Presentations 8 February - CCS Speed Dating – Transport&Value chain

- Trine Mykkeltvedt, NTNU
- Gaute Svenningsen, IFE
- Klas Solberg, DNV
- Yessica Arellano, SINTEF Energy Research
- Dr. Luciano E. Patruno, IFE
- Norbert Hoyer, SLB
- Lars-Erik Svabø, Kongsberg
- Ragnhild Skagestad, SINTEF
- Per Lothe, KNCC
- Gabriele Notaro, DNV
- Ingvild Ombudstvedt, IOM Law
- Dr. Rolf Golombek, Frisch Centre
- Markus Steen, SINTEF
- Arvid Nøttveit/Åsta Dyrnes Nordø, NORCE

Trine Mykkeltvedt

RESEARCHER

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

Impact of CO_2 impurities and additives in CCS (ImpreCCS)

Trine Mykkeltvedt has a phD in applied mathematics from the University of Bergen and has worked as a researcher in NORCE for eight years focusing on various research questions connected to modeling and simulation of CO_2 storage.

The Research Council of Norway

GASSNOVA

Impact of CO_2 impurities and additives in CCS

Sigurd Weidemann Løvseth, Sarah Gasda, Bahareh Khosravi,
Yessica Arellano, **Trine Mykkeltvedt** and many more

CLIMIT summit 2023

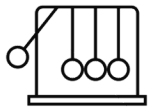
BACKGROUND for this project

Goal: To reduce costs and risks of CO_2 storage by predicting the impact of important impurities and additives on CO_2 viscosity, density and thermal conductivity

cost & risk: identify where better knowledge of fluid properties is most needed

data: new experimental data on viscosity, density, and thermal conductivity

correlations: for transport properties usable for industry



impact: quantify for injection and reservoirs through simulation

educate: a phD student and several master students

WHAT did we do in this project

- Knowledge of gaps in the experimental data for CO_2 rich mixtures
- Constructed a viscosity/density experimental facility and the setup was commissioned
- New viscosity data CO_2+H_2(7%, 20%), CO_2+N_2
- New thermal conductivity data CO_2+N_2 and CO_2+CH_4
- PhD student will defend spring 2023

B. Khosravi, S. W. Løvseth, A. Austegard, C. Einen, H.G. J. Stang, I. Snustad, J. Jakobsen, H. Rekstad

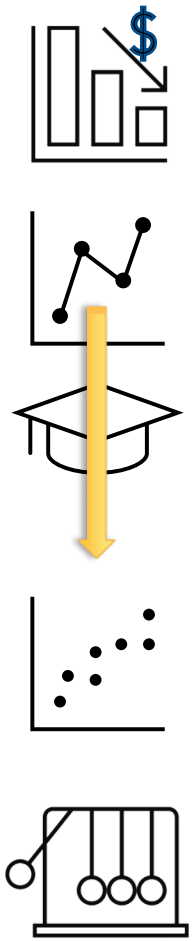
Viscosity measurements of CO_2-rich; CO_2 + N_2 and CO_2 + H_2 mixtures in gas or supercritical phase at temperatures between 273 and 473 K and pressures up to 8.7 MPa

Bahareh Khosravi [a,*], Benjamin Betken [b], Jana P. Jakobsen [a], Sigurd W. Løvseth [c], Roland Span [b]

Liquid and Dense Phase Thermal Conductivity Measurements of CO_2 + N_2 and CO_2 + CH_4 Mixtures at Temperatures from 223 K to 308 K and Pressures up to 20 MPa

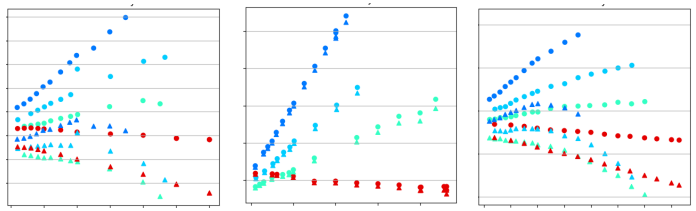
Dongchan Kim, Sigurd Weidemann Løvseth,* Arash Arami-Niya, and Eric F. May

WHAT did we do in this project

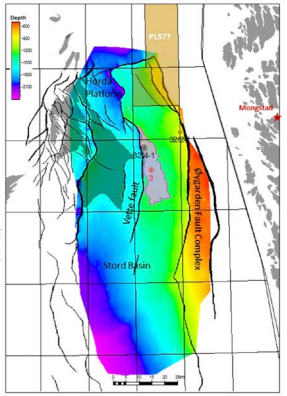


- Coupled experimental data for transport properties and reservoir modeling for CO_2-rich mixtures
- Studied consequences of impurities on the field scale:

  potentially increased migration distance with impurities, looked at phase partitioning and change in storage capacity



Smeaheia



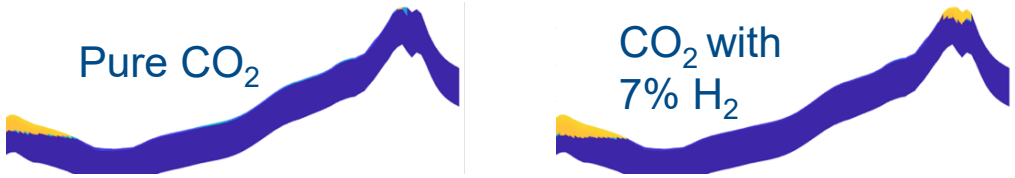
ghgt-16

16th International Conference on Greenhouse Gas Control Technologies, GHGT-16

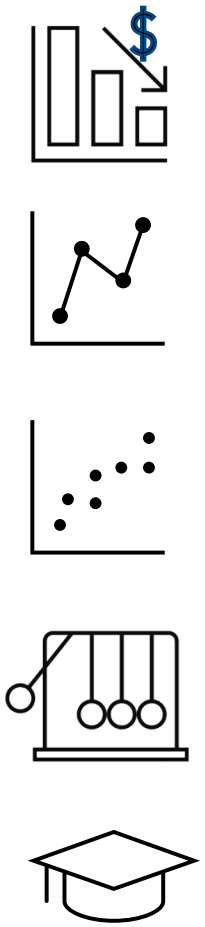
23rd -27th October 2022, Lyon, France

Impact of impurities on CO_2 plume migration with application to CCS for H_2 production

Trine S. Mykkeltvedt[a*], Svenn Tveit[a], Bahareh Khosravi[b], Ove Sævareid[a], Sarah Gasda[a,c]



WHY this project was important



Increased knowledge and started to close large gaps for experimental data for CO_2 rich mixtures

Constructed a new infrastructure for measuring viscosity and density, this will contribute to important knowledge in years to come

The project showed us that it is still an open question how to better connect experimental data for fluid transport and reservoir modelling

Thanks for your attention!

In memory of
Sigurd Weidemann Løvseth
- project leader and a champion for CCS

NCCS
NORWEGIAN CCS RESEARCH CENTRE
Industry-driven innovation for fast-track CCS deployment

FME
CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH
The Research Council of Norway

Gaute Svenningsen

SENIOR SCIENTIST

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

Kjeller Dense Phase CO_2 Corrosion Project (KDC-III)

From 2007 Gaute has been working as a corrosion scientist at the Institute for Energy Technology (IFE). His work has mainly been focused on H_2S and CO_2 corrosion of carbon steel, with particular focus on corrosion related to CCS the last 5 years. Gaute is the project manager for the Kjeller Dense phase CO_2 project (KDC).

The Research Council of Norway

GASSNOVA

CLIMIT-Demo project 618094
Kjeller Dense Phase CO_2 Corrosion JIP (KDC-III)

Gaute Svenningsen, Bjørn Helge Morland,
Morten Tjelta and Arne Dugstad

Corrosion department
Institute for Energy Technology (IFE)
NO-2007 Kjeller, Norway

Why are impurities in the captured CO_2 a problem??

- The captured CO_2 is not 100% pure.
  Typically ppm-levels of e.g. H_2O, O_2, NOx, SOx and H_2S (impurities)
- May cause corrosion and other problems which compromises the safety of the CO_2-transport system
- Impurities can be removed, but it is costly (OPEX / CAPEX)
- Use of stainless steel too costly except short distances
- Need to find a combination of materials and upper limit for impurities that minimizes the risk of corrosion and other problems, while also minimising the cost material, construction and operational cost

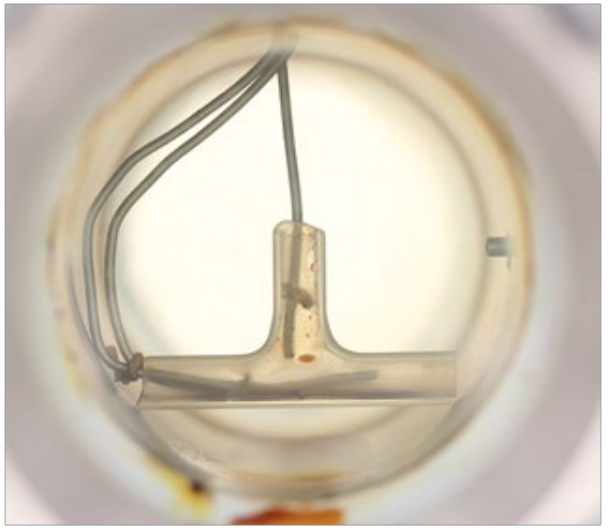
KDC-III hard facts

- 15 MNOK total budget
  - 43% CLIMIT funding
- 2018 to 2022
- Industrial partners:
  - ArcelorMittal, BP, Equinor, Gassco, Shell, TotalEnergies and Vallourec
- Technical partners: IFE and OLI Systems Inc.

The results

- Safe impurity limits have been verified @ +25°C and 100bar**
- It has been shown experimentally that
  - Some CO_2 blends are chemically stable (no reactions).
  - Certain CO_2 blends result in chemical reactions.
  - Certain CO_2 blends result in formation of sulfuric and nitric acid, which are corrosive to carbon steel*
- The results are used to
  - Tune the OLI model for simulation of CO_2 streams
  - Better knowledge for material selection for CCS-chains
  - Improved CO_2 specifications for CCS-projects
  - Input to ISO standards
- Plans of new phase of the project (KDC-IV)

(a) 20 hours: SO_2 /O_2



(e) 102 hours: All impurities

*Morland, Tjelta, Norby, Svenningsen, *International Journal of Greenhouse Gas Control, 87, (2019) pp. 246-255.*

**Morland, Dugstad, Svenningsen, *International Journal of Greenhouse Gas Control, 119, (2022) p. 103697.*

Follow IFE on social media

www.ife.no

facebook.com/energiteknikk/

@energiteknikk

Klas Solberg

ENGINEER

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

CO_2 Safe&Sour JIP: H_2S challenges in CCS pipelines

Klas Solberg is a mechanical engineer working in the DNV technology Centre Høvik. He is the project manager for the CO_2 Safe&Sour JIP by DNV. The project aims to investigate the integrity of CO_2 pipelines when expanding their gas specifications, mainly focusing on the risk for sulfide stress cracking and corrosion associated with increased H_2S levels. In 2021 he received his PhD in fatigue and fracture from NTNU.

The Research Council of Norway

GASSNOVA

CO_2 Safe&Sour Joint Industry Project

H_2S challenges in CO_2 pipelines

Klas Solberg, PhD

CO_2 Safe & Sour JIP

The Northern Lights pipeline is being developed with tight tolerances for impurities, including H_2S.

Increased tolerance levels for impurities can give considerable value to CCS projects:
- Makes CCS more accessible for different sources/customers
- Limiting customers need for gas processing

Goal	• Increase tolerance levels for impurities resulting in sour service conditions. • Enable cost effective development of Northern Lights and other CCS Hub projects.
Objective	• Understand the implication of H_2S on the integrity of CO2 pipelines and quantify limits for safe operation.
End-state	• Knowledge basis for update of DNV-RP-F104 on allowable H_2S limits in operation.

Phase 1

equinor, Shell, TotalEnergies, GASSCO, IFE, wood., CLIMIT

Phase 2 extension

ExxonMobil, Woodside, vallourec, COCAS, subsea 7, ArcelorMittal, Tenaris, CORINTH PIPEWORKS

Contact: klas.solberg@dnv.com

Why is H_2S a problem?

