Presentations 9 February – Technical session – Transport&Value chain

- Ben Alcock, SINTEF
- Julian Straus, SINTEF
- Frank Wettland, Altera Infrastructure
- Bente Helen Leinum, DNV

Ben Alcock

SENIOR RESEARCHER

CLIMIT SUMMIT

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7–9 February

CO_2 EPOC: The effect of CO_2 on polymer materials used in the CO_2 transport network

Ben Alcock is a Senior Researcher at SINTEF Industry, based in the group Polymer and Composite Materials. Ben received his PhD in 2004 from Queen Mary, University of London, UK, in the area of thermoplastic composite materials. He has worked in R&D in both academia in UK and Netherlands, and in industry in UK and Switzerland.

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CO_2 EPOC: The effect of CO_2 on polymer materials used in the CO_2 transport network

Ben Alcock
SINTEF Industry

2020-2025

Funded by
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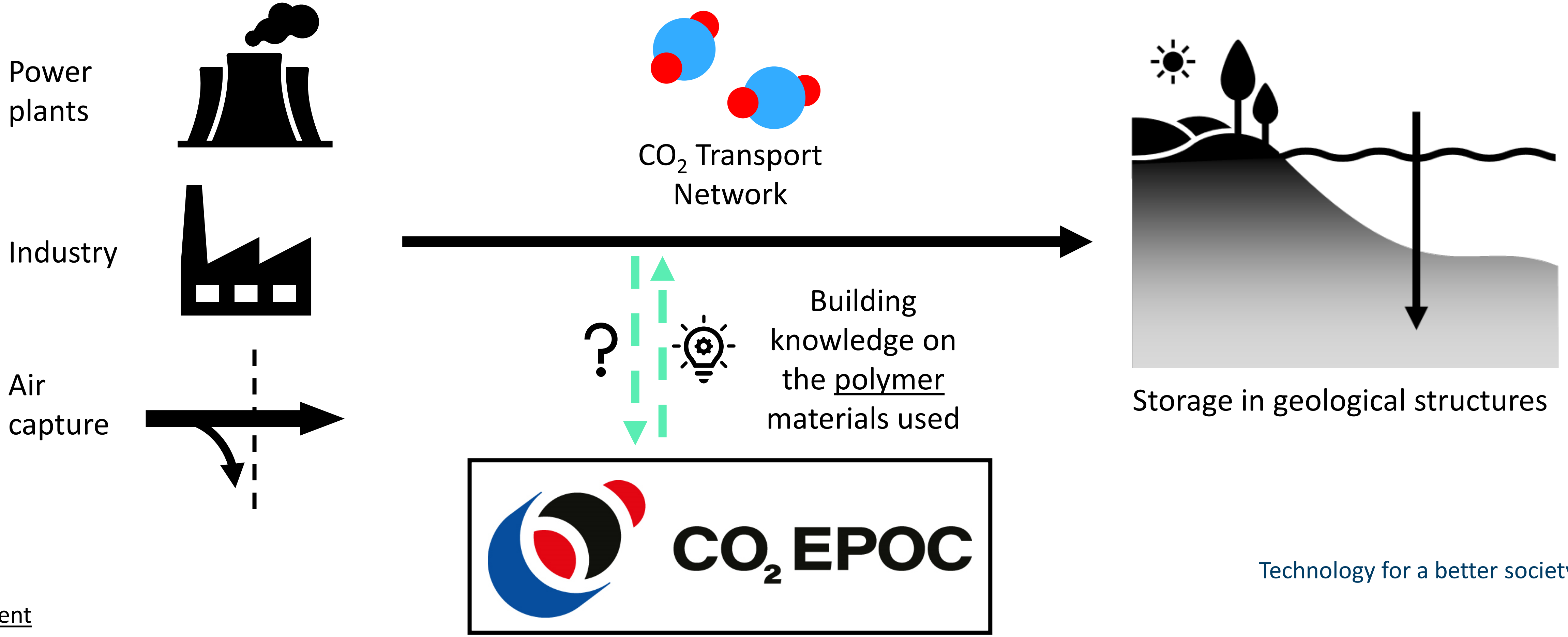
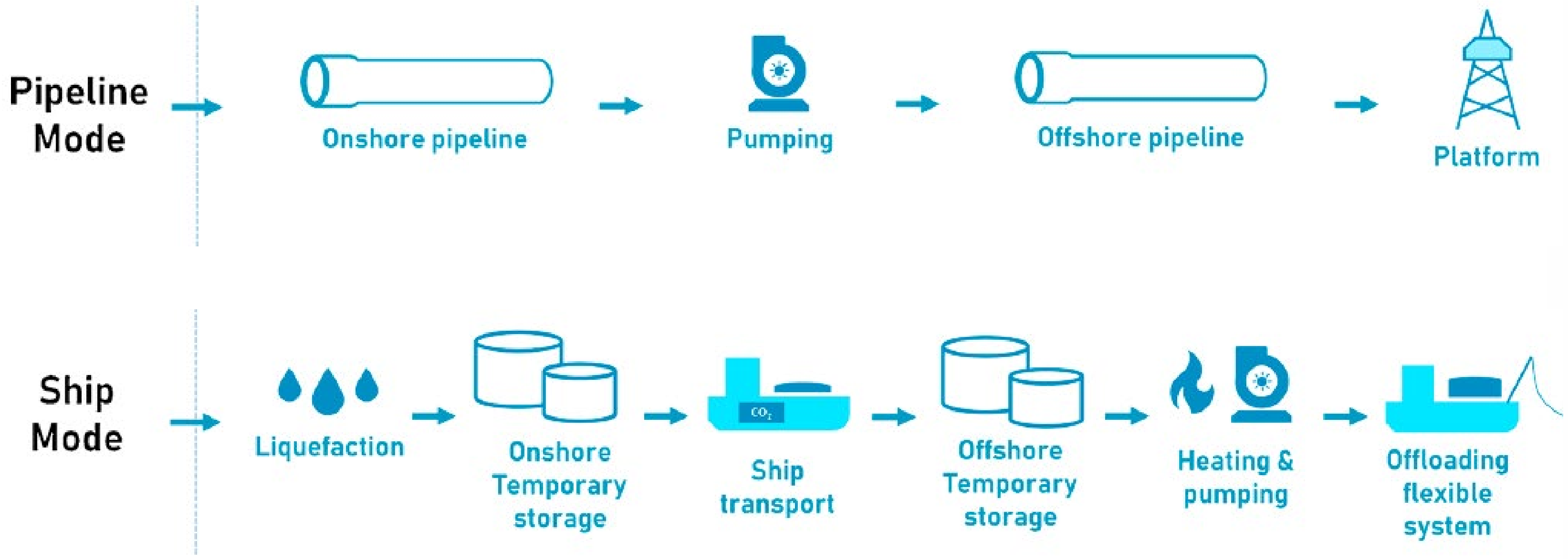
How does CO2 EPOC contribute to Longship?

