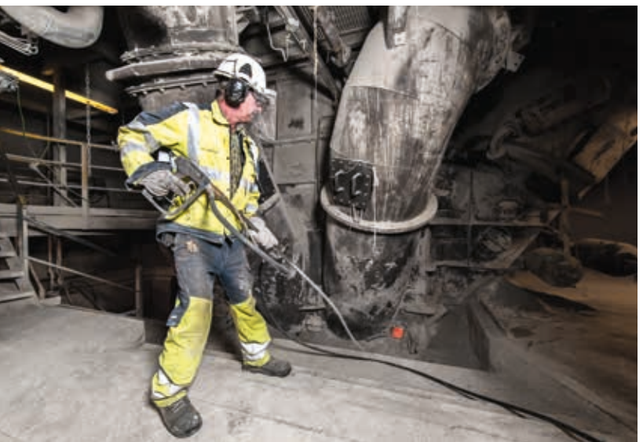
Four different technologies are tested:
> Aker Solutions
Amine technology
> RTI
Solid sorbents
> DNV GL/ NTNU/ Yodfat Engineers
Membrane technology
> Alstom
Carbonate cycle

that we would be testing in a real situation, not just in a laboratory," says Liv Bjerge. All of the technologies yielded good results for $CO_2$ capture, but they have different demands as regards no space, adaptation and energy required. "We have tested both membrane technology and solid adsorbents, and several technologies could be relevant for our industry in a somewhat longer perspective. The most mature technology, in a 2020 perspective, is Aker Solutions' amine technology. We therefore chose to go further with this technology," says Bjerge.

**ENERGY-INTENSIVE PROCESS** $CO_2$ capture with amine technology is thus a method that is ready for use now, but it is energy-intensive, which is a bottleneck for Norcem. "If we were to capture all $CO_2$ in the production, we would need to build a separate power plant, and that can hardly be the way to go. We have therefore looked at the possibility of using waste heat from the cement production, and this seems promising. It looks like the waste heat provides enough energy to be able to capture 400 000 tonnes, which entails a reduction of half of the emissions from the plant without increased energy costs." Aker Solutions concluded its research project with Norcem in October 2015. They will now conduct a feasibility study to map weaknesses and risks of a full-scale plant. After the feasibility study is concluded, Liv will have a decision basis to present to the parent company in Germany. "What we are doing in Brevik not only affects us, it will provide important experience and valuable lessons for both our group and the global cement industry."

**STORAGE CHALLENGES** Norwegian authorities have the ambition to realise at least one full-scale demonstration plant by 2020, but Liv Bjerge thinks this is a tight deadline. "There is currently no permanent solution for storage of $CO_2$, and this is sorely needed. In order to move on with this, it needs to be a permanent solution, not just tests lasting a few years. Moreover, we cannot take responsibility for transport and storage of $CO_2$. This is why the authorities must act," says Bjerge. She is still both enthusiastic and optimistic about the future. "I hope and believe we can achieve this in Norway. It is important that someone leads the way and gets the ball rolling. No one will compete with us on more environmentally-friendly concrete." ✱

> HAPPY: Istvan Stiller has worked at the cement plant in Brevik for nearly 30 years.



> HOT: High temperatures are required to turn limestone into cement.

# Testing technology at Tiller

**When using new technology, it makes sense to test on a small scale first, which is exactly what they are doing at SINTEF's $CO_2$ lab at Tiller outside Trondheim. The method for capturing $CO_2$ at Mongstad and in Brevik was first tested here.**