- Impurities in CO_2 stream
- Corrosion
- H_2S promotes Hydrogen absorption in the pipeline steel
- Hydrogen embrittlement - cracking
- Gas specification (limit for impurities)
- Costly to remove from CO_2 stream

High H_2S levels are expected from:

- Steel plants
- Power plants
- Natural Gas plants
- BioGas

klas.solberg@dnv.com

www.dnv.com

Yessica Arellano

RESEARCH SCIENTIST

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

Monitoring and Control of Networks for CCS

Yessica Arellano has two M.S.c 's degrees in Gas and in Oil and Gas Engineering. Her doctoral research focused on multiphase flow monitoring through electromagnetic measurements. She has over 15 years of working experience, encompassing project management for the Oil and Gas Industry, technology consultancy, and R&D services. Currently, Yessica works as a Research Scientist in SINTEF Energy research.

The Research Council of Norway

GASSNOVA

MACON CCS

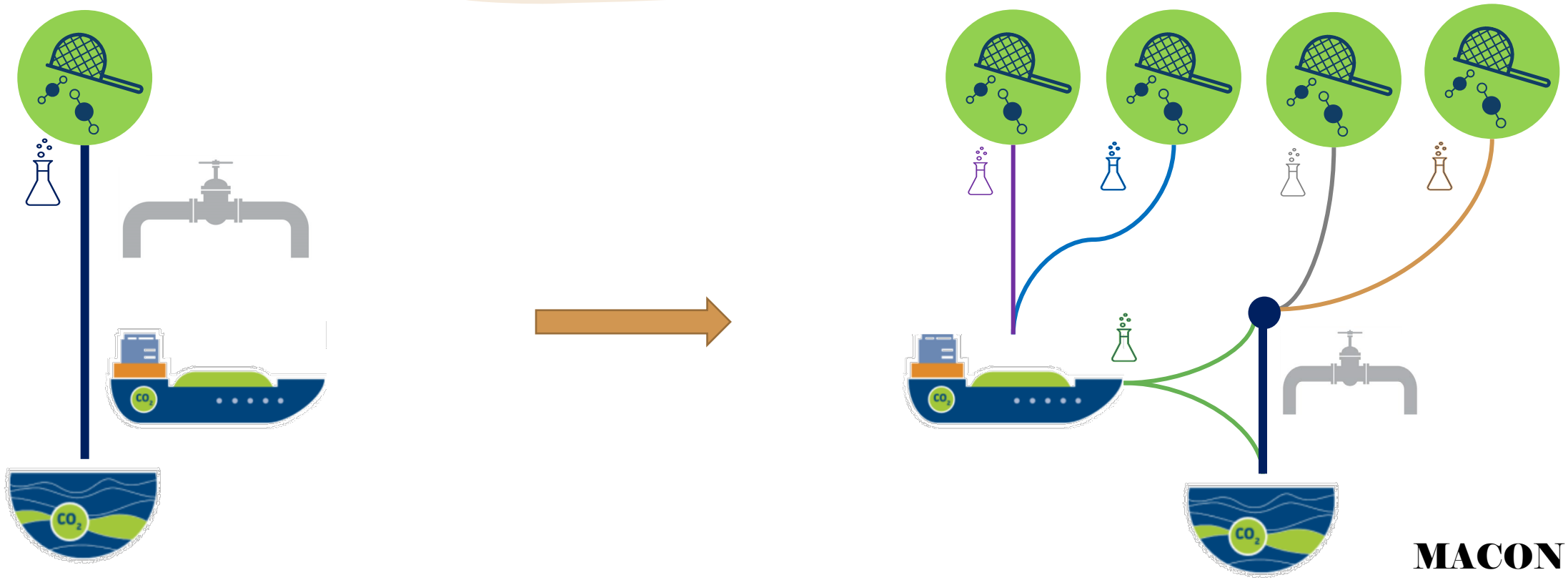
MONITORING AND CONTROL OF NETWORKS FOR CCS

YESSICA ARELLANO

FEB 2023 - CIMIT SUMMIT

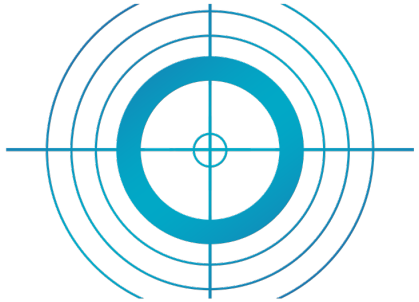
SINTEF NTNU roxar EMERSON GROUP COMPANY KROHNE neo NORSK ELEKTRO OPTIKK AS TechnipFMC

CO_2 transport within CCS will evolve into networks



MACON CCS

Eyes on the target



Prediction of CO_2 flow behaviours in pipes

- Develop EoS with faster resolution times and better extrapolation
- Assess the performance of one commercial flow simulator

Advance un SoA measurement technologies

- Flow measurement
- Composition/second phase identification

Documentation of lessons learned and advancement in the design, monitoring, and control of networks for CCS

Highlights

Imaging measurement technologies for CCS

Yessica Arellano
Department of Gas Technology
SINTEF Energy Research
Trondheim, Norway
yessica.arellano@sintef.no

Stian Husevik Stavland
Department of Physics and Technology
University of Bergen
Bergen, Norway
Stian.Stavland@uib.no

Elvia Chavez Panduro
Department of Gas Technology
SINTEF Energy Research
Trondheim, Norway
elvia.chavez.panduro@sintef.no

Børge Hamre
Department of Physics and Technology
University of Bergen
Bergen, Norway
Borge.Hamre@uib.no

Bjørn Tore Hjertaker
Department of Physics and Technology
University of Bergen
Bergen, Norway
Bjorn.Hjertaker@uib.no

IEEE Signal Processing Society

IoT-Based Monitoring in Carbon Capture and Storage Systems

Apoorva Chawla, Yessica Arellano, Martin Viktor Johansson, Hossein Darvishi, Khadija Shaneen, Matteo Vitali, Francesco Finotti, and Pierluigi Salvo Rossi

DECEMBER 202

IEEE iotm Internet of Things Magazine

beyond MACON CCS

Universitas Bergensis

SIGNIFY
SENSOR VALIDATION FOR DIGITAL TWINS OF SAFETY-CRITICAL SYSTEMS

Summer Student (i)
Master Student (i)
PhD Student (u)

Thank you!

MACON CCS

Dr. Luciano E. Patruno

DEPARTMENT MANAGER –
FLOW TECHNOLOGY

Phenomenological study of unstable two-phase CO_2 flow in a pipeline system

Dr. Patruno is a nuclear engineer educated at the Balseiro Institute in Argentina. He took his PhD at NTNU focused on multiphase flow systems containing a dispersed phase. He has held several positions within R&D and product development in major oil and gas vendor companies during the last 12 years. Currently is the head of the flow technology department at IFE, where he works with multiphase CO_2 flows, leading research facilities for Norway and the EU.

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

The Research Council of Norway

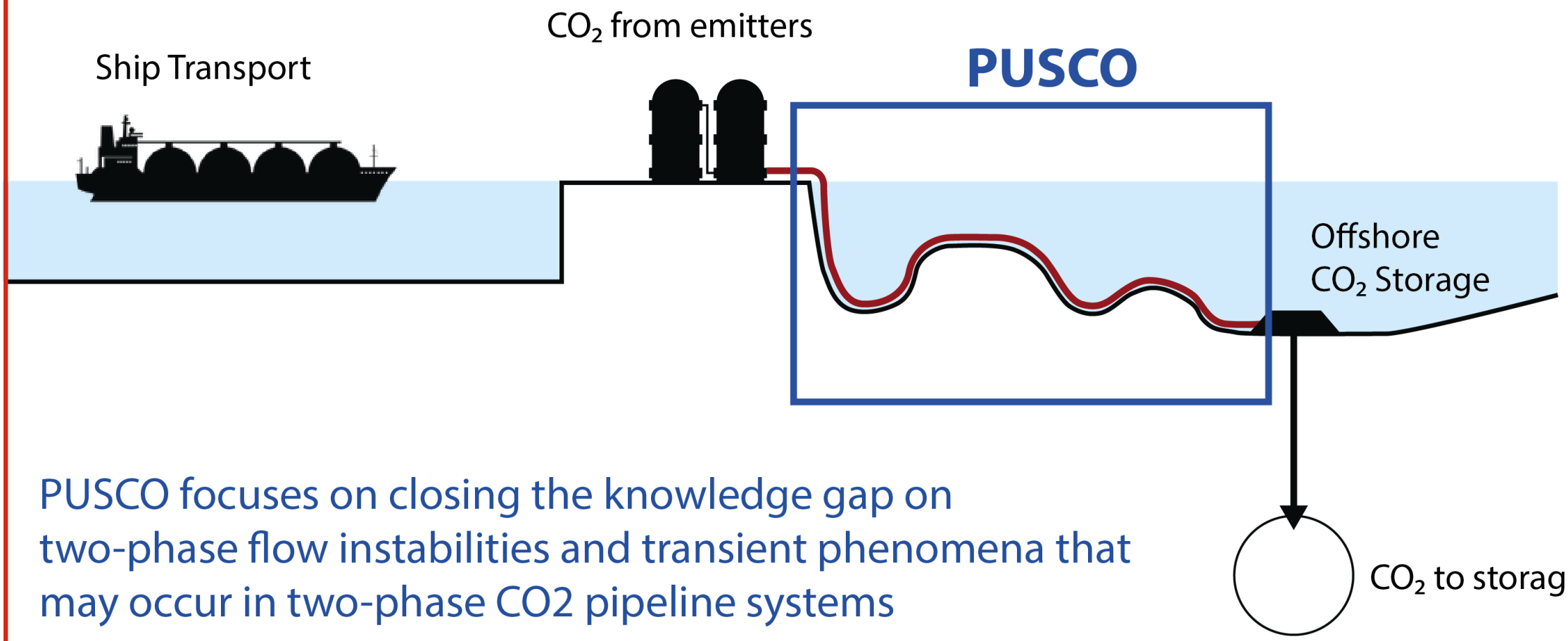
GASSNOVA

PUSCO: Phenomenological study of unstable two-phase CO_2 flow in a pipeline system

Project number: 326624 - KSPKOMPETANSE21

Luciano E. Patruno – Department Manager Fluid Flow

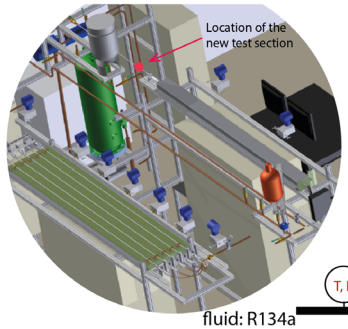
Northern Lights

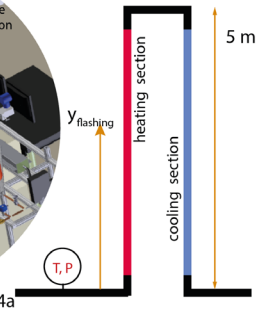


PUSCO focuses on closing the knowledge gap on two-phase flow instabilities and transient phenomena that may occur in two-phase CO2 pipeline systems

WP1

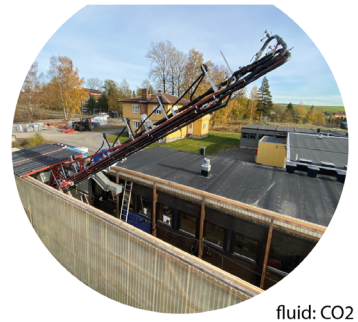
NTNU

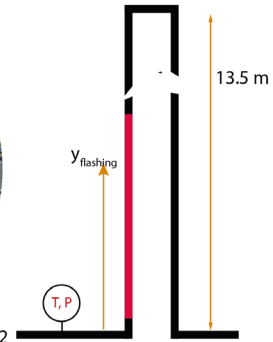




fluid: R134a

IFE



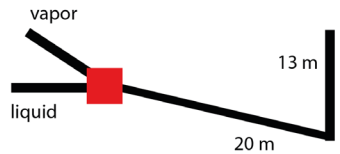


fluid: CO2

WP2

IFE

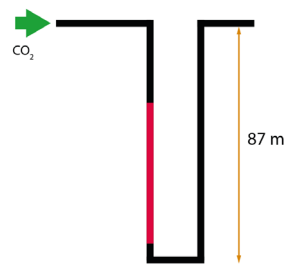
Terrain-induced sluggning experiment



Flow and pressure transients experiment

WP3

SINTEF



Thank you!