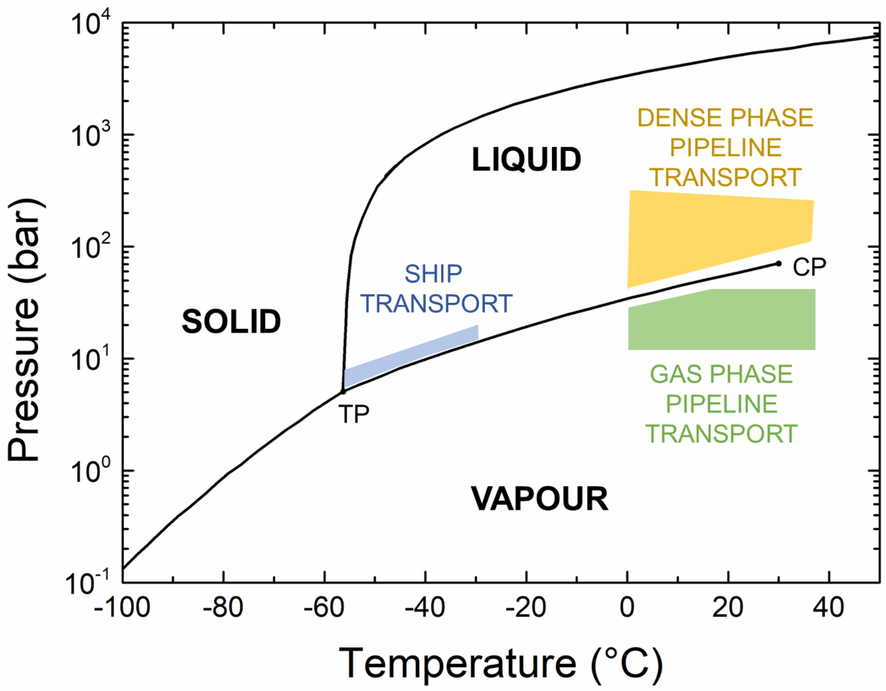
CO_2 EPOC

Carbon capture and storage is an essential part of the strategy to reduce global emissions



How can we transport CO_2 from capture to storage?





- Transport is usually more economical when density is higher
- State of CO_2 depends on temperature and pressure
- Any leakage during transport undermines the efforts of CO_2 capture

https://doi.org/10.1016/j.ijggc.2019.102930

Examples of uses of polymers in gas/liquid transport?

Elastomers

- O-rings, Seals
- Gaskets

Thermoplastics

- Thermoplastic liners for metallic pipes, storage vessels
- Pump coatings
- Valve seat components

Hard Thermosets

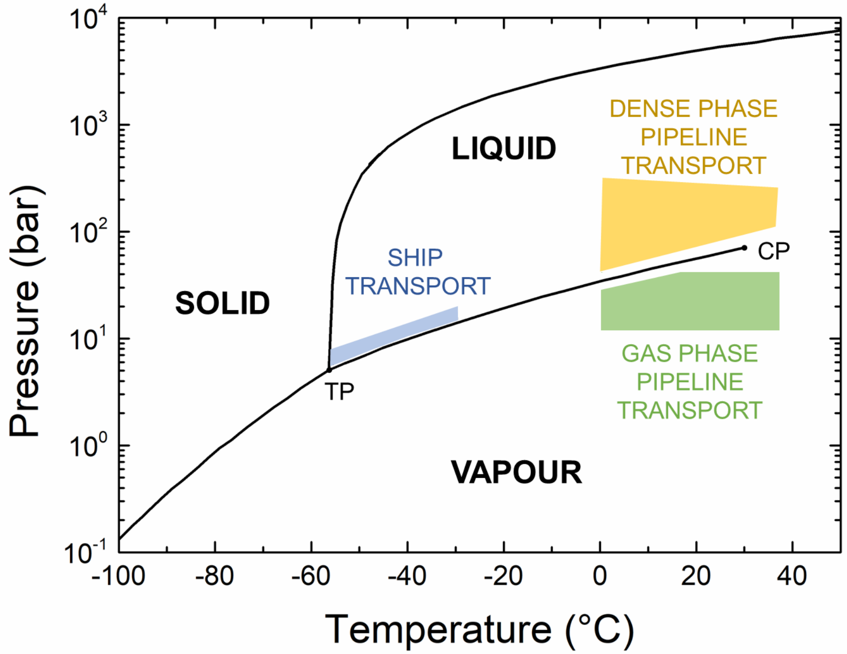
- Epoxy liners for metallic pipes
- Matrices for fibre reinforced composites (e.g. pipes, pressure vessels)

