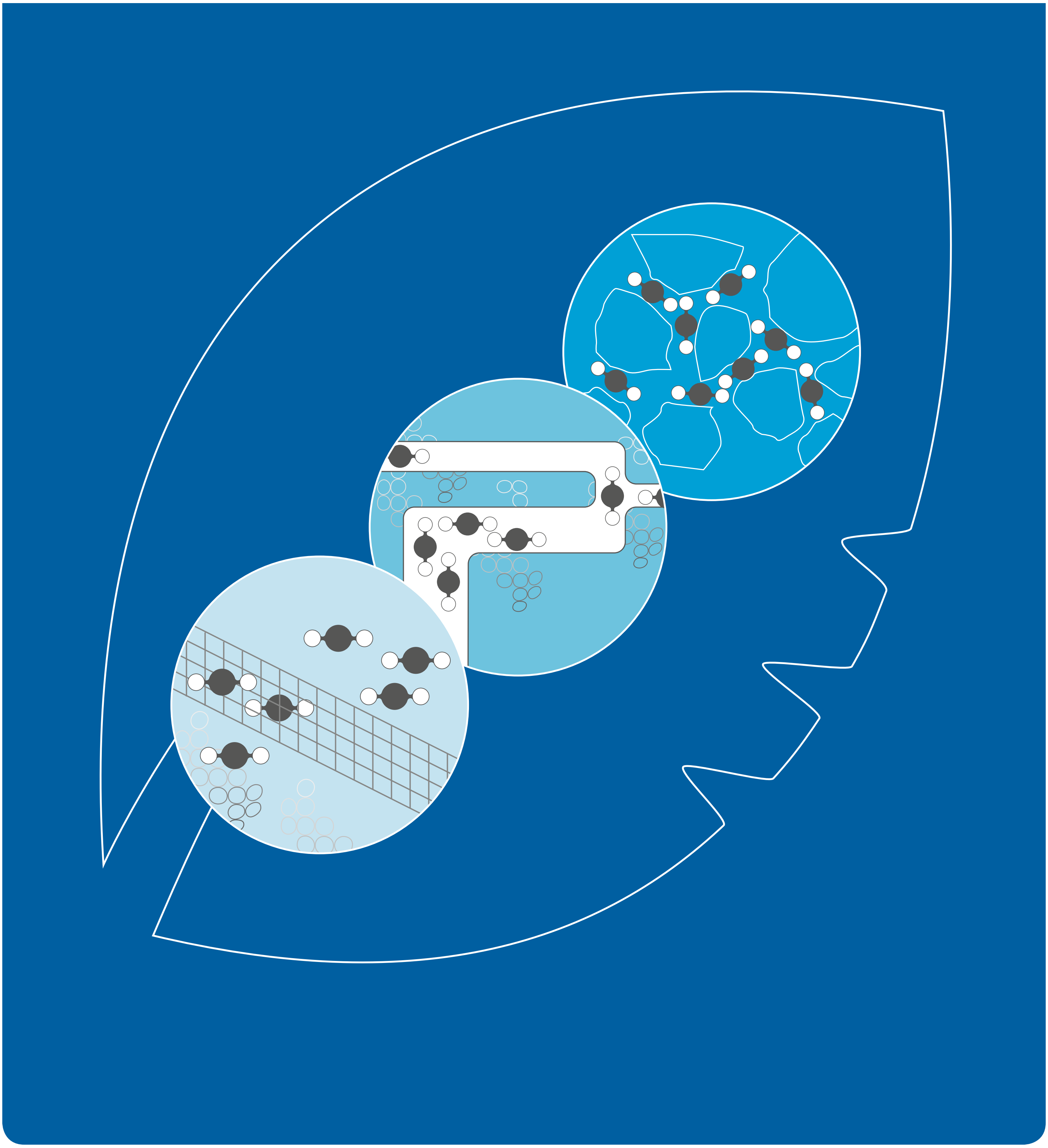
CLIMIT

PROGRAMME PLAN 2010–2012



Contents

Carbon Capture and Storage

I Summary

The CLIMIT programme was established in 2005 to support the development of technology for Carbon Capture and Storage (CCS in the following) applied to gas power. In 2008, the scope of this financial support scheme was broadened to include all fossil fuel-based power generation; and as of 2010, it will also include industrial point source emissions.

Norway's commitments in the field of CCS were originally based on the objective of supporting the development of technology to enable domestic gas power generation. In the future, however, these activities will increasingly focus on international participation in the development of CCS technology, as part of a strategy for reducing global CO_2 emissions from industry and power generation, while at the same time contributing to the global energy supply. According to the International Energy Agency (IEA), it is expected that fossil fuels will have to play a major role for global energy supply for many years to come[1]. In order to meet the greenhouse gas reductions needed to limit global warming, CCS must be implemented in coal and gas-fired power generation to a considerable extent[1,2]. In this connection, attention has been called to the need for capturing CO_2 from industrial emissions and biomass combustion[2]. It is expected that considerable international markets will develop for the provision of CCS-related services.

Norway has good technical and industrial capacities for contributing to this work. As a significant exporter of oil and natural gas, it could be argued that Norway is especially motivated to actively participate in the development of CCS technology.

