CCS overview - the Norwegian experience

Seminar on Evaluation of CO2 Storage Potential
ITB, Indonesia, 10-11 december 2012

Dr. Per Christer Lund, Counsellor Science and Technology

Norwegian Embassy in Tokyo

We give local ideas global opportunities

Norway keen to exploit its carbon capture lead

Clean energy

Oslo wants to turn an environmental imperative into a commercial opportunity, writes Joshua Chaffin

One hour by helicopter from the Norwegian coast, the mammoth Sleipner platform rises more than 200 metres above the grey water of the North Sea. Named after a mythical eight-legged horse, it sucks natural gas from dozens of underwater wells and then sends it through a tangle of pipelines to destinations across Europe.

But a lone pipe, painted green, never reaches the mainland's kitchen stoves or furnaces. Inside is a stream of carbon dioxide, a natural gas byproduct that is one of the main causes of global warming. The green pipe carries the CO_2 from Sleipner back underwater and deposits it into a reservoir more than one kilometre beneath the ocean floor.

There, at least in theory, it will rest for thousands of years. Since 1996, Statoil, the Norwegian state-owned energy company that operates Sleipner, has disposed of almost 13m tonnes of CO_2 in this way.

Statoil has taken repeated images of the undersea reservoir since it began injecting CO_2. Thus far, it has shown no signs of leakage.

That has made Sleipner something of a holy site for believers in carbon capture and storage (CCS), a promising but controversial technology in the fight against climate change.

Now Statoil is trying to turn an environmental imperative into a lucrative commercial opportunity: it has dedicated a group of geologists to mapping the undersea region with the aim of one day providing carbon storage for power plants and manufacturers across Europe.

"We want to build a business at Statoil as a carbon dioxide storage provider," says Kristofer Hetland, a Statoil executive.

The fate of Norway's carbon capture plans will have ramifications well beyond the North Sea. The International Energy Agency has identified CCS as a cornerstone in the fight against climate change. It is calling for 3,400 projects worldwide by 2050 – along with investments in renewable energy, energy efficiency and nuclear energy – to keep global warming within reasonable bounds.

The European Union, the US and China are all investing billions of dollars in the technology in an effort to bring down its costs and make it widely available over the next decade. They are also hoping that their energy and infrastructure companies will gain a commercial advantage.

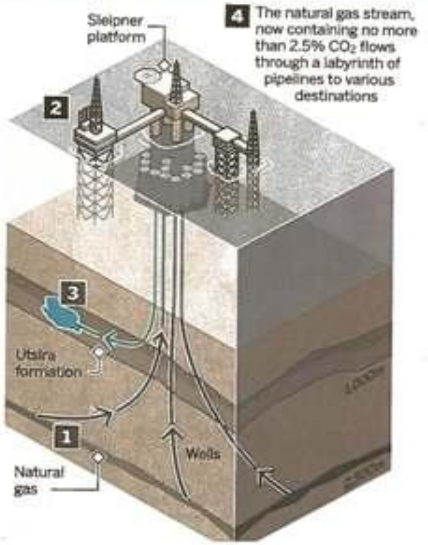
But thanks to Sleipner, Statoil remains the leader in the field. The company began to bury the field's CO_2 after the government imposed a tax on carbon in the early 1990s. The technology to do so was


Sleipner: keeping CO_2 out of the atmosphere

Carbon capture and storage funding committed to date*

How it works

1. Natural gas (containing 9% carbon dioxide) is siphoned to the Sleipner platform from wells that extend about 2,500m below the surface
2. CO_2 is extracted from the gas via absorption towers on the platform
3. It is injected into the Utsira sandstone formation about 1km below the seabed – also known as a saline aquifier – where it is stored
4. The natural gas stream, now containing no more than 2.5% CO_2 flows through a labyrinth of pipelines to various destinations



where oil companies began injecting CO_2 into depleted wells in the 1970s to enhance production.

"What is so important about Sleipner is the track record," says Chris Davies, a member of the European Parliament and a staunch advocate of carbon capture. "CO_2 has been injected into the rocks below the North Sea there for more than a decade, and there appears to be have been no leakage whatsoever."

The venture's success, said Mr Davies, provided confidence that it could be replicated again and again.

But expanding CCS beyond Sleipner will not be easy. One problem is that it remains far more difficult and expensive to capture CO_2 from a power plant or factory than from a natural gas well.

That has become evident at the Norwegian coastal city of Mongstad, where the government had planned to build a power plant and oil refinery equipped with CCS technology. The idea was to provide an example of how CO_2 could be captured at onshore industrial facilities and then piped offshore for storage. But in May Oslo was forced to shelve those plans amid rising costs and questions about the technology.

CCS sceptics claim the technology will never be economically viable and that government funds should instead be directed at wind, solar and other forms of renewable energy. While supporters dispute this, they acknowledge that the depressed price of carbon on Europe's emissions trading system is providing little incentive for companies to make the necessary investments.

Another challenge is public acceptance. Like nuclear before it, CCS is fast becoming a bogeyman in communities across Europe, where residents

lead to the release of toxic gas. Those concerns have already halted a project in the Netherlands, where Shell was planning to inject CO_2 into a depleted gas well just down the street from an Ikea store. They are also slowing efforts in Germany to pass legislation that would govern carbon transport and storage.

The disastrous BP oil spill in the Gulf of Mexico has cast a new shadow of risk over the practice of boring holes beneath the ocean floor. It is also leading some MEPs to call for a review of CCS policy.

"Just like oil drilling, you have the same potential danger with carbon capture and storage," says Bas Eickhout, a Green MEP from the Netherlands.

> 'We want to build a business at Statoil as a carbon dioxide storage provider'

Statoil executives and their allies insist their work should not be compared with the BP spill because Statoil is operating at a depth of just 80m in the North Sea, compared with several thousand in the Gulf of Mexico.

Mike Stephenson, head of the British Geological Survey's energy division, sympathises with the public's concerns but says that CO_2 could be safely stored for thousands – if not millions – of years in saline aquifers, where it solidifies after binding with the surrounding brine and minerals.

"The public are right to worry because you are putting CO_2 into the ground and hoping it will stay there for a very long time," he says. "But the

Norway's CO2 footprint.

Share of the world's population:	0,07 %
3 x higher CO2-emission per capita than average:	0,21 %
13 x higher CO2-emission (oil & gas export):	2,73 %

World's 2nd largest exporter of natural gas
World's 5th largest exporter of oil
The petroleum industry is important for Norway:
- **One half of total exports**
- **One fourth of GDP**
- **One third of total Government income**

World's largest Sovereign Wealth Fund USD 526 billion

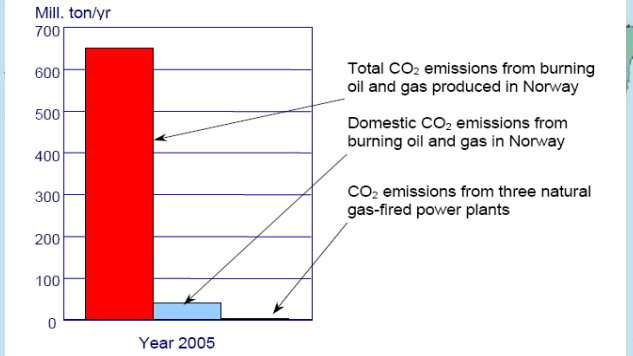


Figure 5. CO_2 emissions "originating" from Norway[18]

