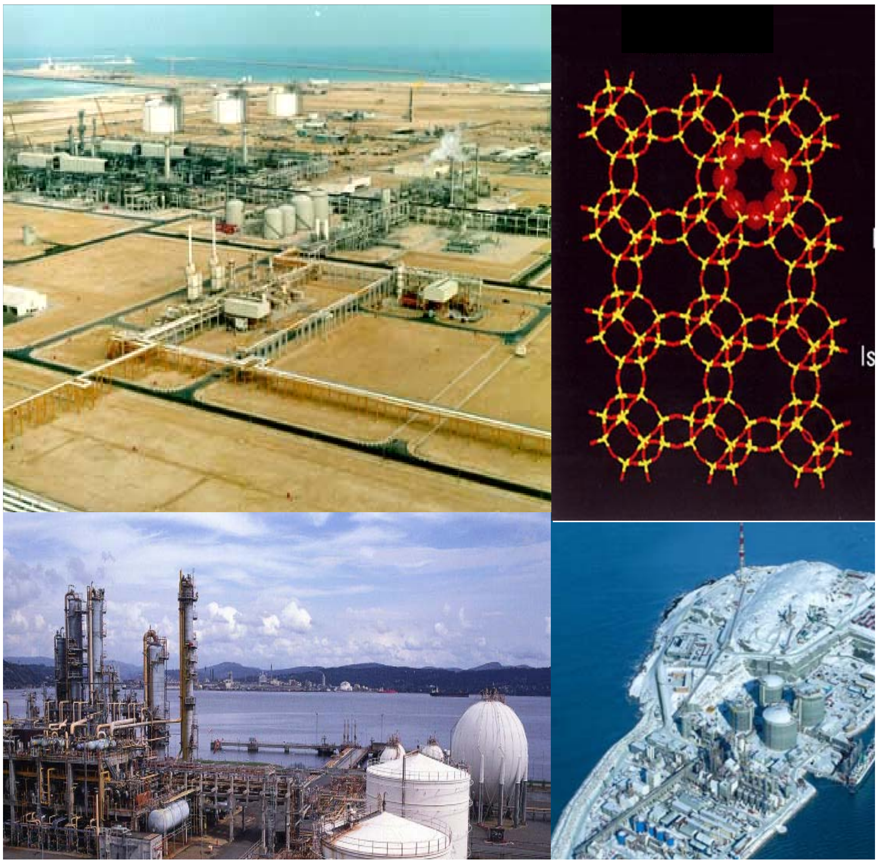
TTA8
Technology Strategy for Gas Technologies

Lead Party
Hydro

TTA - Group Companies and Organisations
AkerKværner, ConocoPhillips, Gassco, StatoilHydro, Shell, Total, Sintef, Det Norske Veritas, Vetco



Executive summary

TTA8 – Gas technologies points out the various routes Norway can follow to capitalise on the vast resources of natural gas that will be produced in the years to come by developing a strong technology and competence platform. A broad view is taken for the value creation having as basis the continued gas export from NCS to Europe, but also a strong focus on development of gas resources in other parts of the world. The latter can also be seen as part of international positioning for upstream resources and does also include involvements in projects, and export of technology and products. The TTA has structured the analysis into 3 main areas:

- Gas transport and processing (pipeline, LNG, other)
- Gas conversion to fuels, chemicals and materials
- CO_2 management

In this report, for each of these areas, scenarios based on a gap analysis are presented. One of the key goals has been to identify pacing and emerging technologies for the next 20 years. Based on this, technologies have been mapped according to importance for future competitiveness and technology ambitions. This also includes primary funding responsibilities (public and/or industry). It is acknowledged by the TTA that Norway cannot be a leading technology player in all aspects of the gas value chain. For some technologies we should be an active player and developer, whilst for other technologies we should become a competent buyer and user.

The bullet list below reflects the key issues in the updated recommendations:.

- Further strengthen effort on basic technologies relevant for LNG technologies. i.e. fluid mechanics, heat transfer, material technology etc needed to develop more energy efficient LNG technologies both for land based installations and floating facilities

- Further strengthen the effort on basic technologies needed to develop energy efficient and cost efficient synthesis gas processes with minimum environmental impact.

- Further strengthen the effort on basic technologies needed to develop energy efficient and environment friendly technologies for CO_2 removal from natural gas.

A more detailed list of other important issues in the three technology areas are given below:

Gas transport and processing are optimised operations, capacity utilization and cost effectiveness in existing infrastructure through, for example, improved methods for maintenance, energy efficiency programs, handling of trace components in gas streams (H_2S, CO_2, Methanol) and more efficient extraction of heavy components (NGL, LPG). Furthermore, we need to develop a robust technology basis for non-pipeline transportation of gas from regions that are not accessible today by pipeline infrastructure. This includes

Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG), Heavy Liquefied Gas (HLG), Natural Gas Hydrates (NGH) for transport, and the like. The versatility of these technologies for new regions (e.g. Arctic and remote areas) needs to be researched and improved.

For **Gas conversion to fuels, chemicals and materials** it is expected that the existing Norwegian gas based industry, including petrochemicals, will be developed further and key issues in this regard are increased unit capacities and increased energy efficiency.

In countries with strong national petroleum companies, participation in downstream business development may strengthen the Norwegian industry's position for access to upstream assets. Gas to Liquids (GTL) and Gas to Olefins (GTO) are good examples of downstream pacing gas technologies in this area with Norwegian companies as leading players technologically and commercially. Other pacing and emerging areas are offshore direct gas conversion to transportable liquids or other products, hydrogen as an energy carrier and gas conversion in Arctic areas. New products that use gas as feedstock, for example nano materials, are likely to be developed in the future.

CO_2 management encompasses improved energy efficiency to reduce CO_2 emissions, CO_2 removal from natural gas to meet gas sales specifications, and carbon dioxide capture, transport and storage (CCS) technologies. Amongst prioritized areas are geological storage both in saline aquifers and in depleting oil and gas reservoirs (EOR or EGR). We need to develop CCS technology at competitive costs and acceptable environmental standards. We need methods to manage risks and to do accounting, verification and monitoring of CO_2 emissions and emission reductions along the CO_2 value chain. There is a need to further develop and increase our competence for predicting permeability, integrity and capacity of formations. Important areas are good geological reservoir models for combined optimization of EOR effect and storage of CO_2, as well as topside modifications/management of back-produced CO_2. The development and management of a CO_2 infrastructure is key to successful CCS. CO_2 capture technologies for fossil fuel power generation is emphasised as an area where Norway needs to continue its efforts by establishing both pilot and full-scale demonstration plants.. The same is the case for energy efficiency – where improved process optimisation and control are important both offshore and onshore.