For CO_2 transport: Advantageous to use polymer materials which are already used in oil and gas transport

↓

Enables reuse of existing infrastructure

Example: elastomers used in seals in the CO_2 transport

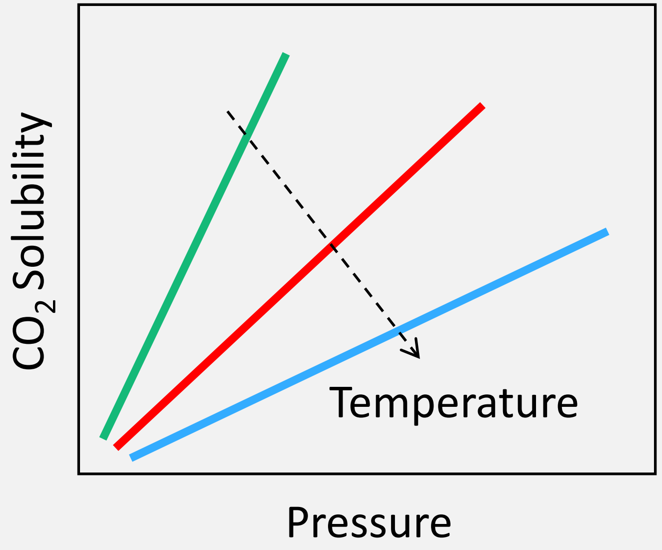


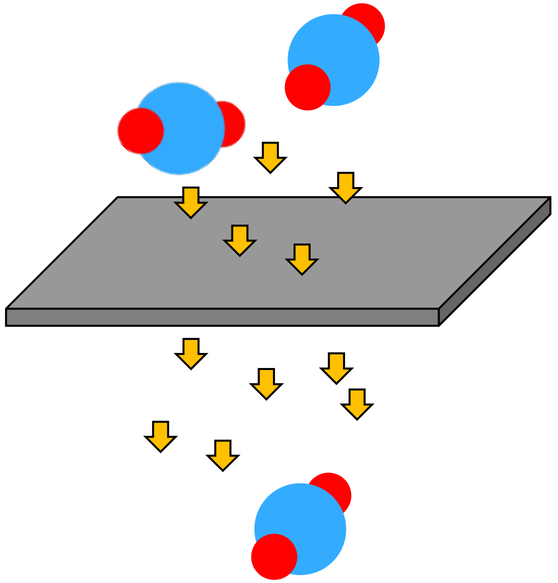
- A simple o-ring, used as a primary barrier to leakage loss of CO_2
- A small but essential component to prevent leakage
- May be exposed to static and cyclic pressurizations

Examples of how CO_2 can affect an elastomer

- CO_2 will diffuse through polymers
  - Elastomers are not perfect barriers
  - Barrier properties are temperature and pressure dependent

Measuring transport properties of CO_2 in polymers and building predictive models

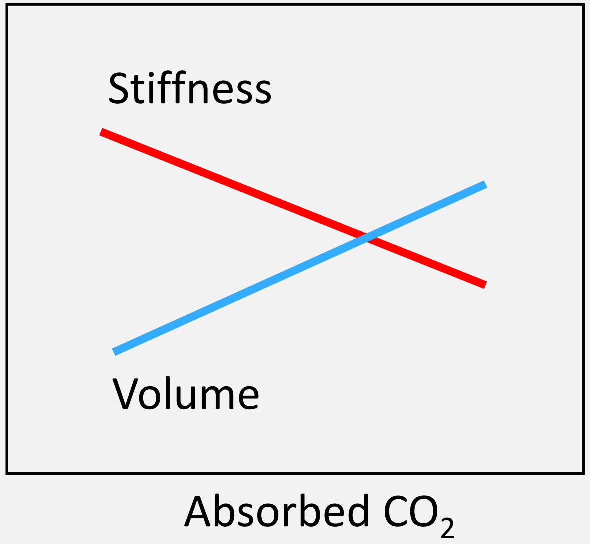


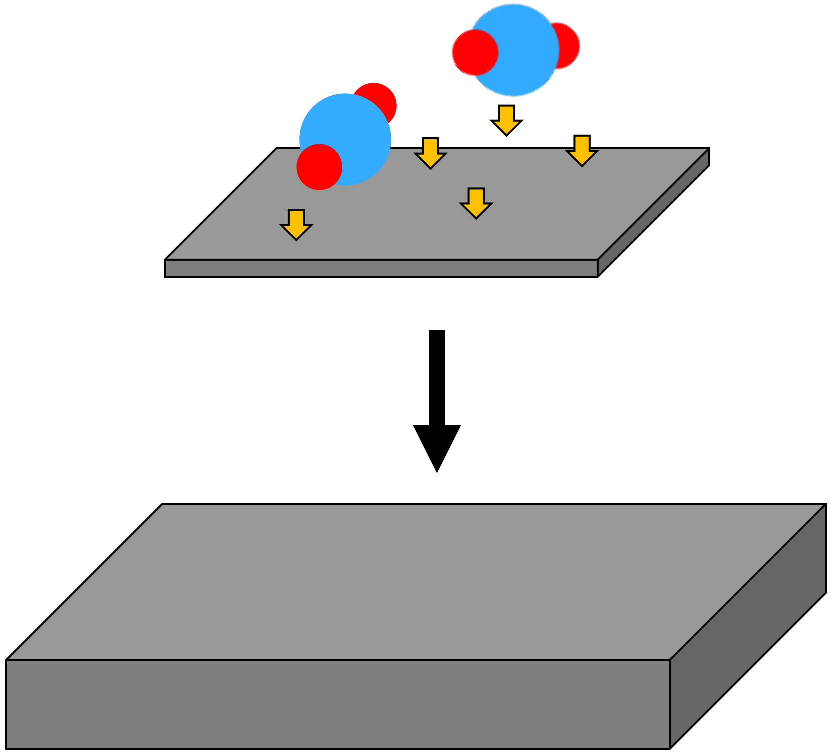


Examples of how CO_2 can affect an elastomer

- CO_2 is soluble in many polymers: elastomers can swell
  - Volumetric expansion
  - Reduction in stiffness