Courtesy: www.worldmapper.org

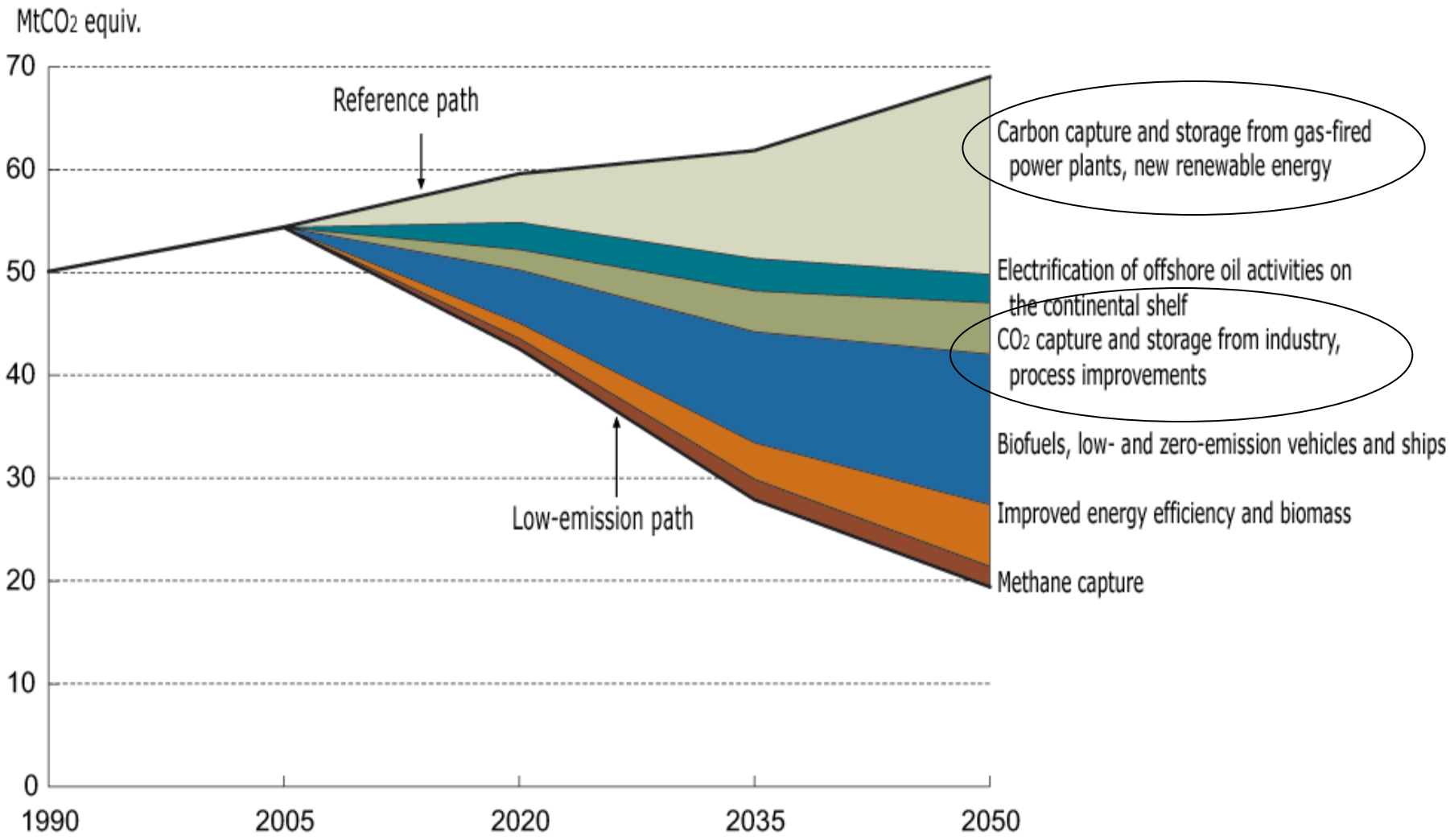
The Norwegian Climate Policy

Political consensus:

- Global target: limit average temperature hike to 2° C above pre-industrial level
- Strengthen Norway's "Kyoto commitment" from 1% above 1990-level to 9% below 1990 level
- Reduce Norway's carbon emission footprint with 30% within 2020
  - Reduction of 15-17 MtonCO2 including forestation
- Norway shall be "carbon neutral" within 2050
  - Carbon emission reductions may be domestic/offshore reductions or through purchase of international emission credits
  - However – the target is that 50%-65% of the reduction shall be domestically

White Paper No. 34 (2006-2007) On Norwegian Climate Policy, published on 22 June 2007
Agreement on the White Paper between the government parties and three opposition parties ("Klimaforliket"), signed 17 January 2008

How to get there?



Status Norwegian CCS technology development

INNOVATION NORWAY

Research

- **Mapping of storage potential in North Sea**
- **CLIMIT-programme** (Technology development state aid)
- **Research centres** (for Environmentally Friendly Energy)
  - BIGCCS Centre (CCS)
  - SUCCESS (CO_2 storage)

Development

- **CO_2 storage field laboratories** (Svalbard and Hurum)

Demonstration

- **CO_2 Technology Centre Mongstad – TCM**
  - In operation May 2012

Pre-commercial

- **CCS from CHP at Mongstad**
  - Under planning/Planned decision 2016
  - Technology qualification programme

Commercial

- **Sleipner** - 16 yrs of sub sea bed CO_2 storage
- **Industry participation** - to develop an ownership and operation model for CO_2 transport and storage

Source: Gassnova

Norwegian CCS projects

Snøhvit LNG

0,7 mill ton/yr, 2007

Svalbard CO2 project

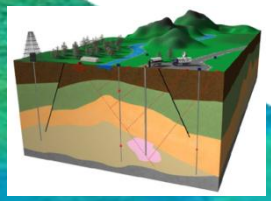
Storage from coal power

Mongstad refinery & power plant

0,1 m ton/yr., 2011

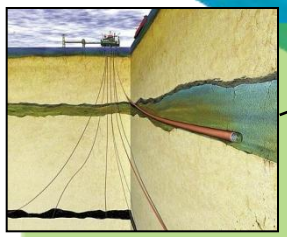
1,4 mton/yr, 2016-18

NORWAY



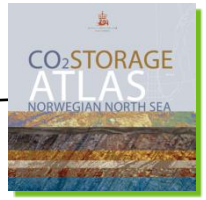
Hurum CO2 Field Lab

Land-based storage, leakage surveillance



Sleipner reinjection

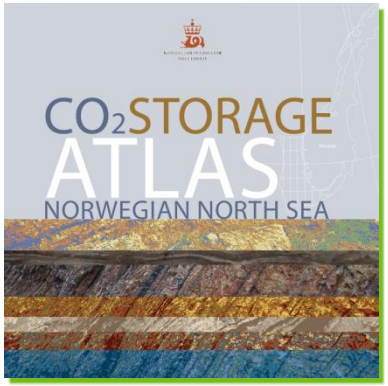
1 million tonnes/yr since 1996



CO2 storage Atlas

Mapping of Norwegian North Sea

Mapping of CO2 storage potentials in Norwegian North Sea

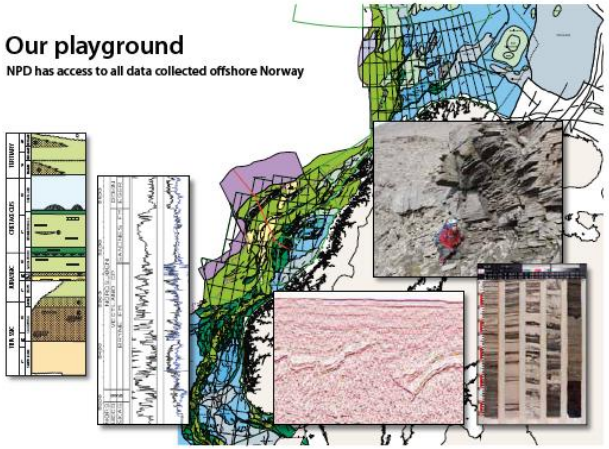


Prepared by the Norwegian Petroleum Directorate

Objective – to map possible sites for long-term storage of CO2

Study of all geological formations and hydrocarbon fields on the Norwegian part of the North Sea:

