DEPARTMENT OF MATHEMATICS

CCUS: Storage - challenges and solutions

Guttorm Alendal

With input from

Anna Oleynik, Kristian Gundersen, Truls Johannessen, Sarah Gasda, Abdirahman Omar, and lots of others.

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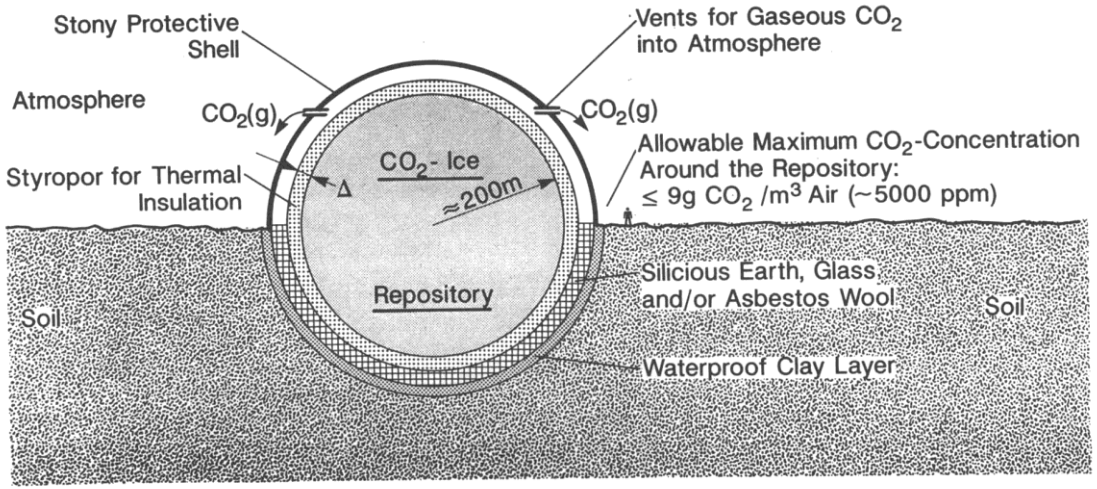
CCUS: Storage - challenges and solutions

Photo: Sask Power: The official launch of the Boundary Dam carbon capture and storage facility in Estevan on Oct. 2, 2014.

Guttorm Alendal, professor at the department of mathematics, UiB, will present on issues related to

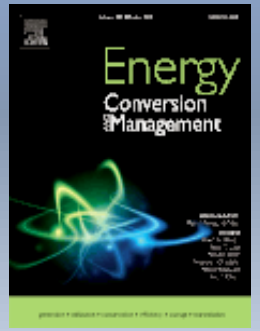

Princeville
Koloa
Honolulu
HAWAIIAN ISLANDS
Lahaina
Kihei
HAWAII
Waimea
Hilo
Kailua-Kona
Island of Hawai'i
Volcano
Google

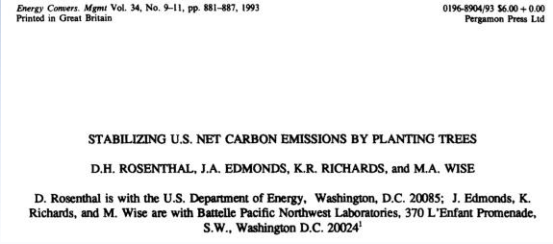
IEA Carbon Dioxide Disposal Symposium
Oxford, United Kingdom
29th-31st March 1993



SEIFRITZ: TERRESTRIAL STORAGE OF CO_2-DRY ICE

Fig. 1 The preliminary lay-out of a thermally insulated CO_2 repository possessing an initial radius of R_o = 200 m (Source: Seifritz)





Energy Convers. Mgmt Vol. 34, No. 9–11, pp. 881–887, 1993
Printed in Great Britain

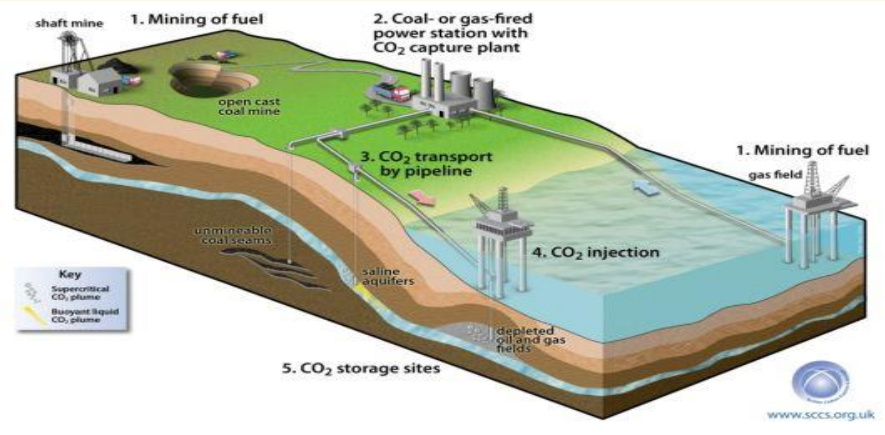
0196-8904/93 $6.00 + 0.00
Pergamon Press Ltd

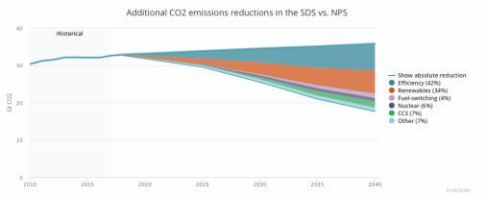
STABILIZING U.S. NET CARBON EMISSIONS BY PLANTING TREES

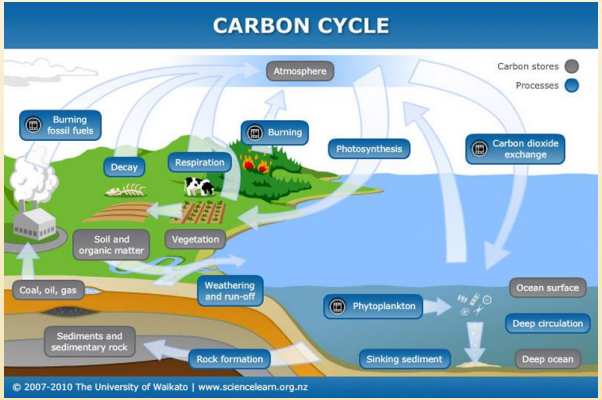
D.H. ROSENTHAL, J.A. EDMONDS, K.R. RICHARDS, and M.A. WISE

D. Rosenthal is with the U.S. Department of Energy, Washington, D.C. 20085; J. Edmonds, K. Richards, and M. Wise are with Battelle Pacific Northwest Laboratories, 370 L'Enfant Promenade, S.W., Washington D.C. 20024[1]