Understanding the effects of CO_2 on mechanical and physical properties



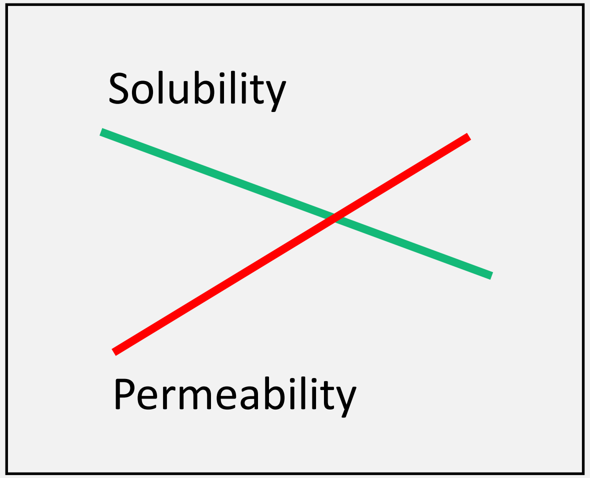


Examples of how CO_2 can affect an elastomer

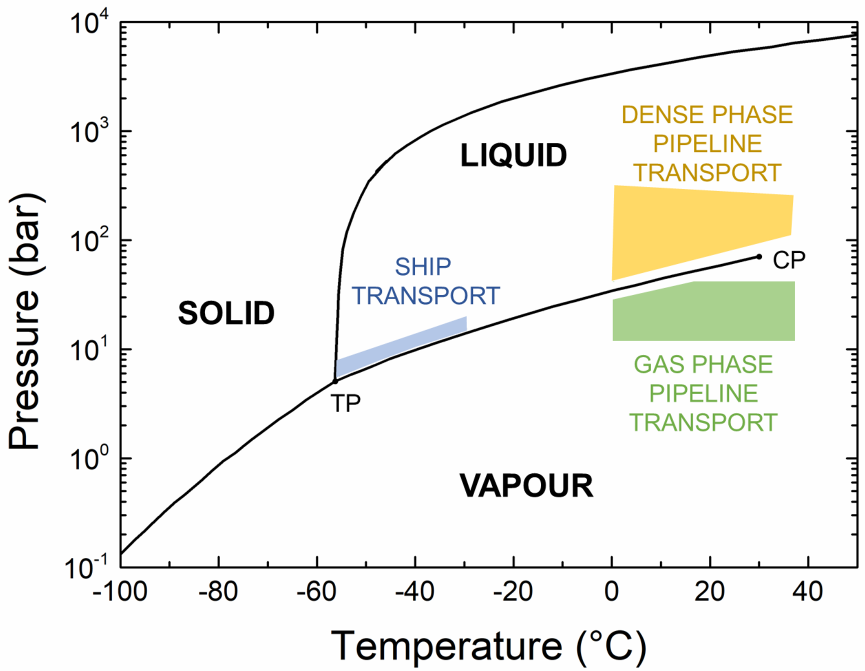
- Ship transport of CO_2 involves low temperatures
  - Temperatures in some ship transport scenarios are too low for elastomers typically used in oil and gas transport

CO₂EPOC

Understanding combined effect of absorbed CO_2 and low temperature

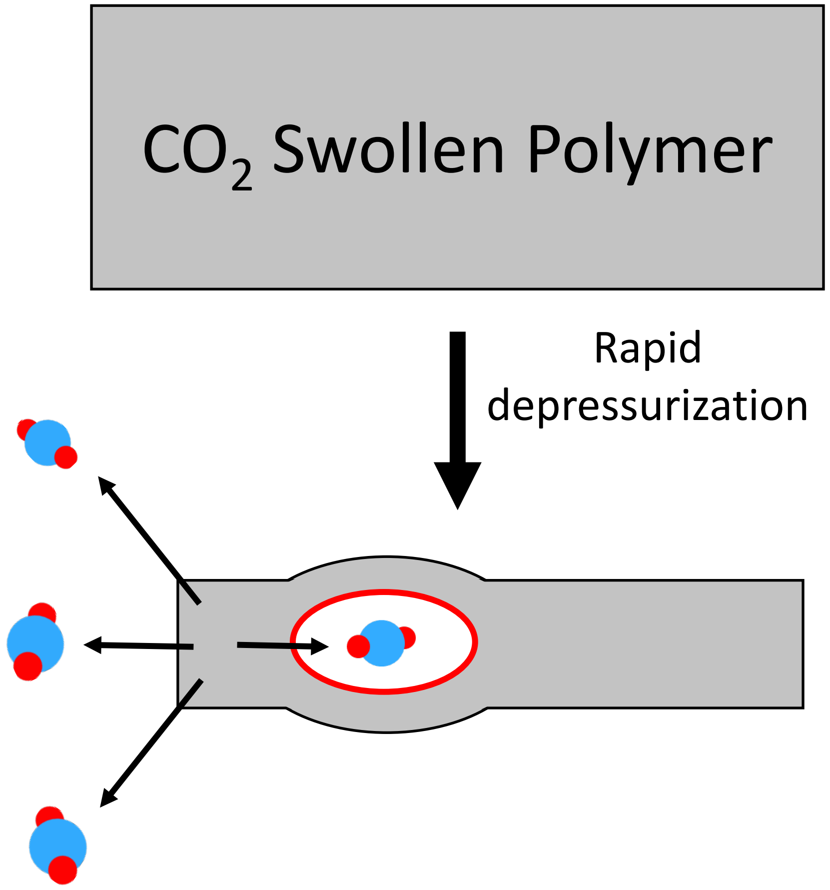


Temperature



Examples of how CO_2 can affect an elastomer?