TotalEnergies


equinor


GASSCO


NTNU
Norwegian University of
Science and Technology


SINTEF


The Research Council
of Norway

Norbert Hoyer

FLOW ASSURANCE PROGRAM MANAGER

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

Enable successful CCS projects through accurate and robust simulation of multiphase transport and injection of pure CO_2 and CO_2 dominated fluids

Norbert Hoyer is responsible for the Flow Assurance technology offered by SLB. This includes the OLGA and PIPESIM simulators and related cloud-based solutions. He holds a master's in mechanical engineering from The Technical University of Munich and a PhD in informatics from The University of Oslo.

The Research Council of Norway

GASSNOVA

OLGA CO_2 REACH

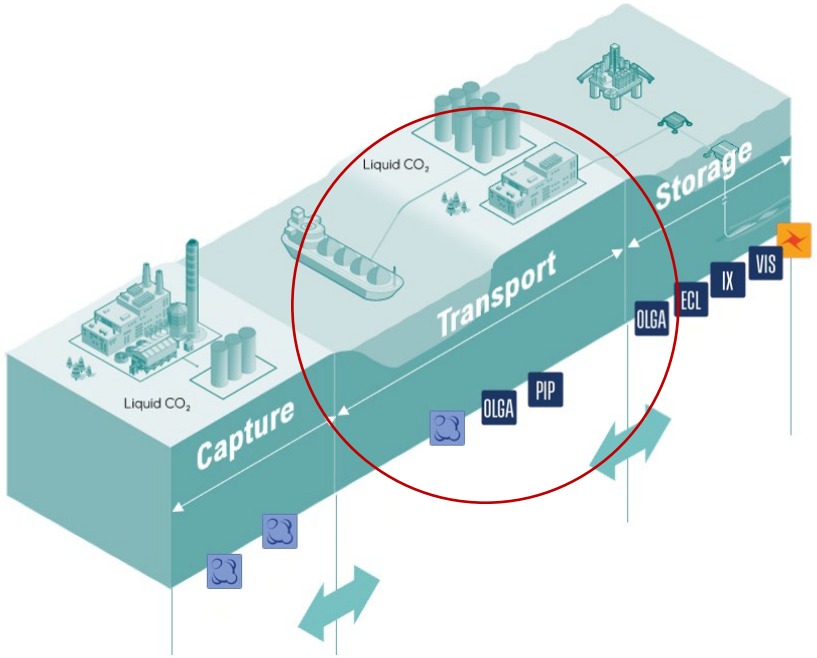
Norbert Hoyer

Flow assurance program manager

CLIMIT 2023

We are a global technology company, driving energy innovation for a balanced planet

SLB provides an End to End CCS digital offering



SLB-Private

Multiphase flow CO_2 transport in pipelines and wells with OLGA is a key technology to deliver CCS at scale

Key milestones

1. 2020 Industry round-table
2. 2020-2022 technology bench-marking – CO2FACT
3. 2021 systematic gap analysis to design the scope of CO2REACH – Best practices for CO_2 computations
4. 2022 CO2REACH Kick-off

Today OLGA provides reliable results for the majority of CO_2 flow transport scenarios

But improvement potential identified

Bench marked on laboratory and field data

Correct computations for single and dense phase CO_2 transport verified on operating assets

Some specific multiphase design cases requires special attention

- Computational robustness / speed
- Downward multiphase flow in wells
- Design loads for accidental depressurization
- Significant thermodynamic and compositional gradients

CO_2 REACH addresses the technological gaps to deliver CO_2 multiphase transport at scale

- → Major gains in numerical stability
- → Novel thermal modelling capturing the unique thermo-mechanical behavior of CO_2
- → Increased reliability of flow models for CO_2 injection
- → Process equipment models accounting for the specific properties of CO_2

Lars-Erik Svabø

DEVELOPMENT MANAGER LEDAFLOW

Simulating dynamically the full CCS value chain; from carbon capture to CO_2 injection into depleted reservoirs and saline aquifers

Worked in Kongsberg since 2007 with our dynamic simulators, K-Spice and LedaFlow. Have had different positions related to the simulator business, Project manager, Sales Director, Head of Operations, and today responsible for the development of the dynamic simulators. Work very closely with our LedaFlow partners; SINTEF Industry, TotalEnergies and ConocoPhillips. Heading the R&D initiatives for CCS with LedaFlow within Kongsberg.

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

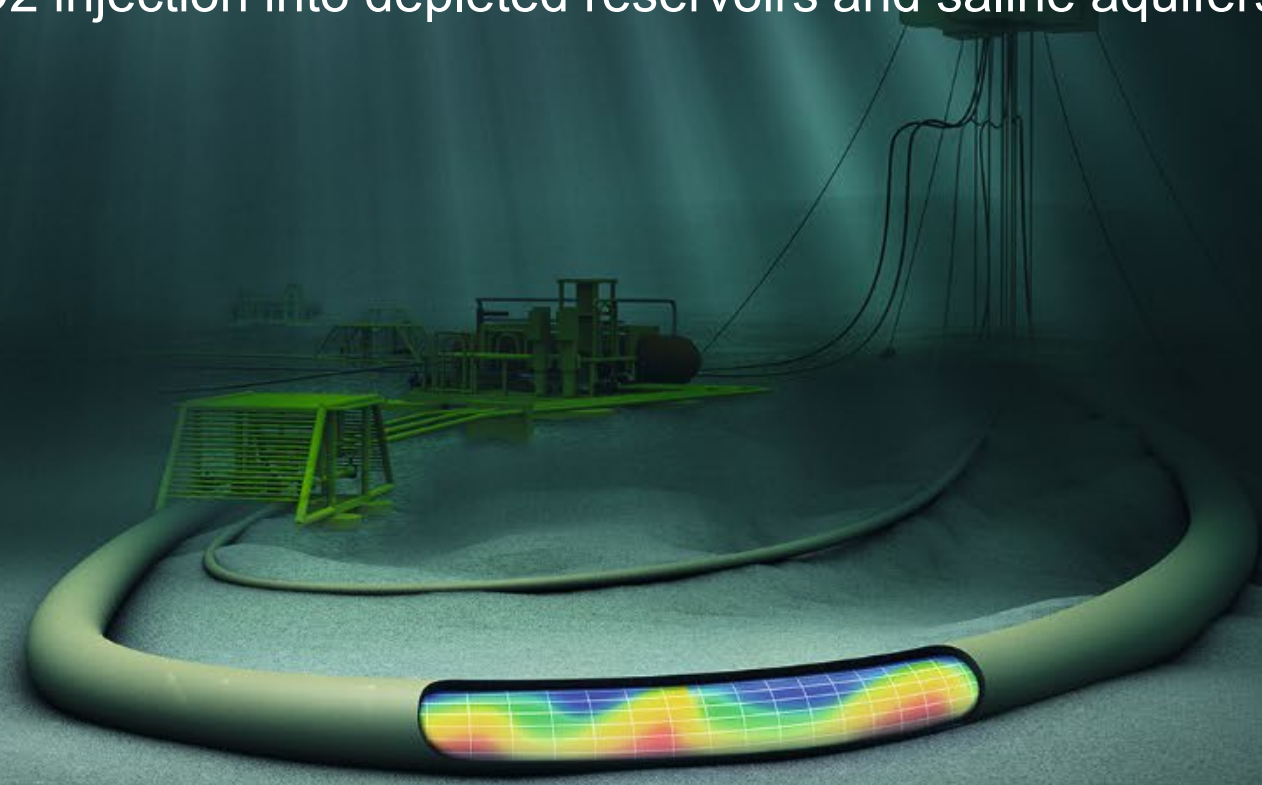
The Research Council of Norway

GASSNOVA

Simulating dynamically the whole CCS value chain

From carbon capture to CO2 injection into depleted reservoirs and saline aquifers

CLIMIT Summit 2023



Lars-Erik Svabø
Manager SW development dynamic simulators

KONGSBERG PROPRIETARY: This document contains KONGSBERG information which is proprietary and confidential. Any disclosure, copying, distribution or use is prohibited if not otherwise explicitly agreed with KONGSBERG in writing. Any authorised reproduction in whole or in part, must include this legend. © 2016 KONGSBERG – All rights reserved.

What is flow assurance and why is it important in CO2 transport?

- It is important to have multiphase flow tools in order to design CCS systems in a way that is safe and to make sure we can meet the design criteria
- There will be multiphase flow in the wells, since at least initially the reservoir pressure is low.
- During dynamic events (e.g., depressurization) you can experience multiphase flow in pipelines, even if they are designed to operate in single phase
- Need systems to accurately capture the phase behavior of CO2 as it transitions between vapor, liquid and super-critical phases, particularly as it leaves the wellbore and enters the reservoir.

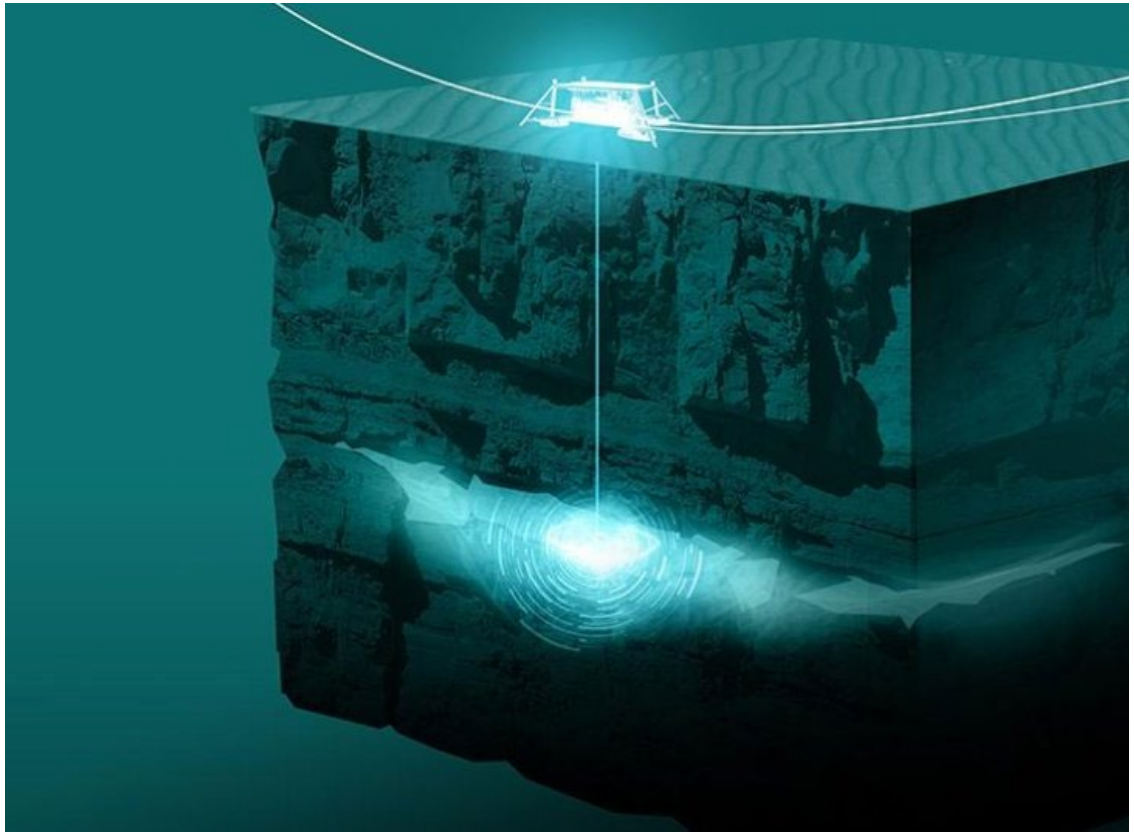


Image: Norwegian Petroleum Directorate.05.04.22
https://www.npd.no/globalassets/1-npd/fakta/co-to/ccs.jpg

Kongsberg Digital (KDI)

OPERATE YOUR ASSETS SMARTER, SAFER AND GREENER

OUR PRODUCTS

Every day our products create impact by turning data into better actions, helping organizations automate work and drive value over the entire asset lifecycle.