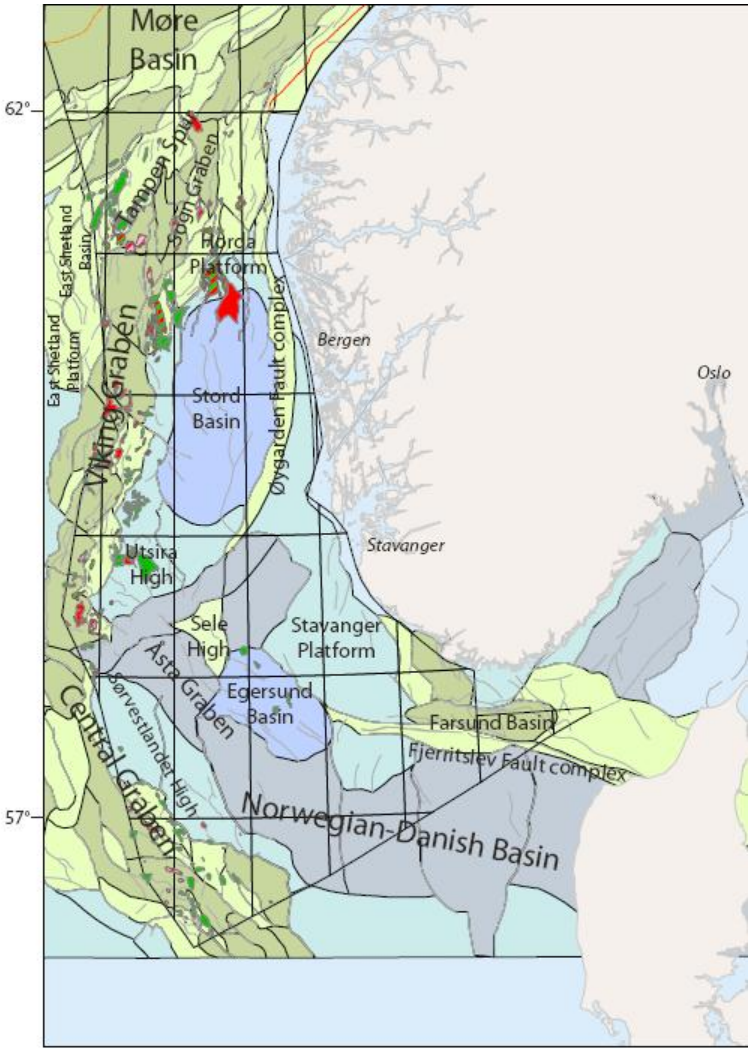
- **Accumulation of 40 years oil and gas exploration activity**
- **Huge amount of seismic data, exploration and production wells.**



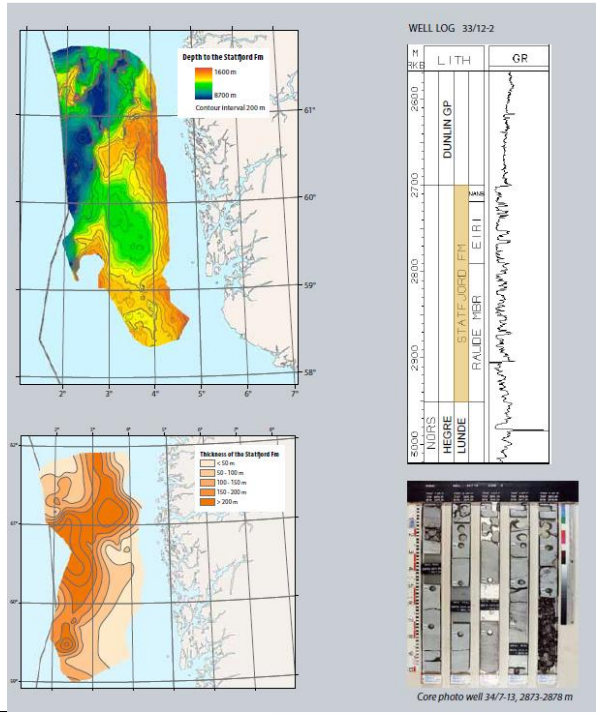
21 geological formations assessed – grouped into saline aquisfers

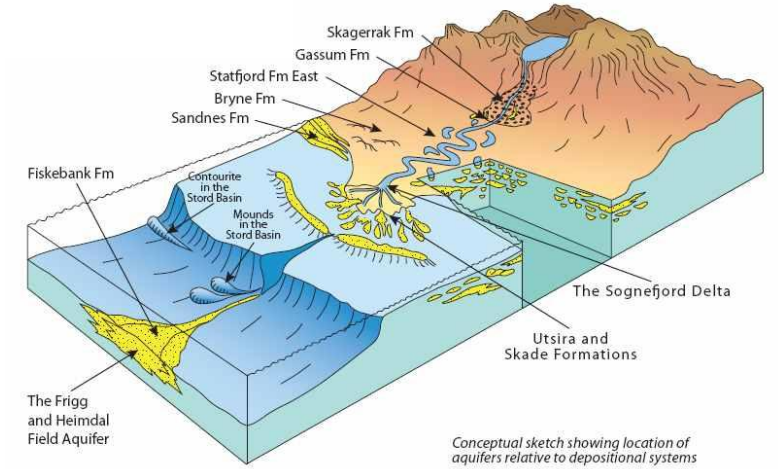
www.npd.no/Global/Norsk/3-Publikasjoner/Rapporter/PDF/CO2-ATLAS-lav.pdf

Geological provinces



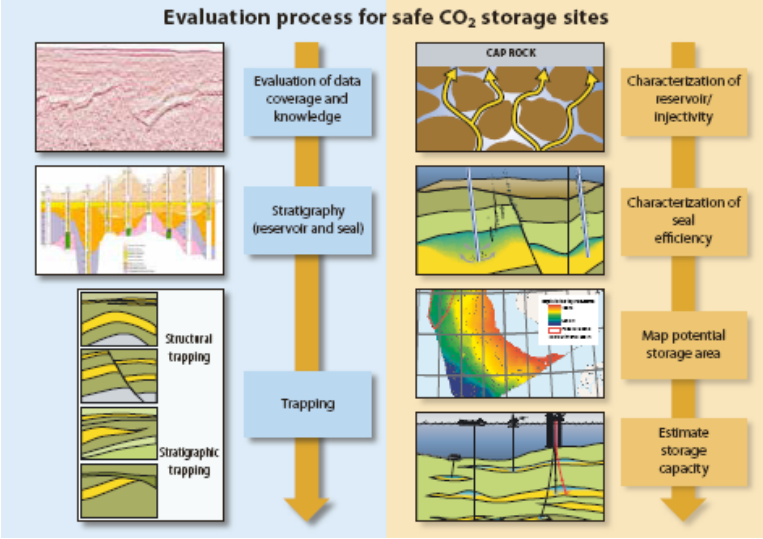
The Statfjord Formation



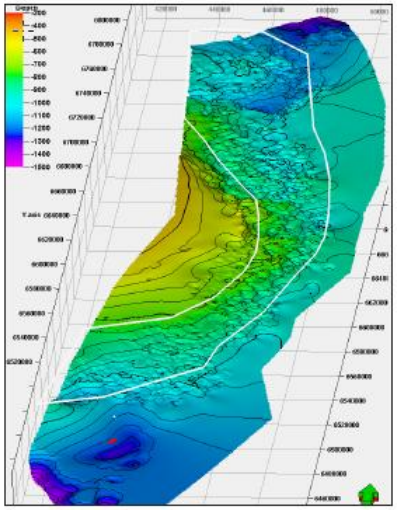


Conceptual sketch showing location of aquifers relative to depositional systems

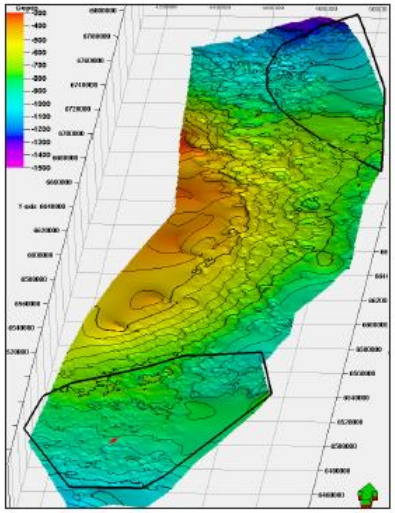
Methodology – data collection, mapping and analysis



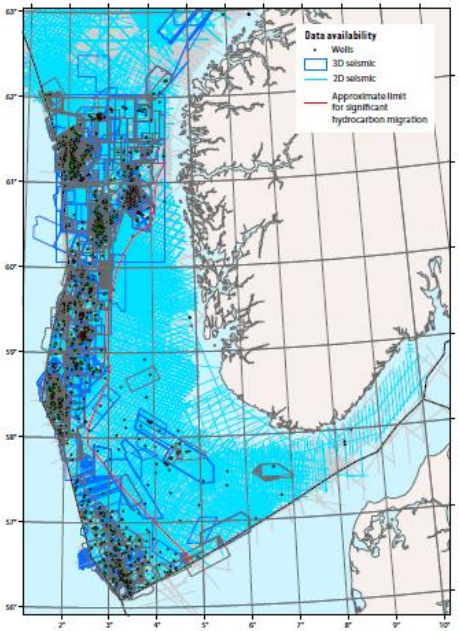
The Utsira and Skade aquifer



Top of Skade Formation. The white polygon indicates area which may be favorable for CO_2 storage. Red dot shows Sleipner injection area. The grid squares are 20 km x 20 km.