- Dissolved CO_2 can lead to rapid decompression damage
  - Blister, tear formation
  - Catastrophic seal failure



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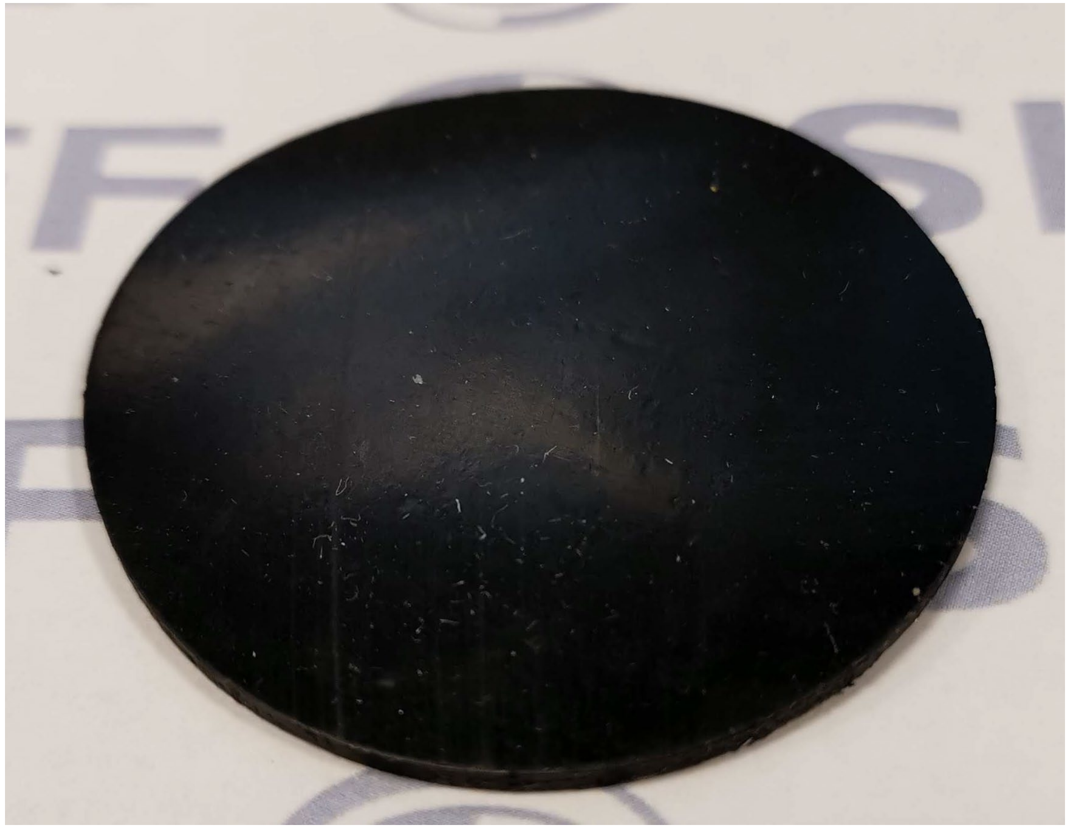
Blistering of elastomers exposed to CO_2



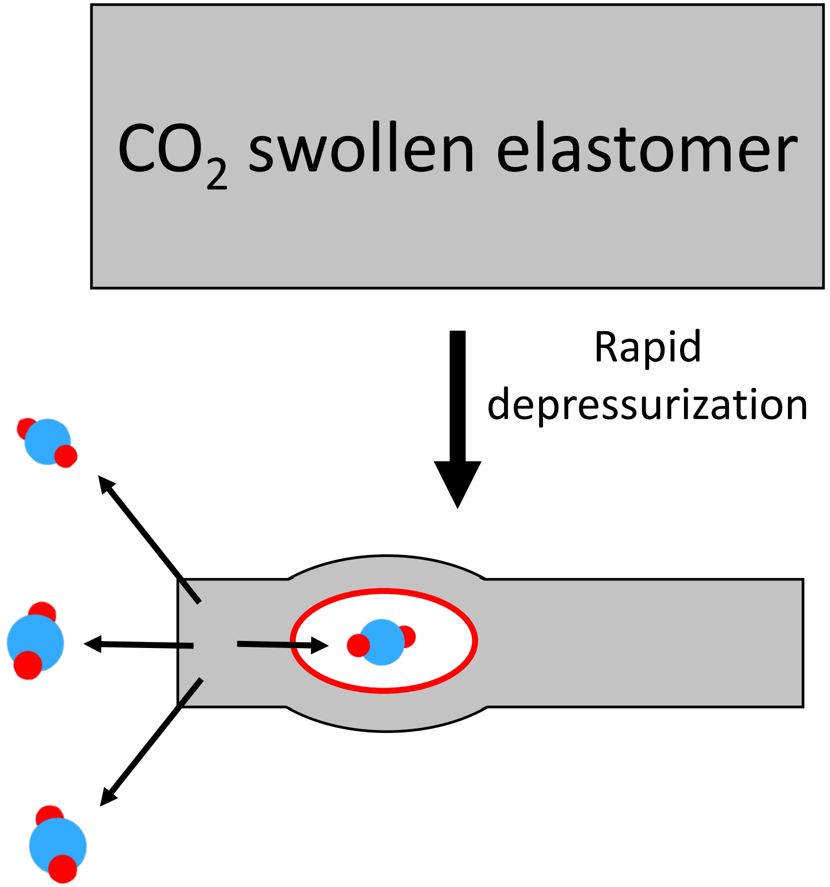
Examples of how CO_2 can affect an elastomer?