Vessel Insight

Our vessel-to-cloud data infrastructure enables customers to unlock the value of their data.

READ ABOUT VESSEL INSIGHT →

Kognitwin®

Our Dynamic Digital Twin is an enabler for digitalization of oil & gas assets at scale.

READ MORE ABOUT KOGNITWIN →

Maritime Simulation

We provide advanced simulation systems for maritime education, training and studies.

READ ABOUT MARITIME SIMULATION →

SiteCom®

A complete ecosystem for safer and reliable drilling and wells operations.

READ ABOUT SITECOM® →

Kognitwin® Grid

From traditional systems to smart and more complex grid.

READ ABOUT KOGNITWIN GRID →

K-Spice®

Dynamic process simulation.

READ ABOUT K-SPICE® →

LedaFlow®

Flow simulation software in wells, flowlines and processing facilities.

READ ABOUT LEDAFLOW® →

Rig Manager

Rig management software solution.

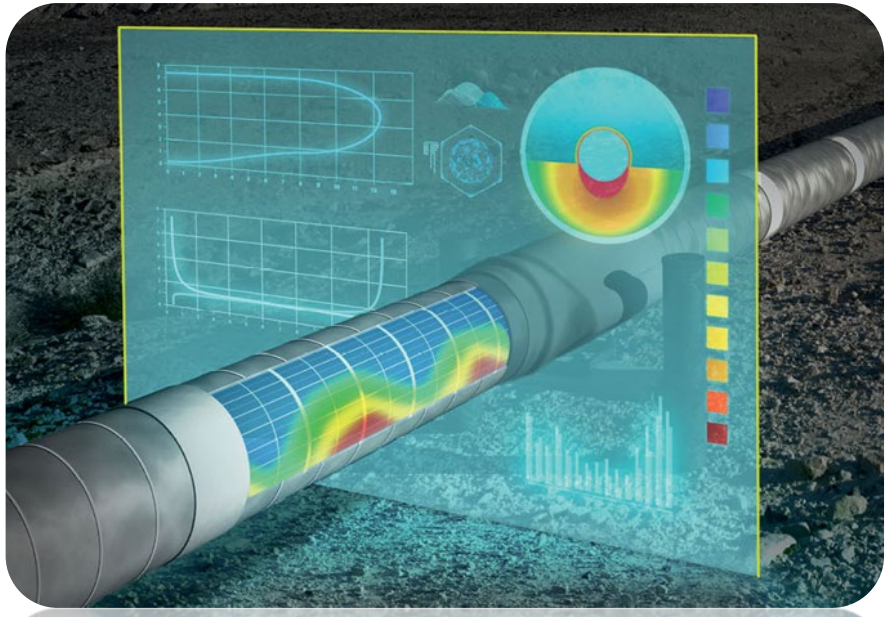
READ ABOUT RIG MANAGER →

- More than 35 years of experience with dynamic simulators
- The dynamic simulator group in KDI
  - Close to 90 engineer with strong domain background
  - R&D department of 20 development engineers with PhD and master degree
  - Global presence; Europe, US and Asia

Our dynamic simulators

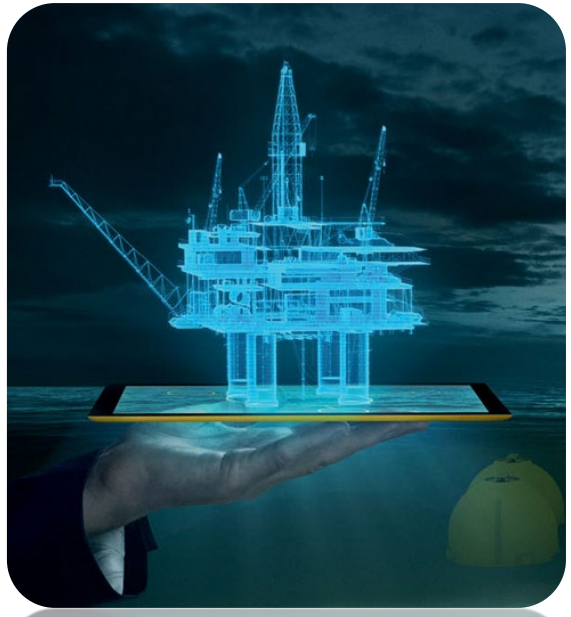
LedaFlow®

- Dynamic **multiphase flow simulator**
  LedaFlow is based on models that are closer to the actual physics of multiphase flow and provides a step change in accuracy and detail

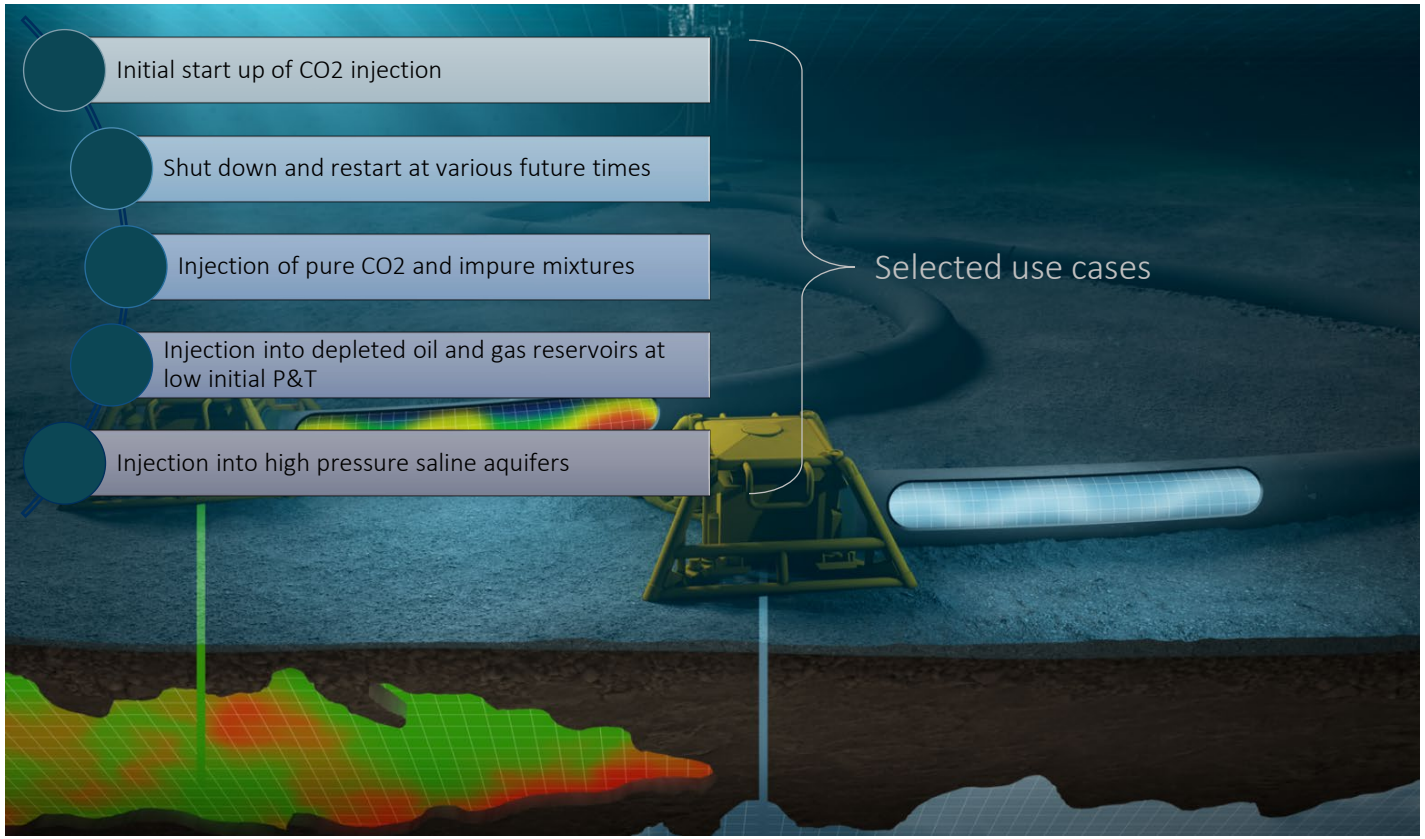


K-Spice

- Dynamic **lifecycle process simulator** for design, verification, operator training and real-time decision support



CLIMIT-Demo project 621306 “GELECO2” Model and simulate CO_2 injection (03/22-02/24)



- **Problem statement**: Flow assurance and wells teams want to better understand the transient effects related to CO2 injection
- **Scope** of the JIP: Integrate and manage the interaction between currently separated well and reservoir systems
- **Goal**: Will release commercially two-way coupling between LedaFlow and reservoir simulator (GEM)
- **Funded** by the industry as an JIP and by CLIMIT
  - Neptune Energy, TotalEnergies, EBN BV, Wintershall DEA, JX Nippon, Eni, Repsol, Storegga, BP, Pertamina
- First alpha version **released** to the partners December 2022

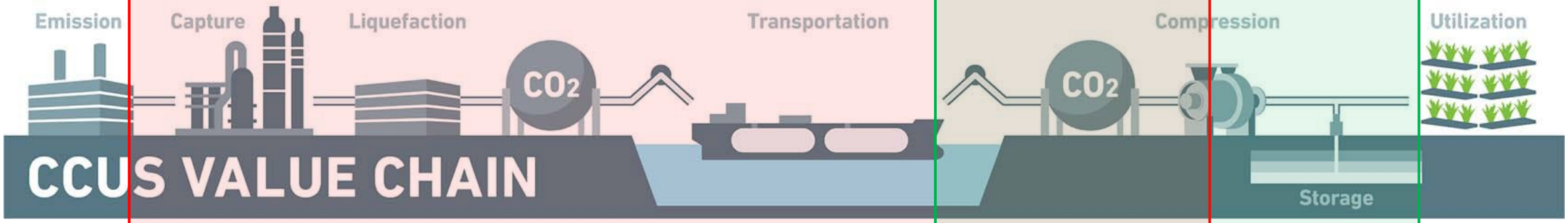
K-Spice and LedaFlow modelling of the whole CCS value chain

CO2 capture from waste-gas

CO2 liquefication

CO2 transport loading and offloading

Injection of CO2 into depleted reservoirs or saline aquifers linking to reservoir simulators



K-Spice

LedaFlow

Drying of CO2

CO2 single phase pipeline transport

CO2 multiphase flow

Ragnhild Skagestad

SENIOR RESEARCHER

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

CO_2los III

Ragnhild Skagestad is the project manager of the CO_2 ship transport project CO_2los III which is a cooperation among SINTEF, Brevik Engineering and several industry partners from both ship, supplier and energy companies. Ragnhild holds a Master's degree in mechanical engineering from 2004, and since then she has worked with sustainable development, CO_2 capture and transport and early phase cost estimation.