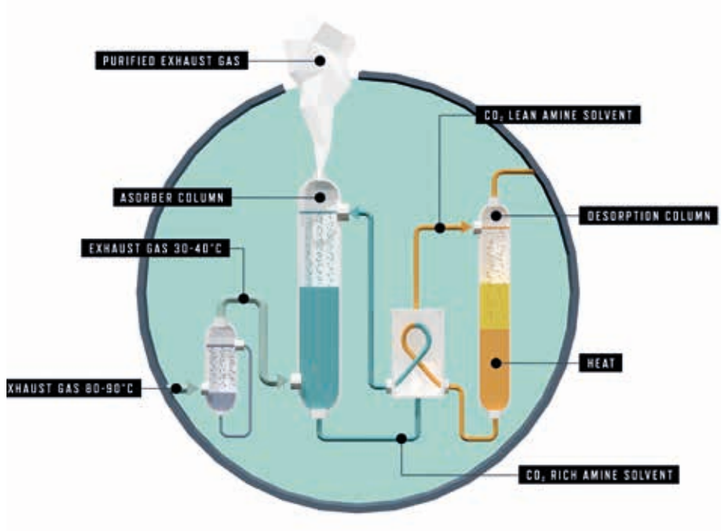
Morten Ryen  Geir Mogen

If you drive south from Trondheim along county road 885, you will spot a tall, white building above the trees on the other side of Nidelven (river) after about ten kilometres. The building boasts the name "SINTEF" in big letters, which confirms that this is the site of some type of research or laboratory activities. This is "Tillerriggen" (the Tiller Rig), SINTEF's $CO_2$ lab.

**"THE TILLER RIG"** Such a tall and towering building may seem out of place in the rural surroundings, but there is a good reason for this. On the inside is a 28-metre tall absorption tower that is used for $CO_2$ capture. "We can test $CO_2$ capture from various exhaust gas sources (industry, gas power plants or coal power plants) from the facility," explains Mejdell. Mejdell is responsible for daily operations and the test campaigns conducted here. "We use amine technology, which is an established and well-known technology. The tests are about making the process as efficient and environmentally-friendly as possible, while also reducing costs."

**CONTROLLED SURROUNDINGS** The $CO_2$ lab at Tiller was established in connection with the SOLVit research programme, of which SINTEF, NTNU and Aker Solutions are partners. The Tiller rig is partially financed with support from the CLIMIT programme. "Though this facility is quite large, it is still miniature in comparison to how a full-scale facility at a cement plant or gas power plant would look," says Mejdell. "The advantage here is that we can influence various parameters in the process in a controlled laboratory setting, and the trials will also be considerably less expensive than they would be in full-scale."

**SIMPLE TECHNOLOGY** The campaigns mostly involve testing various solvents, →




> CARBON CAPTURE: The exaust gas is first chilled before it is added to an amine mixture in an absorption tower. Cleaned exhaust gas is emitted, while the amine mixture saturated with $CO_2$ is led to a desorption tower where it is heated so that $CO_2$ is separated out. $CO_2$ is collected for storage. The amine mixture is transported back, and the process repeats.

which are the chemical liquids used to bind $CO_2$ in the exhaust gas. "The solvents are a mixture of different chemicals with varying abilities to absorb $CO_2$, and they also set different demands on energy consumption. In the SOLVit project, we tested numerous solvents in the lab to find the ones most suitable. The best were then tested here, before being tested in a larger scale, for example at the Technology Centre Mongstad and Norcem's cement plant in Brevik," says Mejdell. The method for capturing $CO_2$ with amine technology is relatively simple. Exhaust gas is released up through the tower, and the solvent is added from the top. Internally, the 28-metre tall absorption tower is supplied with a special packing material that helps create the best possible contact between the solvent and exhaust gas. When the solvent is saturated with $CO_2$ after having passed down through the absorption tower, it is heated to release the $CO_2$. The gas is compressed and collected in tanks, while the solvent is pumped back in for re-use.

**ADAPTED TO THE SOURCES** The technology must be adapted to the various sources, but the method is otherwise ready for use – whether on exhaust gas from industry, gas power plants or coal power plants. "Exhaust gas from a cement plant like the one in Brevik contains 15–20 per cent $CO_2$, while emissions from a gas power plant are only 3–5 per cent $CO_2$. In addition to $CO_2$, coal power plants contain a lot of sulphur. We are therefore also developing technology that can capture sulphur from the exhaust gas," says Mejdell. "Overall, we have come very far with development of this type of capture technology. The biggest challenge now is getting an economy and infrastructure into place that makes it possible to store large volumes of $CO_2$." ✱

# CCS is a key element in securing the values on the Norwegian continental shelf

**"The petroleum industry needs to be more pro-active and take greater responsibility for the $CO_2$ emissions they cause," according to Nils A. Røkke, executive vice president sustainability at SINTEF. Carbon capture and storage can give natural gas a longer life in the low emission society.**

"If there is one country in Europe that should be interested in CCS, it is Norway", says Nils A. Røkke. "Being a major petroleum exporter, we implicitly emit 11 times more greenhouse gases than we emit on own turf. These are emissions we do not include in our national emission budget and is thus an issue the buyer has to deal with. It's hard to imagine that to be a permanent solution" compensation for the cost of emissions will be sought upstream the value chain.