The CLIMIT Programme Plan for this period focuses on those areas in which the Norwegian research and industrial community assumes that Norway can make the biggest impact. In this connection, CO_2 transport and storage and flue gas treatment are specifically emphasised.

The programme will focus on:

- Providing long-term and broadly-based support to research and development within the scope of the programme's priority areas.
- Contributing to piloting and demonstration of technology within the next 5 years. The first full-scale demonstration plants, which are to be built in 2015-20, will presumably be based on this technology.
- Stimulating the development of new, "step change" technology that can be supported at pilot and demonstration scale after 2015.
- Contributing to the demonstration and commercialisation of new, pioneering technology in the period after 2015-20.

It is expected that in the course of 2010, CLIMIT's mandate will be expanded to include CO_2 capture from industrial emissions. To a certain extent, this programme plan reflects this expansion. Financial support of such measures requires, after notification, the approval by the EFTA Surveillance Authority (ESA). The CLIMIT programme will provide further specification of its priority areas.

II Introduction

The IEA[1,2] expects that global energy consumption will increase by 45 % until 2030, unless considerable measures are implemented. Even with considerable efforts aimed at increasing the share of renewable energy, the global rise in energy consumption will primarily be based on fossil fuels. This could lead to a temperature increase of as much as 6 °C by the end of this century[3]. Following recommendations by, among others, the Intergovernmental Panel of Climate Change (IPCC)[3], several countries have decided on a goal of keeping global warming in this century below 2 °C. In the light of this, the European Union (EU) has committed itself to a 20 % cut in greenhouse gas emissions by 2020[4]. As part of its inter-party climate change compromise, Norway has gone even further, and has ambitions of a 30 % cut by 2020[5].

The IEA's "BLUE scenario"[2] aims to stabilise the global temperature increase at 2 °C. This requires a 50 % reduction of current greenhouse gas emissions. The IEA underlines in[1] that this is an extremely ambitious goal requiring a "revolution in the way we produce and consume energy". The scenario implies focusing on the development of more or less all types of energy. CCS is an important part of the scenario, and could contribute to about 19 % of emission reductions by 2050. The IEA widens the concept of CCS to also include industrial emissions and emissions from the thermal conversion of biomass[2], and their analyses show that CO_2 capture from industry will be just as important as CCS in the power sector. Furthermore, the IEA mentions that gas power with CCS could become a significant priority area within the next 30-40 years.

According to IEA's scenario[2], 18 large-scale carbon capture plants will have to be built worldwide by 2015, 100 plants by 2020 and 3400 plants by 2050 in order to meet global emission reduction targets.

The EU also expects CCS to play a major role if the reduction of greenhouse gas emissions is to be achieved in time. The EU has ambitions of having 12 CCS demonstration plants in operation by 2015, of which six already have received considerable funding.

IEA estimates[2] that global investments for full-scale CCS plants will be in the order of USD 5000 billion in the years from 2010 to 2050. Future costs for full-scale CCS are estimated to be around EUR 60-90 per ton CO_2 in 2015, and EUR 35-50 per ton CO_2 in 2020[6]. Most of the costs are linked to capturing CO_2. The expected decrease in costs between now and 2020 is possible, assuming the implementation of a successful international demonstration programme combined with a considerable extent of research and international cooperation.

The Norwegian government's plans for publicly-funded full-scale CCS facilities and test centres in Norway[7] lay the foundation for future needs in research and development. Considerable synergies can be expected between this CCS commitment and future CO_2 capture from thermal biomass plants and industrial emissions.

Applying a comprehensive, integrated approach to CCS technology and infrastructure gives a significant added value potential for Norway and Norwegian industry and considerable societal benefits of developing CCS solutions.

III Carbon Capture and Storage in Norway

The IPCC[2] and the IEA[1,2] emphasise that the climate change challenge we are facing is so substantial that we have to start reducing CO_2 emissions quickly and even before having established the framework conditions and mechanisms for a commercial global market. CCS is one of many measures being developed to reduce anthropogenic CO_2 emissions.

Norwegian authorities are actively participating in international efforts aimed at securing the future energy supply and reducing greenhouse gas emissions. The climate change compromise[5] between the Norwegian government and the opposition sets ambitious goals for the reduction of greenhouse gas emissions in Norway until 2020. One-third of these cuts, about 16 million tons, are to be made domestically.

In a non-commercial market that needs to quickly obtain new technology, national authorities must take on more responsibility than usual for research and development. Scale-up and verification of technology in pilot and demonstration plants are normally steps in the industrial commercialisation of new technology that are managed by industry itself. However, in a non-commercial market there are no commercial operators to carry out such costly projects. Public support for pilot and demonstration projects can thus help to speed up market access for new technology.

Motivation for working on CCS in Norway includes:

- Developing competitive Norwegian CCS technology for future global markets.
- Developing technologies that enable the continued use of fossil fuels in power generation in accordance with such strategies as IAE's 450 ppm scenario ("BLUE Scenario")[2].
- Contributing to securing Norway's power supply and achieving its CO_2 emission reductions by constructing domestic plants.
- Reducing Norway's CO_2 emissions from industry and providing a basis for developing a competitive industry adapted to a future carbon-restricted economy.
- Generating added value through CO_2 storage on the Norwegian shelf.