Carbon Capture and Storage (CCS) Implementation







Capture + Transport + Storage

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

equinor

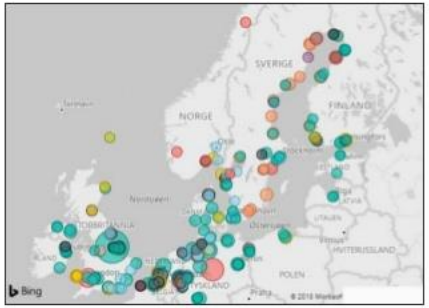
Norwegian full scale CCS demonstration project

equinor

Visualisation of land facilities (Naturgassparken in Øygarden)

equinor

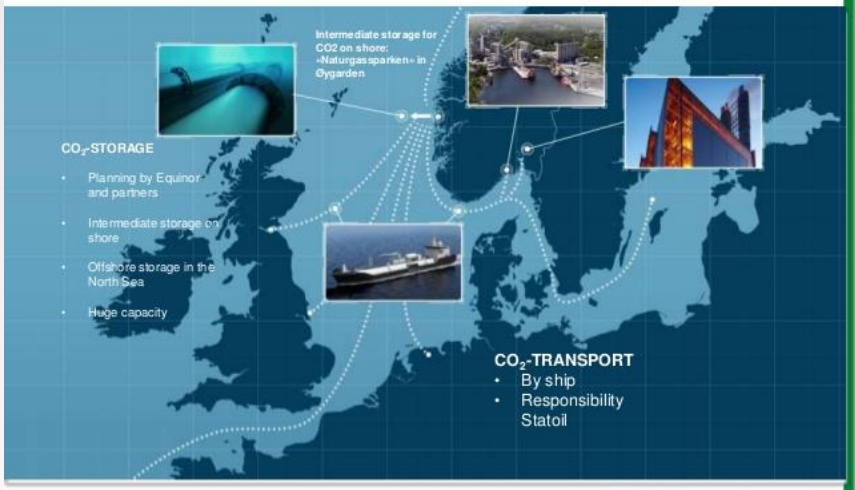
"Open access" offer for CO_2 sources to establish capture



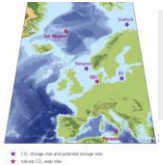
Sectors with largest potential

- Hydrogen from natural gas
- Waste incineration
- Cement
- Biomass and biofuel
- Steel production
- Refinery
- Aluminium

Norcem is part of the Norwegian full scale CCS demonstration project



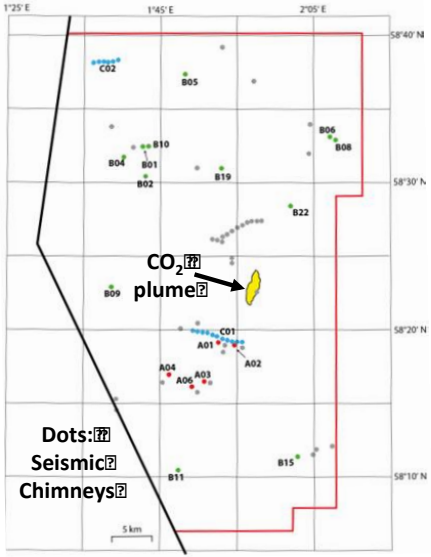
HEIDELBERGCEMENT

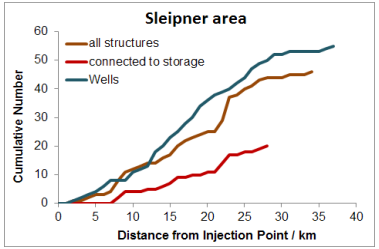


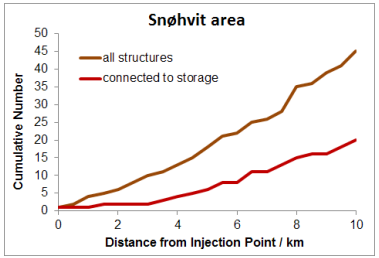
: Impact on Marine Ecosystems

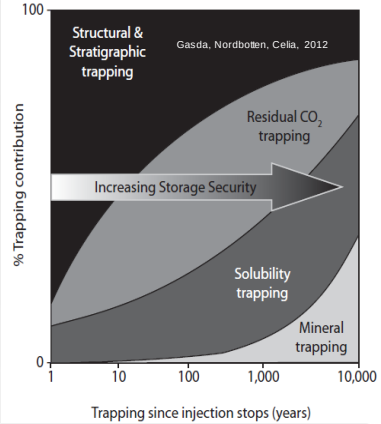
Abundance of seismic chimneys and pipes in the overburden

Map of Sleipner area







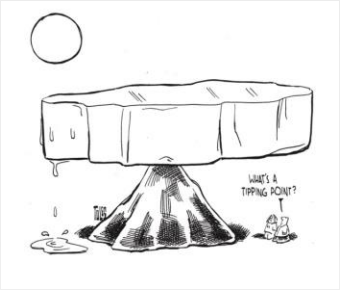


Severity measured in Environmental Value / Propensity to Leak	Severity of environmental impact			
	Incidental	Moderate	Major	Critical
Unlikely	*Negligible/small negative*	*Negligible/small negative*	*Moderate negative*	*Large negative*
Possible	*Negligible/small negative*	*Moderate negative*	*Large negative*	*Severe negative*
Very Likely	*Moderate negative*	*Large negative*	*Severe negative*	*Severe negative*

Post ECO_2

Prior ECO_2

CCS and the marine environment.



- A leak to marine waters
  - Might add stress to an already stressed ocean.
  - Need to avoid vulnerable areas, part of EIA.
  - Reduce benefit from CCS technology.
- A marine monitoring program
  - Required by regulations.
  - Stewardship.
  - Assurance against unjustified allegations.
  - Has three phases, detect, localize and quantify.
  - Can be part of sustainable management of marine waters/marine spatial planning.
- Looks for changes in the environment
  - Biota, bacterial mats
  - Bubble plumes/trains
  - Chemical signals.

Capture + Transport + Storage + Leakage Impact + Assurance Monitoring = CCS Implementation

OSPAR CONVENTION FOR THE PROTECTION OF THE MARINE ENVIRONMENT OF THE NORTH-EAST ATLANTIC

OSPAR Guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations[1]

(Reference Number: 2007-12)

Monitoring migration of CO_2 streams and mobilised substances within and above the formation during the injection phase

6.14 Monitoring would be done for at least two different purposes:

a. detection of potential leakages from sub-seabed geologic storage; and
b. verification that such leakage does not occur.