**NOT JUST A TRANSITION** Røkke has worked with $CO_2$ issues for several years, both as a researcher in SINTEF and as a previous member of the programme board for the CLIMIT research programme. He believes CCS is an essential technology in order to achieve the global climate goals, and a unique opportunity for Norway. "Many talk about CCS as a transitory solution, almost as a necessary evil on the way to the low emission society. It is much more than this. Particularly for some industry segments, CCS is the very solution for deep emission cuts. Energy intensive industries such as fertilizer, cement, glass and steel have few other options for deep emission cuts than CCS. As an example we do not know how to make cement without releasing $CO_2$, this is the very basis of the process.

Making natural gas an attractive option also for a carbon, restrained Europe is possible. We just need to deliver a product where the $CO_2$ emission are offset or removed. The technology can give natural gas a longer lifetime in the low emission society. "When we started CLIMIT, our mandate was 'fixing' the problem with $CO_2$ emissions from gas power plants. The idea was that Norway would have $CO_2$-free gas power plants and would sell the energy to Europe. CCS can increase the value of the Norwegian oil and gas activities, but in order to do this we must acknowledge our challenges, and seize the opportunity to do something about them. Now." If natural gas is to appear as a sustainable alternative, Røkke believes we should store as much $CO_2$ as the gas causes. "Europe needs our gas, but they do not need the emissions," he says. Next, he imagines that we can use the natural gas as a raw material to produce hydrogen directly on the platforms, and sell pure hydrogen to Europe. Both scenarios presume injection of $CO_2$ in the subsurface.

**NOW OR NEVER** Røkke believes it is crucial that we handle the $CO_2$ problem if we want to continue selling Norwegian natural gas to Europe. If not, he fears the oil and gas industry will experience the same decline as the coal companies. "Just a few years ago, the coal companies were raking it in, but then the energy revolution arrived in Europe. Now, no one wants coal if they can avoid it," says Røkke. "They had a chance to invest in CCS technology. They had the money. Now it seems as if it may be too late." He fears that the authorities and the Norwegian oil and gas industry are not fully acknowledging the new realities quickly enough. "There is no such thing as 'business as usual' in the energy and climate revolution we are in the midst of. The time of denial is over." ✱

> Oscar Graff in Aker Solutions elieves the support from CLIMIT was essential in allowing them to get as far as they have with the technology.

# Saw the commercial potential early on

**Aker Solutions has been a key initiator for turning research-based knowledge into practically useable technology. After about seven years of research and testing, the company now has capture technology that is ready for the market.**

"We saw already in 2005 that $CO_2$ capture would catch on, and thought that we as technologists may have something to contribute," says Oscar Graff, technical director in Aker Solutions. The company quickly concluded that subsequent cleaning of exhaust gas was the technology they knew most about. "It was also the technology we had the most faith in. It is flexible, robust and we thought it would be leading for the first decades," says Graff.

**CRUICIAL TESTING** Aker Clean Carbon (now wholly owned by Aker Solutions) was established in 2007 and entered into a partnership with SINTEF and NTNU at around the same time. Together, they applied for funds from CLIMIT in 2008. This became the start of the SOLVit research programme, which would develop and test new, improved chemical mixtures that can bind and release $CO_2$. "It was essential for us to have research partners with solid expertise. In addition, we have educated several PhD, postdoc and master students in the programme. We also wanted a test facility that could be used to test real, industrial exhaust gases," says Graff.

"This was why we built our mobile capture plant (MTU) in 2008, which most recently has been testing for 18 months in Brevik at Norcem's cement plant." The Tiller rig, or SINTEF's $CO_2$ lab, was also constructed partially with funds from SOLVit. This has been important for testing the properties of the various solvents in a controlled setting. "We have tested about 90 different solvents to find the best and most cost-efficient options for different types of exhaust gas," says Graff. Thanks to SOLVit, the company currently offers solvents with very low degradation, and that are many times better than previous solvents.