Norway's commitment in the field of CCS enables the utilisation of synergies linked to carbon capture from power plants, industrial emissions and CO_2 separation from natural gas. Energy integration between petroleum activities, industry, power generation and carbon capture can contribute to laying the foundation for a future-oriented and competitive industry in Norway in a future carbon-restricted economy. For the petroleum sector, CCS could become an important framework condition for future operations. Thus, CCS could become an important factor for future offshore value creation and within the Norwegian petroleum industry. Another option for Norway is to develop commercial CO_2 storage on the Norwegian shelf. This would also enable the export of CO_2-free gas power to the European mainland.

The Norwegian government[1,2,7] has set its sights on establishing a value chain for the transport and injection of CO_2 in Norway. This commitment is broadly-based, and includes research and development, demonstration projects and large projects like the European CO_2 Technology Centre Mongstad (TCM), and eventually full-scale carbon capture at Mongstad and Kårstø.

State support for CCS was bolstered through the Storting's (Norwegian parliament) climate change compromise in 2008[5]. As a direct result thereof, two centres for environment-friendly energy within CCS were established (BIGCCS and SUCCESS).

The CLIMIT programme is a major policy instrument for the Norwegian commitment in the field. The programme was initiated to increase research activities and facilitate technology development and demonstration, and to thereby accelerate the development of a more environment and climate-friendly energy system.

The CLIMIT programme is based on cooperation between Gassnova SF and the Research Council of Norway, and its mandate includes providing knowledge and solutions for:

- Pre-combustion, in-process or post-combustion CO_2 capture in connection with power generation, and CO_2 capture from industrial emissions
- Compression and transport of CO_2
- Long-term storage or other uses that secure permanent storage of CO_2

The programme has overlaps with and links to other research programmes; The RENERGI programme covers renewable energy, energy efficiency and energy systems, and includes relevant activities within the social sciences. The RENERGI programme has also co-funded social studies linked to CCS. The PETROMAKS programme covers R&D in the Norwegian petroleum and natural gas sector. Expertise on reservoirs, etc. is of considerable importance for the CLIMIT programme, and especially the use of CO_2 to enhance oil recovery is an issue of clearly overlapping interests for PETROMAKS and CLIMIT. Climate research in the Research Council is mainly organised via the NORKLIMA programme, and the knowledge generated there is highly important for CLIMIT and vice versa.

Three strategy committees have been appointed to be in charge of the research strategies for the fields of petroleum, energy and climate, respectively. The committee OG21 covers petroleum and natural gas activities and assigns the general strategy for PETROMAKS and DEMO 2000. Accordingly, the committee Energi21[8] prepares the general strategy for RENERGI, whereas Klima21 is to prepare the strategy for Norwegian climate research. The issue of CCS has been especially emphasised as one of the priority areas in Energi21, but the CLIMIT programme has to also take the strategies of OG21 and Klima21 into consideration.

IV CLIMIT – Background, funding and organisation

The CLIMIT programme was established on 1 January 2005. The background for establishing the programme is described in the Report to the Storting No. 47 (2003-2004). CLIMIT manages two funding schemes, with a total of nearly NOK 200 million at their disposal in 2010:

1) Pilot and demo: A gas technology fund of NOK 2 billion was established by the Storting in 2004 to secure the funding of Gassnova's financial allocations to pilot and demonstration projects. The annual returns of the fund are in the order of NOK 82 million.
2) R&D activities administered by the Research Council receive annual national budget allocations. For 2010 this amounts to NOK 100 million.

The programme board is appointed by the Ministry of Petroleum and Energy (see www.climit.no) and is responsible for strategies and grant allocations. Gassnova SF is in charge of coordinating the CLIMIT programme.

Gassnova SF and the Research Council of Norway cooperate on the technical evaluation of CLIMIT applications and projects. In addition, Gassnova is responsible for technology management and proactively seeking the establishment of industrial arenas for technology development.

The CLIMIT programme's allocation of grants to projects on power generation with CCS is approved and notified as state support in agreement with EEA regulations by the EFTA Surveillance Authority (ESA). In 2010, the CLIMIT programme will apply for notification of the support scheme to also include industrial emissions[10].

This revision of the CLIMIT Programme Plan has been based on a process that included SWOT and Foresight analyses in the programme's priority areas. The analyses were performed with participants from industry, research and public administration.

V CLIMIT's goals

The objective of the CLIMIT programme is to:

Accelerate the commercialisation of CCS by financial stimulation of research, development and demonstration.

Some of Norway's efforts in the CLIMIT programme were previously aimed at meeting domestic electricity demands by enabling the development of gas power without CO_2 emissions. In today's situation, with an expected power surplus, this alone would not be a significant driver for own technology development. In accordance with changing framework conditions and the government's white paper on research (9), the programme has placed more emphasis on developing technology for an international market, thereby helping to solve global climate and energy challenges.