- Dissolved CO_2 can lead to rapid decompression damage
  - Blister, tear formation
  - Catastrophic seal failure

CO2 EPOC

How does RGD damage evolve after exposure to CO_2?

Understanding the effect of material formulation on CO_2 RGD resistance



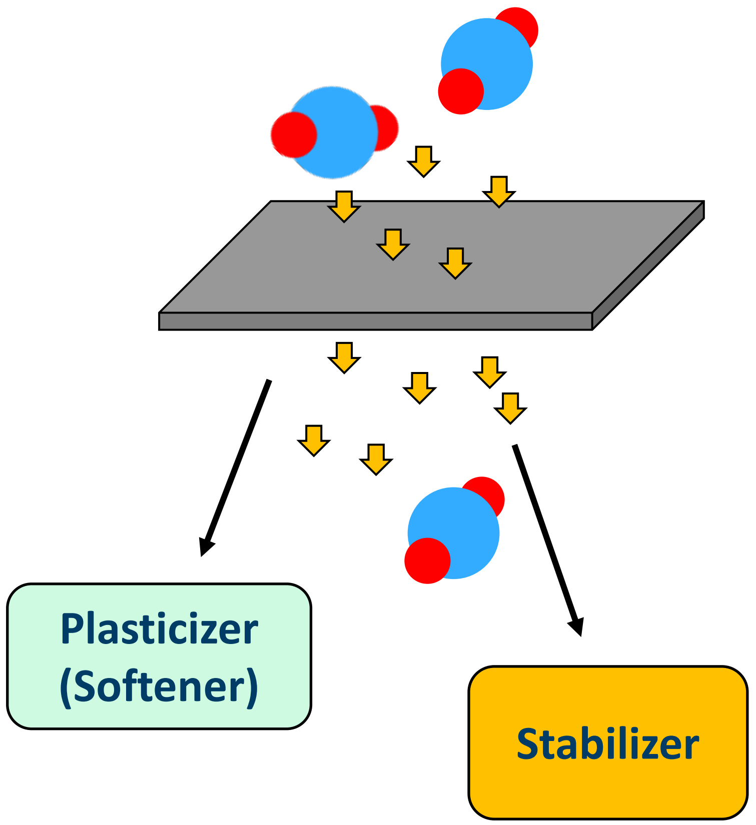
Examples of how CO_2 can affect an elastomer?

- CO_2 may extract non-bound additives from elastomers
  - Removal of functional additives
  - Change in properties
  - Reduction in lifetime/premature failure

CO2 EPOC

How can CO_2 exposure change material formulation? How does this change affect performance?

→ Identifying the long term effects of CO_2 exposure



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CO2EPOC

CO_2 may not be 100% pure

Examples of highest level of impurities contained in captured CO_2 emissions from different sites (Neele et al., 2017).

Source Type	Coal-fired power plant				Natural gas processing	Synthetic gas processing
Capture technology	Amine-based absorption	Ammonia-based absorption	Selexol-based absorption	Oxyfuel combustion	Amine-based absorption	Rectisol-based absorption
Gaseous stream concentration [a]						
CO_2	99.8 %	99.8 %	98.2 %	95.3 %	95.0 %	96.7 %
N_2	2000	2000	6000	2.5 %	5000	30
O_2	200	200	1	1.6 %	–	5
Ar	100	100	500	6000	–	–
NO_x	50	50	–	100	–	–
SO_x	10	10	–	100	–	–
CO	10	10	400	50	–	1000
H_2S	–	–	100	–	200	9000
H_2	–	–	1.0 %	–	–	500
CH_4	–	–	1000	–	4.0 %	7000
C_2+	–	–	–	–	5000	1.5 %
NH_3	1	100	–	–	–	–
Amine	1	–	–	–	–	–