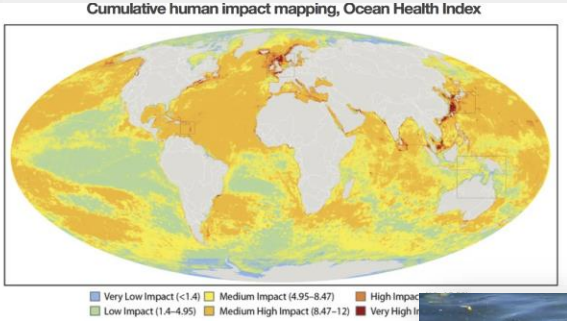
6.15 A monitoring programme should attempt to quantify the mass and distribution of CO_2 in each storage site and should record related biological and geochemical parameters. The monitoring programme should include:

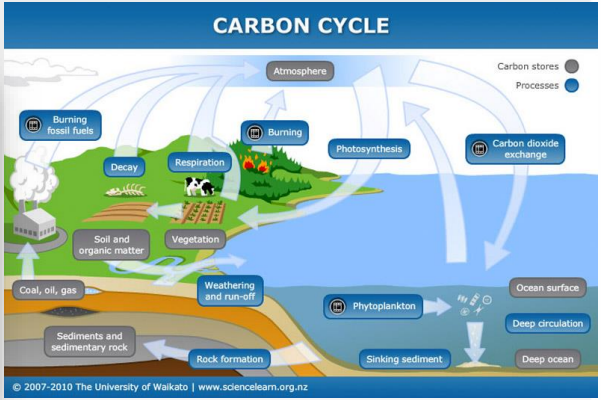
a. monitoring for performance confirmation;
b. monitoring to detect possible leakages;
c. monitoring of local environmental impacts on ecosystems; and
d. monitoring of the effectiveness of CO_2 storage as a greenhouse gas mitigation technology.

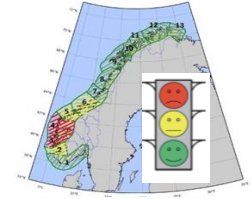
Life under water

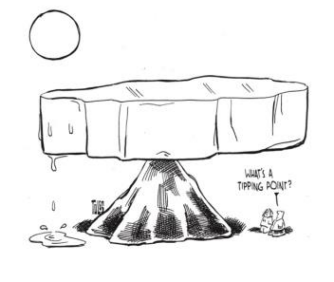
Key business themes addressed by this SDG

- Marine biodiversity
- Ocean acidification
- Environmental investments
- Spills
- Sustainable sourcing
- Water discharge to oceans



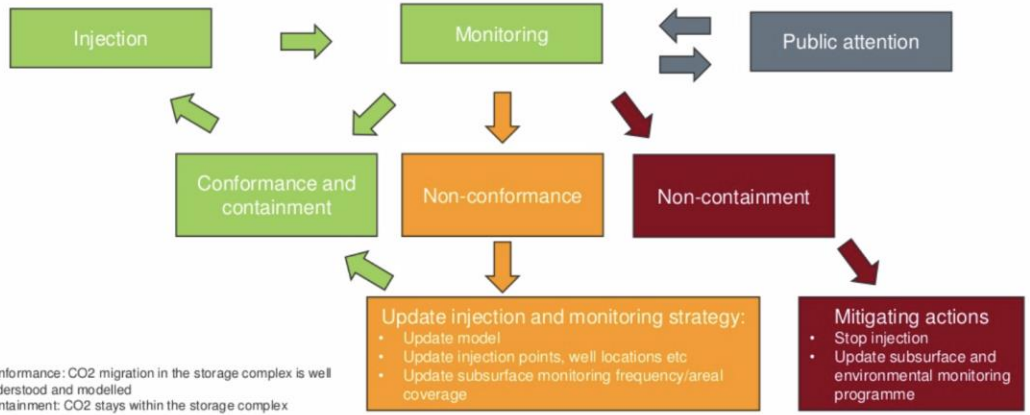






equinor

Monitoring, strategy



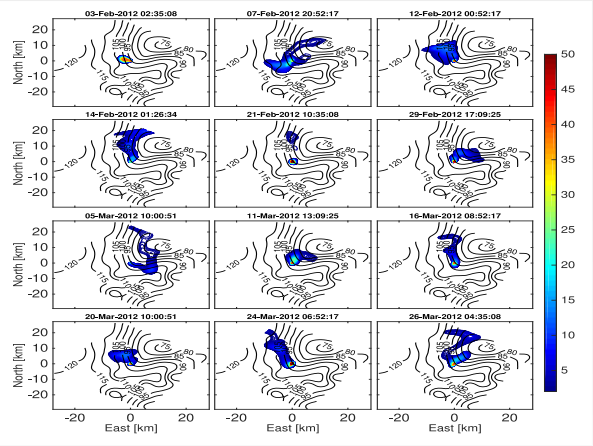
Conformance: CO2 migration in the storage complex is well understood and modelled
Containment: CO2 stays within the storage complex

CCS main project portfolio

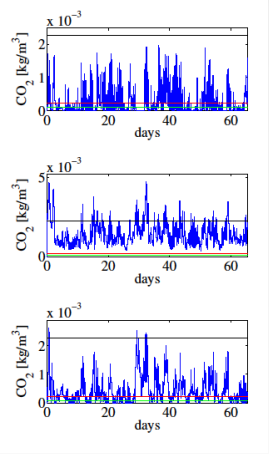
- CarboOcean, EU FP6, 2005-2009.
- CO2Marine I & II, CLIMIT demo,(2007 & 2009).
- CO2base, CLIMIT demo, (2011-2013).
- SECURE, CLIMIT FoU, (2010-2014).
- SUCCESS, FME, (2010-2017)
- ECO2, EU FP7, (2011-2015).
- STEMM-CCS, EU HORIZON2020 , (2016-2020)
- BayMoDe, CLIMIT FoU, (2016-2020)
- ACTOM, ERA-Net, (2019-2022)
- Academia agreement (2019-2023)

The challenge

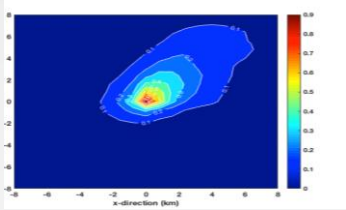
- Temporal and spatial varying signal from an unknown source in a highly varying environment.