The Research Council of Norway

GASSNOVA

CO2LOS

CO2 Logistics by Ship Phase III

Partners:

Air Liquide creative oxygen

bp

BREVIK engineering

equinor

GASSCO

Imodco Part of the SBM Offshore® Group

Mitsubishi Corporation

MITSUBISHI HEAVY INDUSTRIES

MOL 商船三井 Mitsui O.S.K. Lines

SINTEF

TotalEnergies

Project co-sponsor:

CLIMIT

CO2LOS III (2021-2023)

CLIMIT SUMMIT 8.2.2023
Project owner: Brevik Engineering AS

Presented by Ragnhild Skagestad, SINTEF INDUSTRY

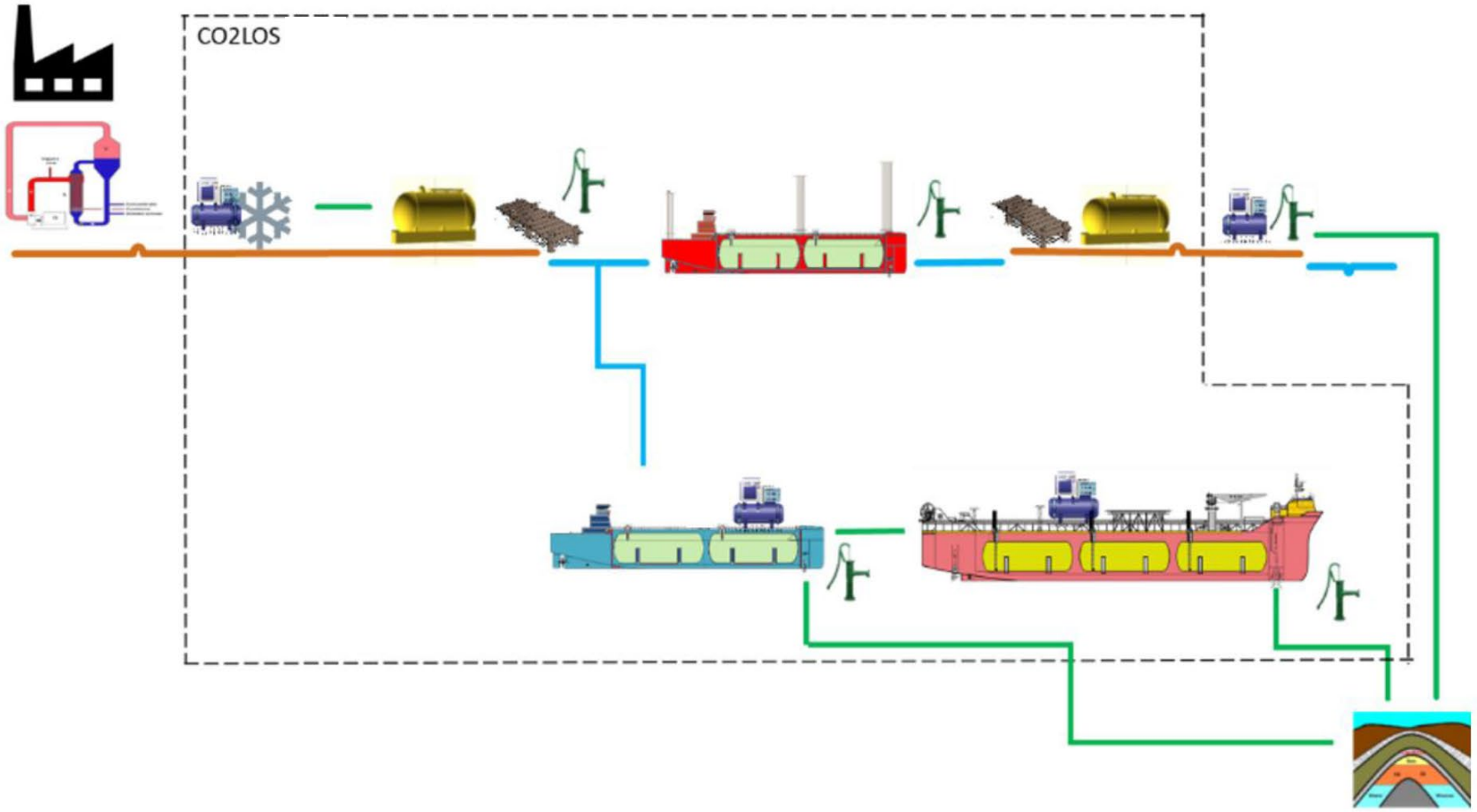
CO2LOS III

- The project started in November 2021 and have a duration of 17 months (planned finished in April 2023).
- Follow the path from CO2LOS I and II
- Project owner: Brevik Engineering AS
- The project budget is 9,5 mNOK
- Funding from partners and CLIMIT (Gassnova)
  - CLIMIT funds up to: 3,044 mNOK

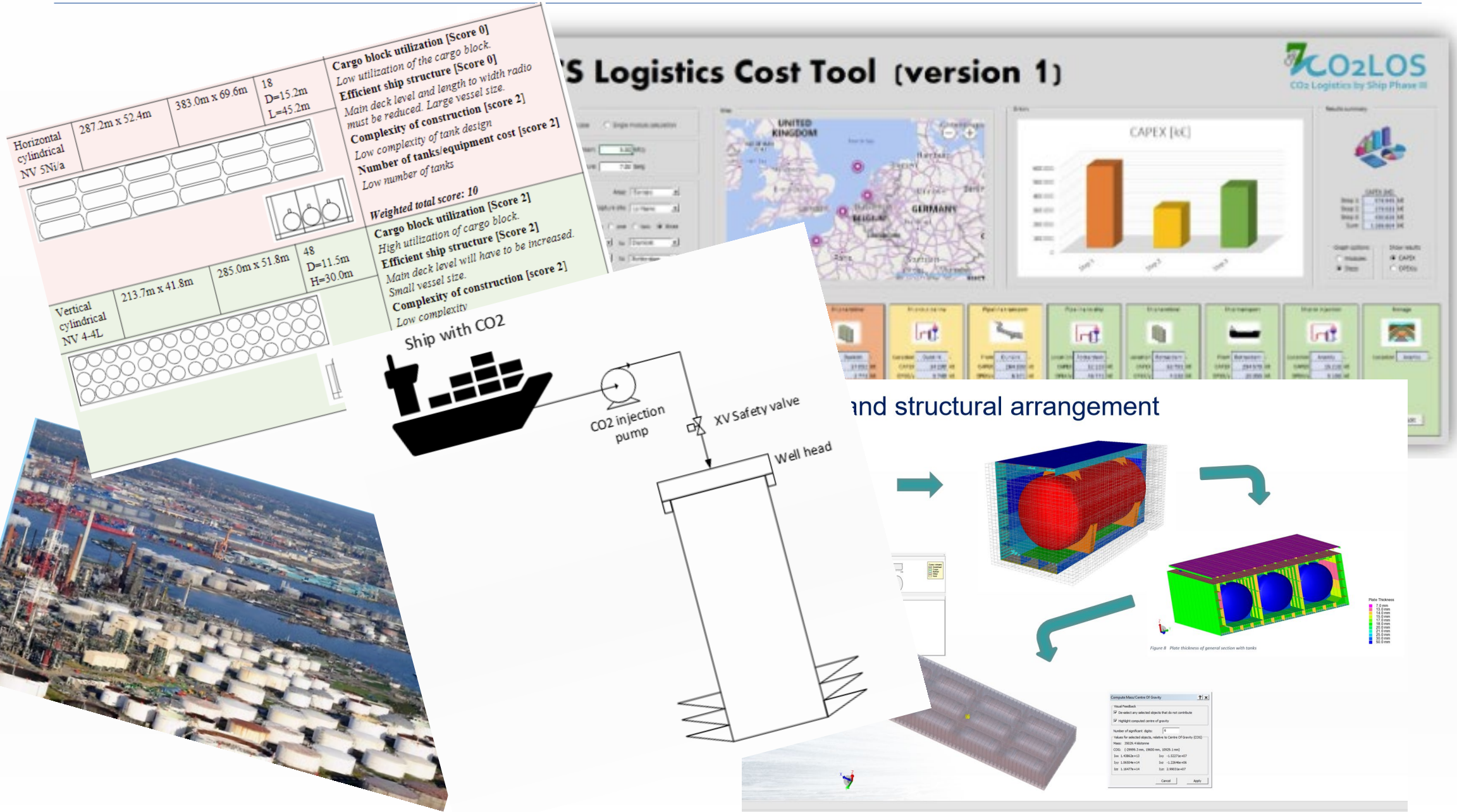
Scope:

Reduce the cost of CO_2 transportation by investigating design of large CO2 ship (>50 kt) and design of floating/mobile terminals for condition/storage before transport. In addition, a cost model for pipe/ship cost is developed.