Within this context, CLIMIT must focus on those priority areas in which Norway is qualified for making significant contributions. This can be achieved by:

- Providing extensive support to research and development to contribute to the development of new concepts for CCS which can help to reduce costs.
- Utilising Norway's professional engineering environment and experience, and potential suppliers to develop business related to storage in geological formations. This includes utilising the North Sea as a recipient of CO_2 from the European mainland.
- Building on Norway's experience, infrastructure and commercial base with regard to flue gas treatment, and by utilising synergies in treating flue gas from power plants and industry.

Based on the expected schedule for developing commercial CCS, which presumably will occur around 2020[2,11], we would like to call attention to these goals for the CLIMIT programme in the following chapters:

- Provide long-term and broadly-based support to research and development within the scope of the programme's priority areas, as described in the following.
- Contribute to piloting and demonstration of known technology within the next 5 years. The first full-scale demonstration plants, which are to be built in 2015-20, are expected to be based on this technology.
- Stimulate the development of new, pioneering technology that can be supported at pilot and demonstration scale after 2015.
- Contribute to the commercialisation of new, pioneering technology in the period after 2015-20.

Roadmap	2010-2014	2015-2019	2020-
Research and development	Dark blue	Dark blue	Dark blue
Pilot-demo / field trials – known technology	Dark blue	Light blue	White
Pilot-demo – new technology	Light blue	Dark blue	Light blue
Full-scale demo / early mover	Light blue	Dark blue	White
Commercial market	White	Light blue	Dark blue

Figure 1: Roadmap for developing CCS in Norway through 2020.
Dark blue = activity
Light blue = reduced activity
White = no activity

To achieve the goal of commercialisation in 2020, there is a need for long-term and broadly-based research, development and demonstration with cooperation between research institutes, universities and industry as a vital factor for the development of a broad portfolio. Close cooperation with the supply industry and industrial users shall ensure continued efforts within technology scale-up, verification and commercialisation. The CLIMIT programme can provide support to activities in all phases of developing and demonstration of new technology.

VI Support schemes in CLIMIT

In a Norwegian context, the CLIMIT programme is unique, as the grant scheme covers the entire innovation chain from basic research to demonstration.

CLIMIT - Research and Development (R&D): Supports long-term and broad capacity and technology development through targeted calls for proposals under the auspices of the Research Council of Norway. Grants are awarded to three different types of projects:

- **User-directed innovation programmes (BIP).** Applications submitted by private enterprise or other users. Users must contribute at least 50 % of the project's funding. Cooperation between enterprises and the use of research institutes as partners and subcontractors benefit such projects considerably.
- **Knowledge-building projects with user involvement (KMB).** Applications primarily submitted by research institutes. At least 20 % of project funding must be covered by contributions from private enterprise.
- **Researcher projects** are primarily targeted at universities and colleges, and can receive 100 % funding from the Research Council. Education, such as PhD degrees, is given priority.

For all project types, but especially for KMB and researcher projects, international cooperation is essential. As of late 2009/early 2010, the Research Council of Norway is in the process of approving a new strategy for international cooperation, and the general principles of this strategy will also apply to the R&D part of the CLIMIT programme.

CLIMIT – Demonstration (demo): An open call for proposals, primarily targeted at piloting and demonstration of commercially promising technology which has been thoroughly documented in previous research. Priority is given to projects that contribute to the scale-up and verification of cost-efficient, future-oriented technology concepts for CCS. Projects must contribute to CCS-related technology and capacity development in Norway, and include a business plan. The grant scheme has been notified to provide support to projects within the following categories (ESA):

- **Fundamental research:** means experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena, processes or observable facts, without any direct practical application or use in view.
- **Industrial research:** means the planned research or critical investigation aimed at the acquisition of new knowledge and skills for developing new products, processes or services or for bringing about a significant improvement in existing products, processes or services. It comprises the creation of components parts to complex systems, which is necessary for the industrial research, notably for generic technology validation, to the exclusion of prototypes.
- **Experimental development:** means acquiring, combining and using existing knowledge for the purpose of producing plans and arrangements or designs for new, altered or improved products, processes or services. Activities may typically include development of plan drawings for the purpose of commercial use.
- **Development of commercially applicable prototypes and pilots,** where necessary as part of the commercialisation process.
- **Pre- projects** for planning and maturing larger research and pilot/demonstration projects.