**IMPORTANT INDUSTRIAL PARTNERS** It has always been important for Aker Solutions to have key industrial partners, in addition to the research communities. "The fact that an external player wants to take part is always a good test to see if we are on the right track. That is why we have always had key industrial partners from the user side taking part, such as EnBW, Statkraft, Scottish Power and E.ON," says Graff. "The support from CLIMIT has also been crucial. Without it, we would not have made it this far, and it would have been considerably more difficult to get industrial partners." Graff believes we have come far on research and development of carbon capture in Norway, but believes it is vital that commercial plants are built in order for the industry to keep developing in Europe. "For Aker Solutions, the technology is relevant for cleaning industrial emissions, natural gas and for use in improved oil recovery. We have expertise and experience along the entire value chain, but it is not currently profitable," he says. "The framework conditions are not in place". ✱

# Reinertsen wants to be part of the solution

*The plan is to have a commercial product ready in early 2017.*

**Imagine a future where natural gas from the North Sea is transformed into clean hydrogen, and the $CO_2$ gas that remains is pumped back into the reservoir. Reinertsen believes they can achieve this with an ultra-thin palladium membrane.**

Morten Ryen  Geir Mogen

Torkild Reinertsen and Frode Roness are sitting in a roomy corner office, with an unobstructed view of Munkholmen and Trondheimsfjorden, with a 20-cm glass tube in their hands. On the inside is a steel pipe clad in something resembling aluminium foil. "This is the future," says Reinertsen.

**GREEN BUSINESS** Reinertsen AS is a family-owned engineering company, founded just after World War II. The company, which currently has about 2 500 employees, delivers everything from advanced offshore technology, to consulting engineering services. Though a declining oil price has made things tougher for the company recently, Torkild Reinertsen is convinced that oil and gas will remain important in the future. "There are a number of markets and applications where there are no alternatives today, so we will need oil and gas for several decades in the future. However, the climate problem is real enough, which is why we must make this industry as clean and sustainable as possible," he says. This is where the little glass tube comes in.

**PALLADIUM MAGIC** The shiny metal may resemble aluminium, but it is entirely different. It is a thin film of palladium – a rare and very expensive element with unique properties. Only hydrogen atoms can pass through the film, while $CO_2$ and other gases are left behind. When the film is placed over a porous pipe which gas is sent through, hydrogen will be separated through the membrane. The technology can thus be used to produce hydrogen without emitting $CO_2$. Reinertsen wants to use the technology for $CO_2$ capture in gas power plants. The next step will be to test the technology at Statoil's methanol plant at Tjeldbergodden. "Several years have passed since we first contacted SINTEF and NTNU for help with $CO_2$ capture," says Frode Roness, who headed the project. "They proposed using a palladium membrane. However, the existing membranes were too thick to use practically in a large scale. The challenge has therefore been making the membranes as thin as possible, and large enough. We have achieved this, thanks to an A-team of SINTEFs researchers and support from CLIMIT. Now we can produce one square metre at a time." The film is placed over porous pipes that are assembled into modules. Only the number of modules limits the cleaning capacity.

**URGENCY** Though the technology is not new, Reinertsen has a competitive advantage by having the thinnest and most effective membrane. In order to keep this advantage, they need to get to the market as soon as possible. "The plan is to have a commercial product ready in early 2017, or perhaps even late-2016," says Torkild Reinertsen. "Our hope is then that many customers will test the technology in their existing plants. Though this is primarily intended to be a cleaning technology, it could very well become relevant for producing hydrogen. Hydrogen can be used for both energy production and as a fuel in the transport sector, and has the benefit of the only 'waste' being clean water. Traditional hydrogen production through electrolysis, however, is very energy-intensive, which is not necessarily the best thing for the environment. The palladium technology requires little energy. "Imagine using this technology on platforms out in the North Sea. This allows us to produce hydrogen in large quantities, while also injecting the surplus of $CO_2$ directly down into the oil and gas fields where it will contribute to a higher recovery rate before being permanently stored," says Torkild Reinertsen jubilantly. "Then we could achieve 'low carbon' gas business that are also sustainable in a low emission society. ✱

## PALLADIUM TECHNOLOGY

- Developed at SINTEF since the early-1990s.
- $CO_2$ is separated using a 1.5-micrometre thick membrane made from palladium alloys.
- The technology has been validated and developed in cooperation with oil companies via several EU projects and projects supported by the Research Council of Norway.
- A 400 MW power plant will require a membrane area of 11 000 $m^2$.