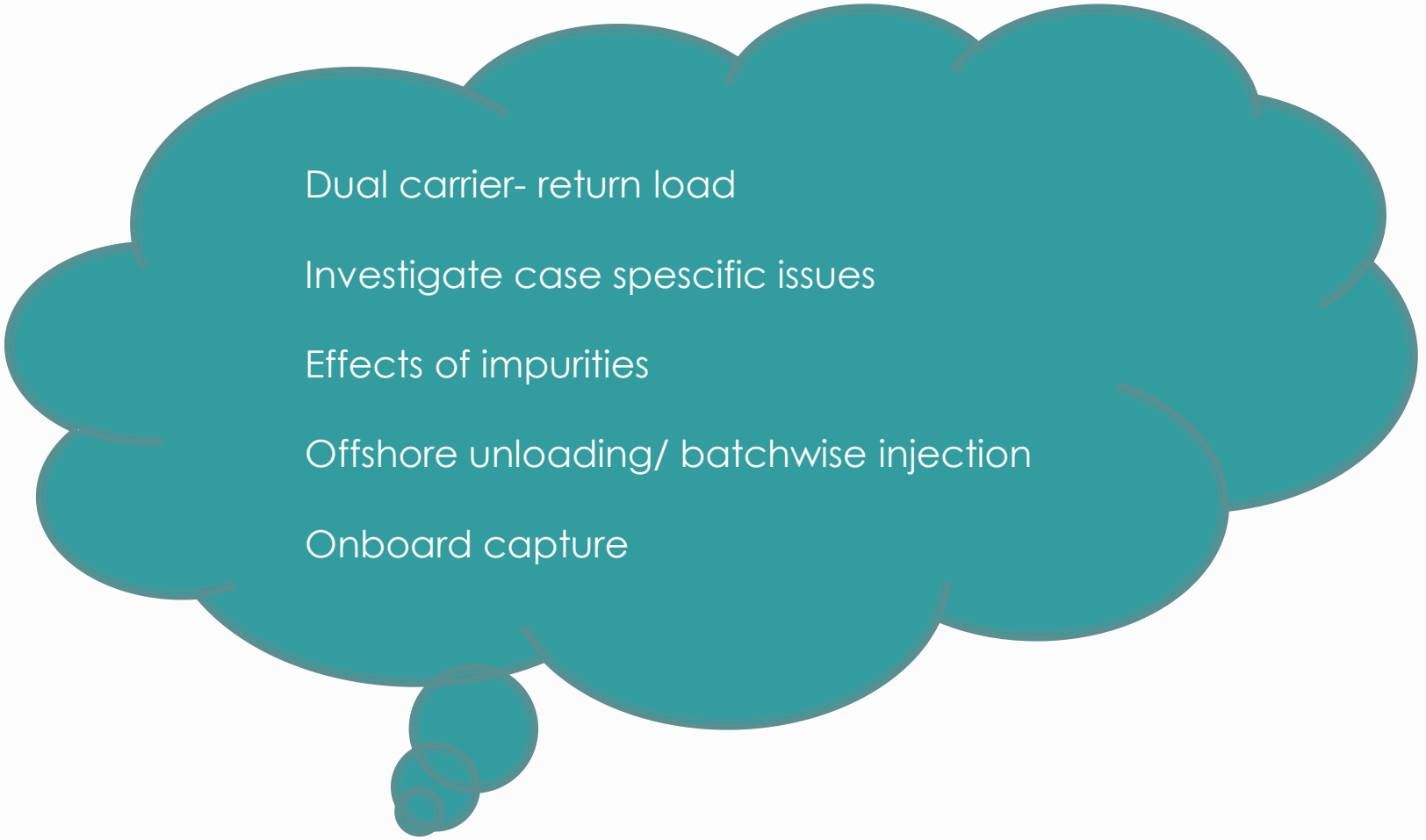
OUR FOCUS AREA



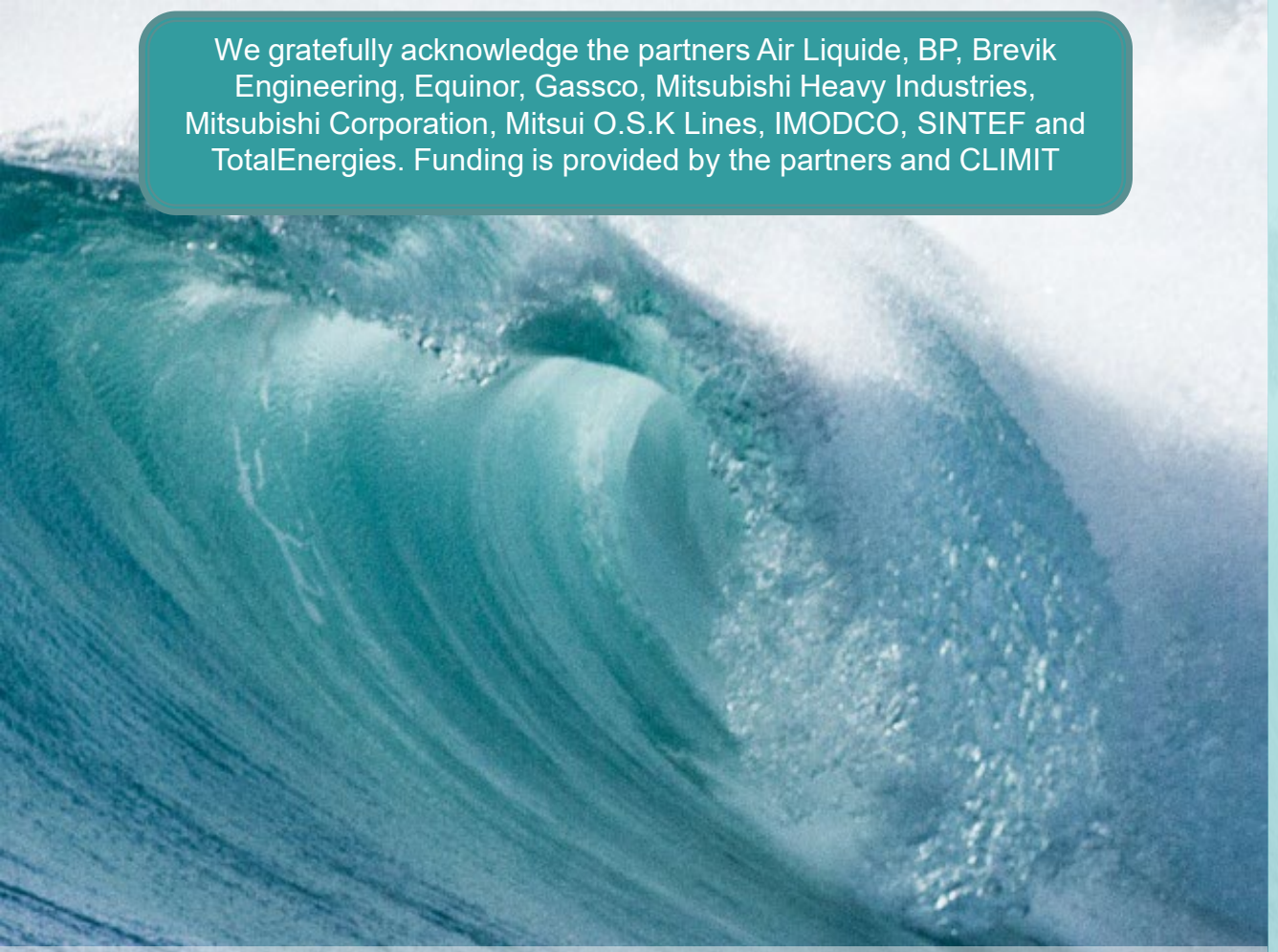
Overview of the project and outputs



New scope are under discussion- open for new partners-



We gratefully acknowledge the partners Air Liquide, BP, Brevik Engineering, Equinor, Gassco, Mitsubishi Heavy Industries, Mitsubishi Corporation, Mitsui O.S.K Lines, IMODCO, SINTEF and TotalEnergies. Funding is provided by the partners and CLIMIT



CO2LOS

CO2 Logistics by Ship Phase III

More info:

www.sintef.no/CO2LOS

Project Manager:

Ragnhild Skagestad, SINTEF AS,

ragnhild.skagestad@sintef.no,

mob +47 97026390

Project Owner Representative:

Martin Hay, Brevik Engineering AS,

martin.hay@brevik.com,

mob +47 90125579

WPs in the project

- WP1 – Cost Estimation Tool for CCS Scenarios
- WP2 - Tank Arrangement for Large CO_2 Carriers
- WP3 – Floating CO_2 Terminals
- WP4 – Zero Emission Shipping
- WP5 – Roadmap to Unmanned FSI
- WP6 – Potential for Batchwise Injection
- WP7 – Class Codes and Regulations for CO_2 Shipping

Per Lothe

SPECIAL TECHNICAL ADVISOR TECHNOLOGY

PCO_2 Technology review and design verification

Mechanical Engineer from NTNU. Experience from Norsk Hydro Oil and Gas followed by Statoil before joining Knutsen OAS Shipping in 1999. Responsible for development of new technology in Knutsen with focus on new technology toward the shipping segment. Have been working for KNCC since January 2022 with LCO_2 transport using technology for ambient temperature transport at elevated pressure.

CLIMIT SUMMIT
#CLIMITSUMMIT2023
7–9 February
The Research Council of Norway
GASSNOVA

PCO2 Technology review and design verification

A CLIMIT-Demo project

Knutsen NYK Carbon Carriers

Established in 2022 between Knutsen OAS Shipping and NYK to offer LCO2 transport based on the Company's unique competence within all shipping segments and offshore operations in particular

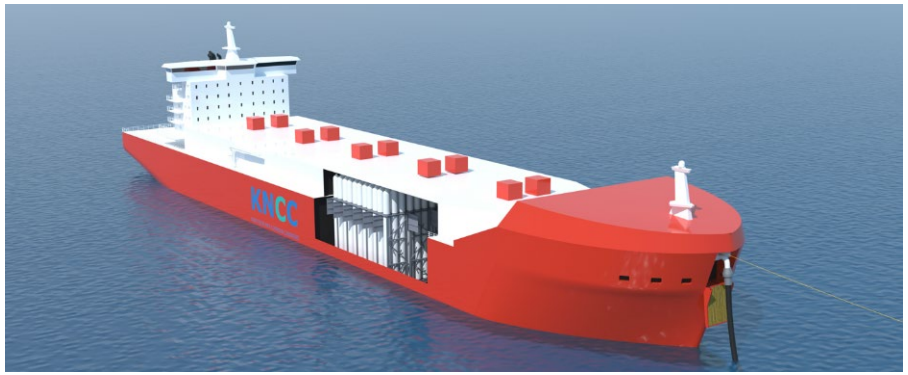
Knutsen OAS Shipping

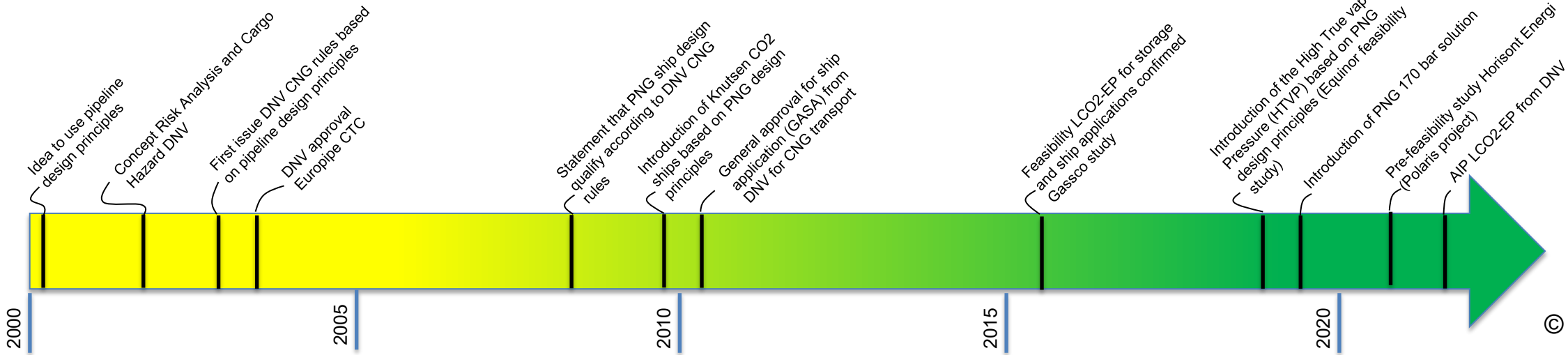
KNCC

NYK LINE
NIPPON YUSEN KAISHA

Background for entering the CO2 transportation market

- LCO2 transport is based on more that 20 years development for transport of pressurized gasses, an innovative technology developed by Knutsen OAS Shipping using vertical positioned pipelines cylinders as tanks, the best known and explored cylindrical design available.
- **The unique technology will be able to transport LCO2 at elevated pressure (LCO2-EP) at temperatures above freezing**
- To operate above freezing has many advantages considering the entire value chain from capture to final storage into onshore and offshore sinks
- To transport LCO2 at the above condition is a new application and to verify and document the LCO2-EP thermodynamics and operations, a test rig is under construction at ResQ training center close to Haugesund.

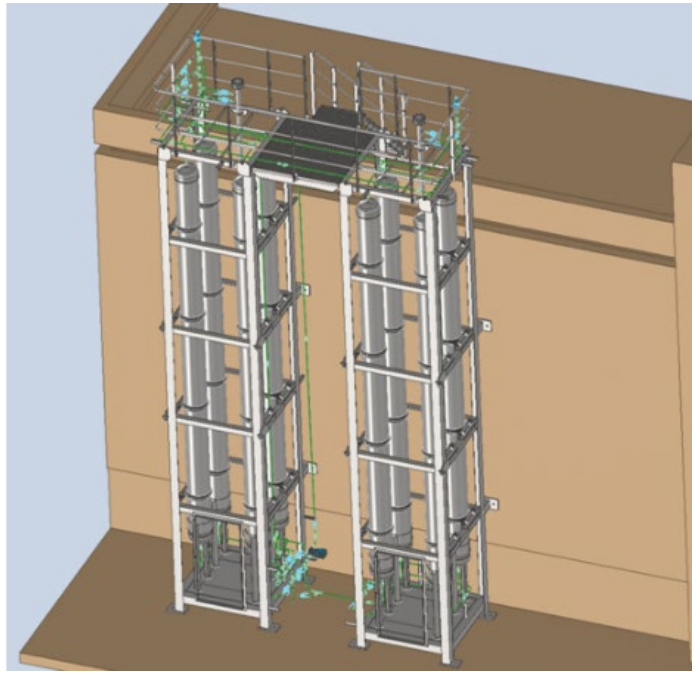




©KNCC

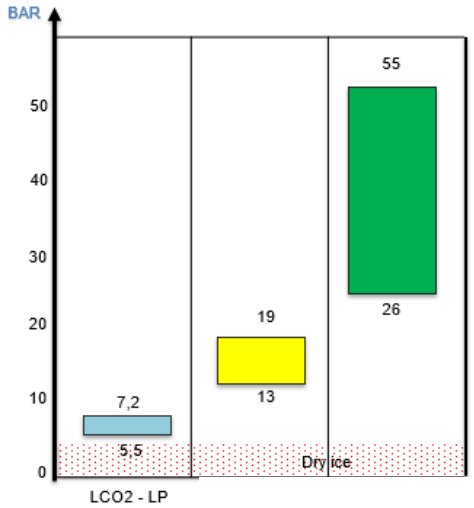
Test rig at ResQ, Haugesund

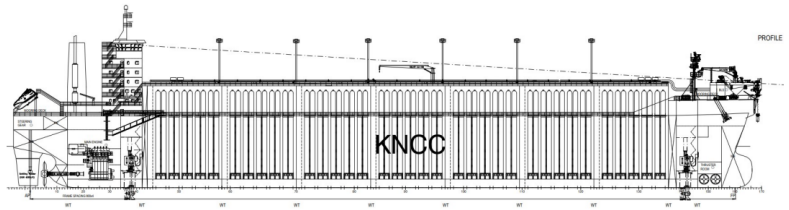
- Limited experience with large CO2 waste storage and transport above freezing temperature.
- The cabinets with storage pipes was installed January 2023.
- Installation of piping, valves monitoring equipment and pumps are ongoing and is expected to be ready for LCO2 testing end of March 2023.
- CO2 is delivered by Nippon Gasses and first filling is scheduled to be after commissioning
- Projects partners are CapeOmega, DNV and supported by CLIMIT.
- Noticed huge interest among CO2 emitters to visit the rig as knowledge of CO2 handling and operation in large volumes is still lacking
- The budget frame is about 10 MNOK and testing is scheduled to go on through 2023.