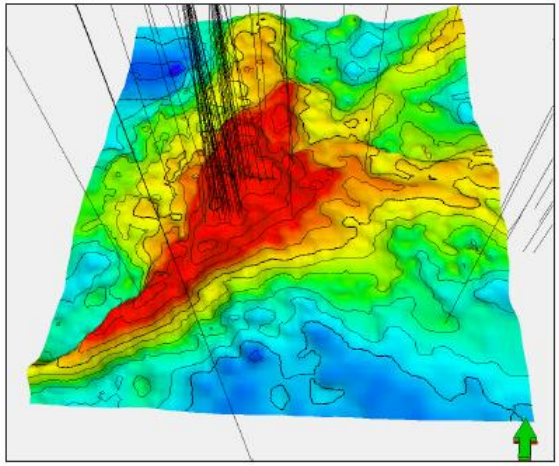


Top of Utsira Formation. The black polygons indicate areas which may be favorable for CO_2 storage.



www.npd.no/en/Regulations/Regulations/Petroleumactivities

Storage of CO_2 in abandoned fields



Structural map of the Frigg field with all wells

Summary of findings

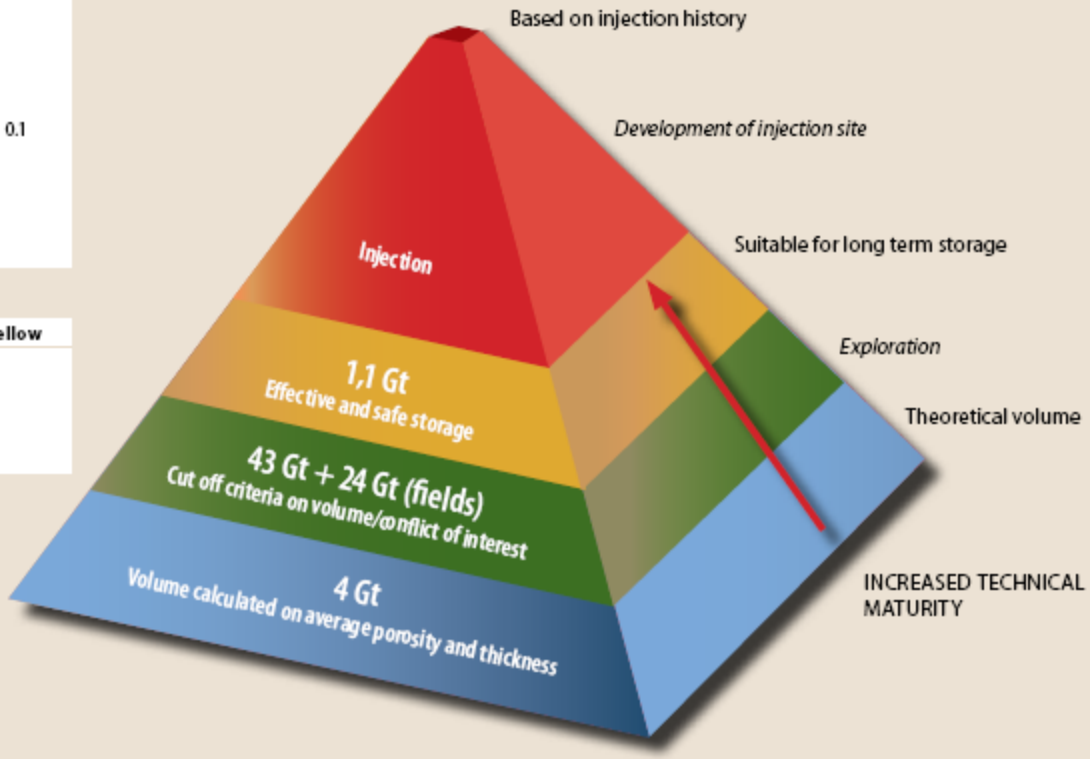
Storage capacity in Gigatons and technical maturity

Aquifers

Basin/reservoir	Storage capacity	Maturity		
	Total	Blue	Green	Yellow
Utsira and Skade	15.8		14.8	1
Bryne/Sandnes southern parts	13.6		13.6	
Sognefjord Delta east	4.1		4.1	
Statfjordfm øst	3.6		3.6	
Gassum	2.9	2.9		
Bryne/Sandnes Farsund basin	2.3		2.3	
Johansen and Cook	1.8		1.7	0.1
Fiskebank	1	1		
Hugin East	0.1		0.1	
Stord basin, Jura	0.1	0.1		
Stord basin , mounds	0.05	0.05		

Field related

		Blue	Green	Yellow
Abandoned fields	3		3	
Fields in production 2030	4		4	
2050	6		6	
Sognefjord delta including Troll	14		14	



www.npd.no/en/Publications/Reports/CO2-Storage-Atlas-/

CO2 Field Lab - Hurum

Norwegian/French/UK project to determine sensitivity of monitoring system for CO2 migration and leakage.
www.sintef.no/co2fieldlab

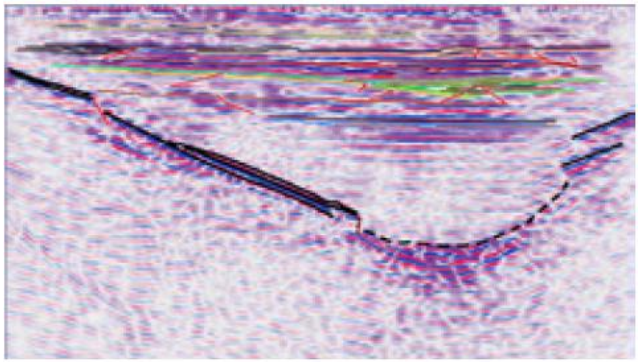
Phase 1 *(Completed in January 2011)*

- Site characterisation (2009 - 2010)
  - Geological surveys using ERT, GPR and 2D seismics have been performed at the site
  - A 330-m deep appraisal well has been successfully drilled and logged
  - Hydrodynamic appraisals at several depths
  - Updating geological and flow models using acquired data
- The site was found suitable for controlled injection experiments in Phase 2

Overview of the field laboratory site

Phase 2 *(Started in May 2011)*

- CO_2 injection & monitoring (2011 - 2013)
  - Drilling of injection and monitoring wells
  - Shallow CO_2 injection: 10-30 m (September 2011)
  - Deep CO_2 injection: 100-300 m, 200 tonnes (2012 - 2013)
  - Monitoring techniques include seismic, electromagnetic, gravimetric, downhole, chemical, geochemical, ecological and atmospheric methods
  - Investigate detectability and sensitivity
  - Ensure safe operations and clean site abandonmnent
  - Development of a monitoring protocol and certificate



Migrated image from the performed 2D seismic survey

Project initiated by Univ. of Svalbard.

Phase 1 - identify storage areas:

- sandstone layers with saline ground water
- Three wells were drilled in 2007 and 2008
- 4th well 2009 (970meters)

Phase 2 - injectivity tests of reservoir

- Ongoing.

Phase 3 - Medium scale CCS

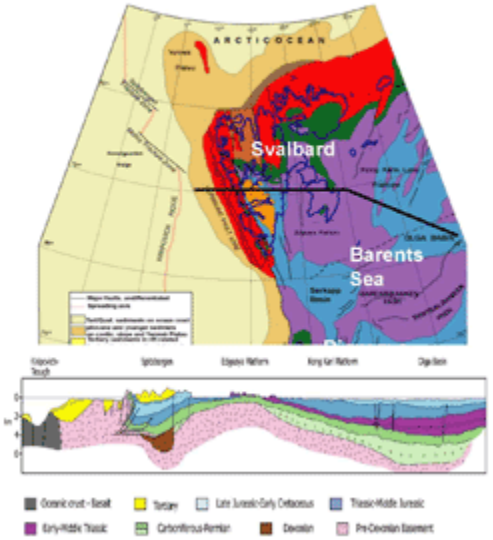
- From the coal power plant in Longyearbyen
- 2013 - 2017

Phase 4 - Full scale CCS

- 2017 - 2025

Why testing CCS on Svalbard?

the geology ....