# The Norwegian shelf can become Europe's $CO_2$ storage

**If Grethe Tangen at SINTEF gets her way, Norway will fill depleted oil and gas fields with $CO_2$ from all of Europe. This not only lightens our conscience for all the oil and gas we have produced, but it could also be profitable.**

For more than 45 years, we have provided oil and gas from the Norwegian continental shelf. This has made Norway a rich country. Now, we may secure our future welfare by filling the empty reservoirs and vast sandstone formations with all the greenhouse gas that Europe wants to get rid of. "If the large-scale CCS projects fail to appear, it won't be for a lack of technology," says Grethe Tangen, senior scientist at SINTEF Petroleum Research, and head of the project "Basis for large-scale $CO_2$ storage on the Norwegian shelf". The project has looked into the possibilities of starting such storage as early as 2018.

"We know how to capture $CO_2$, we know how to transport it and we know how to inject it under the seabed. There are no technical obstacles. If the price for emitting $CO_2$ is high enough, the need for storage will come."

**BIG PICTURE THINKING** A number of research institutions develop technology for capture, transport and storage of $CO_2$. Grethe Tangen and her colleagues endeavour to see the big picture and the realism of a full-scale CCS project. "In order for this to work in practice, someone must be able to identify risks and challenges along the entire chain," she says. "How should $CO_2$ from industry be treated before it is transported by ship? At what temperatures should gas be injected? Will the gas stay in place after injection? How can we prevent leaks? What can we do if something unexpected happens? We need to ask these types of questions. It is also important to look at the consequences of alternative decisions and changes in various parameters. Does it create problems? Does it have consequences for profitability?"

**OPTIMIST** Though there undoubtedly are many challenges, Grethe Tangen is exclusively enthusiastic about the possibility of storing $CO_2$ from Europe on the Norwegian shelf. "CCS is an indispensable part of the solution to the climate change challenges. When you look at the volume of $CO_2$ that must be stored in order to reach the two-degree target, you may get discouraged. At the same time, I am more optimistic than ever. We can do this if we want to. We have demonstrated that it is possible, and we have the natural conditions in place for being able to store nearly unlimited volumes of $CO_2$. We also have the experience from offshore oil and gas activity that will be important to achieve this in practice. Thus, we have a unique opportunity to do something that makes a difference in the big picture. Not just for Norway, but for all of Europe.

**DEADLINE** The technology push is critical to maintain momentum in CCS, as there is no market clamouring for solutions. "This is exactly why CLIMIT has been so important. We have been able to work with technology development in a long-term perspective without being dependant on market demand," says Tangen, who believes we need to carry the ambitious thinking further. "The projects must be of such a dimension that they have a real impact. We know it is possible, and now we must decide to do it. We can be ready with storage capacity when the market comes. But we need to hurry, because it could take as much as five to ten years to prepare a storage site on the shelf."

> *CCS is an indispensable part of the solution to the climate change challenges.*

**NEED TO TAKE THE LEAD** She believes Norway should take a leading role both in the development of the technology and in establishing the framework conditions required to create a market. No other nation has better preconditions. "Denmark has positioned itself in wind power, Germany in solar energy – Norway could become Europe's $CO_2$ storage. This is an area where we are very knowledgeable and the results will benefit us if we are successful. It is essential for Norway to secure the values on the Norwegian shelf, but also to embark a transition into an economy that is less dependent on oil," says Tangen. "I believe CCS is a key to fulfil both these ambitions." ✱

> Grethe Tangen, senior scientist at SINTEF Petroleum Research, believes Norway should use depleted oil and gas reservoirs to store $CO_2$ from all over Europe.

> Philip Ringrose at Statoil is confident that it can be entirely safe to store $CO_2$ underneath the seabed.