1 Introduction

TTA Gas Technologies' responsibility is value creation for Gas-To-Market concepts and CO_2 issues related to these concepts, as illustrated in Figure 1. Gas source comprises gas fields and associated gas, offshore and onshore; dry gas as well as NGL (Natural Gas Liquids). The processing steps can vary from drying and condensate extraction, to liquefaction or chemical conversion to products. The products are transported via pipeline or ship to the market. The main markets for gas are the energy market, the fuels market and chemicals and materials. This means that the TTA covers a very wide spectrum of gas utilizations, ranging from power production to synthetic fuels and petrochemicals. CO_2 may be produced at all the processing steps and as depicted in the Figure 1 this TTA also deals with how we can manage emissions of CO_2 throughout the chain ultimately storing it or using it for enhanced hydrocarbon recovery**.**

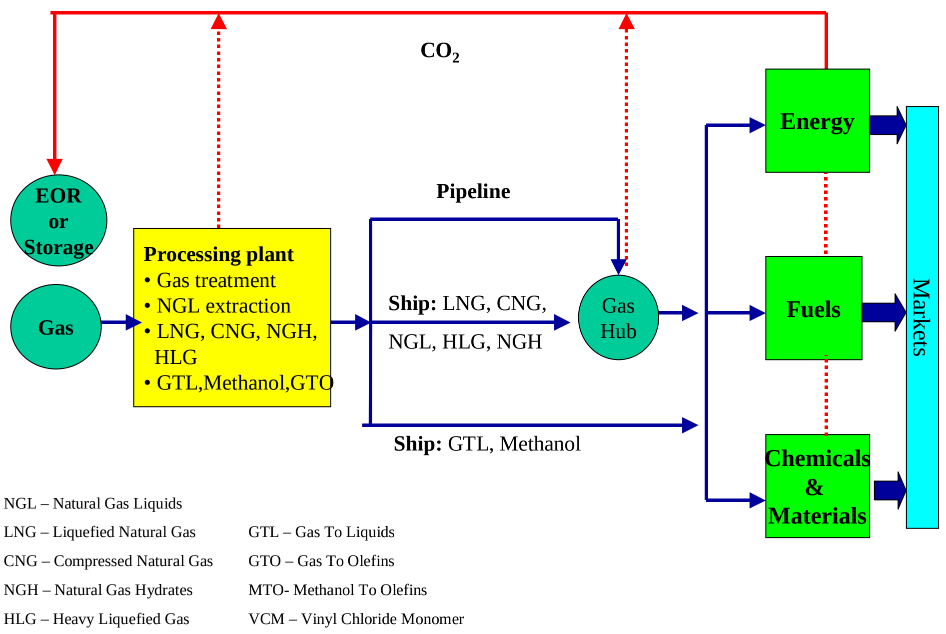


Figure 1. Gas-To-Market schemes.

Within this context three main technology areas have been defined:

- Gas transport (Pipeline, LNG, other).
- Gas conversion to fuels, chemicals and materials
- CO_2 management

It is important to see gas technologies and related competence in an international perspective since gas is becoming more and more sought after in the market for energy, fuels and chemicals worldwide. Gas technologies and competence are potentially important export products and can also be a strong enabler for international partnerships and strategic positioning. Consequently, value creation from gas will become more and more important for Norway in a broad context.

2 TTA methodology

The TTA has carried out a Gap Analysis for the three main technology areas above by describing present situation (today) and possible scenarios for 2020. Based on this analysis, technology developments, business drivers and trends, framework conditions etc. within each main area have been grouped in three main blocks: Base and Key, Pacing and Emerging. Reference is made to Figure 2.

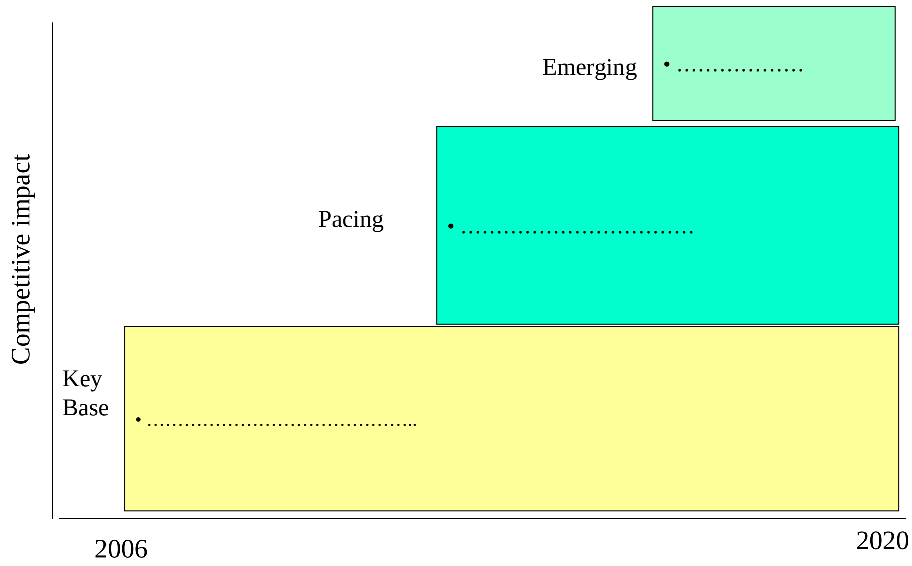


Figure 2. Format for Gap Analysis based Scenarios.

The terms Base, Key, Pacing and Emerging are adapted from a methodology developed by Arthur D Little. Base and Key are descriptions of the present industry and technology situation and how this is expected to develop from today's position. In our context these are considered as more or less mandatory steps or events unless a more passive role than our competitors is desired. For technology, Base represents "yesterdays" source of competitive advantage, while Key represents "today's" source of competitive advantage. Pacing describes plausible business opportunities based on developments underway today, and for technology pacing is "tomorrows" source of competitive advantage. Emerging describes longer-term challenges and technology opportunities that could develop into business opportunities in the future – or not. Higher risks are usually considered for the emerging opportunities and technologies and many will not be realized.

Based on this, the technologies have been mapped as illustrated in Figure 3. In these maps individual technologies (or technology areas) are placed according to expected business impact (Base, Key, Pacing, Emerging) and technology ambition. The various levels of Technology Ambition are (Arthur D Little):

- **Clear Leader**: Sets the pace and direction of technological development. Leadership recognised throughout the industry
- **Strong**: Able to set new directions. Capabilities above average compared to other majors. Clearly ahead of most of the pack
- **Favourable**: Able to sustain technological competitiveness in general and/or leadership in technical niches. Capabilities comparable to other majors, “in the pack”
- **Tenable**: Unable to set independent course. Continually in catch-up mode. Capabilities behind those of most majors. “Behind the pack”
- **Weak**: Unable to sustain quality of technical outputs versus competitors. Short-term fire-fighting focus. Reliant on suppliers or partners for these technologies.

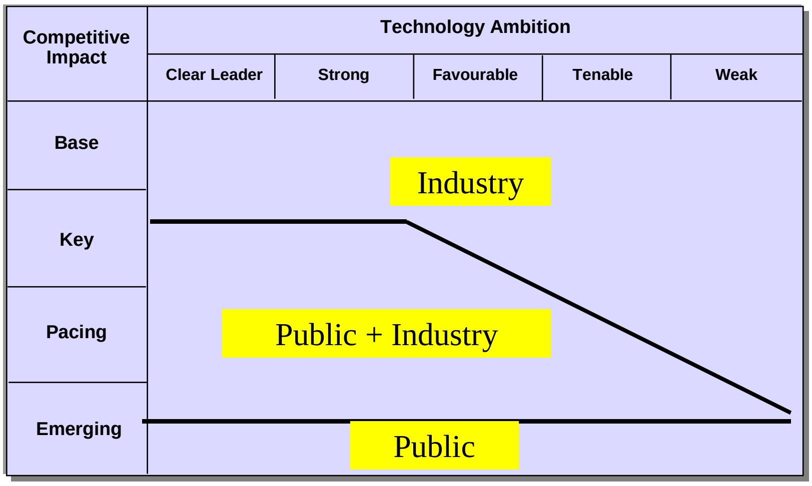


Figure 3. Technology ambition and funding map.

Figure 3 also indicates primary R&D financing responsibility. Industry and Public imply that R&D financing is predominantly, respectively, an industry or public responsibility, while Public + Industry means joint financing.

3 TTA Vision and Objectives

The vision developed by the Gas Technologies TTA is twofold:

- Norway, a leading gas technology nation in the 21st century with the gas industry as a key industrial sector.
- Norway, a leading international gas technology player that promotes Norwegian operatorships internationally and the export of technology, products and services.