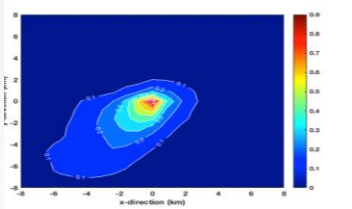
Snapshots of concentrations



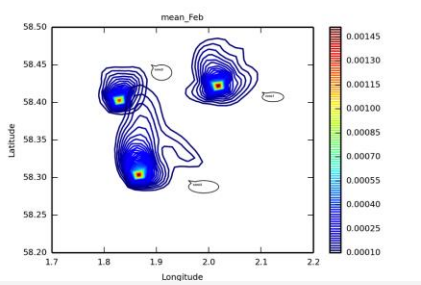
Time series



Footprint



Area monitored



Spatial dependency of seep location

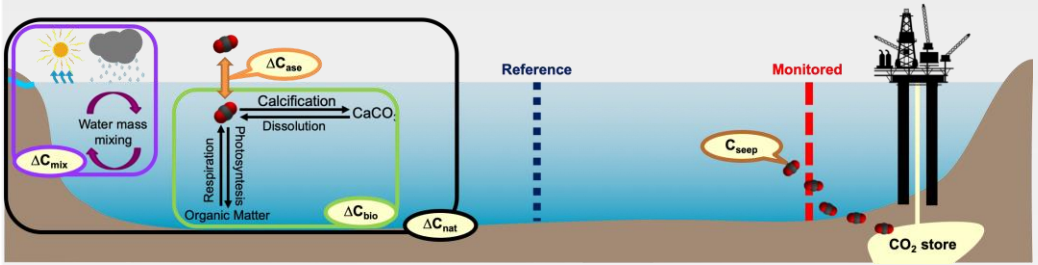

Journal of Geophysical Research: Oceans

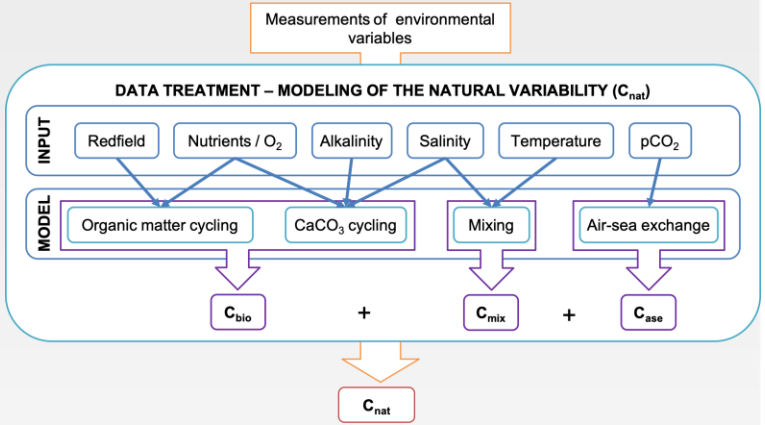
RESEARCH ARTICLE

Simulating spatial and temporal varying CO_2 signals from sources at the seafloor to help designing risk-based monitoring programs

decision\nature	L	$\neg L$
L	true	false positive
$\neg L$	false negative	true

THE STOICHIOMETRIC C_{SEEP} METHOD





- The stoichiometric **C_{seep} method model** the processes governing the **natural variability** of the **seawater CO_2** system,.
- can be used to **define** DIC **detection thresholds** suitable for offshore CCS monitoring.
- can be **automated** with *in situ* **sensor-based measurements** and **algorithms**.
- **Site-specific baselines** with high spatiotemporal resolution are needed
  - to accurately **parameterize the natural drivers** of the variability in seawater DIC at a specific location, and
  - to **choose** the best **reference station** representative of the monitored area and not affected by seeps.


LIMNOLOGY and OCEANOGRAPHY

ASLO

The effect of submarine CO_2 vents on seawater: Implications for detection of subsea carbon sequestration leakage

Helle Augdal Botnen,[*1] Abdirahman M. Omar,[1,2] Ingunn Thorseth,[3] Truls Johannessen,[1,2] Guttorm Alendal[4]

[1]Faculty of Mathematics and Natural Sciences, Geophysical Institute, University of Bergen 5007 Bergen, Norway
[2]Uni-Research Climate, 5007 Bergen, Norway
[3]Department of Biology/Earth Sciences, Centre for Geobiology, University of Bergen, Bergen, Norway
[4]Department of Mathematics, University of Bergen, Bergen, Norway

STEMM-CCS – Horizon 2020

- Funded by CALL FOR COMPETITIVE LOW-CARBON ENERGY (LCE-15-2015) “Enabling decarbonisation of the fossil fuel-based power sector and energy intensive industry through CCS”
- Total Budget €15.9 M
- March 2016 – February 2020
- Coordinator: Dr Doug Connelly –National Oceanography Centre
- Industrial Partner - Shell

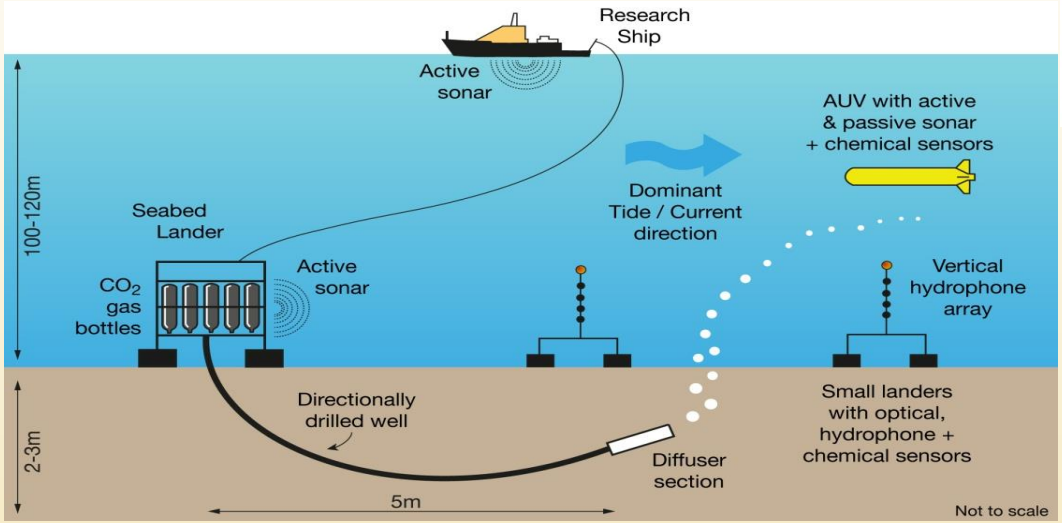
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 654462

Partners

National Oceanography Centre, NERC, UK
University of Southampton, UK
GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany
Shell, Netherlands
Plymouth Marine Laboratory, UK
Seascape Consultants Ltd, UK
Heriot Watt University, UK
University of Tromsø, Norway
Max Planck Institute for Marine Microbiology, Germany
Technical University Graz, Austria
University of Bergen, Norway
NIVA, Norwegian Institute for Water Research, Norway
NORCE, Bergen, Norway

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Main Experiment - 2019



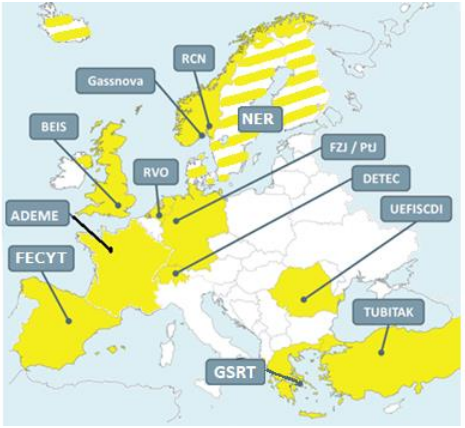
Schematic of the shallow sub-surface release of CO_2 gas in sediments (< 5 m depth) near Peterhead (Goldeneye) CCS demonstration project. Note that this small-scale release in near-surface sediment does not affect the integrity of the CCS Storage Site.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

ACT – Accelerating CCS Technologies

This is ACT

- Funding agencies from Europe and USA
- Aims to accelerate and mature CCUS technologies
- Makes funds available for R&D and innovation projects.