The project in a business perspective

- LCO2-EP containment system provide a large operating flexibility.
- Our background and our containment technology give us a unique position in an emerging market.
- Our customers are emitters, sink operators and oil companies.
- Challenge for all projects to get transport service in a value chain from capture to sink.





Huge market potential

Source:
Rystad Energy Dec. 2022

CCUS projects

Operation	In pipeline	Capacity in operation	Capacity in pipeline
62	387	40	> 514
Project count	Project count	Mtpa	Mtpa

Gabriele Notaro

PRINCIPAL ENGINEER

Technology Qualification of a low-pressure CO_2 shipping solution

Gabriele has background in Naval Architecture and Marine Engineering from University of Genoa, Italy. Joined DNV in 2007 and worked as structural engineer in Maritime Advisory with attention to ultimate strength of vessels and offshore structures, rule development, R&D, design verification, trouble shooting. Member of ISSC since 2015, he is currently joinig the «Renewable Energy» committee.

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

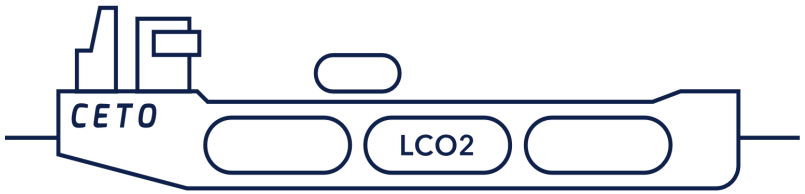
The Research Council of Norway

GASSNOVA

WHEN TRUST MATTERS

DNV

CETO



Technology Qualification of Low-Pressure CO_2 ship transport

Climit Summit

Gabriele Notaro

08 February 2023

CLIMIT-Demo project no 620320

CO_2 ship transport today

- **Limited volumes and ship size** (Dedicated carrier of 1250-1800 m^3)
- **Medium pressure** condition (15-20 barg,-30℃) mature technology
- Two vessels have been ordered for Northern Lights (Medium pressure, 7500 m3)

Source: Yara International ASA

LP ship transport

- CCS projects in development today feature larger volumes of CO2 than transported by ships today or in Northern Lights Phase 1
- Medium pressure ship transport may not be the best solution for future CCS projects?

Possible solution is *transportation at **low-pressure** condition (7-10 barg, -50℃)*

no operational experience

DNV

LP ship transport Advantages

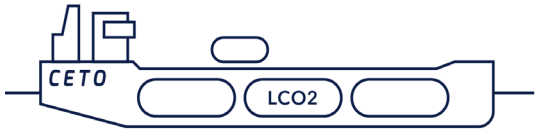
- Larger cargo tanks (larger diameters) for increased vessel's capacity
- Increased liquid density allowing for more CO_2 per transported unit volume
- Enabling more flexible ship arrangement
- Believed to lower the transportation cost

$$s \geq \frac{p_c \cdot D_o}{20 \cdot \sigma_t \cdot v + p_c} + c$$

Uncertainties

- Risk of **dry ice formation** during cargo handling impairing the reliability of operation
- **Accuracy** of **process simulations** and thermodynamic predictions
- **Fatigue and structural integrity** of critical details cargo tanks and cargo tank support
- Appropriate tank materials in relation to **strength**, **low temperature** performance, fabrication and costs
- **Liquefaction at low pressure**, and storage of large volume of CO_2

Technology Qualification and activities



Objective

Identify, resolve and mitigate the **technical uncertainties** to qualify a low-pressure CO_2 shipping solution, enabling larger ships and increased volume of CO_2 for a safe and **cost-effective** transportation chain

Feed Gas

Pre-combustion captured CO_2 source is selected

20°C

1.3 bara

Liquefaction plant

Liquefaction at 7 bara, 1.6 MT/year

Storage tank 45 000 m3, 7-7.1 bara -49°C

Holding mode, loading mode, receive warm gas from ballast tanker

Ship and containment system

Prod. Condition LCO2: -46 to -49°C at 7-8 bara

Nominal volume: 30 000 m3

Holding time: target 3 days (7 max) per leg

Use of extra high tensile steel

Cargo handling operations (interaction ship-storage tank, loading offloading, boil off) medium scale testing, process simulations, thermodynamics

DNV

Thank you for your kind attention

https://www.dnv.com/maritime/jip/ceto/index.html

Gabriele.Notaro@dnv.com
www.dnv.com

ghgt-16

16th International Conference on Greenhouse Gas Control Technologies, GHGT-16

23rd -27th October 2022, Lyon, France

CETO: Technology Qualification of Low-Pressure CO2 Ship Transport

Gabriele Notaro[a]*, Jed Belgaroui[b], Knut Maråk[c], Roe Tverrå[d], Steve Burthom[e], Erik Mathias Sørhaug[a]

[a]DNV AS, Veritasveien 1 1362 Høvik, Norway
TotalEnergies E&P Norge AS, Finnestadveien 44, 4029 Stavanger
[c]Equinor, Arkitekt Ebbells veg 10, 7053 Rotvoll
[d] Gassco AS, Bygnesvegen 75, 4250 Kopervik
[e]Shell Global Solutions International B.V., Grasweg 31, 1031 HW Amsterdam

Abstract

The objective of the study is to provide evidence of the technical feasibility of a low-pressure CO_2 ship transportation concept, by mitigating the risks and removing uncertainties related to design, construction, and operation through the execution of the Technology Qualification Programme, as described in Recommended Practice DNV-RP-A203, Technology qualification.
Liquid CO_2 (LCO_2) is currently transported in ships as a semi-refrigerated liquid under pressure as for other gases (LPG, LNG) but has different properties which pose some challenges to the value chain. Pure CO_2 has a triple-point at 5.12 bar and -56.6 °C, hence cannot be transported in liquid form at pressure below the triple point (dry-ice). Its density is about double that of LPG/LNG, challenging the design and safety performance of the cargo containment system.
As per date, transport of CO_2 via ship takes place at small scale (food grade CO_2) and at medium-pressure (i.e., about 15 bar at -28 °C). A medium-pressure value chain has limited risk due to its technical maturity, substantial pressure margin to the triple point and limited volumes of transported gas.
A low-pressure transport system (operating at about 7 bara and -49 °C) is foreseen as a possible solution to accommodate the expected increased demand for transportation of CO_2 for CCS purposes. The pressure reduction enables larger ship tank diameter compared to medium-pressure, flexibility in ship cargo hold arrangement and, hence increased cargo capacities with presumably reduced transportation costs. On the other hand, moving towards a lower pressure increases the power demand for liquefaction and narrows the margin to the triple point, increasing risk of dry ice formation. The lower operating temperature may challenge the choice of materials with respect to performance and costs, especially with regards to the containment system.
Several concepts have been developed assuming that low-pressure is feasible, but there is limited, or no practical experience of the technical uncertainties related to a low-pressure value chain. This paper describes the scope and available results of desktop studies and experimental activities deemed necessary to investigate the fundamentals of a low-pressure value chain. It deals with a concept design of a dedicated carrier and containment system (and material for construction), conditioning and liquefaction plant, onshore storage, and loading-offloading operations.

Keywords: "Technology Qualification; Liquid CO2; low pressure; CCS; Shipping of LCO2"

* Corresponding author. Tel.: +47 91572009, *E-mail address:* Gabriele.Notaro@dnv.com

Ingvild Ombudstvedt

CEO/LAWYER

Development of technical standards to support commercialization and further R&D for CCUS

Ingvild Ombudstvedt is the owner and founder of IOM Law. She has been working on legal issues relating to CCS, CCU, CCUS and petroleum since 2012 and has through her work from Arntzen de Besche Law Firm (Oslo office), the Global CCS Institute (Brussels office) and IOM Law gained extensive experience developing and advising on regulatory framework for CCS, CCUS and negative emissions. This includes drafting a legislation proposal for negative emissions.

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

The Research Council of Norway

GASSNOVA


Development of technical standards to support commercialization and further R&D for CCUS

CLIMIT Summit 8-9 February 2023

Ingvild Ombudstvedt, IOM Law

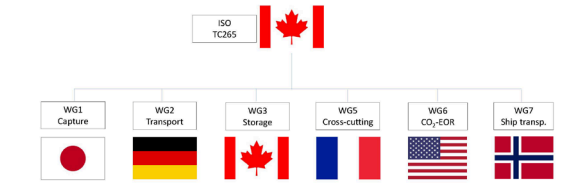
Privately developed standards under the ISO TC265

- Intent: *"prepare International Standards for the design, construction, operation, environmental planning and management, risk management, quantification, monitoring and verification, and related activities in the field of CCS"*

- A wide range of stakeholders and countries involved
  - 24 countries participating
  - 14 observing members
  - 6 working groups (WG)
  - 9 Liaisons (+ liaison ISO committees)

- 12 publications and counting

- Referred to in legal frameworks and regulatory processes
  - Norwegian CO_2 safety regulation guidelines
  - US 45Q
  - Referred to in Danish permitting and tender processes for CO_2 storage



ISO TC265 Carbon Dioxide Capture, Transportation and Geological Storage

TC265 standards support commercialization and R&D

- Technology neutrality
  - No patented rights
  - No explicit descriptions of technology or product
  - Fits both onshore and offshore
- Regulatory neutrality
  - Performance-based rather than descriptive
  - No time periods specified
  - No criteria for reporting
  - No criteria for decommissioning
  - No explicit references to e.g. transfer of liability
- Complements other standards
  - TC265 standards
  - Other ISO standards
  - Specific technical standards from other standardization bodies

Well-suited for, e.g.:

- Contractual frameworks for hubs and clusters, and cross-border collaboration
- Cost reductions
- Filling gaps in frameworks and addressing technical requirements
- Permitting
- Accessing incentives
- Securing funding
- Public acceptance

Acknowledgements

CLIMIT

Ingvild Ombudstvedt
iom@iomlaw.no
+47 468 64 221

Thank you!

Further reading

- ISO/TC 265 website: https://www.iso.org/committee/648607.html
- Ombudstvedt, I. and Jaroy, A.; International standards support commercial deployment of CCS and CO_2-EOR https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3366317
- Ombudstvedt, I. and Nyberget, J.; 10 years of ISO TC 265: Culture, politics, COVID, and progress. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4286145

IOM Law at a glance

- Founded January 2017
- Specialized in CO_2 capture, transport, use and storage, including negative emissions, with extensive experience from oil and gas, international law and climate change policy
- Six team members, based in Son (Norway), Tasmania (Australia) and Copenhagen (Denmark)
- Formal education from Norway, England, Denmark, Belgium, Turkey, Hong Kong, Japan, Australia and the United States






Dr. Rolf Golombek

SENIOR RESEARCHER

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

Developing value chains for CO_2 storage and blue hydrogen in Europe

Rolf Golombek holds a PhD in economics on natural gas markets in Europe from the University of Oslo. He has been with the Frisch Centre, a research centre named after the Norwegian Nobel prize winner in economics, for a number of years. The Frisch centre conducts applied economic research.

The Research Council of Norway

GASSNOVA

Developing value chains for CO_2 storage and blue hydrogen in Europe

- Multi-disciplinary project with economists, political scientists and lawyers
- Frisch centre, OsloMet, NMBU, Fridtjof Nansen Institute and Law at UiO

- Starting point: no commercial market for storage of CO_2

- Classic coordination problem:
- A plant may not be willing to invest in capture facilities before a reliable solution for storage of captured CO_2 exists
- An actor considering investing in storage facilities may not be willing to invest before being confident that there are customers demanding storage services
- Blue hydrogen producer: double coordination problem

The coordination problem – possible outcomes

- Economic theory: 3 alternative outcomes
  - No investment (trivial outcome)
  - Moderate investment
  - High investment (super outcome)

- Model of the CCS market with plants, terminals and one storage actor
- Alternative market structures
- The government can help the market to reach high levels of investment
- To reach the best super outcome, the government needs to support the storage actor
- Integration of terminals and storage actor is helpful on the way towards the super outcome
- Numerical illustration: North-European CCS market if CO_2 price exceeds 70 euro/tCO2

Extensions

- Northern Lights: a game changer?
  - More easy to kick off a European CO_2 market?
  - Are there first-mover advantages? To whom?