The common objectives for the research community and the industry is to further strengthen the basic knowledge related to usage of natural gas and use this knowledge to develop efficient industrial solutions in all areas of commercial usage of natural gas. The most important areas are:

- Gas transport:
    - Main focus shall be on basic technology areas relevant for LNG technologies, i.e. fluid mechanics, heat transfer, material technology and thermodynamic properties of natural gas mixtures. The overall objective is to develop more energy efficient LNG technologies both for land based installations and floating facilities.

- Gas Conversion:
    - Conversion of the hydrocarbon feedstock to synthesis gas is the basis for most gas conversion processes (hydrogen, GTL, MTO etc) and should be the main priority area.The objective is to develop more energy efficient and cost efficient synthesis gas processes and the main target is cost reduction by at least 25%. The environmental impact should be minimised (integrated CO_2 capture).

- CO_2 management:
    - CO_2 management is addressed in several national programs. In this program the main objective is to further develop basic technologies needed to develop energy efficient technologies with minimum environmental impact for CO_2 removal from natural gas. The target is to reduce energy consumption by 30% and with no use of chemicals graded as yellow or red. Further, to contribute to development of the CO_2 chain through transport and storage of CO_2.

4 Environmental considerations

Due attention must be paid to safety and protection of the environment. The industry aims to reduce the amount of chemicals in use, and develop more environmentally acceptable substitutes. In addition we should strive for less use of energy in processing and transport of natural gas. This is not only a question of practising good environmental stewardship – it is compulsory if we are to meet the increasingly stringent demands from the society and authorities.

Gas transport: In the gas transport area one of the main contributions to reduced environmental impact is related to the development of more energy efficient gas processes and transport solutions. LNG production is relative energy intensive and increased effort to improve these processes can give a substantial contribution to reduced environmental impact.

Gas Conversion: Conversion of natural gas to other chemical substances like GTL products, olefins, methanol and hydrogen are energy demanding processes (20 -25% of energy in the gas is used in the process), and an important part of the proposed development areas is related to increased energy efficiency, especially in synthesis gas processes. In addition to the synthesis gas focus, the area of CO2 capture from gas conversion processes is recommended. CO2 capture from internal process streams has a potential for more cost efficient capture technologies.

CO2 management: The whole areas related to CO2 management are in general relevant for reduction of environmental impact of utilisation of natural gas. CO2 extraction from natural gas is based on state of the art processing to meet sales gas specifications (2, 5%). The suggested area related to natural gas processing includes less use of chemical with less harmful environmental impact. In addition the area CO2 management technologies include safe transport and storage of CO2. This is the most essential area for reduction of environmental impact in TTA 8 and probably in OG21 as whole.

5 Future challenges and technology gaps

In this Chapter future challenges and technology gaps are summarized for each of the three main areas.

5.1 Gas transport (Pipeline, LNG, CNG, NGH, HLG, other)

The Gap Analysis based Scenarios for this area are found in Figure 4

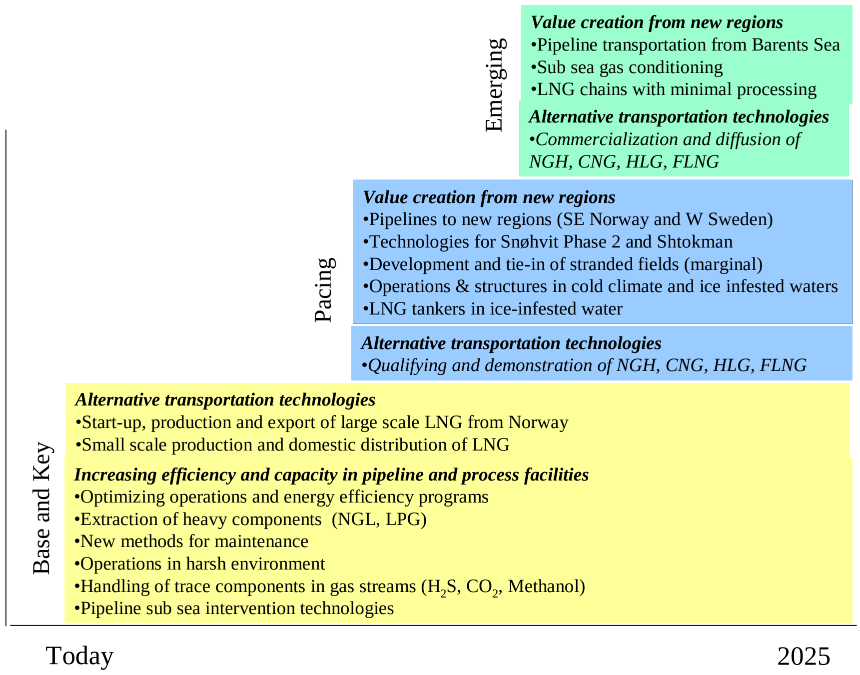


Figure 4. Gap Analysis based Scenarios. Gas transport and Processing.

Natural gas is presently being delivered to the market via pipelines or in a liquefied form (LNG). Several of the growing gas markets are far away from the fields and pipeline transport is not a viable option. LNG is a proven transport method for large volumes and this market segment is growing rapidly. The issue of non-pipeline transport solutions becomes more urgent for Norway as the distance between market and new discoveries on the Norwegian Continental Shelf is increasing (Northern areas). Another challenge for the NCS is marginal fields that may require alternative technological solutions in order to be developed.

At present, all gas being produced in Norway or elsewhere in Europe is delivered through pipelines. The first large scale LNG plant started up in Norway at the end 2007.

One characteristic of liquefaction plants located in Arctic areas is the large range of air temperature between summer and winter. This could be easily twice or three times what is existing in the majority of liquefaction plants. This involves problems in the design of the exchangers and in the conception of the liquefaction stages.

Several non-pipeline technologies are pacing and emerging, in particular Compressed Natural Gas (CNG), Heavy Liquefied Gas (HLG) and Natural Gas Hydrates (NGH). Gas transport by trains and trucks are also increasing. Thus, gas transport becomes more flexible in terms of quantities, distance and transportation methods.

Norway's present technological position within gas processing and transport is the result of, not only being in the vicinity of the expanding Europe market, but also a product of political and legislative incentives. Governmental incentives could be licence conditions, taxes and regulations. For instance, gas often comes as a by-product of oil production, but the associated gas must nevertheless be given a proper end use (not flared). An example of a governmental incentive is certain tax relief for the Melkøya LNG plant, which is a pioneering project.

Based on the past achievements, Norway's base and key technology will continue to be construction and operation of offshore pipelines. With reference to Figure 4, the pipeline technology development is based upon the following main areas:

- Supply security (high regularity)
- All aspects of cost reductions, hereunder maintenance methods, pipeline sub sea intervention and energy efficiency measures
- Protection of nature from pollution and other industrial impacts, hereunder handling of trace components in gas streams
- Safety

LNG technology is moving from pacing to key in a Norwegian perspective. Focus should be on technology for operations and structures in cold climate and ice-infested waters. Technology position and ownership can also be important in order to get access to new reserves and to maintain an international position.

Technologies for processing and transportation of CNG, HLG and NGH are already known, however, at present, there is no production for commercial purposes. Such technologies are seen as pacing or emerging. Offshore LNG production (FLNG) is another alternative for medium to large gas fields. It should be noticed that floating liquefaction units should address different challenges than a land based plant. The most important is the safety, regarding the dimensions of the barge. This means that the conception of the liquefaction process to be put on a barge must be different from a liquefaction process onshore. Transport technologies such as CNG, HLG, NGH, FLNG and others are being developed and are expected to be commercial before 2015.