Co-funded by the European Commission within the Horizon 2020

The ambition of ACT

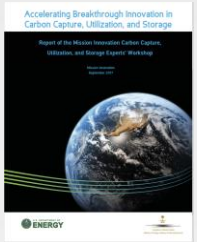
- Fund research and innovation projects that can lead to safe and cost effective CCUS technology development
- Establish international cooperation for accelerated CCUS deployment in the power and industry sectors
- Cooperating on joint calls and knowledge sharing

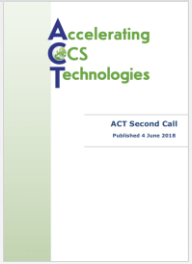

Norcem Cement Plant,


Rotterdam Harbour

Co-funded by the European Commission within the Horizon 2020

Monitoring, verification and performance metrics





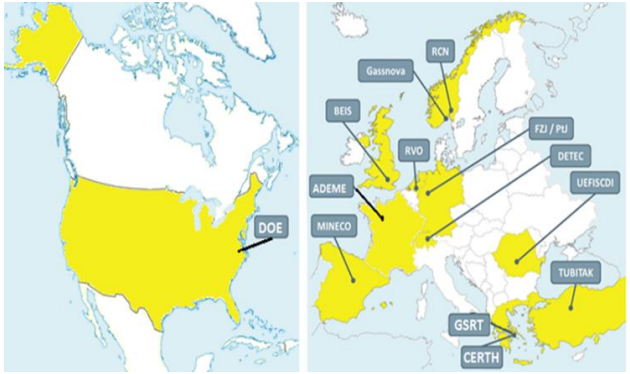
PRD S-4: *Developing Smart Convergence Monitoring to Demonstrate Containment and Enable Storage Site Closure*

PRD S-5: *Realizing Smart Monitoring to Assess Anomalies and Provide Assurance*

- How to treat different data streams, alone and together?
- Automatic decisions and recommendation tools when detecting anomalies.
- Metrics.
- Visualisation and pedagogical tools for communication.
- Social aspects on how to communicate risks and uncertainties.

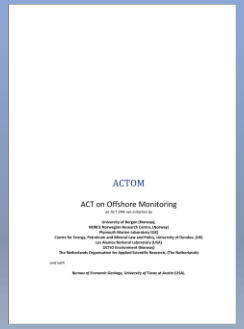
ACT2: The 2018 Call

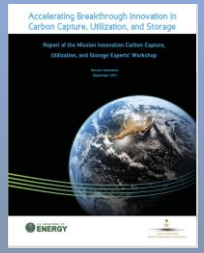
- 47 pre-proposals
- 26 full proposals
- 12 projects invited to negotiations
- New project will be announced as soon as contracts and consortium agreements are signed



Co-funded by the European Commission within the Horizon 2020

ACTOM; Act on Offshore Monitoring



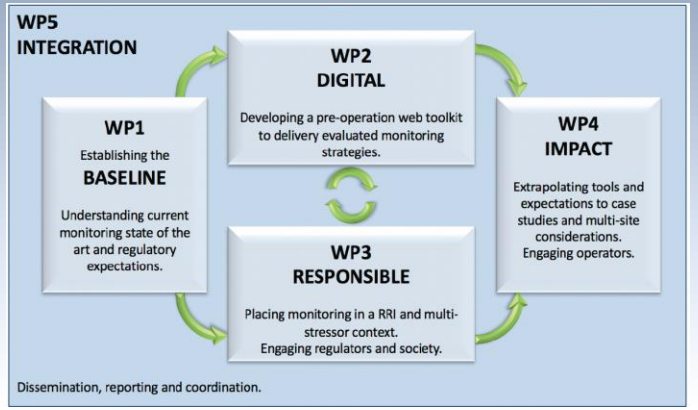


ACTOM will address two of the *Mission Innovation4* Storage Priority Research Directions:

- ***PRD S-5: Realizing Smart Monitoring to Assess Anomalies and Provide Assurance***
- ***PRD S-4: Developing Smart Convergence Monitoring to Demonstrate Containment and Enable Storage Site Closure***

and the *Mission Innovation* Crosscutting Priority Research Directions:

- ***PRD CC-3: Incorporating Social Aspects into Decision-Making***



...the primary objective of ACTOM is **to develop internationally applicable capabilities for the design and execution of appropriate, rigorous and cost-effective monitoring of offshore carbon storage, aligning industrial, societal and regulative expectations with technological capabilities and limitations.**

UiB: Faculty of Law, BIO, GFI and MATH.

Project integration

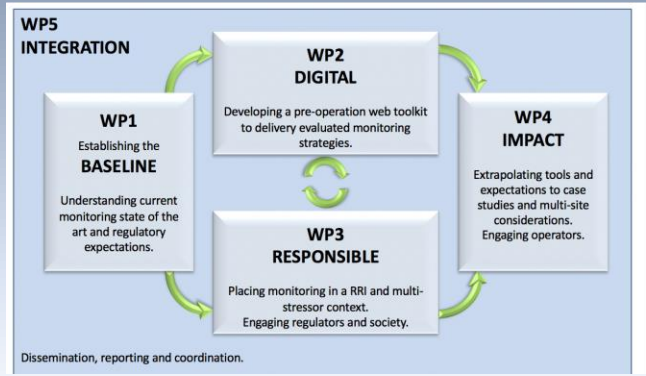
***WP1 BASELINE (Abdirahman Omar, Sigrid E. Schütz)**: Monitoring the marine environment.* Will survey the regulatory requirements and opportunities and technical limitations laying the foundation for the marine monitoring program. This activity will underpin the other WPs, providing the necessary information on what level of assurance is expected from a monitoring program, alongside the present capabilities of marine measurements and monitoring.

***WP2 DIGITAL (Jerry Blackford)**: Design and build of the pre-operational web toolkit.* Will be responsible for building the toolkit based on verified algorithms for detecting weak signals in a highly variable environment and designing monitoring programs.

***WP3 RESPONSIBILITY (Dorothy Dankel, Sigrid E. Schütz)**: Responsible CCUS monitoring process*. Will study how the monitoring program can be used to communicate risks and benefits of subsea storage, and as a tool for public engagement through the Responsible Research and Innovation (RRI) framework.

***WP4 IMPACT (Sarah Gasda)**: Scenarios and site studies.* Will utilize the web toolkit built in WP2 and the knowledge learned in WP3 to study policy scenarios and demonstrate the toolkit on the P18 and Smeaheia storage sites as well as study sites in the Gulf of Mexico.