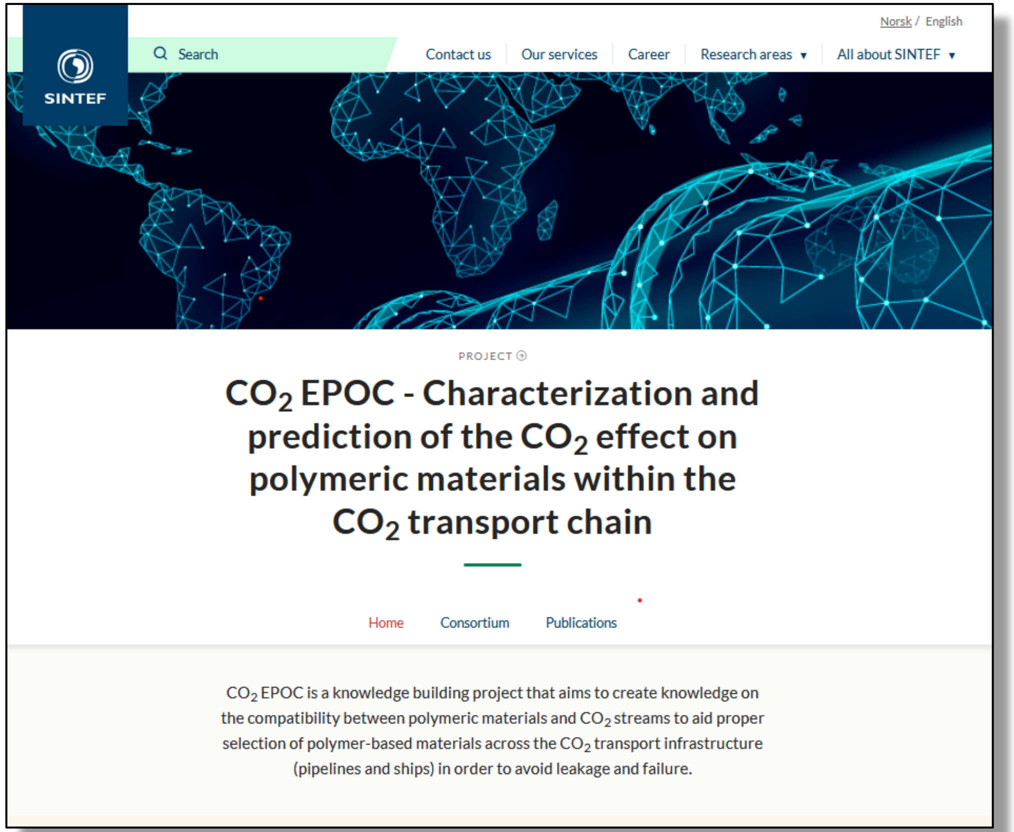
[a] the values are reported in mol% (where indicated) or in ppmv. Water content not included. Desulphurisation included.

Source: doi.org/10.1016/j.ijggc.2019.102930, based on doi:10.1016/j.egypro.2017.03.1789

Summary

- CO_2 transport creates some challenging conditions for polymer materials
- Reuse of existing O&G infrastructure for CO_2 transport has economic advantages
- Polymers which perform best in some O&G applications may not be the best in CO_2 transport applications

- The CO2 EPOC project aims to:
  - identify which polymers are most suitable for use in CO_2 transport chains, starting from current industrial practice
  - achieve experimental characterization of these polymers covering the operational windows required by the different transport modes
  - develop models to describe polymer performance in the operating conditions of interest
  - provide a reliable prediction of the short- and long-term effects of impure CO_2 on polymeric materials



https://www.sintef.no/en/projects/2020/co2-epoc/

CO2 EPOC Research Team

SINTEF

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Technology for a better society

Julian Straus

RESEARCH SCIENTIST

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Energy export and CO_2 infrastructure development – CleanExport

M.Sc. in Chemical and Bioengineering in 2013 from ETH Zurich (awarded with *Willy-Studer Award* for highest GPA, financed through a scholarship of the *Excellence Scholarship and Opportunity Program* of ETH)
Ph.D. in Chemical process control in 2018 from NTNU
Working in SINTEF Energy Research as research scientist since 2018

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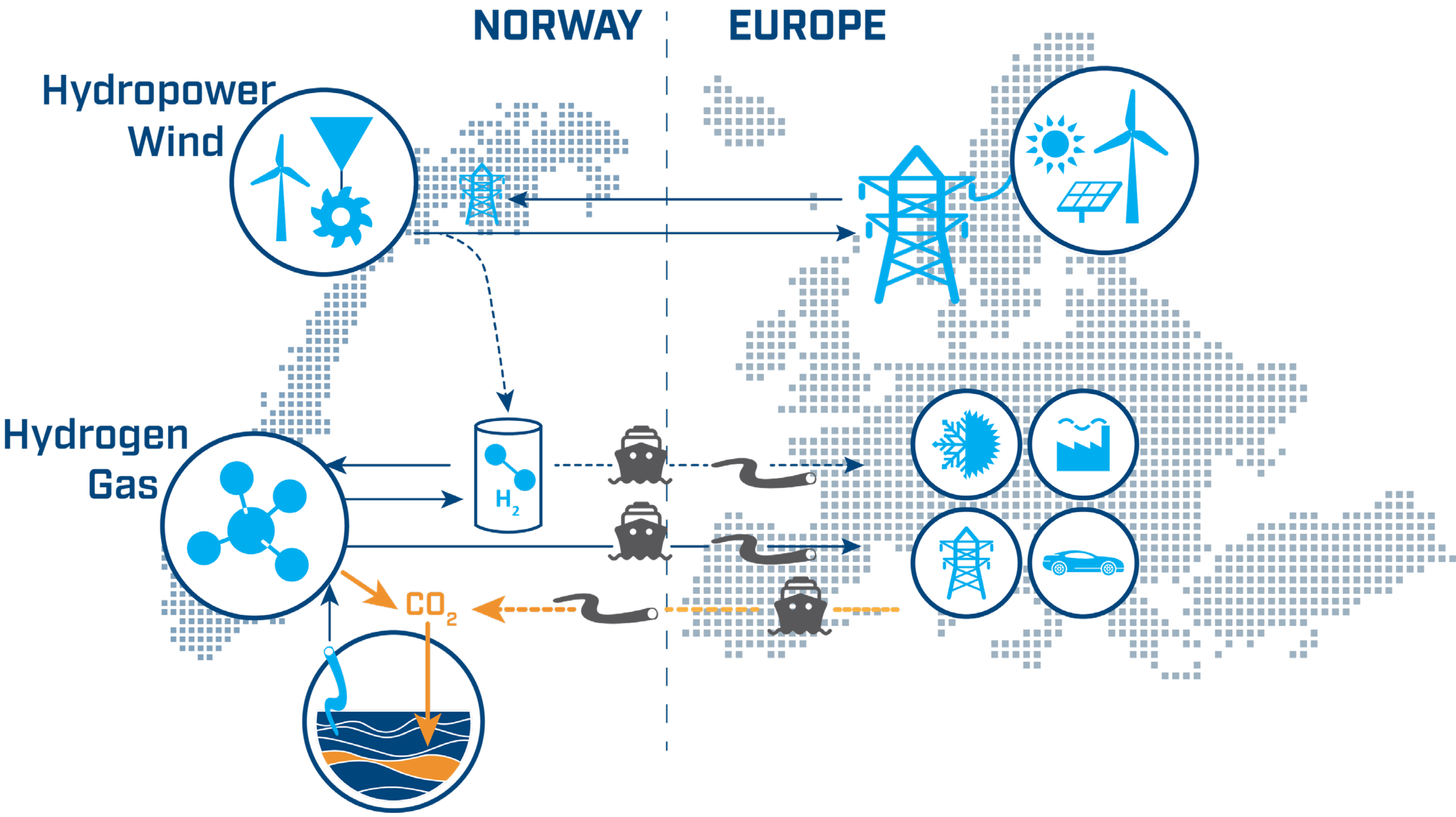
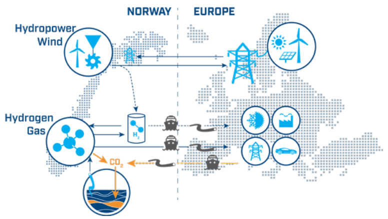