It is recommended that the future development of natural gas transportation and processing technologies in Norway must be given favourable economic and political work conditions, such as:

- There are several ongoing and promising development studies for offshore gas pipeline projects to South Eastern Norway and Western Sweden.
- All Barents Sea hydrocarbons will most likely be transported in tailored and independent transport solutions to market as the pipeline infrastructure in North Sea

and Norwegian Sea has limited vacant capacity prior to 2020. A key issue is to maintain efficient model and economic mechanisms and incentives for ensuring investment in new infrastructure.

- In order to stimulate the industrial use of gas, new energy based on gas must operate under the same economic regime as traditional energy sources for industry in Norway.

5.2 Gas conversion to fuels, chemicals and materials

Gas conversion to fuels, chemical and materials represent an increased value creation and the product values are in the range 2-40 times higher than the gas value depending on the degree of conversion. Conversion to materials typically has a higher value creation (and costs more) than conversion to fuels and base chemicals such as ethylene and propylene.

The main elements in this area are shown in Figure 5.

Figure 5. Major products and routes from natural gas to fuels, chemicals and materials

Currently, major industrial products from natural gas are methanol and ammonia, with synthesis gas as key intermediate in both cases. Hydrogen is also a very important product, e.g. for use in refineries. StatoilHydro's methanol plant at Tjeldbergodden is Europe's largest methanol plant and a 35% capacity expansion is under planning. Yara is a world leading ammonia and fertilizer producer.. Most of Yara's ammonia production uses natural gas as feedstock. StatoilHydro is a significant producer of hydrogen for use in refineries.

Natural Gas Liquids (NGL) are feedstock for production of ethylene and propylene, the two most important petrochemical building blocks. Production of ethylene and propylene from NGL takes place in Noretyl's plant in Grenland. The olefins are used in production of polyolefins and of Vinyl Chloride Monomer (VCM) by Ineos. VCM is the raw material for production of PVC, and Ineos is Europe's largest PVC manufacturer with VCM and PVC plants in Norway and abroad.

The result of the Gap Analysis based Scenarios for this area is shown in Figure 6.

The Norwegian gas-based industry briefly described above is expected to develop further and key issues in this regard are increased unit capacities and increased energy efficiency, both contributing to reduced production costs. It is also expected that this industry will expand further internationally, to a large degree through Joint Ventures.

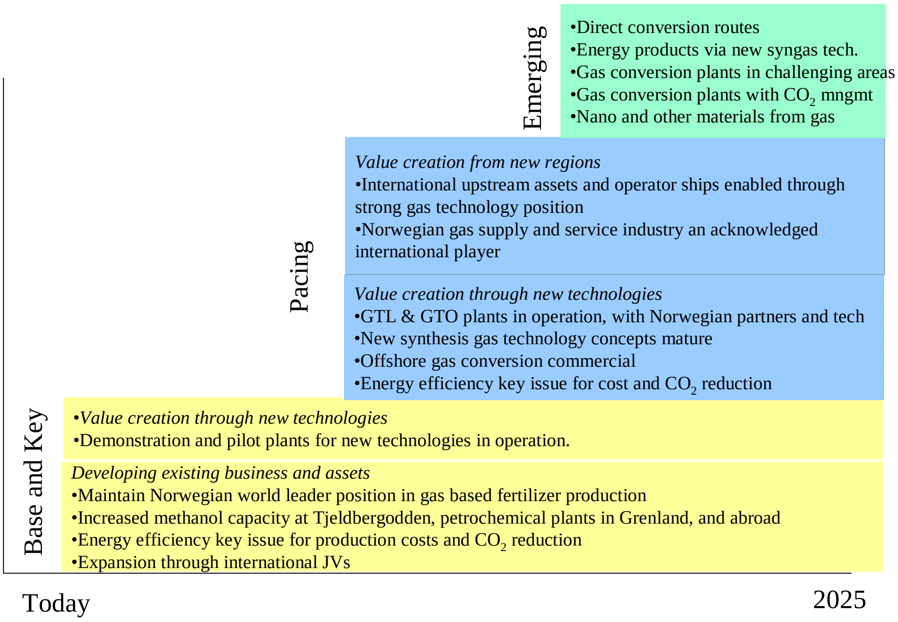


Figure 6. Gap Analysis based Scenarios. Gas conversion to fuels, chemicals and materials.

Pacing technologies within gas conversion are Gas to Liquids (GTL) and Gas to Olefins (GTO) with Norwegian companies as leading players. GTL products after upgrading are typically high quality diesel, light and heavy oils. GTO, where Methanol-To-Olefins is the last step, represents a new route to light olefins that are the basic building blocks of the petrochemical industry, cf. Figure 5. Demonstration plants are in operation today for both GTL and GTO technologies and commercial plants outside Norway are expected in the near future. Another pacing area is commercialisation of offshore gas conversion to transportable liquids (methanol, synthetic crude or other). Synthesis gas production is a critical technology in gas conversion, cf. Figure 5 and strong competence in this area is required.

It seems to be a developing trend that in countries with strong national petroleum companies, downstream business development increases the possibilities for access to upstream assets. Gas technologies such as GTL and GTO are good examples of this.

Identified emerging technologies are direct conversion routes, hydrogen as energy carrier and gas conversion in Arctic areas.

In all conversion products from the processes above, FT-products, olefins via methanol or hydrogen, synthesis gas is the common key process. Synthesis gas technology is a common expression for the processes converting hydrocarbon feed stocks to synthesis gas (hydrogen, carbon monoxide, carbon dioxide and water). There are two established main types of synthesis gas production technologies, steam reforming and auto thermal reforming. The reforming processes are both capital intensive and energy intensive, and radical technology improvements both in conversion chemical routs and technology design, could change the commercial potential for gas conversion in general.

There are no thermodynamic limitations for performing the synthesis gas reactions at pressure and temperature different from to days practice. The main limitations are related to material of construction and reaction kinetics, and improvements in these areas could be of significant importance. Further, introduction of new internal separation systems (membranes) in the synthesis gas process could alter the equilibrium situation and open for more efficient processes. Improved process design for increasing heat transfer and heat integration (process intensification) could also give a substantial contribution to more efficient synthesis gas processes.

New products where gas is feedstock are likely to occur in the future, one example is nano materials. Elkem and StatoilHydro are operating a pilot plant for conversion of natural gas to carbon nano fibres at Fiskå Verk in Kristiansand. Such products do not consume large gas volumes but may represent a significant value creation.

5.3 CO_2 Management

CO_2 management encompasses improved energy efficiency to reduce emissions and save energy, CO_2 removal from natural gas to meet gas sales specifications, and CO_2 capture, transport and storage (CCS) technologies from power plants. It is also possible to reuse captured CO_2 in industrial processes.

TTA8 considers in particular CO_2 separation from natural gas and management along the gas value chain excluding capture from power plants.

Storage can also include enhanced oil or gas recovery (EOR/EGR) - making valuable use of the carbon dioxide. A key issue for EOR/EGR is the reuse and management of back-produced CO_2. This issue is often complicated by the space and weight addition limitations on installations for offshore oil and gas production. Given the new price interval seen for oil recently it is likely that CO_2 EOR will happen in the near future for offshore applications. The NPD report of 2005 concluded a break even price of 33$/bbl oil for Gullfaks and Ekofisk. This is a level which now has been passed with a robust margin.

To make CO_2 management happen at large it is required to develop and implement a regulatory framework that allows a market and business to emerge. It is also necessary to gain public acceptance for these methods of cutting emissions.