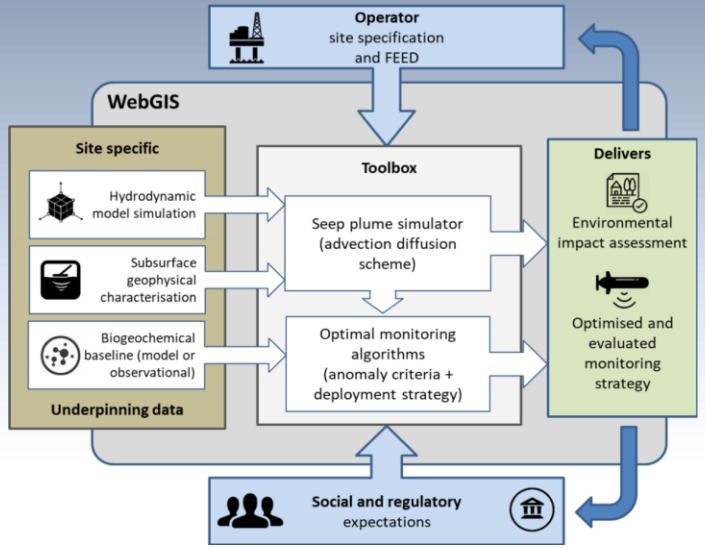
***WP5 INTEGRATION (Guttorm Alendal)**: Dissemination, reporting and coordination.* Assure easy communication in this highly cross-disciplinary project, both in the core project group, in the extended collaboration group, and beyond the project. Responsible to periodic reporting to ACT.



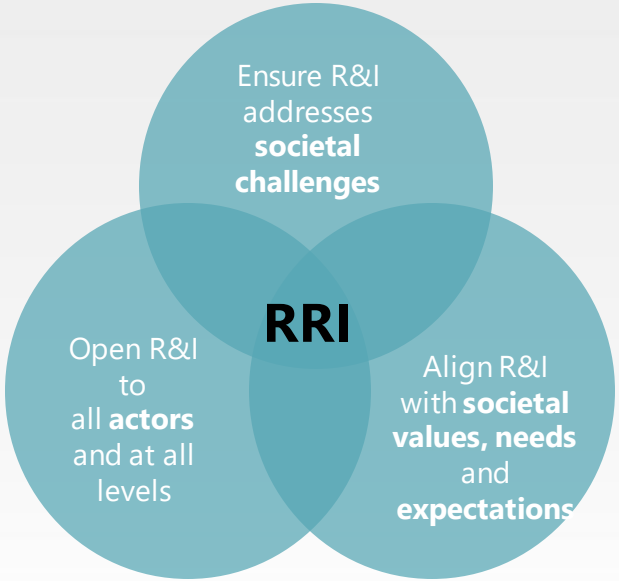
The monitoring tool kit

The tool kit will be:

- adaptable to any offshore region targeted for storage
- capable of evolving as algorithms and new methodologies are developed
- updatable with underpinning data as this comes on stream.
- allow operators to demonstrate conformity to regulations and expectations
- a tool alluding to multi-site cooperation on monitoring.



The social and RRI aspects.



RRI seeks to **bring issues related to R&I into the open** in order to anticipate their consequences, and to **involve society** in discussing how science and technology may help us **create the world we want**.

CLIMIT

dCod 1.0
decoding the systems toxicology of atlantic cod

SENTER FOR DIGITALT LIV NORGE

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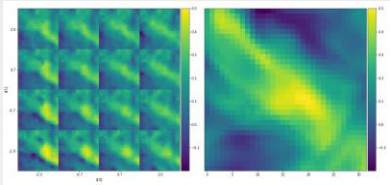
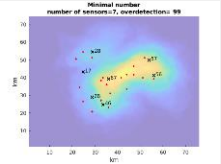
$$\frac{\partial c}{\partial t} = D\triangle c - w \cdot \nabla c + f, \quad x \in \Omega, \quad t \in [0, T],$$

The role of math:

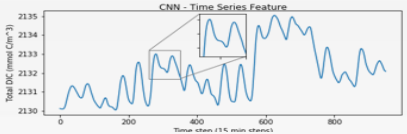
- Current statistics



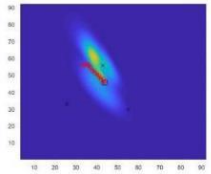
- Optimal sensors placement

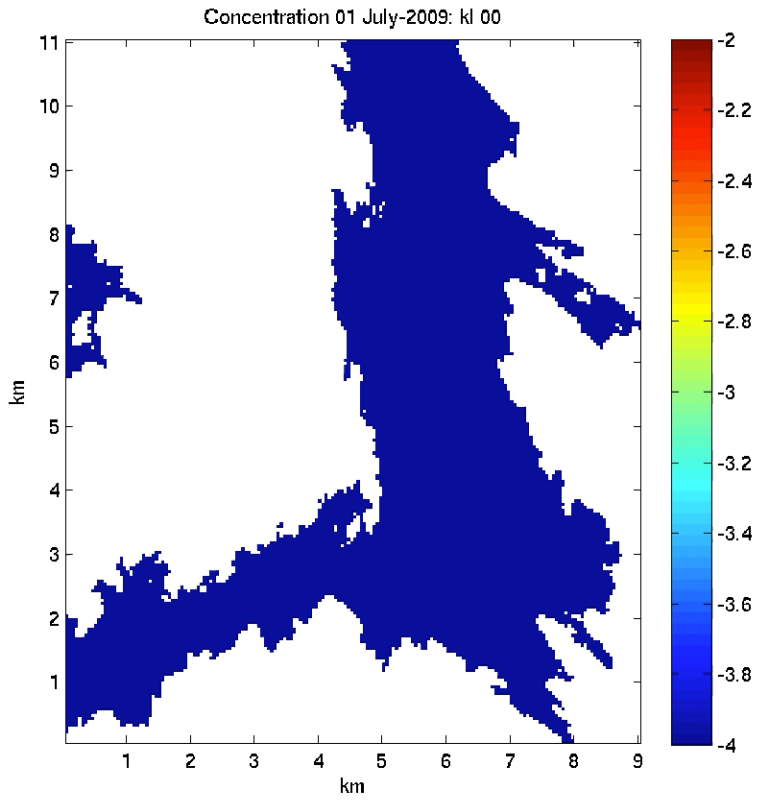


- Leak detection



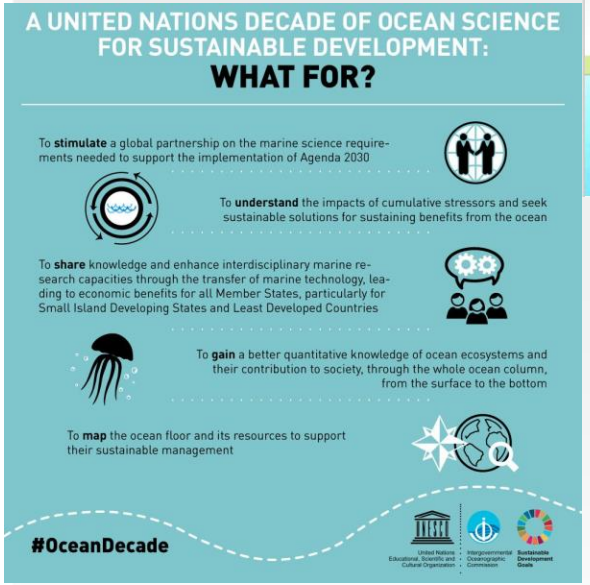
- Leak localization

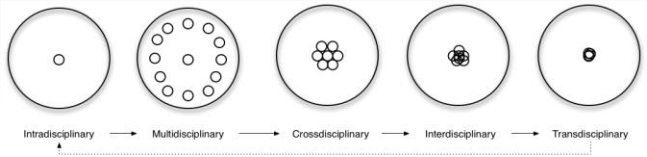




- Aggregation zones
- Representative measurements.
- Plast, JPI Oceans, Plast.
- Fish farming, SFI.