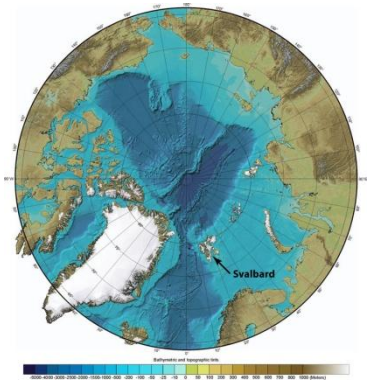
- Svalbard represents an uplifted part of the Barents Sea
- Svalbard's rocks contain oil-gas in the Barents Sea
- Svalbard offers rocks suitable for CO2 storage
- Contrary to Svalbard, rocks of mainland Norway with very few storage possibilities
  - ✓ Wrong type of rock
  - ✓ Utilized land
  - ✓ Conflicts around use of land and subsurface
  - ✓ HMS of the public

Partners:

- **ConocoPhillips, Statoil, Store Norske, Gassnova (Norwegian government), Statkraft, Lundin Norway and Leonhard Nilsen.**

Research and operational partners:

- **Univ. of Bergen, Univ. of Oslo, NTNU, SINTEF, NORSAR, IFE, NGI, NGU, Add Energy and BJ Services.**

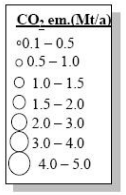


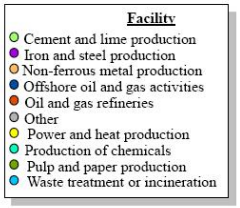
Joint Nordic approach to CCS

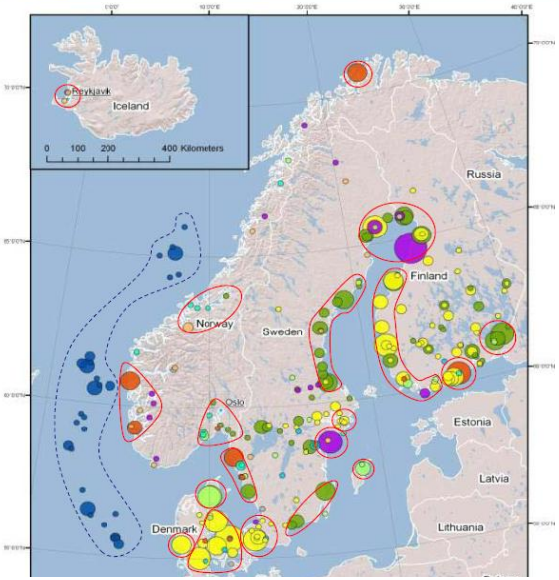
INNOVATION NORWAY

norden
Top-level Research Initiative

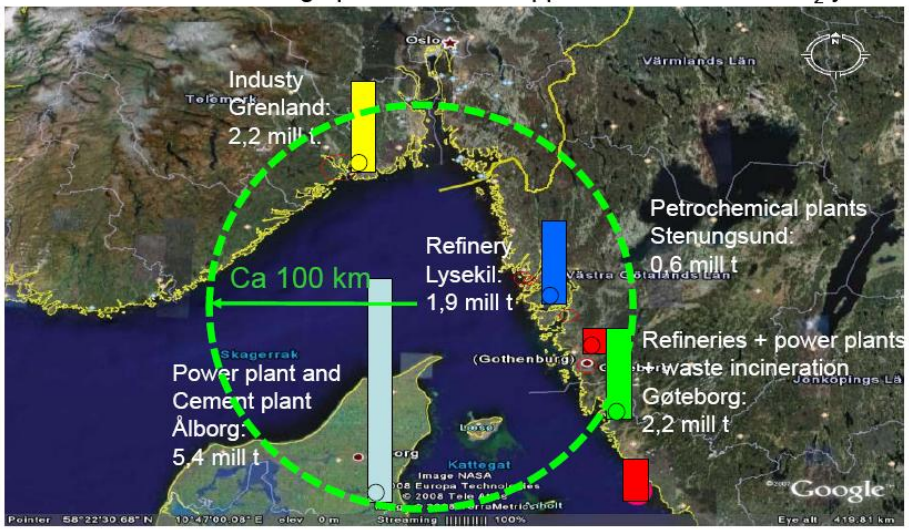
GIS-database over largest CO_2 emitting facilities

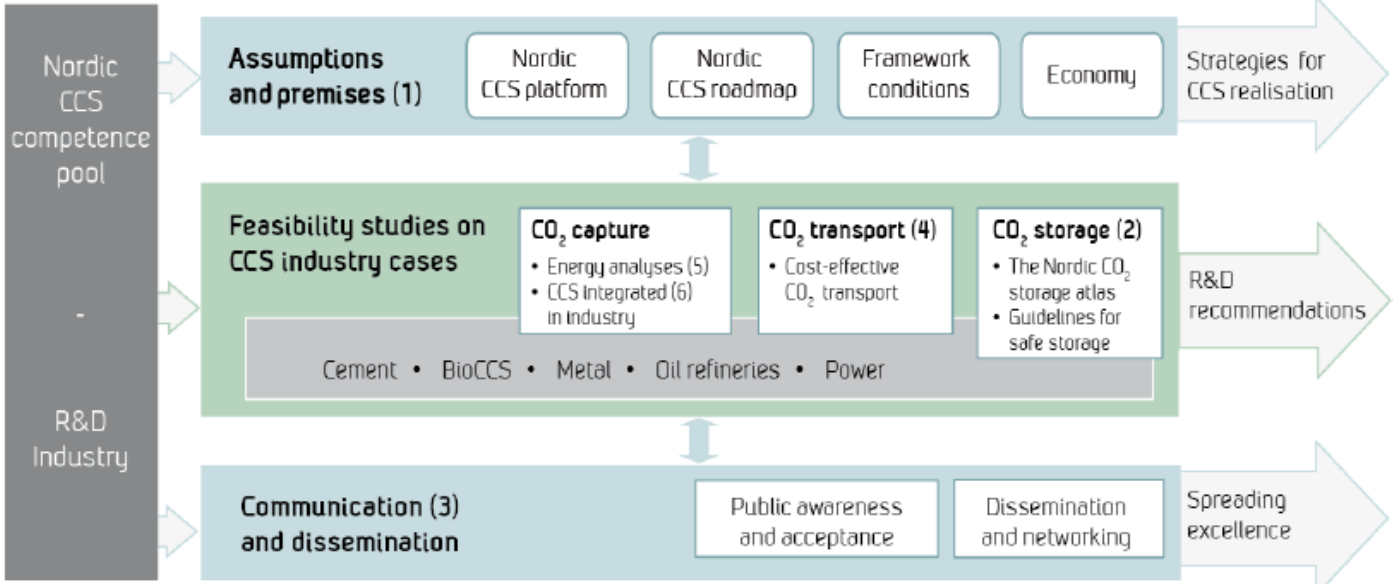






Total emissions from large point sources: Approx 13 mill tonnes CO_2/year



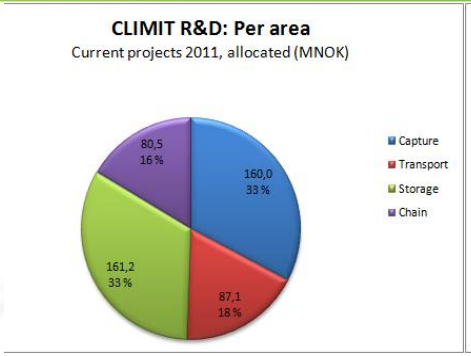


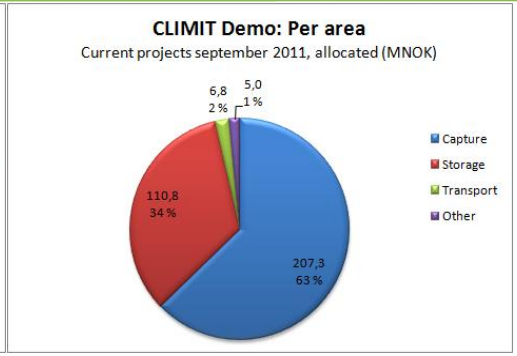
The Norwegian CO2 Capture Research Structure