The whole CO_2 value chain is considered in this TTA, as shown in Figure 7, but focus is as mentioned on activities outside power production The areas discussed have a considerable overlap with those covered also by other parts of the Norwegian funding system, such as Gassnova SF and the Research Council of Norway (RCN).

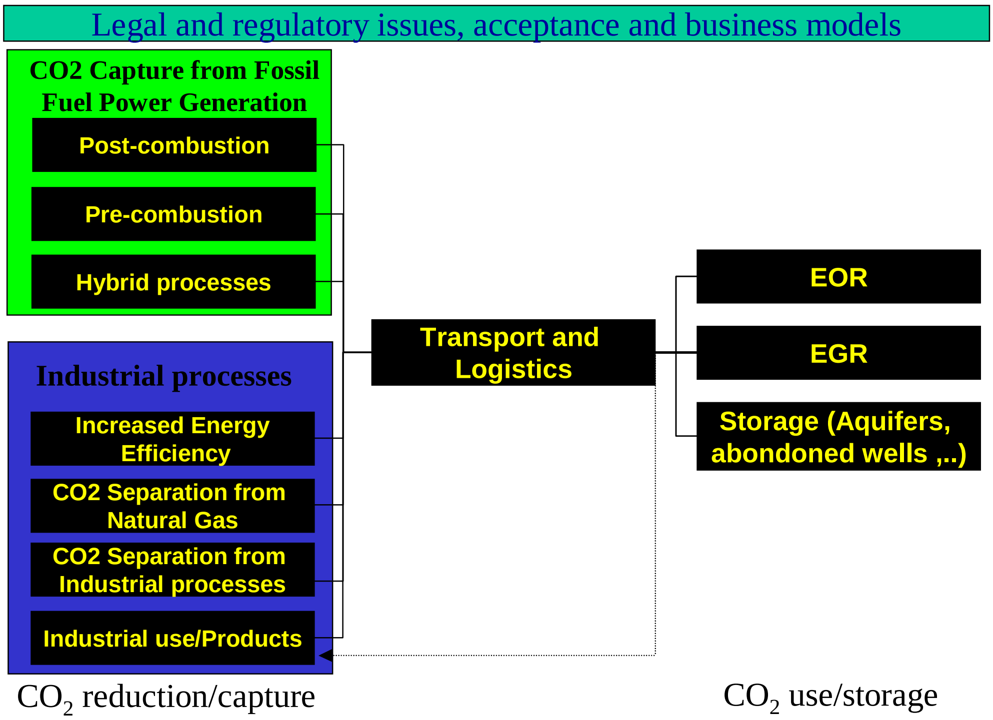


Figure 7. CO_2 – value chain elements relevant for TTA8.

The summary of the Gap Analysis based Scenarios is given in Figure 8. The Base & Key level prescribes a scenario where energy efficiency will be pursued by normal market mechanisms and where CCS is becoming an accepted method with an established framework for curbing greenhouse gas emissions (notably CO_2). The scenario, furthermore, prescribes that Norway has grasped the opportunity for pioneering an integrated CO_2 value chain. The Pacing level envisages a scenario that capitalizes on the Base level – commercially, technologically and regulatory. It shows how the Base and Key activities have paved the way for similar schemes internationally. The Emerging scenario outlines the case where Norway and NCS successfully have pioneered CCS and become a lighthouse example, e.g. resembling the position that Denmark has achieved in terms of wind energy. Norwegian activities and policies have then become a door opener into the international market for the Norwegian companies and institutions that have a strong position within several CO_2 technologies and areas. This can be similar to how Norwegian technology within other areas has succeeded internationally, e.g. sub sea technologies, floating production and concrete platforms.

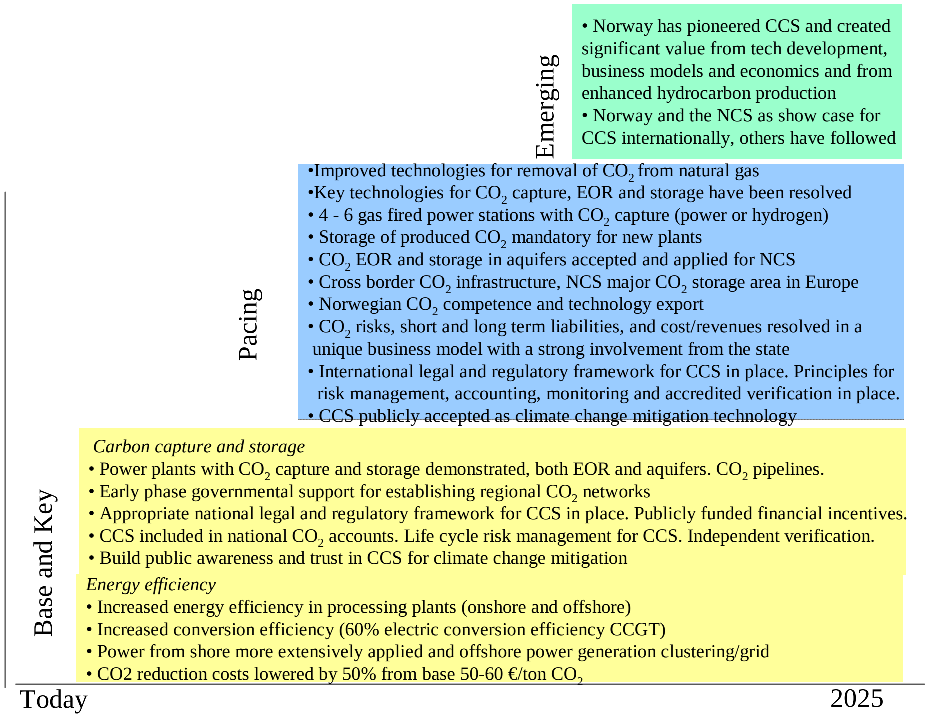


Figure 8. Gap Analysis based Scenarios for CO_2 management.

The present status for CO_2 management is broadly as follows:

In terms of energy efficiency and CO_2-reductions on NCS offshore platforms, the most cost-effective measures have already been implemented. This is due to the Norwegian CO_2 tax. An example is the installation of three combined-cycles offshore. Onshore processing and downstream plants also have made significant energy efficiency improvements during recent years.

Statoil is a pioneer in geological storage of CO_2 removed from natural gas: Sleipner (1996) in the North Sea, Snøhvit (2008)in the Barents Sea and In Salah (2004) in Algeria.

Offshore use of CO_2 for EOR is a less explored field, while CO_2 for EOR onshore was pioneered by Shell in the 1970's. Several studies of CO_2 for EOR on NCS have been performed, including the government-initiated CO_2 value chain project led by Gassco. StatoilHydro and Shell also initiated a CO_2 value chain project in Mid-Norway, this was however not commercially pursued.

There are still many unresolved issues with regards to CO_2 management. It is also clear that the realisation of a CO_2 value chain will require a cooperative effort between authorities and industry. The key future challenges within CO_2 management will be:

Producing enough energy while reducing GHG emissions: To stabilize CO_2 concentrations in the atmosphere by reducing CO_2 emissions is a major environmental challenge for the coming decades. The global challenge to produce sufficient energy for the world and reduce greenhouse gas (GHG) emissions at the same time is huge and will require a portfolio of measures and involve many different business areas. Increased energy efficiency, carbon dioxide capture and storage (CCS), and use of alternative non-fossil energy sources are the three main alternatives to reduce CO_2 emissions.

Increased energy efficiency: This is an important measure to reduce CO_2 emissions since the usable energy output is increased for a given energy input (fuel). Energy efficiency will also become increasingly important as fuel/energy prices increase irrespective of the CO_2 issue. Increasing energy efficiency is a continuous activity for offshore as well as offshore facilities.