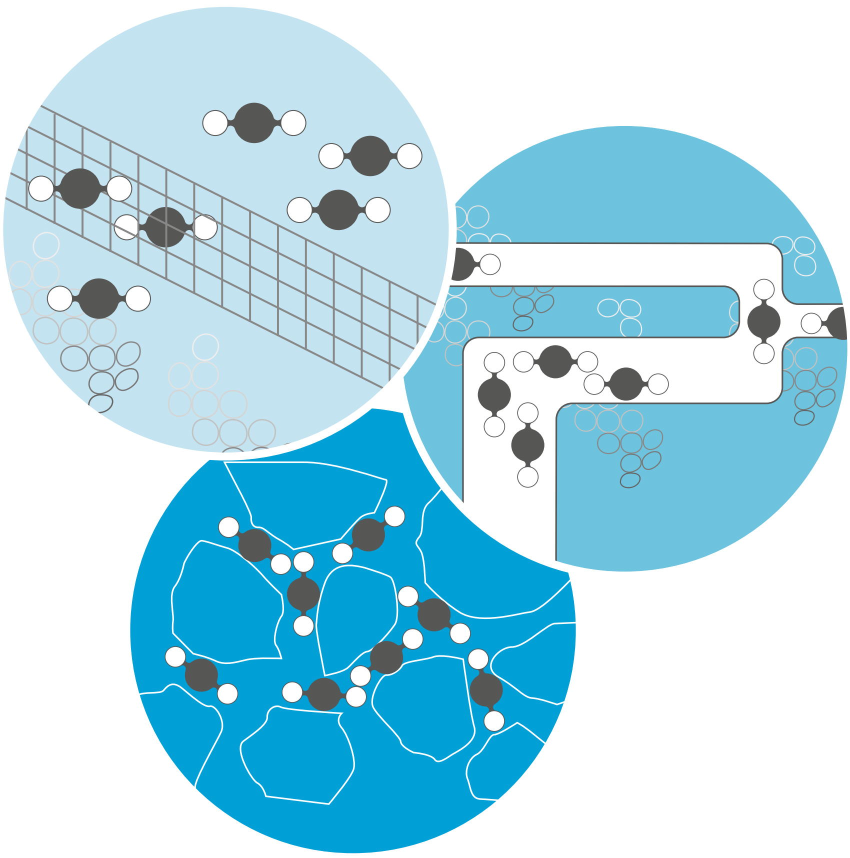
For more specific definitions, see EFTA Decision No. 302/05/COL[9].

The criteria and guidelines for CLIMIT-demo differ from those of CLIMIT-R&D by focusing more on the business potential and securing rights with commercialisation in mind.

For the criteria on which grants are awarded, see www.climit.no

VII Priority areas in CLIMIT

The CLIMIT programme's priority areas have been assessed and prioritised through dialogue with industry and research environments. In this process, the main challenges and goals for the plan period were formulated, and preliminary goals for the following period were outlined. Priority areas and goals are included in the roadmap as described in the following:



1. CO_2 capture

The main goal of the priority area is to:

- Improve the cost and energy efficiency of CO_2 capture
- Develop new and untested technology with large potential for improvement
- Assess the environmental effects of CO_2 capture

The field of CO_2 capture is traditionally divided into pre and post-combustion capture and oxy-fuel combustion. This refers to whether CO_2 is captured before (pre) or after (post) combustion, or if the fuel is burned in pure oxygen (oxyfuel). All three technologies will probably be represented in the first full-scale carbon capture facilities that are to be constructed in 2015-2020. For Europe, this assumption is further strengthened by the fact that the European Union's Economic Recovery Package (ERP) will provide support to full-scale pre and post-combustion and oxyfuel projects. Of the three technologies, amine-based CO_2 capture is considered to be the most mature. Plants with capacities of more than 300,000 tons CO_2 per year have been built, and there are few, albeit established, suppliers.

So far, none of the "known" carbon capture technologies have been proven to be significantly more cost-efficient than the others. Therefore, it is important to invest broadly in all promising technologies. However, post-combustion is deeply rooted in the Norwegian gas industry due to its use in the removal of naturally occurring CO_2 in natural gas. The efforts within this field in the CLIMIT programme will contribute to supporting the authorities' commitment to TCM and full-scale carbon capture at the combined heat and power plant at Mongstad. These efforts will also be relevant for CO_2 capture from industrial sources.

Today's challenges for CO_2 capture are related to investment and operating costs, energy requirements and the environment. However, for the deployment of this technology it is important that CO_2 capture becomes a natural part of flue gas treatment, i.e., that in the long run, emitters become responsible for CO_2 removal in the same way as they are today when it comes to removing such pollutants as dust, sulphur and nitrogen oxides.

Cost and energy efficiency

The goal for the plan period is to obtain cost-efficient carbon capture processes with low energy requirements and little environmental impact. For amine-based, post-combustion CO_2 capture, the goal for the plan period is based on the ambitions of the CLIMIT project SOLVit, which has a target of 2.7 GJ/t CO_2 for amine regeneration.

It is still a challenge for the known CO_2 capture technologies to reduce the loss of energy efficiency of the power plants to below 10 %. Chemical looping combustion (CLC) and processes that include the use of fuel cells are examples of technologies with a potential for higher energy efficiency, but are presently far from being commercially viable.

In this plan period, the main priorities are post-combustion CO_2 capture with focus on new and improved chemicals with a low energy demand, low degradation and negligible environmental impact. Another priority is process integration, including thermal integration internally in the capture process, as well as integration with the CO_2 source and possible auxiliary systems. In general, high priority is given to cost-efficient solutions with innovative processes, use of alternative materials, etc.

CLIMIT would also like to support projects on pre-combustion and oxyfuel. Activities within these two technologies would include the development of a gas turbine combustion chamber for hydrogen, and the production of oxygen for application as oxyfuel.

New and untested technology

The goal for the plan period is to develop a larger portfolio of projects related to new and untested technology. An estimated minimum of ten percent of the funding allocated via the CLIMIT programme should go to projects based on innovative ideas with a potential for significant reductions of costs, energy demands and/or environmental effects.