INNOVATION NORWAY

MINISTRY OF PETROLEUM AND ENERGY

The Gas Technology Fund
26.5 billion Yen





The Research Council of Norway

GASSNOVA

The Technology Research Program CLIMIT
2.6 billion Yen

AkerSolutions

SARGAS
ZERO EMISSION POWER

cmr Prototech

tel-tek Telemark Technological Research & Development Centre

Statoil

DNV

Industry
4+ billion Yen/yr

Project support

Research → **Innovation** → **Demonstration** → **Commercialization**

Source: Gassnova

Norwegian CCS R&D clusters

INNOVATION NORWAY

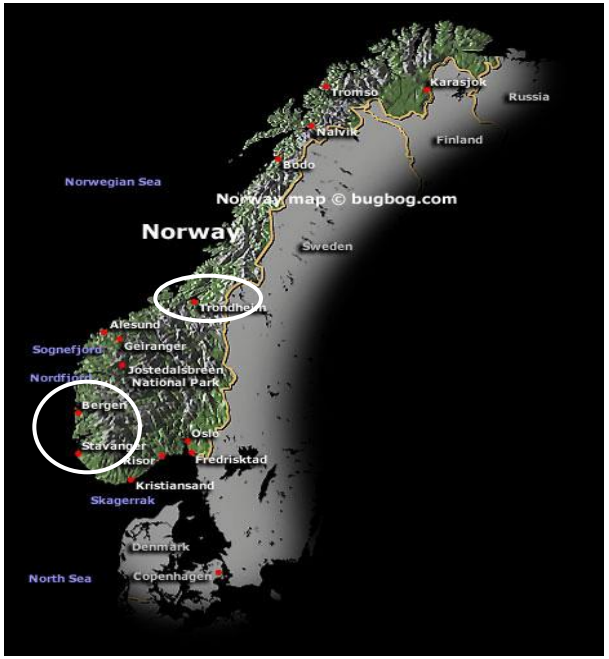
BIGCCS

International CCS Research Centre

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

success

SUbsurface CO2 storage- Critical Elements and Superior Strategy



Co-ordinator SINTEF Energy Research

R&D providers

- SINTEF, NTNU
- CICERO
- University of Oslo
- Deutsche Luft und Raumfahrt – DLR
- Technische Universität Munchen-TUM
- Co-operation with Sandia Nat. Labs Livermore

Funding (includes storage and EOR):

- Approx 65/35 % funded by Research Council of Norway/Industry
- 2001- 2006: Total of approx. 13 M€
- 2007 – 2011: 98 MNOK-12M€ (BIGCO2)
- 2007 – 2011: 107 MNOK- 13M€ (BIGH2)
- 2006 – 2012: 50 MNOK- 6M€ (BIGCLC)

Industrial consortium

- Aker Clean Carbon
- GE Global Research (Münich-DE)
- Statkraft
- StatoilHydro
- ALSTOM (Zürich-CH)
- SHELL
- ConocoPhillips
- TOTAL

Vision of the BIGCCS Centre:

- to enable sustainable power generation from fossil fuels
  - cost-effective CO2 capture,
  - safe transport,
  - underground storage of CO2.

The BIGCCS Centre is set to achieve the following goals:

- 90% CO2 capture rate
- 50% cost reductions
- Less than 6 percentage points fuel-to electricity penalty compared to state-of-the-art fossil fuel power generation

The BIGCCS Centre:

- develops new knowledge and technology required to accelerate deployment of large scale CCS,
- through international co-operation.
- Innovation and value creation is promoted throughout the CO2 value chain.

success

SUbsurface CO2 storage- Critical Elements and Superior Strategy

INNOVATION NORWAY

www.fme-success.no

Vision

- To provide a sound scientific base for CO2 injection, storage and monitoring, to fill gaps in strategic knowledge, and provide a system for learning and development of new competency
- Budget 160 MNOK over 8 yrs

Partners:

- Christian Michelsen Research (CMR)
- Institute for Energy Technology (IFE)
- Norwegian Institute for Water Research (NIVA)
- Norwegian Geotechnical Institute (NGI)
- Unifob (CIPR)
- University of Bergen (UiB)
- University of Oslo (UiO)
- University Centre in Svalbard (UNIS) - UNIS CO2 LAB

Research topics:

- Quantification and modelling of reactions and flow in storages
- Integrity and retention capacity of sealing materials
- Relation between flow, reactions and geomechanical response
- Flow and reaction in faults and fractures
- Test, calibrate and develop new monitoring techniques
- Ecological impact of CO2 exposure - marine monitoring methods
- Extensive high quality education for CO2 storage

cmr

IFE Institutt for energiteknikk

NIVA Norsk institutt for vannforskning

NGI

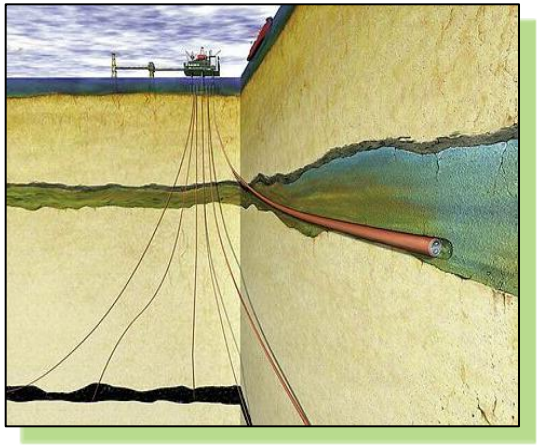
UNI FOB UNIVERSITETSFORSKNING BERGEN

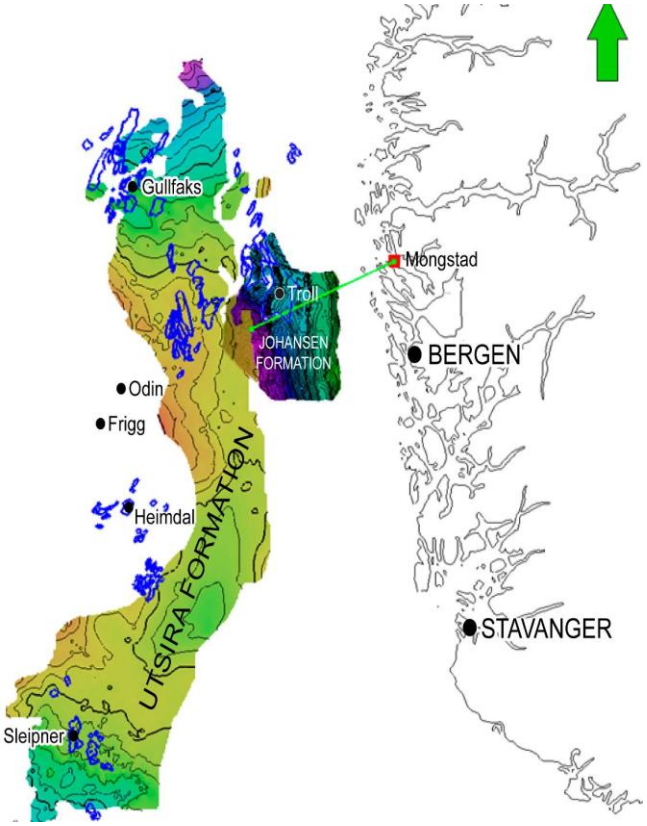
UNIS

Sleipner: 16 yrs of sub sea bed CO_2 storage

Photo: Statoil

The Sleipner experience – the starting point





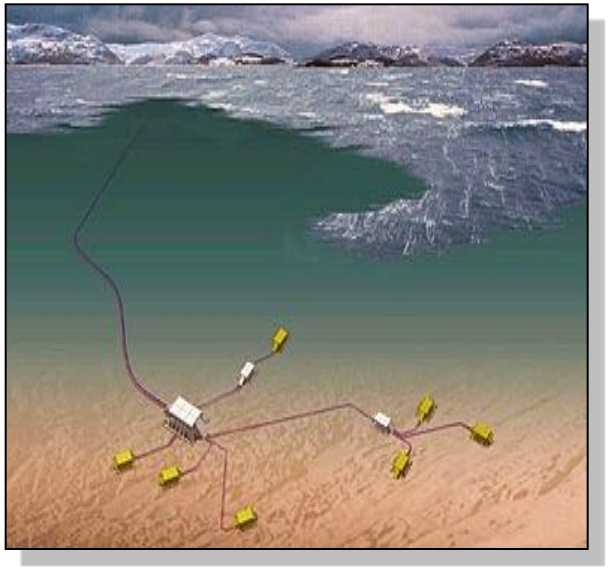
- Started in 1996 – now 15 year of CO2-injection
- Separating and injecting nearly 1 mill. tons CO2 annually
- Storing in saline aquifer above natural gas reservoir
- Conditions: 100 bar, 10% CO2 down to 2.5% CO2
- Uses an amine system, MDEA
- Driver: the ~45US$/ton CO2-tax imposed in 1992
- Learning and confidence building through a series of large EU-wide R&D programs