Carbon Dioxide Capture and Storage (CCS): The demand for energy in the world will continue to grow, it is also likely that fossil fuels will prevail as the main energy source in this century. CCS can make a major impact on curbing CO_2 emissions. Based on the recent IPCC Special Report on Carbon Capture and Storage, the Fourth Assessment report (FAR) and the IEA Energy technology perspectives (ETP 2008) it is deemed likely that CCS technologies can mitigate about 25% of the reductions required to limit atmospheric CO_2 concentrations to 450-490 ppmv (at present reckoned equivalent to a 2 – 2,4^{o}C average temperature increase).This is the largest potential contributor for mitigation after end user efficiency.

CCS is already an area with high focus in Norway by authorities, NGO's, the public and the oil and gas industry. The main challenges for CCS are to:

- Develop CCS technology at competitive costs and acceptable environmental standards, and an economically viable value chain for CCS
- Increase the number of CCS demonstration projects, and the public awareness and acceptance
- Clarify the national and international legal and regulatory frameworks CCS ;
- Manage risks, monitoring, accounting and verification of CCS in terms of emissions and emission reductions

Increased Recovery: CO_2 for EOR has the potential to reduce initial CO_2 storage costs. From a CO_2 mitigation perspective it is important to remember, though, that the EOR opportunity will be time-limited. It will need to be followed by pure CO_2 storage in a longer-term perspective. From a pure increased recovery perspective CO_2 for EOR will need to be competitive with other EOR alternatives. Moreover, CO_2 will eventually break through into the primary hydrocarbon stream from an oil and/or gas field. Ways of handling this for existing installations will have to be considered. These points illustrate some of the challenges that arise when trying to connect multiple interests into a viable business model for the CO_2 value chain.

Development of new fields: CO_2 represents a challenge for new fields that contain high CO_2 levels, as these needs to be removed to meet gas sales specifications. More efficient and economic CO_2 separation technologies can be the key to unlock these resources.

6 R&D priorities, time frame and funding

This chapter seeks to highlight areas where specific efforts are needed to fill the identified gaps. These have been made specific within the three sub-areas identified. However, a true cross-cutting issue among these sub-areas is basic knowledge building to prepare Norway for the future challenges. Basic research and knowledge building are the key for all the topics described. This ranges from the education at Universities and Institutes Master of Science programmes and through PhD studies and research programmes with Post Doc opportunities. Research performed in the industry is an integral part of this effort. An obvious opportunity would be to establish more MSc programmes within Gas Technology that will require a strengthening of academic positions at relevant universities. Such activities will be required to recruit knowledgeable people for the industry and for the underpinning research needed for this area.

6.1 GAS TRANSPORT AND PROCESSING

The technology mapping according to the methodology described in Chapter 2 for this area is shown in Figure 9.

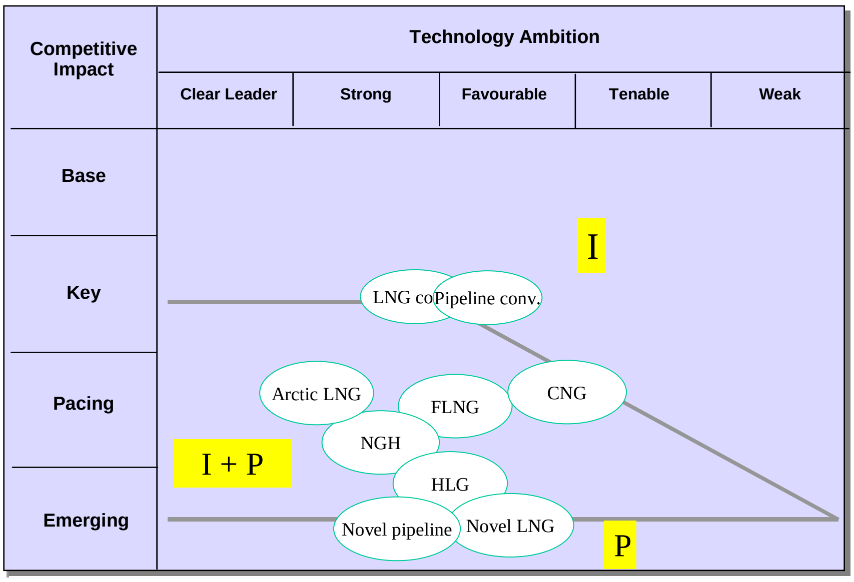


Figure 9. Technology ambition and funding map. Gas Transport and Processing.

Base and key technologies will prevail as preferred technologies until new technology has been qualified and is being taken up (diffused) by the industry. It is thus important to carry out incremental and applied research in order to increase efficiency and reduce costs by applying existing technology. R& D activities pertinent for development of prevailing technologies in gas transportation and processing as well as improving value creation from the NCS are identified in the list below:

R&D for improving efficiency and capacity in pipeline transport and processing

- Optimise operations, capacity utilization and cost effectiveness
- Develop new methods for maintenance
- Develop energy efficiency programs
- Improve operations in harsh environment
- Improve handling of trace components in gas streams (H_2S, CO_2, Methanol) without using yellow or red products
- Develop pipeline subsea intervention technologies

R&D for improving value creation

- Improve technology for extraction of heavy components (NGL, LPG)
- Pursue R&D within basic knowledge for LNG processes
- Develop technology for successful start-up, production and export of large scale LNG
- Develop technology for small scale production and domestic distribution of LNG

R&D activities must also be designed to enhance pacing and emerging technologies for transporting natural gas more efficient and cost effective. Such technology should also make possible transportation and processing solutions from regions that today are not accessible.

R&D for increasing efficiency and capacities by new technologies

- Qualifying and demonstration of CNG, FLNG,NGH, and HLG
- Commercialization and diffusion of CNG, FLNG NGH, and HLG
- Concepts for liquefied natural gas transport with CO_2 return load

R&D for improving value creation from new regions

- Pipelines to new regions (South East Norway and Sweden)
- Technologies for Snøhvit Phase 2 and Shtokman
- Development and tie-in of stranded fields
- Construction and operations in cold climate, permafrost areas, and ice- infested waters
- LNG tankers in ice-infested water
- Pipeline transportation from Barents sea
- Chemical-free gas processing
- Sub sea gas conditioning
- Liquefied gas chains with minimal or no pre-processing (simplified process)
- New concepts for liquefied gas to power chains, with CO_2 management

6.2 Conversion to fuels, chemicals and materials

The technology map for this area is found in Figure 10.

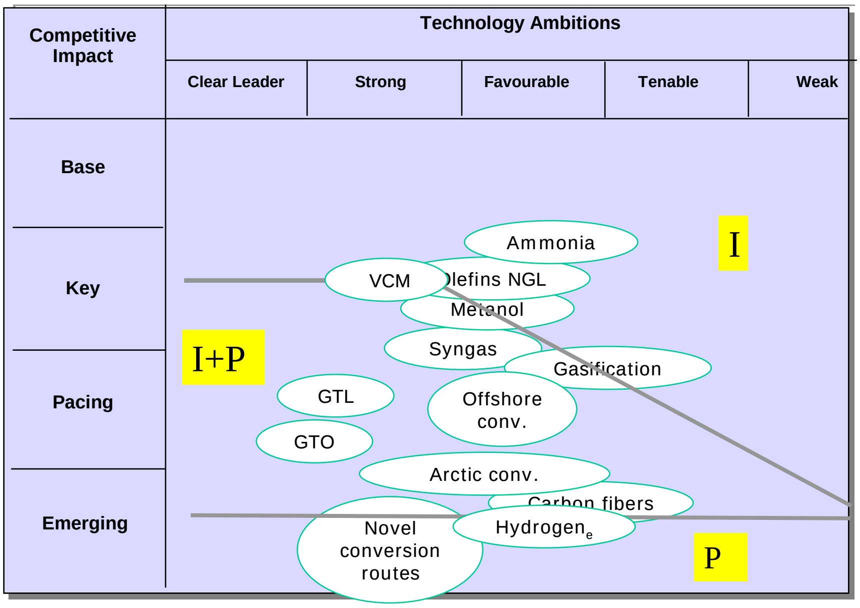


Figure 10. Technology ambition and funding map. Gas conversion to fuels, chemicals and materials

It is expected that the established methanol, ammonia and olefin industry based on Base and Key technologies, will continue to optimize operation mostly by industry funding. However, pacing elements of these technologies such as offshore conversion, which could be of interest for Arctic areas, will certainly need both industry and public funding.