In order to reduce costs, energy demands and environmental impact, it is necessary to develop innovative concepts for CO_2 capture. The CLIMIT programme would thus like to focus on supporting the development of new, highly efficient processes that are not based on small, incremental improvements of conventional technology, but which have the potential for step change improvements.

Assessing environmental effects

The goal for the plan period is that the understanding of the environmental effects of chemical emissions to the atmosphere should be sufficient to enable an impact assessment process for an amine-based, post-consumption CO_2 capture plant. Another goal is to verify technology to enable a reduction of emission levels.

Tomorrow's CO_2 capture processes must be developed with minimisation of environmental impact in mind. The CLIMIT programme therefore wishes to support activities that assess environmental effects and measures aimed at mitigating the causes. In the short term, there is considerable interest in the issue of atmospheric emissions from amine-based capture processes, but projects based on other capture technologies are also welcome.

For amine-based CO_2 capture, there is a need for R&D on such topics as analysis of actual emissions from the CO_2 capture process, understanding the underlying chemistry in the reactor, atmospheric transport and reactions, and the effect of depositions on humans, animals and plants. In parallel, processes need to be developed to reduce actual chemical emissions to a documented safe level.

In the strategy process prior to formulating this programme plan, the challenges linked to CO_2 capture from industrial emissions were not specifically analysed. This will be done when the mandate from the Ministry of Petroleum and Energy for the extended support scheme has been issued.

		2010-2012	2013-
Environment	Environmental impact: post-combustion	Sound understanding of environmental effects	
	Emission reduction	Verified technology	Ready for full-scale applications
Energy efficiency	Solvent development*	2.7 GJ/t CO_2	2.1 GJ/t CO_2
	Hydrogen burner	Concept selected	Development with supplier
	Oxygen production	One project	Project with supplier
New & untested technology	Financial to non-traditional solutions	10 % of CLIMIT	10 % of CLIMIT

** Based on the CLIMIT SOLVit program.*

Fig. 2. Roadmap for CO_2 capture.

2. CO_2 transport

The main goal of the priority area is to:

- Develop, validate and demonstrate technology for safe and cost-efficient CO_2 transport

The strength of this technology area is that it builds on technology that to a certain degree is mature and established. There are no evident technical show-stoppers. However, some potential cost drivers have been identified, as well as a need for more knowledge within certain important areas, which will be more specifically described below.

Large-scale CO_2 transport systems will presumably include combinations of pipelines and ships. In the USA, there has been pipeline transport of CO_2 (only onshore) from natural sources for the purpose of enhanced oil recovery for more than 30 years. In spite of this experience, there are still numerous unanswered questions in connection with CO_2 pipeline transport at the scale we are talking about here. There is also some uncertainty regarding the transport of more or less impure CO_2 from different types of industry and power plants. The composition of the CO_2-containing fraction from a CO_2 capture plant can vary considerably depending on which CO_2 capture technology is used. Thus, there is a need for further development within several aspects of CO_2 transport.

The following priority areas have been identified in the field of CO_2 transport:

Basic knowledge and infrastructure

The goal for the programme period is to obtain basic knowledge and an understanding of those areas of CO_2 transport which are described in the following paragraphs.

For pure CO_2, satisfactory equations of state exist. However, there is a need for better thermodynamic models for gas mixtures with varying CO_2 contents relevant for CCS. These models must be confirmed by experimental studies. There is also a need for basic studies of corrosion, solubility of water in CO_2 and models for hydrate formation as a function of varying gas composition. Another priority area includes the identification of new material composites, coatings, etc. that can reduce the investment costs and/or the operating costs of CO_2 pipelines.

High priority is given to infrastructure development by establishing the laboratory, pilot and demonstration equipment needed to conduct realistically sized experiments for developing and confirming theories and methods.

Recommended standards and guidelines

The goal for the programme period is to establish the technical foundation for standards and guidelines for all aspects of offshore and onshore CO_2 transport that can assure the quality and integrity of the transport systems and thereby ensure broad international acceptance.

Operations and flow assurance

The goal for the programme period is to close all significant knowledge gaps regarding operations and flow assurance in order to secure safe and cost-efficient pipeline transport of CO_2. This includes such issues as cost-efficient utilisation of CO_2 pipeline networks, procedures for safe depressurisation, drying, leak detection, hydrate formation, etc.

Health, safety and environment (HSE)

The goal for this area is to establish basic knowledge in order to assess all HSE aspects of CO_2 transport. Issues that will be given priority include release and dispersion models for blowdown and leakage, as well as quantitative risk analyses.

Critical equipment components and materials in the transport chain

The goal for the programme period is to contribute to the development and qualification of equipment components. Another goal is to close the knowledge gap regarding the choice of materials and material combinations. For example, standard pumps and compressors are not optimised for CO_2 in those amounts and with such contents of impurities that can occur in large-scale CCS systems. Other issues such as choice of materials, seals, etc. related to varying contents of impurities must also be addressed.

Alternative transport methods

The goal for the programme period is to conduct feasibility studies and perhaps small-scale pilot studies of alternative transport methods. CO_2 transport systems will probably have to be based on a combination of pipelines and ships. However, the development of innovative transport solutions should not be ruled out. Thus, there is a need for further development within several aspects of CO_2 transport.