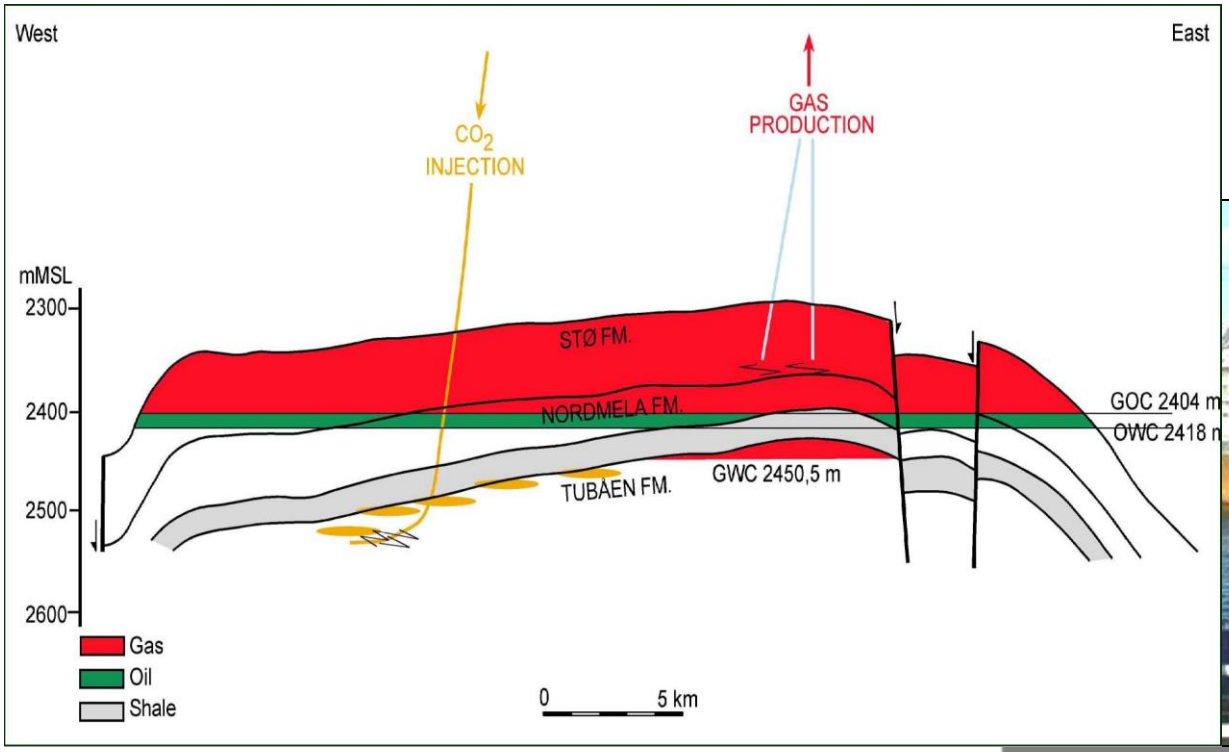
Source: Statoil

Sleipner reinjection – 1:34

Snøhvit LNG with CCS

- Piped CO2 separated from natural gas (5-8% CO2) in onshore LNG plant, and re-injecting in sandstone below natural gas reservoir
- 145 km subsea pipeline transport.
- CCS started April 2008 – capacity 700,000 ton/yr



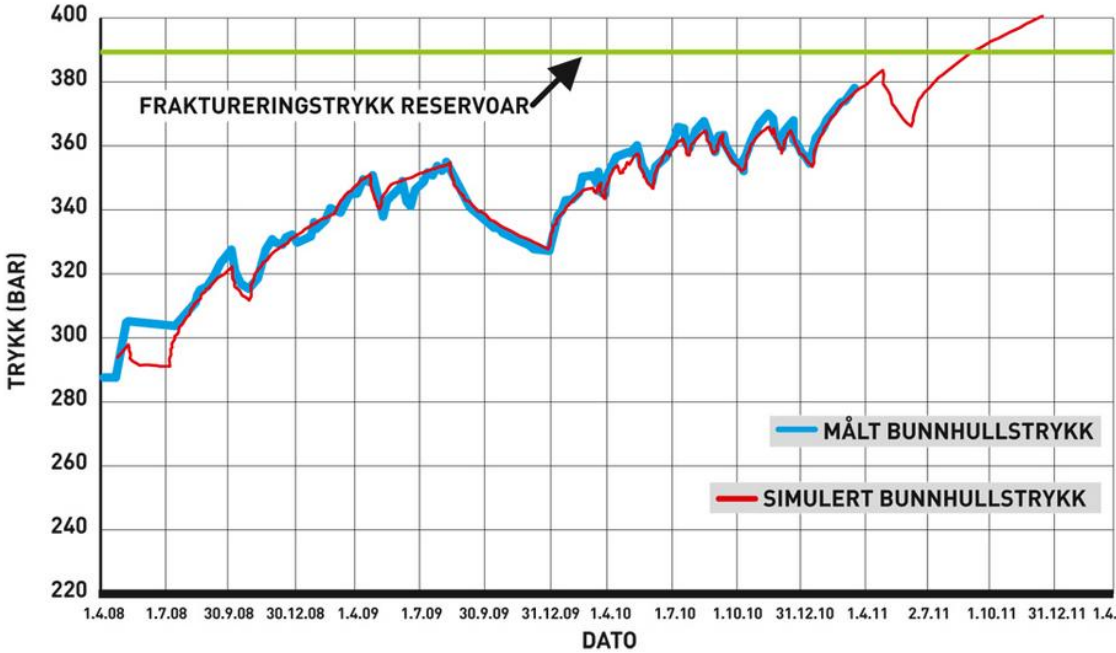


Snøvit – injection status

Reservoir estimated capacity 23 million ton

However – CO2 did not distribute uniformly in the reservoir as expected

- Local pressure buildup.
- Estimations and measures done May 2011 indicate fracture pressure will be reached by end of 2011
- Solutions
  - More injection wells to improve flow
  - Injection into **gas** reservoir



INNOVATION NORWAY

The CO2 Technology Centre Mongstad (TCM)

INNOVATION NORWAY

TECHNOLOGY CENTRE MONGSTAD — catching our future

TCM – Highlights

- **2005** Government policy: No carbon based power generation in Norway without CCS
- **2006** State and Statoil agreed 2-staged approach:
  - 1: Demonstrate and develop capture technologies (TCM)
  - 2: Build large scale (1 mTons CO2/year) capture plant
- **2009** Investment decision taken for TCM: = USD1Billion
  Partnership established (TCM DA)
- **2012** Five year initial test period started

Source: Gassnova

Technology Center Mongstad – 3:09

Demonstration Portfolio: CO2 Technology Centre Mongstad

Owners expectations:

- CO2 capture technology owned by vendors verified
- Reduced cost and risk
- Contribute to development of market
- Contribute to International deployment

GASSNOVA	Statoil		sasol
75.12%	20%	2.44%	2.44%

Source: Gassnova

Full-scale CCS at Mongstad planning process

Full-scale CO2 capture from gas fired power plant

- Important part of post-combustion technology development

International competition

Technology qualification programme (TQP)