For pacing technologies it will be beneficial to have both solely industry funded research and collaborative research between industry and research institutes and universities. Even if most of the pacing technologies potentially could be funded by the industry due to strong commercial driving forces for at least some of these gas technologies, e.g. GTL and GTO, it is of extremely high importance to have parallel research activities at the universities and research institutes to ensure recruitment and competence build up within future important technologies for Norwegian industry. The SPUNG generation (former students participating in the SPUNG research program) hold central R&D positions in leading Norwegian companies today focusing on development of gas technologies.

Generally, there is a strong need for reduced production costs for all conversion technologies in order to be able to compete with gas sales and realize increased value creation from gas. This explains the need for further research in for example for synthesis gas technology, which is commercially available today, however is key to most gas conversion and a step change in cost reduction for synthesis gas would increase competitiveness.

Emerging technologies include gas conversion to materials, hydrogen as energy carrier, and direct and other radical concepts for conversion of natural gas to e.g. fuels, methanol, olefins or other products. For emerging technologies we suggest mainly public funding, but with industry as a discussion partner.

6.3 CO_2 Management

Technology ambitions and suggested funding for CO_2 management R&D are shown in Figure 11.

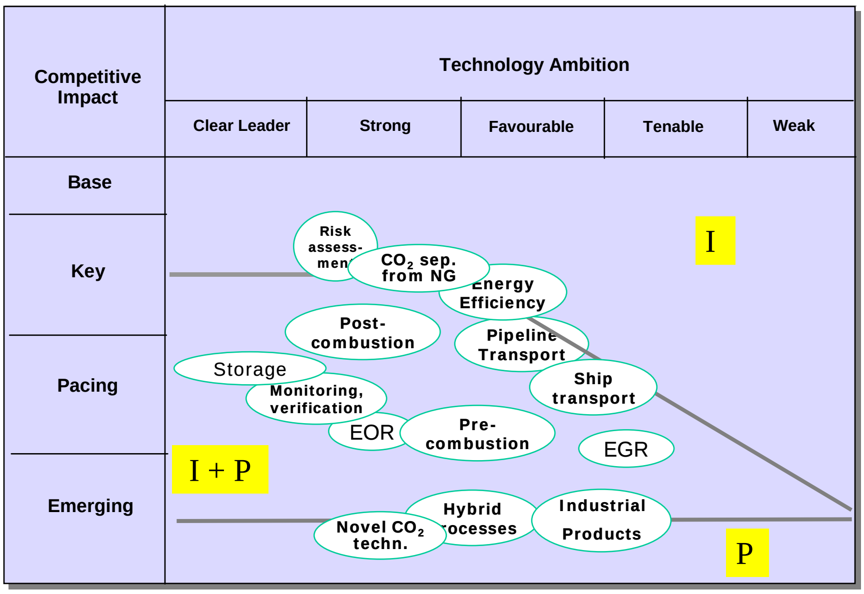


Figure 11. Technology ambition and funding map. CO_2 management

CO_2 management is an emerging business area which clearly needs joint efforts by industry and authorities to materialize and succeed. Hence collaborative R&D between industry and authorities should be the predominant form of R&D. The following priority areas have been identified:

Geological storage: Norway has a unique position within offshore geological storage of CO_2 in aquifers (Sleipner and Snøhvit). We should further develop and increase our competence for predicting permeability, integrity and capacity of formations such as deep saline formations, depleting and depleted oil and gas reservoirs. We need to define criteria and methods for selecting optimal storage sites and optimal CCS solutions in terms of risks, costs, environmental friendliness, sustainability, safety, long-term robustness and liability, etc. It is now believed that the recently published CO_2-storage directive of EU will pave the road for a legal framework for storage.

Offshore CO_2 EOR: This technology has never been applied and Norway is in position to pioneer the field. CO_2 EOR will always need to be combined with storage from a CO_2 mitigation perspective. Important areas in addition to those mentioned under geological storage are good reservoir models for CO_2 EOR, combined optimization of EOR effect and storage of CO_2, and topside modifications/management of back-produced CO_2. Some of these areas are also covered by other TTA's. The development and management of a CO_2 infrastructure is key to CO_2 EOR and storage.

Accounting, monitoring and verification: We need to develop technologies for measuring amounts of CO_2 stored, leak detection, and mitigation of leaks along the CO_2 value chain. The work should address aspects such as estimation accuracy, future predictions, monitoring, risk management, and credits towards internationally agreed schemes. It is important to harmonize these schemes with existing risk-based regulatory frameworks for petroleum activities in the North Sea, EU's Emission Trading Scheme and the UNFCCC flexible mechanisms.

CO_2 capture technologies for fossil fuel power generation: Few countries have the same focus on CO_2 capture from natural gas power plants as Norway. Technology is crucial for making progress towards the long-term goal of full-scale solutions for injection and permanent geological storage of $CO_{2.}$ Technology areas are post-combustion, pre-combustion and hybrid processes (oxyfuel etc.). Challenges are the costs and risks associated with applying new technologies, minimizing efficiency loss, and the large amounts of CO_2 needed at an injection site for economic viability. This area is covered under the CLIMIT program in Norway with the operative bodies Gassnova SF and the RCN.

CO_2 separation from natural gas: This technology area is important for development of fields with high CO_2 content, on the NSC and internationally, as well as for managing back-produced CO_2 if CO_2 is applied for EOR. Focus should be on new innovative and cost-efficient technologies. This area overlaps strongly with Gas transport and processing, cf. previous Chapter.

CO_2 transport: Cost-efficient transportation by ship or pipeline, logistics. CO_2 qualification guidelines will have to be developed detailing the term "overwhelmingly consisting of CO_2".

Energy efficiency: Improved process optimisation and control offshore and onshore. This will mainly be improvement of existing technologies by industry.

From a CO_2 management perspective the use of CO_2 as a feedstock for industrial products or mineralization will only be a niche area with limited practical storage potential and residence time (industrial use). It has hence not been prioritised.

7 Overall Roadmap for Gas Technologies

The overall roadmap for Gas Technologies is shown in Figure 12. It compiles the main conclusions regarding opportunities and technology ambitions for the three main areas; gas transport and processing, gas conversion, and CO_2 management.