14 LIFE BELOW WATER


A UNITED NATIONS DECADE OF OCEAN SCIENCE FOR SUSTAINABLE DEVELOPMENT:
WHAT FOR?
To stimulate a global partnership on the marine science requirements needed to support the implementation of Agenda 2030
To understand the impacts of cumulative stressors and seek sustainable solutions for sustaining benefits from the ocean
To share knowledge and enhance interdisciplinary marine research capacities through the transfer of marine technology, leading to economic benefits for all Member States, particularly for Small Island Developing States and Least Developed Countries
To gain a better quantitative knowledge of ocean ecosystems and their contribution to society, through the whole ocean column, from the surface to the bottom
To map the ocean floor and its resources to support their sustainable management
#OceanDecade
United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission
Sustainable Development Goals


Intradisciplinary
Multidisciplinary
Crossdisciplinary
Interdisciplinary
Transdisciplinary


European
MARINE BOARD
Advancing Seas & Ocean Science


mareano
samler kunnskap om havet
Startsiden
Kart
Data
Tema
Nyheter
Om MAREANO
Resultater
Bilder/video
Kontakt
English
Samler kunnskap om havet


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS


OCEAN'S 8
ne planet
NE OCEAN


INTEGRATED AND SUSTAINED OCEAN OBSERVING: A EUROPEAN STRATEGY
STAKEHOLDER FORUM: 8 MARCH 2018, BRUSSELS
SHARE YOUR THINKING AND IDEAS ON THE CRITICAL QUESTIONS FOR THE SUSTAINABLE DEVELOPMENT OF THE EUROPEAN OCEAN OBSERVING SYSTEM, AND WHAT WE NEED TO DO AS A COMMUNITY TO ADDRESS THESE
The EOOS 2018 Forum is bringing together ocean observing funders, implementers and users for the first time to explore how we can work together and what we need to do to make this vision a reality.
Our focus will be the sustainability of the current observing system and how we can ensure its fitness for purpose.
Topics to be discussed:
• Making the European observing system fit for purpose - what are the priorities?
• Making a case to funders - what are the benefits of EOOS?
• What would a fully integrated and sustained EOOS look like?
• What are the relationships and skills needed to support an integrated system?
• What are the key messages and who needs to hear them?
JOIN THE EOOS FORUM ON 8 MARCH TO CONTRIBUTE TO THE EOOS STRATEGY AND IMPLEMENTATION PLAN AND TRANSMIT YOUR IDEAS ACROSS OCEAN OBSERVING FUNDERS, IMPLEMENTERS AND USERS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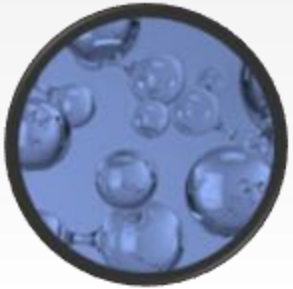
BERGEN CCUS/HYDROGEN CENTER

An UiB initiative to unite regional CCUS and hydrogen value chain activities with holistic, cross-disciplinary approach in context with UN's SDG

FOCUS AREAS

Safe CO_2 Storage Marine Monitoring	Carbon Usage Energy Generation	Hydrogen Safety Storage and Production	Legal Framework Market Mechanisms	Public Relations Societal Acceptance

BERGEN CCUS/HYDROGEN CENTER

Safe CO_2 Storage	Carbon Usage	Hydrogen Safety	Legal Framework	Public Relations
Marine Monitoring	Energy Generation	Storage and Production	Market Mechanisms	Societal Acceptance

A Bergen-based, cross-disciplinary workgroup established to explore collaborative possibilities

Assoc. Prof. Kristine Spildo
Dept. of Chemistry, UiB

Prof. Sigrid Schültz
Faculty of Law, UiB

Dr. Sarah Gasda
Senior Researcher, NORCE

Assoc. Prof. Erlend Tvinnereim
political science, UiB

Prof. Guttorm Alendal
Dept. of Mathematics, UiB

Prof. Martin Fernø
Dept. of Physics and Technology, UiB

Prof. Atle Rotevatn
Dept. of Earth Science, UiB

Prof. Ernst Nordtveit
Faculty of Law, UiB

PERCCSEPTIONS

Onshore storage has limited public acceptance, but will offshore storage increase acceptance?

- Funder: Research Council Norway, CLIMIT
- 2019 – 2022, NOK 4.6m
- NORCE Norwegian Research Centre and Kiel Institute for the World Economy

Associate Professor, UiB

Endre Tvinnereim

Researcher, IFW Kiel

Christine Merk

Forsker II, Norce

Gisle Andersen

Forsker II, Norce

Ole Martin Lægreid

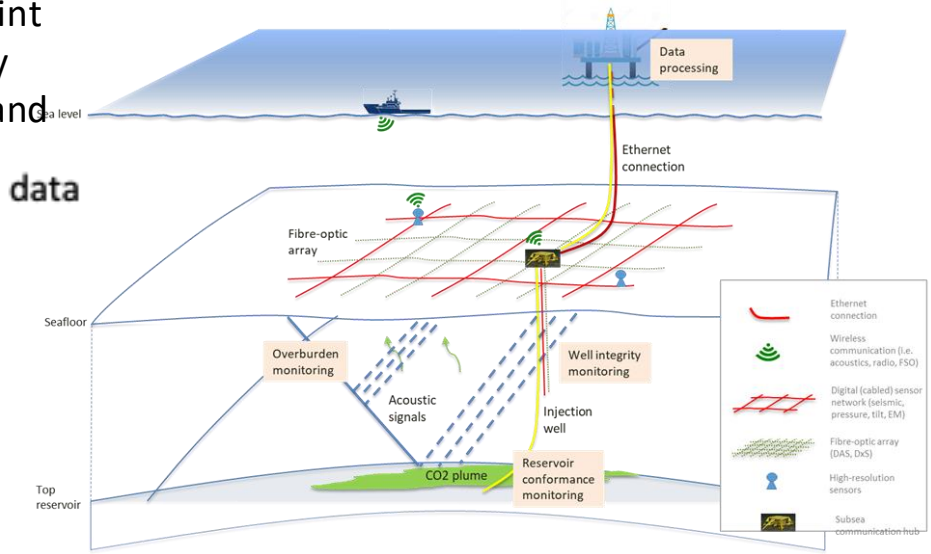
CLIMIT

Research questions:

- Does acceptance of large-scale CCS storage depend on where the emissions come from (i.e., whether they are domestic or imported)?
- Does CCS acceptance depend on whether CO_2 is stored onshore or offshore?
- Does the prospect of exporting CO2 to other jurisdictions (specifically: from Germany to Norway) reduce support for CCS (e.g., due to fairness concerns)?
- Does the source of the CO2 - e.g., from coal-fired power vs. from cement/metals/waste - matter for acceptance?
- Does the presentation of CCS as a mitigation option displace other efforts to mitigate? Alternatively, does it enhance efficacy and reduce worry?