- Basis for technology selection 2nd quarter 2014

License agreement

- Open competition for qualified suppliers of chosen technology

FEED phase

- Basis for final investment decision (FID) 2nd quarter 2016

100 % funded by the Norwegian State

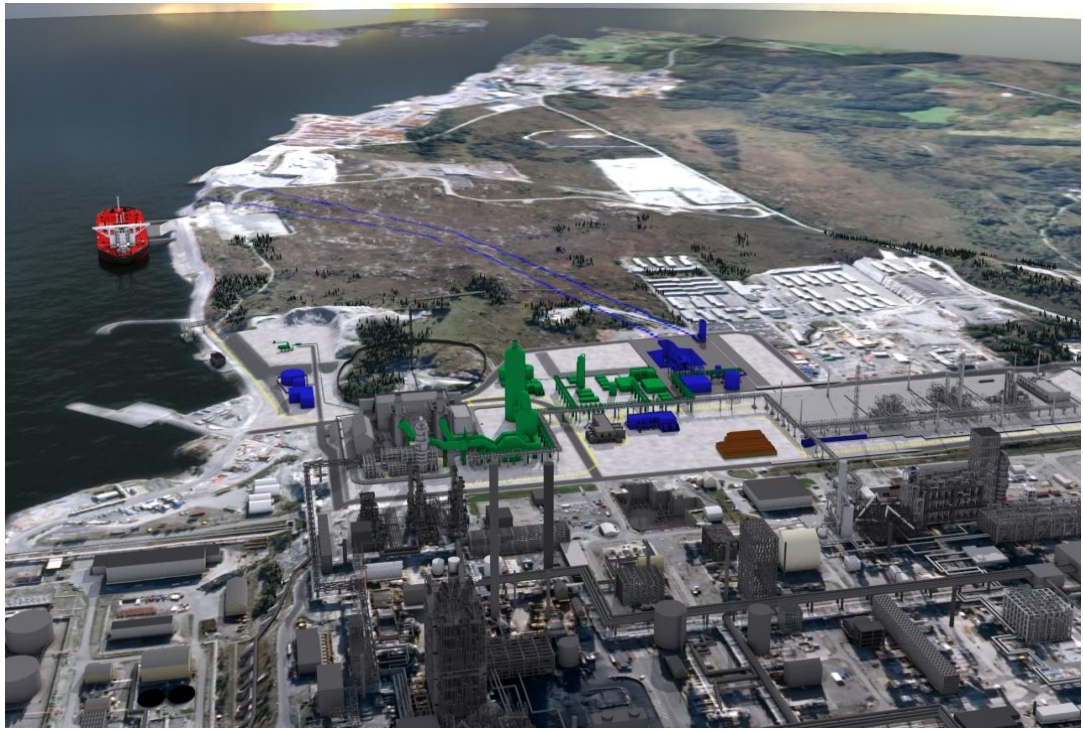
- Gassnova represents the Norwegian State
- Statoil as project developer

Source: Gassnova

Full-scale CCS at Mongstad
Technology Qualification Programme

Five participating technology suppliers covering three technologies

- Amine technology
  - Aker Clean Carbon
  - Mitsubishi
  - Powerspan /Huaneng Clean Research Institute
- Chilled ammonia technology
  - Alstom
- Amino acid salt technology
  - Siemens



Source: Gassnova

TECHNOLOGY CENTRE MONGSTAD

catching our future

More than 4000 visitors to date

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TECHNOLOGY CENTRE MONGSTAD

Combat climate change through technology

Frontpage | Carbon Capture | Technologies | Construction project | About TCM | Press center | SEARCH

TCM - Catching our Future | What does TCM do? | What is happening now?

MILESTONE MONGSTAD

NEWS

Groundbreaking environmental surveys

TCM has during the last year, prior to the start-up, conducted environmental surveys of air, vegetation and water in a

TCM Inauguration makes headlines globally

News about the inauguration of the world's largest carbon capture test facility at Mongstad, Norway, has spread

Stoltenberg: TCM is important for the world

Yesterday, the Norwegian Prime

ABOUT TCM

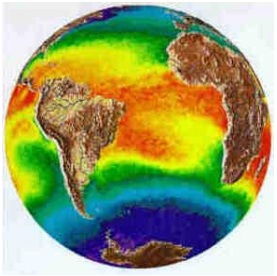
Knowledge gained will prepare the ground for CO_2 capture initiatives to combat climate change. TCM is a joint venture between the Norwegian state, Statoil, Shell and Sasol.

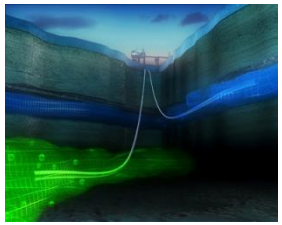
EXTERNAL NEWS

Read more at www.tcmda.com

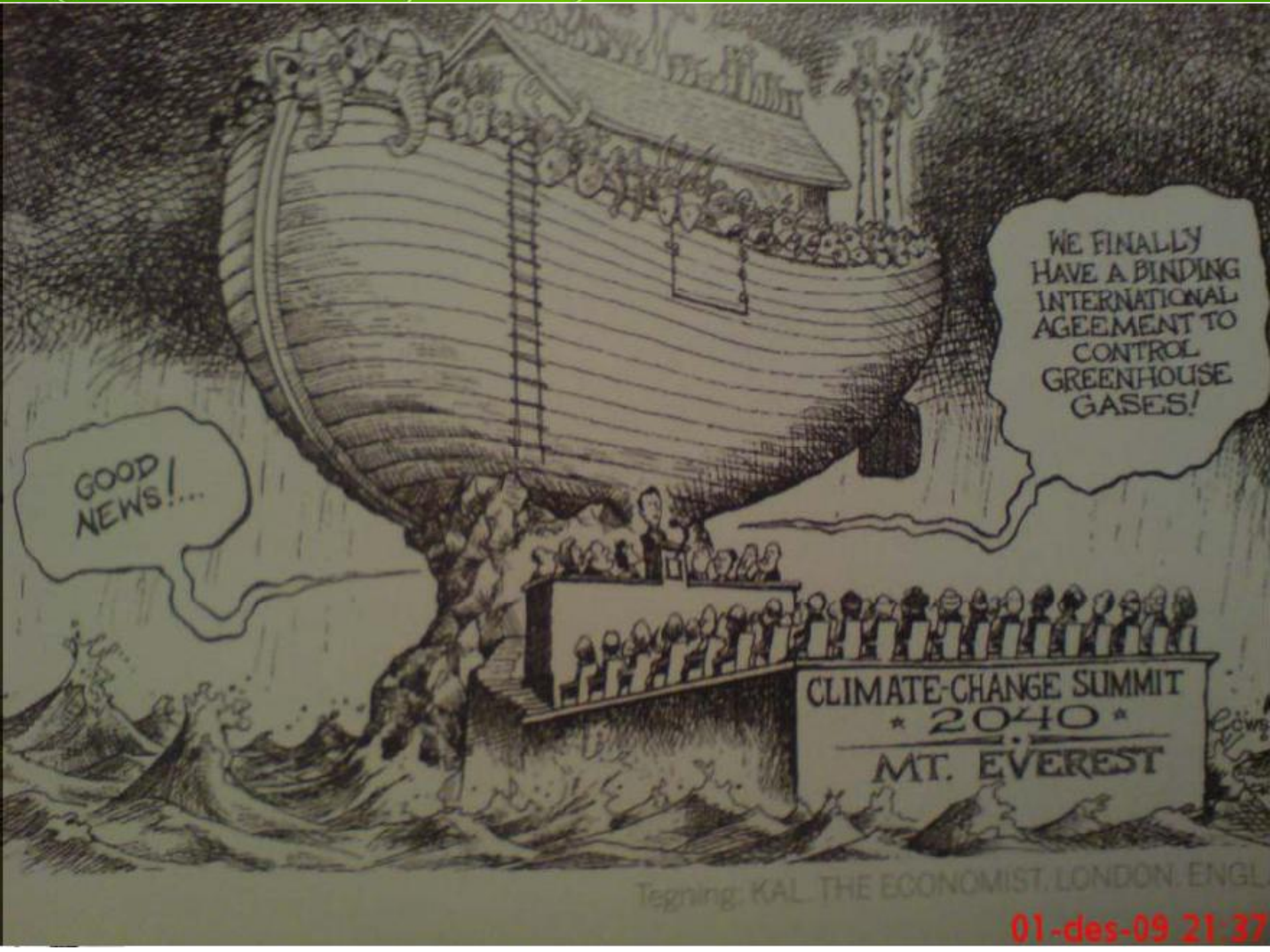
Summary

- Norway is "part of the problem" of global climate change.
- Norwegian government has strong commitment to be "part of the solution"
  - Reduce Norway's carbon footprint domestically
  - Fund research and development of CCS technologies
  - Fund pilots and full—scale carbon capture projects (TCM)
  - Support and promote industry engagement in CCS
  - Norway is world-leader on CCS technology; Sleipner, Mongstad, Snøvit projects; R&D clusters at SINTEF and other research clusters





- Norway is promoting CCS on global arenas; political meetings; media; summits.
- Norway is supporting and actively participating in the important CCS intuitions and organizations.
- Norway is a significant financial supporter to global CCS initiatives.



Tegning: KAL, THE ECONOMIST, LONDON, ENGL