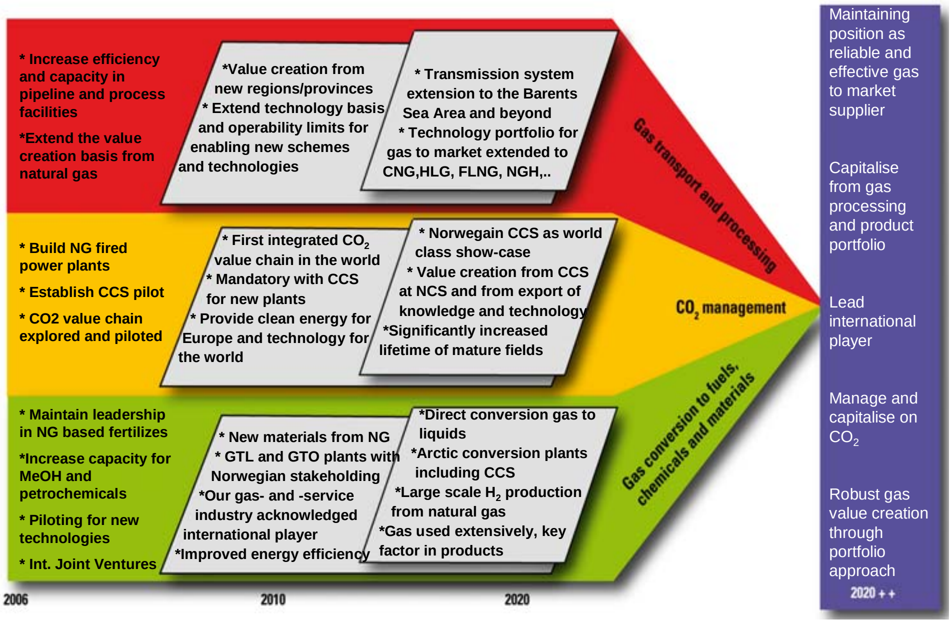


Figure 12. Overall Roadmap for Gas Technologies: Gas transport and processing (red), CO_2 management (yellow) and gas conversion (green).

The base layer identifies key technologies that will have to be pursued to maintain Norway's role as a key provider of gas and gas technology. These are non-negotiable steps that need to be pursued to avoid a declining position. The second layer represents near term options and possibilities that could further enhance the Norwegian position. They have a reasonable risk profile, and require appropriate resources and drive to become realized. At the top layer we have documented some of our "dreams", what we may achieve with a progressive approach and strong policies to drive innovation. Given that enough elements of this overall roadmap are pursued, we could get to the attractive 2020+ position.

8 Link to other TTAs

The main links to other TTAs are:

TTA1 Environmentally sound operations: CO_2 management
TTA 3 Enhanced recovery: CO_2 management
TTA 6 Sub sea processing and transportation: Tie-on of stranded fields (marginal) and sub sea gas conditioning.

9 Recommendations

The main recommendations are based upon the objectives as derived from our Vision:

- Norway, a leading gas technology nation in the 21st century with the gas industry as a key industrial sector.
- Norway, a leading international gas technology player that promotes Norwegian operator ships internationally and the export of technology, products and services

Based on this vision and the mandate defined by the OG21 Board, three main gas technology areas are defined:

- Gas transport and processing (pipeline, LNG, other)
- Gas conversion to fuels, chemicals and materials
- CO_2 management

In order for the Norwegian Gas Cluster to become a strong player domestically and abroad, it is considered as a prerequisite to build strong competence and technology positions within selected parts of these areas. Development of a technology tool box that secures Norway's competitiveness within gas technologies should provide a solid platform for future gas utilisation regardless of changing frame conditions.

It is important to find a balance between basic research in selected areas and the use of new technology to develop commercially interesting solutions. The areas where we recommend increasing the effort are:

- Further strengthen effort on basic technologies relevant for LNG solutions. i.e. fluid mechanics, heat transfer, material technology etc needed to develop more energy efficient LNG solutions both for land based installations and floating facilities

    1. Develop efficient solutions for liquefaction taking into account the large range of air temperature, which is one of the characteristics for liquefaction plants in Arctic areas.
    2. Develop liquefaction concepts for floating units based on safety and simplicity as key parameters.
    3. Consolidate the knowledge obtained through the first development of small scale liquefaction plants to improve their efficiency and ease of implementation.

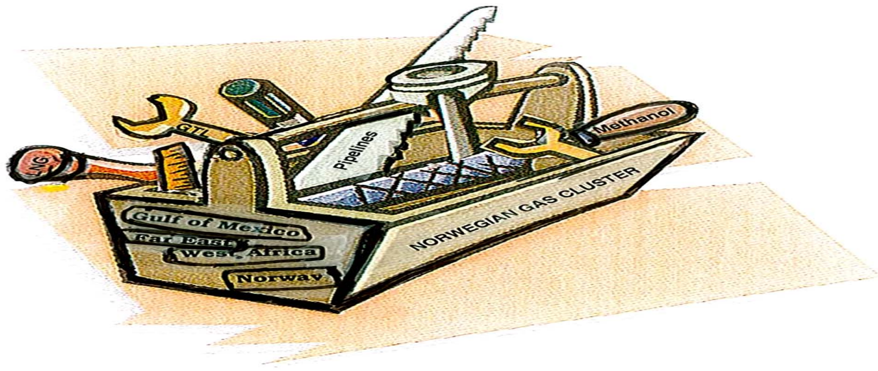
- Further strengthen the effort on basic technologies needed to develop energy efficient and cost efficient synthesis gas processes with minimum environmental impact.
    1. Participate in the development of improved reformer technology
    2. Development of integrated concepts for CO_2 removal from synthesis gas

- Further strengthen the effort on basic technologies needed to develop energy efficient and environment friendly technologies for CO_2 removal from natural gas.
1. New solvents
2. Non solvent based technologies

- Further strengthen the effort in developing methods, such as qualification guidelines, for how to efficiently bring promising basic technology into commercial cost-efficient, technically feasible, environmental friendly, and safe solutions.

TTA8 recommendations are detailed and summarised in Figures 9-11.

Increased focus on education and research is also strongly recommended and applies to all technological areas within this report. We see today an increasing gap between the recruitment required and the oil and gas industry's need the coming years to meet the challenges highlighted in this report.



10 Appendix 1

Table 1: Ongoing projects with Demo 2000 funding in April 2008.

TTA8	Prosject	Company	Duration	End
175957	High pressure composite containment system for associated gas or well-stream storage and transportation	Compressed Energy Technology AS (CETech)	01.07.2006	31.01.2008
182517	MiniLNG Pilot Plant	Sinvent AS	01.09.2007	01.09.2008
182557	Ship Based Production And Transportation Of Hlg (Heavy Liquified Gas)	Aker Kværner Engineering & Technology AS	01.06.2007	15.06.2008

The total budget for all Demo2000 projects given in Table 1 is NOK 10.150. 000 for the whole funding period.

11 Appendix 2

Table 2: Ongoing Petromax funded projects in April 2008.

TTA8	Project	Company	Start	End
162 121	Økt transportutnyttelse gjennom optimalisering av strømningskontroll og operasjonsstyring	Gassco AS	20.01.2004	31.12.2008
163 485	Singing Risers - National competence building initiative on turbulent flow for optimum flow control of gas in export risers and flowlines.	Norsk Marinteknisk Forskningsinstitutt AS, Marintek	01.07.2004	31.12.2008
168 223	Enabling production of remote gas	SINTEF Energiforskning AS	01.04.2005	31.12.2009
173 892	Amplitude-LNG Loading System Fabrication & Qualification	Det Norske Veritas AS - Høvik	01.01.2006	31.12.2008
175 967	Regularity and uncertainty analysis and management for the Norwegian gas processing and transportation system	International Research Institute of Stavanger AS	01.07.2006	30.06.2011
176 137	Liquefaction of Unprocessed Well-Stream	Institutt for energiteknikk - Kjeller	01.07.2006	31.12.2010

The total budget for all Petromax projects given in Table 2 is NOK 69.259. for the whole funding period.