- The impact of competition between storage actors
  - Will price of deposit services be driven too much down?
  - Will there be positive learning effects that benefit all parts of the value chain?

- Efficient business models for CO_2 and hydrogen value chains:
  - How should risk be shared between private actors?
  - Is there a role for the government?

Markus Steen

SENIOR RESEARCH SCIENTIST

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

Socio-technical drivers, opportunities and challenges for large-scale CCUS (CaptureX)

Markus Steen works as Senior Research Scientist in the Department of Technology Management, SINTEF Digital. He holds a PhD in economic geography from the Norwegian University of Science and Technology. His research focuses on industrial development and transformation, innovation processes and sustainability transitions, often with attention to both industry dynamics, policy, and market developments.

The Research Council of Norway

GASSNOVA

CLIMIT Summit - CaptureX

February 2023, Larvik

Senior Research Scientist Markus Steen, SINTEF Digital, Dept. of Technology Management | markus.steen@sintef.no

Teknologi for et bedre samfunn

Background

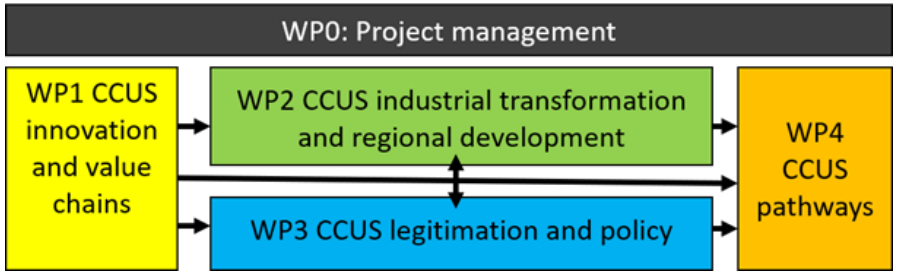
- CCS needed to achieve climate targets
- This need increases as time passes and mitigation is too slow
- CCS has suffered from poor (broadly defined) innovation dynamics

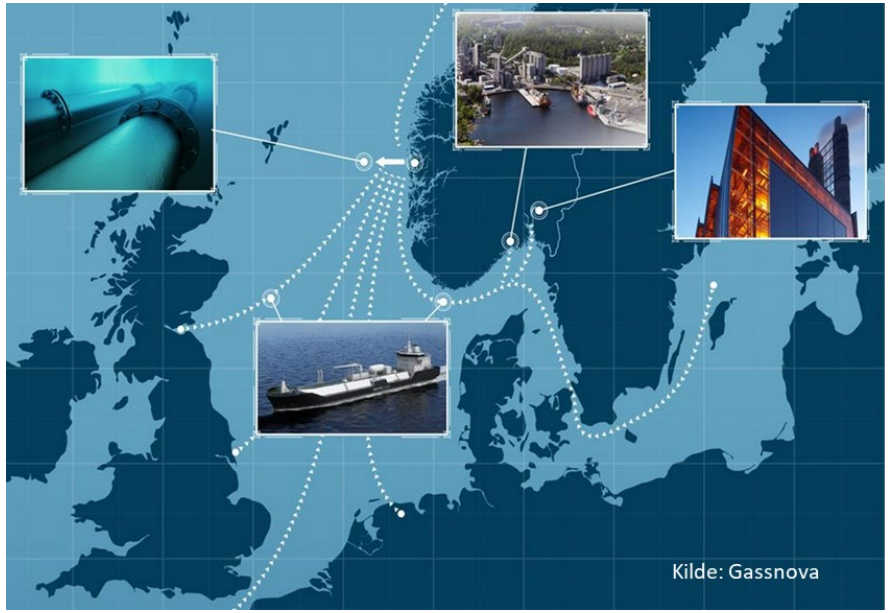
➢ *How to enable large-scale carbon capture and storage?*

CaptureX: a social-science project focusing on…

- Innovation dynamics, across CCUS value chains
- Industrial transformation and regional development
- Legitimation and policy
- CCUS in transition pathways

➢Longship and beyond





Socio-technical drivers, opportunities and challenges for large-scale CCUS (2021-2024)

- **Funding**: Research Council of Norway, CLIMIT programme (research project)
- **Project owner**: SINTEF Digital
- **Project partners**: NTNU, University of Oslo, SINTEF Energy Research, Chalmers University of Technology
- **Project synergies**: CleanExport (RCN CLIMIT), Zero-emission in process industry (Swedish Energy Agency), FME NTRANS (RCN ENERGIX), INTRANSIT (RCN FORINNPOL), VALCCAP (Innovation Fund Denmark)

- 2 post.docs funded by project
- 1 bonus-post.doc at Uppsal/Luleå Uni
- 2 bonus PhDs, one at University of Oslo (INTRANSIT), one at NTNU (FME NTRANS)

- Empirical work well underway
  - Interviews
  - Document analysis
  - Q study of process industry decarbonization Norway (and Sweden)
- CCS innovation system analysis completed
- 4 cases chosen in Norway
- 1 case chosen in UK
- Empirical study of industry and policy strategies for process industry decarbonization in Northern Europe
- Contribute to FME NTRANS user case on CCS and carbon removal

Arvid Nøttveit

CHAIR CLIMIT`S PROGRAMME BOARD

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

Does the nationality of CO_2 matter? Public perceptions of a Northern European market for CO_2 storage (CCSMARKET)

Arvid Nøttveit is a strategic advisor for energy at the Norwegian Research Centre (NORCE) based in Bergen and was CEO of its predecessor Christian Michelsen Research for 14 years. He has been chair of the CLIMIT Programme Board since 2019.

The Research Council of Norway

GASSNOVA

Does the nationality of CO_2 matter? Public perceptions of a Northern European market for CO_2 storage (CCSMARKET)

Arvid Nøttveit,

NORCE

Åsta Dyrnes Nordø

Senior Researcher, Norce

Endre Tvinnereim

Associate Professor, UiB

Gisle Andersen

Senior Researcher, Norce

Christine Merk

Senior Researcher, IFW Kiel

Import/export of CO_2 matters to citizens' attitudes on CCS!

Previous project:

- Researched in Norway and Germany in previous CLIMIT-project
- Common description of CCS + variation in source country and which country is to store it.
  - CO2 source country (source)
  - CO2 storage country (storage)

Main findings:

- Support of CCS depends on how the value chain is presented in Norway, but not in Germany.
- Substantially less support for a project where CO2 from own country is stored domestically than if CO2 is imported from abroad to store.
- Motivation → CCSMARKET

Published in Energy Research & Social Science: *Don't send us your waste gases: Public attitudes toward international carbon dioxide transportation and storage in Europe.*
https://doi.org/10.1016/j.erss.2021.102450

Share of respondents that evaluated the project *somewhat positive* or *very positive*

Germany (N=2500)

source → / *storage*	not spec.	EU	NOR	domestic
not spec.	53%	54%	48%	51%
EU	45%	49%	48%	51%
NOR†				
domestic	57%	50%	51%	54%

Norway (N=2665)

source → / *storage*	not spec.	EU	GER†	domestic
not spec.	77%	73%		64%
EU	67%	70%		56%
GER	68%	68%		42%
domestic	76%	70%		81%

†not part of the experimental design

lowest share of positive answers
higest share of positive answers

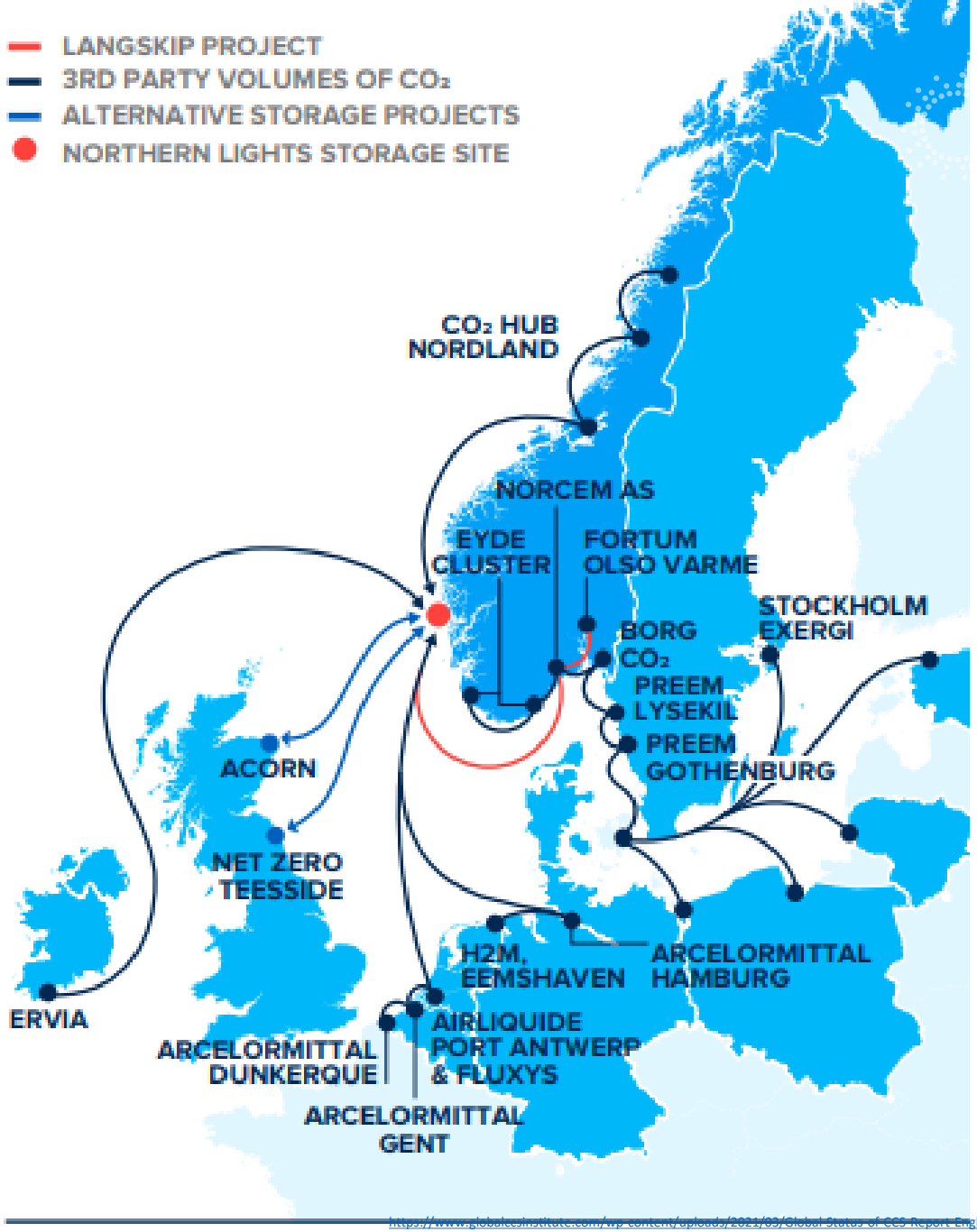
CCSMARKET

Empirical focus:

- Five countries: UK, the Netherlands, Denmark, Germany and Norway.
- Countries selected based on their role as importer/exporter in a Northern European market for CO2 storage:
  - Norway and England: will import CO2 and store themselves
  - The Netherlands and Denmark: will export some CO2 but also store themselves
  - Germany: will only export

Aim of project:

- New knowledge about how transport and storage of CO2 across countries affects citizens' opinions about CCS.
- Better understand the mechanisms behind patterns of support and opposition.



https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Global-Status-of-CCS-Report-English.pdf

FIGURE 8 NORTHERN LIGHTS PROJECT – POTENTIAL SOURCES OF CO_2[h]