ACT DigiMon

The novel DigiMon concept combines digital data from point sensors and distributed fibre-optic sensing technology (DxS), proven ethernet-based digital communication and real time, web-based smart data processing software.



- Optimize instrumentation for minimum use of seismic equipment for early warning
- Design and optimization of communication system
- Design and validation of processing software
- Develop DxS data interpretation workflow
- Designing a human centered monitoring system

NORSK GEOLOGISK FORENING

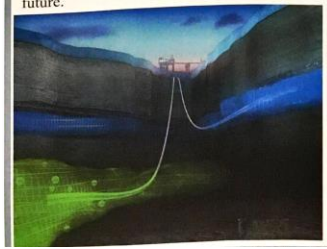
NGF Bergen ønsker deg velkommen til foredrag med Sveinung Hagen:

The future of the oil and gas industry - CO2 capture and storage

CO_2 capture and storage (CCS) can be central in mitigating climate change. Renewable energy production is increasing rapidly around the world. However, hydrocarbons might be needed for decades and CCS technology is essential to lower our carbon footprint.

Equinor and partners started the world's first CCS-project at Sleipner (gas-field in the North Sea) already in 1996 in order to meet sale specification of the natural gas and avoid emissions to atmosphere. Combined with other similar CCS projects (In Salah and Snøhvit), around 25 million tons CO_2 has been stored safely in the subsurface in Equinor projects. Furthermore, the Norwegian state has an ambition to build a full-scale CCS value chain from industrial CO_2 sources, and Equinor together with Shell and Total are responsible for transport and storage of this CO_2.

Sveinung Hagen from Equinor will address both the fundamentals of CCS, and some project specifics related to the latter project. Join this presentation and see how the future of the oil and gas industry will meet the climate challenges of the future.



Tid: Onsdag 30.10.19 kl. 18.00
Sted: Auditorium 5, Realfagsbygget (Allégaten 41)

Som vanlig vil det være lett servering og mulighet for å kjøpe diverse drikke.
Vel møtt!

NGF – Bergen

NORCE

Bergen CCUS Seminar 2019:

CCUS and the Net-Zero Society

The annual seminar organized by NORCE and University of Bergen gathers regional and national actors from research, industry, universities and the public sectors with an interest in realizing CCUS at a large scale. Through this seminar we aim to promote sustainable CCUS solutions both regionally and nationally. We also will highlight advances in research and innovation within the western Norway region. Our goal is to facilitate new partnerships to gain increased value from the Norwegian full-scale project.

The program will occur over 1.5 days and involve a combination of plenary talks, panel discussions, topical scientific sessions, a poster session and reception, and a dinner. We are excited to share with you highlights of the program:

Topical sessions:

- *CCUS beyond the full-scale project*
- *Research for enabling CCUS through EOR*
- *Collaboration between technology, law and society*
- *Monitoring for conformance and assurances*
- *Hydrogen economy and the link to CCUS*
- *Industry initiatives and technology demonstration*

Panel discussions:

- *Bringing the EU to the western Norway*
- *Creating benefits for the region*

Poster session and networking reception

December 3-4, 2019

International Workshop on Offshore Geologic CO_2 Storage

STEMM-CCS

Save the date!

4th International Workshop on Offshore Geologic CO_2 Storage
and
STEMM-CCS Open Science Meeting
11-12th February 2020, Bergen, Norway

We are very pleased to announce that there will be a 4th International Workshop on Offshore Geologic CO_2 Storage in February 2020, hosted by the STEMM-CCS project at the University of Bergen. This workshop will look at how to develop CCS projects with offshore storage. It will address and build on the recommendations and topics raised at the 3rd workshop to update on and take forward offshore storage.
The report and the presentations from the 3rd workshop are available at http://documents.ieaghg.org/index.php/s/jMxFmo9MaH3ltgS and http://www.beg.utexas.edu/gccc/research/goi respectively.

In conjunction with the workshop, the STEMM-CCS open science meeting will share key results, technological developments and experiences from four years of intensive research into the environmental monitoring of offshore CO_2 storage. The aims of the STEMM-CCS project included producing new tools and techniques for environmental monitoring in the offshore CCS arena (including CO_2 emission monitoring, quantification and assessment), delivering best practice, cost effective methodologies and tools for baseline environmental monitoring, and generating new knowledge of the reservoir overburden by direct investigation of natural geological and manmade features. A key part of the project was the demonstration of the new tools and techniques at an offshore site in the North Sea where CO_2 was injected into the sediments in order to create a simulated leak. Presentations will highlight the challenges in conducting a two-vessel offshore experiment involving a wide array of cutting-edge marine technology, including a remotely operated vehicle (ROV), an autonomous underwater vehicle (AUV) and numerous pieces of specialist equipment deployed at the seafloor.

Tim Dixon (Chair of the International Steering Committee)
Katherine Romanak (Co-chair of the International Steering Committee)
Douglas Connelly (STEMM-CCS Coordinator)

GCCC Gulf Coast Carbon Center

ieaghg

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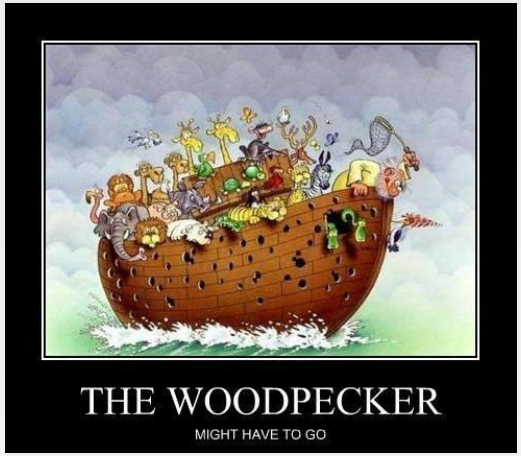

This work has received funding from the European Unions Horizon 2020 research and innovation program under grant agreement 654462, **STEMM-CCS**, and the Research Council of Norway, **BayMoDe** (project no. 254711), **dCod 1.0** (Project no. 248840), and ACT cofund, **ACTOM.**