		2010-2012	2013-
Pipeline transport	Basic knowledge and infrastructure	R&D according to gap analysis	Fundamental gaps closed
	Standards	Guidelines and standards	Realisable
	Material technology	Validation of models	Competent supplier market established
	Operation and Flow Assurance	R&D according to gap analysis	Realisable
	Health, Safety & Environment (HSE)	Establish a basis for assessing all risks associated with CO_2 transport	Continuous improvement
	Critical equipment components	Competent supplier market established	Realisable
Other transport	Alternative transport methods	Feasibility studies	Small-scale pilots; or demo plants

Fig. 3. Roadmap for CO_2 transport.

3. CO_2 storage

The main goals of the priority area are to:

- Develop and verify knowledge and technology for safe and cost-efficient CO_2 storage and monitoring.
- Contribute to developing and verification of methods, service concepts and technology.
- Contribute to increasing knowledge about geological storage.

In line with recommendations of the IPCC and the EU Directive on geological storage, storage in the water column or on the seafloor is not considered to be a realistic alternative[4]. The programme's primary focus is thus providing support to the development of geological storage of CO_2. This implies storage in aquifers that are deep enough so that CO_2 would be in a liquid phase. CO_2 can be stored in aquifers, which are water-carrying, porous sandstone formations, or in depleted oil and gas reservoirs.

By having a well-developed petroleum industry, Norway is in a good position to develop a competitive industry for catering to a future market for CO_2 storage.

National plans and international roadmaps indicate that there will be a commercial market after 2020. However, it is probable that a market for providing services to a series of full-scale demonstration plants will already develop within the plan period and in the years leading up to 2015-2020.

The strength of this technology domain is that it builds on knowledge, technology and methods that to a large extent have been developed by the petroleum industry. In some cases, it is necessary to adapt knowledge, methods and technology to the construction of CO_2 storage facilities, due to documentation requirements and adaptation of technology to prevailing pressure and temperature conditions and the safety regulations that apply to geological CO_2 storage. The goal is to develop a safe, cost-efficient and competitive industry.

Due to the combination of lack of knowledge and conflicting interests, the field of CO_2 storage needs widespread knowledge transfer based on the validation of principles and methods in field trials.

The following priority areas have been identified in the field of geological storage:

Basic knowledge and infrastructure

The goal for the programme period is to increase knowledge on relevant basic geological\geochemical processes and measuring methods. It is furthermore important to contribute to the establishment of infrastructure and field laboratories that enable basic research and method development in all aspects of CO_2 storage.

Continuous knowledge development is needed in such basic subjects as geology, geophysics, geochemistry, geobiochemistry, rock mechanics and flow in porous media in order to improve our understanding of how CO_2 flows and chemically and mechanically affects rock systems. Numeric simulation of CO_2 flow is an especially important tool in the field of geological storage. In the long term, it is important that such methods, in addition to simulating pressure and concentration gradients, also can simulate rock mechanical and geochemical processes.

There is also a need for developing improved and more cost-efficient methods for monitoring offshore CO_2 storage. Preferably, monitoring should be as continuous as possible, and not need extensive support from land or petroleum installations. The geobiochemical and biological processes in surface sediments and on the seafloor must be understood in order to assess the consequences of any CO_2 leakage to the ocean floor.

High priority is given to infrastructure development by establishing field laboratories and other facilities needed to conduct realistically sized experiments for developing and confirming theories and methods. One should aim at achieving a high degree of international cooperation in connection with such activities.

Within the scope of this priority area, there will also be room for supporting other CO_2 storage technologies than injection in geological formations, such as methods for mineralization and storage combined with enhanced oil recovery.

Storage

The goal for the programme period is to develop and verify methods and standards for the estimation of storage potential, and the assessment and quantification of reservoir utilisation, sealing capacity and possible leakage pathways.

Methods and service concepts for the assessment and qualification of storage sites must be developed, confirmed and commercialised. The methodology must meet the requirements for accuracy which are typical for the various phases of project development leading up to investment decisions for CCS projects, and must comply with the demands of the approving authorities. In the early phases, the storage potential linked to different storage concepts and areas on the Norwegian shelf must be identified. High priority is given to the development and validation of mathematical models and software for flow simulation to enable the quantification of the dispersal and leakage of injected CO_2.

Development

The goal for the programme period is to develop, and to the greatest possible extent verify methods, technologies and service concepts to enable commercial use in full-scale storage projects after 2015.

The petroleum industry's methods for drilling and field development must be adapted to the requirements and framework conditions that will apply to CO_2 storage. Wells and other facilities must meet the requirements regarding safety (pressure, temperature, corrosion, lifetime and materials), monitoring and cost reduction. In a longer term perspective, there is a need to develop new "fit for purpose" technology for CCS development, which can significantly reduce the costs of drilling, well completion and development solutions.

These efforts will primarily be directed at suppliers in the petroleum sector, but also include research environments in the field of petroleum technology.

Operations and monitoring

The goal for the programme period is to develop, and to the greatest possible extent verify methods, technologies and service concepts to enable commercial use in full-scale storage projects.