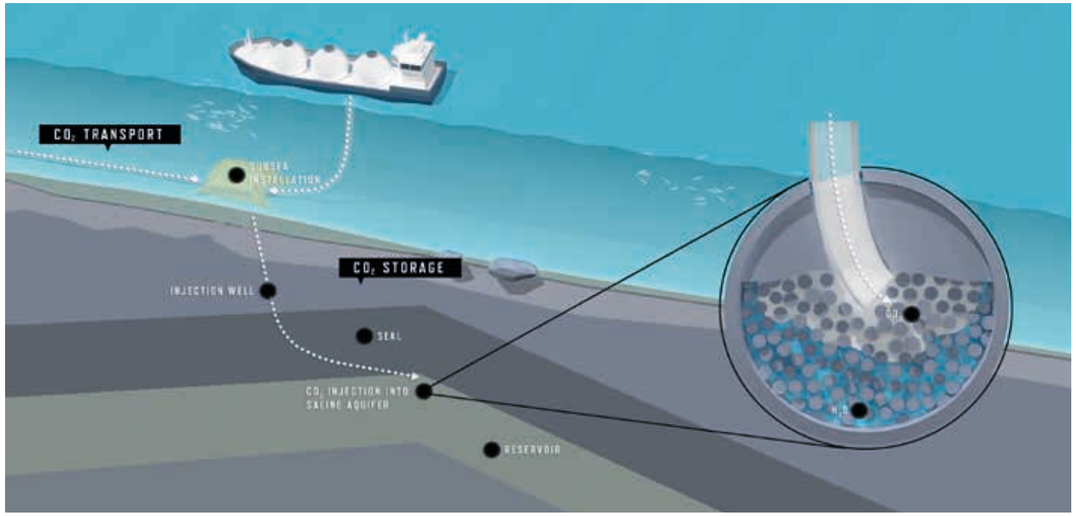
# Storage expert

**Many think it sounds risky to store millions of tonnes of $CO_2$ underneath the seabed. How is it done? Is it safe? What if it leaks out? Philip Ringrose at Statoil can put these concerns to rest. He explains that storage has already been done for 20 years.**

Ringrose is a petroleum geologist in Statoil and Adjunct Prof. at NTNU, and one of Norway's top experts on $CO_2$ storage. He has taken part in storing $CO_2$ underneath the seabed on both Sleipner and Snøhvit on the Norwegian shelf, and in underground reservoirs in In Salah in Algeria. "This type of storage is based on much of the same knowledge that we have from recovery of gas and oil, but technically it is a bit more complicated. It also requires considerable investment in infrastructure if it is to be done on a large scale."

**WANTS TO INSTALL PIPELINES** Ringrose believes the only realistic scenario for large-scale storage is transporting $CO_2$ from shore and to the continental shelf by pipeline. The actual injection process requires accuracy and monitoring, but Ringrose believes the $CO_2$ can remain safely in place once injected. "Many are concerned about whether $CO_2$ can leak out through faults or cracks, or create earthquakes, but research shows there is little risk of this." According to Ringrose, there is nothing in the way of starting to store $CO_2$ at a large scale now, but it has a price – which someone must pay. "$CO_2$ storage will naturally increase the price of fossil energy sources compared with no storage. However, if you compare the energy costs with renewable sources such as wind power or solar energy, it is actually competitive," he says.

**SOMEONE HAS TO PAY** Ringrose believes that Norway, thanks to CLIMIT, is a leader within $CO_2$ storage research, but unfortunately the US and Canada are passing us when it comes to practical application. They have come a long way in using $CO_2$ to recover oil, so-called enhanced oil recovery (EOR), along with storage. "EOR can to some extent pay for the $CO_2$ storage. With other types of storage, the costs will likely have to be incorporated into the energy price," says Ringrose. "Luckily, I am a technologist, not a politician. If the authorities want to store $CO_2$, I can tell them how it is done. I don't have to decide about who pays the cost." ✱




> **STORAGE:** $CO_2$ is injected into porous rocks deep underneath the seabed. There must also be a stable cap rock located over the storage unit that provides a seal.

**FACTS**

ENHANCED RECOVERY

> EOR can make it possible to recover another 300 million cubic metres of oil on the Norwegian shelf.

> This corresponds to 10 per cent of what has already been recovered.

> The reserves could be three times this on the UK shelf.