The operation and monitoring of established CO_2 storage sites will require methods for monitoring the distribution of liquid CO_2 in the reservoir that comply with the public authorities' demands to accuracy. Research and development of new technology will receive support as part of the commitment on basic knowledge. Within the scope of this priority area, support can be provided to adaptation and verification of new methods in field or full-scale trials.

		2010-2012	2013-
Basic knowledge and infrastructure	Increased knowledge of geological, geochemical, flow and rockmechanical processes, and of monitoring methods	R&D according to gap analysis, testing in field labs	R&D according to gap analysis
	Research infrastructure	Field labs established, international cooperation	
	Alternative storage methods	Basic research, technical & financial feasibility studies	Basic research, technical & financial feasibility studies
Storage sites	Methods for assessment of capacity, injectivity, risk and reservoir utilisation	Developed and implemented in national regulations	Improved and validated in field experiments
	Qualify storage capacities on Norwegian shelf	Basis for new storage areas on continental shelf established	Prediction accuracy > 30 %
Development	Subsea and well technology	Existing technology qualified for CO_2	New technology developed and qualified
Operations and monitoring	Monitoring methods and operational safety	Non-compliance procedures, storage site monitoring assessed and validated in field trials	New monitoring methods validated in field experiments
	Reservoir control	Methods for reservoir and pressure control developed	New methods tested and qualified
Environment	Environmental effects of CO_2 leakage in marine environments	Effects of leakage on marine organisms documented	Testing of monitoring methods, established

Fig 4. Roadmap for CO_2 storage.

It is important to plan and conduct CO_2 injection in such a way as to enable maximum utilisation of storage reservoirs, ensure control of reservoir pressure and minimise the risk of leakage. High priority is given to developing knowledge, methods and facilities to ensure reservoir management.

It is expected that stringent safety requirements will be imposed on the operation of CO_2 injection projects. Support can be provided to projects that contribute to the development of simple, cost-efficient,verified and reliable methods for monitoring and identifying leaks and other unexpected incidents in the reservoir, as well as to projects facilitating the development of mitigation or intervention measures in case of leakage.

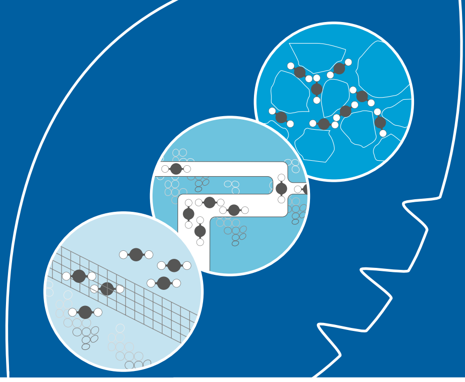
In a somewhat longer term perspective, it is necessary to develop standards, procedures and methods that can be used to close down a storage site and transfer the responsibility from an operator to the authorities.

Environment

The goal for the programme period is to ensure that subseafloor CO_2 storage is to be implemented with a minimal risk of leakage, and in compliance with international conventions and directives (OSPAR, LC, EU's CO_2 storage directive) and national regulations.

An incident of CO_2 leakage to the surface could occur as a stream of CO_2 gas from a leaking well or through faults, or as gradual seepage through the ocean floor. To be able to assess the consequences of leakage, it is important to gain an understanding of how marine organisms will cope with and react to increased CO_2 concentrations and any other substances that could be mobilised by the CO_2. Such knowledge can also be used for monitoring the seafloor (bioindicators) to detect any leaks. These issues shall be assessed and understood by the end of the plan period.

4. The CCS value chain



The priority areas mentioned above describe the main areas of CCS technology. CCS represents a totally new value chain, consisting of business areas of which some will go beyond known interfaces. Limitations, challenges and possibilities will be encountered. Some of these might seem obstructive; however, they could also have a stimulating effect on CCS development. In order to determine and further maximise the societal benefit of CCS, these elements must be combined and commercially and environmentally optimised. This priority area is thus directed at the "CCS value chain", and is intended to link individual technologies with societal aspects of CCS, such as those addressed via Energi 21 and the R&D programme RENERGI.

The following aspects of the CCS value chain are to be emphasised:

- Development of standard cost estimation methodologies and calculation tools.
- Implementing various types of analyses: technical-financial, technical-environmental (including life cycle assessments), total risk and social economic.
- Social or legal studies with significant importance for the commercialisation of relevant technology, including focus on consequences, challenges within the framework conditions and regulations.
- Barriers to the introduction of CCS.

Support can be provided to projects that are based on technology or business concept development in the field of CCS. Projects focusing on technology development, development of service concepts and commercialisation of CCS technology are encouraged to apply an integrated perspective to the challenges and possibilities we are facing.

Applications for projects in which CO_2 is to be integrated in a value chain must specifically include an account of the process's total energy and CO_2 balance, and of aspects related to the safe and climate-compatible long-term storage of captured CO_2.

It must be pointed out that the intention of the CLIMIT programme is to contribute to CO_2 capture at lower energy and investment costs, and to the storage of CO_2 in accordance with national and international agreements and regulations.

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