> Pål Helge Nøkleby in Aker Solutions believes Norway is very well positioned for conducting EOR offshore

*We can probably store considerably more $CO_2$ than the oil we are recovering will represent.*

# Want to use $CO_2$ to recover more oil offshore

**Aker Solutions has extensive expertise within offshore technology to recover oil and gas. They now want to use their experience to extract even more from the fields by injecting $CO_2$ into the reservoirs. All of this will take place on the seabed.**

$CO_2$ from fossil fuels is considered one of the causes of global warming. Does this make it a good idea to use $CO_2$ to extract even more oil from the reservoirs? Pål Helge Nøkleby, director of business development in Aker Solutions, believes it is. "It may sound like a paradox, but there is technology that could give a reduced carbon footprint for the extra produced oil, as much of the injected carbon dioxide will remain in the reservoir. We can probably store considerably more $CO_2$ than the oil we are recovering will emit when combusted. This is done by using the oil reservoir as a $CO_2$ storage in a phase following the commercial oil production," says Nøkleby.

**KNOWN METHOD EOR** – or enhanced oil recovery – is a method that has been known and used to recover oil for 40 years, for example in the US, but for recovery on shore. The method has never been used in a commercial context offshore, for various technological and cost-related reasons. Together with Statoil and CIPR, Aker Solutions has developed a technology concept that could help realise offshore-based $CO_2$ EOR. "What we are proposing is injecting $CO_2$ from vessels down into the reservoir, while simultaneously handling the $CO_2$ that returns with the oil flow in a seabed installation," says Nøkleby. "Now we need to get started on testing, so we can document that it will also work in full-scale."

**USES EXISTING EQUIPMENT** Aker Solutions' concept for offshore EOR has several advantages. They can use many of the equipment components they already use for subsea oil and gas production, such as the Åsgard subsea compressor technology, but assemble the elements in new ways to achieve a functioning production line. "The concept naturally comes with its own set of challenges. We therefore want to test this properly as soon as possible, so the method can hopefully become part of a full-scale process for CCS in 2020," says Nøkleby. One of the challenges is bringing sufficient volumes of $CO_2$ from onshore sources out on to the shelf. There has been talk of pipelines, but Nøkleby does not think this is a realistic option for the first round. "I am convinced that shipping transport will be the right choice in the first generation of offshore $CO_2$ EOR. This is because an EOR project has a limited lifetime, so pipeline installations will be impractical and very costly," says Nøkleby.

**MAJOR VALUE** Major value can be realised if this technology makes the cut. "There are perhaps 300 million cubic metres of oil on the Norwegian shelf that can be recovered with $CO_2$ flooding. This corresponds to about 10 per cent of what we have already collected. On the UK side there might be three times this volume," says Nøkleby. "The best feature is, however, that this method could generate major value creation along with a reduced carbon footprint for the extra produced oil." ✱

# Realistic idealist

**North Sea oil has created both prosperity and welfare in Norway. Head of Cicero Kristin Halvorsen believes that we have a moral obligation to take responsibility for the unfortunate consequences of these oil activities; for example through $CO_2$ capture and storage (CCS).**

Morten Ryen  Styrk Fjærtoft Trondsen

The world has reached an agreement that we must limit the increase in global warming to a well below two degrees. At the same time, acknowledgement is growing that we cannot achieve this with emission cuts and renewable energy sources alone. We are too mired in oil for that. "If we are to have any chance at all of achieving the new target, we must invest in CCS. In addition to reducing greenhouse gas emissions down towards zero, carbon capture and storage is the most important work we could be doing right now," says Kristin Halvorsen.

**REALIST** Kristin Halvorsen has gone from being a politician to being the director of a climate research centre. It is with a solid foundation in climate research and the UN's fifth climate report that she is demanding high ambitions for carbon capture and storage. "It is much too slow to achieve the changes we need," she says. "Unfortunately, we cannot just turn off the oil faucet tomorrow. The world is much too dependent on fossil fuels. Many things would come to a dramatic stop if we suddenly had to do without oil and gas. This is why we need a plan for phasing out the use of fossil fuels, while utilising technology to capture and store $CO_2$."

**WANTS POLITICAL** ACTION Kristin Halvorsen believes the cooperation between Gassnova and the Research Council of Norway on the CLIMIT research programme has been very important for Norwegian knowledge development within CCS. "CLIMIT has given us a much bigger and better toolbox than we had a few years ago. At the same time, this major effort placed Norwegian scientists and Norwegian research communities at the very forefront of this research internationally. This puts us in a unique position," she says. She believes we should continue investing in research and development, but that the technology is mature enough to use now. "The technology is there. Unfortunately, it is not yet profitable to use. It must become much more expensive to emit $CO_2$, but pricing requires political willingness, action and international agreement."

**MUST LEAD BY EXAMPLE** While we are waiting for the world's politicians and a functioning $CO_2$ market, Halvorsen believes we need to get a full-scale project for capture, transport and storage in place in Norway. "Though Mongstad became more complicated and costly than assumed, there is no reason to give up. We need to find another project soon," she says. Having grown up in Porsgrunn, she easily lets her local patriotism show when she makes a proposal. "The cement plant in Brevik! I earnestly believe that this would be both an exciting and important project," she says with a laugh. Kristin Halvorsen believes Norwegian authorities should support companies that want to conduct capture and storage of $CO_2$, even though it is not "profitable under the current framework conditions". "As a major exporter of oil and gas, I believe we have a moral obligation to invest in CCS," she says. "The Norwegian economy and Norwegian welfare are among the world's best, which we largely have the oil to thank for. Is it then not a reasonable expectation that we also clean up after ourselves? There are also several indications that 'the green shift' may come sooner than many expect. It would be a competitive advantage to be at the forefront in this area." ✱

**KRISTIN HALVORSEN**

**POSITION:** Director of CICERO Center for International Climate and Environmental Research Oslo

**CV:** Previous leader of the Socialist Left Party. Member of Parliament from 1989–2013.

Member of the Stoltenberg II Cabinet from 2005–2013.

Norway's first female Minister of Finance, 2005–2009.

Minister of Education and Research 2009–2013.

Has studied social education and criminology at the University of Oslo.

*There is no doubt that CLIMIT is considered important internationally, and Norway is at the research forefront in several areas.*

# Strong in the international arena

**CLIMIT has both strengthened Norway's position internationally, and given Norwegian researchers increased access to international research cooperation. The international networks are crucial in a research movement that aims to address global challenges.**

"There is no doubt that CLIMIT is considered to be important internationally, and Norway is at the research forefront in several areas," says Niels Peter Christensen, chief geologist at Gassnova. Christensen has extensive experience with international research cooperation within CCS. "The CLIMIT

Programme has represented continuity during a period of varying policy support of CCS as a climate mitigation measure. The strength and longevity of the work has undoubtedly given Norway an advantage," he says.

**JOINT EUROPEAN EFFORT** The European Research Area (ERA) is one of several important arenas for European research cooperation. This is where Norway, together with Germany, is attempting to achieve a joint European effort in carbon capture and storage. This could become the largest ever research effort within the field. "The idea is that individual countries will contribute their own funds, and the EU will provide additional top-up financing through Horizon 2020, equivalent to 50 per cent of the countries' contributions. The programme will cover the entire value chain from capture, via transport to storage," says Christensen. He also hopes that European industry will consider this an opportunity to get busy on CCS development. "This gives them a chance to test technology that they will have to start using sooner or later."

**COOPERATION WITH THE US**
Norway has a long tradition of research cooperation with the US, and CLIMIT is no exception. The cooperation between the US and Norway is still in the planning stage, but the contact between the two countries is at a high level. For instance, there have been meetings between our own Minister of Petroleum and Energy and the US Department of Energy, following CLIMIT's initiative. "We have also created meeting places for scientists. As recently as September, researchers from Norway and the US met to discuss which areas could be most relevant for cooperation," says Aage Stangeland, programme coordinator for CLIMIT in the Research Council of Norway. "This will hopefully be the start of collaboration on projects benefitting both parties. Both Norwegian researchers and industrial partners should be of interest to the Americans. Though CLIMIT has been a major and costly effort for Norway, Stangeland believes the programme has been highly valuable. "Through CLIMIT we have developed communities that are noticed internationally. This makes us an attractive partner, and also allows us to gain more in return for our participation in the EU's Horizon 2020 framework

programme," says Stangeland. "Thanks to a close cooperation with skilled industrial partners, I believe the CLIMIT research can lay the foundation for important, new Norwegian business development." ✱