Energy export and CO_2 infrastructure development – CleanExport

Julian Straus – Project manager



The CleanExport project rational

The energy transition needs to happen fast

- Norway needs to prepare and take measures for a **rapidly** changing European energy demand

Decarbonization **and** economic valorization of the energy resources

- Norway's energy resources and infrastructure enable for supporting Europe with **clean** and **secure** energy

How, under which prerequisites, and measured by which KPIs?

> Energy system model-based approach for analysing energy export options in a holistic manner to avoid unconscious bias in analysis

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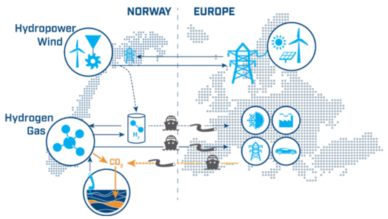
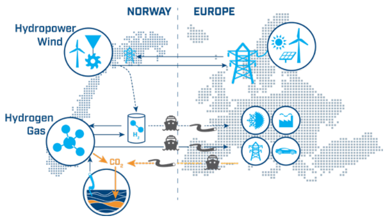


Who is involved in the project?

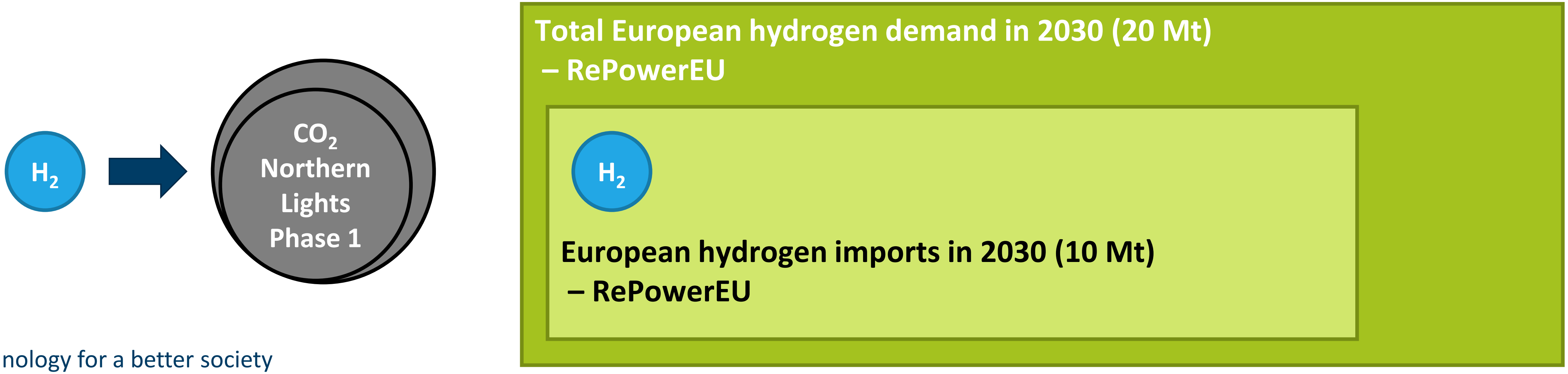
- Industrial partners
  - Electric power industry
  - Oil and gas industry
  - Industrial gas production industry
- Research partners
  - 1 PhD student (industrial economics) and 1 PostDoc (process control)
  - 3 departments of SINTEF focusing on CCS chains, hydrogen production, and energy system modelling
- The Research Council of Norway

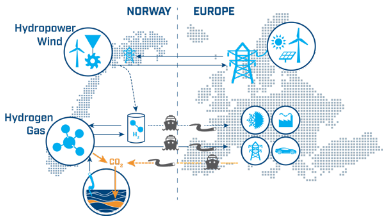
How will CleanExport help CCS?



- Clean energy exports entail two CCS options:
  - Natural gas reforming with CCS in Norway
  - Import of CO_2 from industrial sites in Europe for storage in Norway

- Development of clean energy export can kick-start increased CCS usage due to large volumes of CO_2, *e.g.*, through natural gas reforming with CCS:





How will CleanExport help CCS?

- Model based analysis of CO_2 infrastructure development in conjunction with:
  - Required energy demand (and development of infrastructure for supplying the required electricity)
  - Export infrastructure development (hydrogen pipelines, power transmission lines, etc.)
- Different case studies and corresponding scenarios

➢ Identifying of potential cost-optimal CO_2 transport networks on the Norwegian Continental Shelf

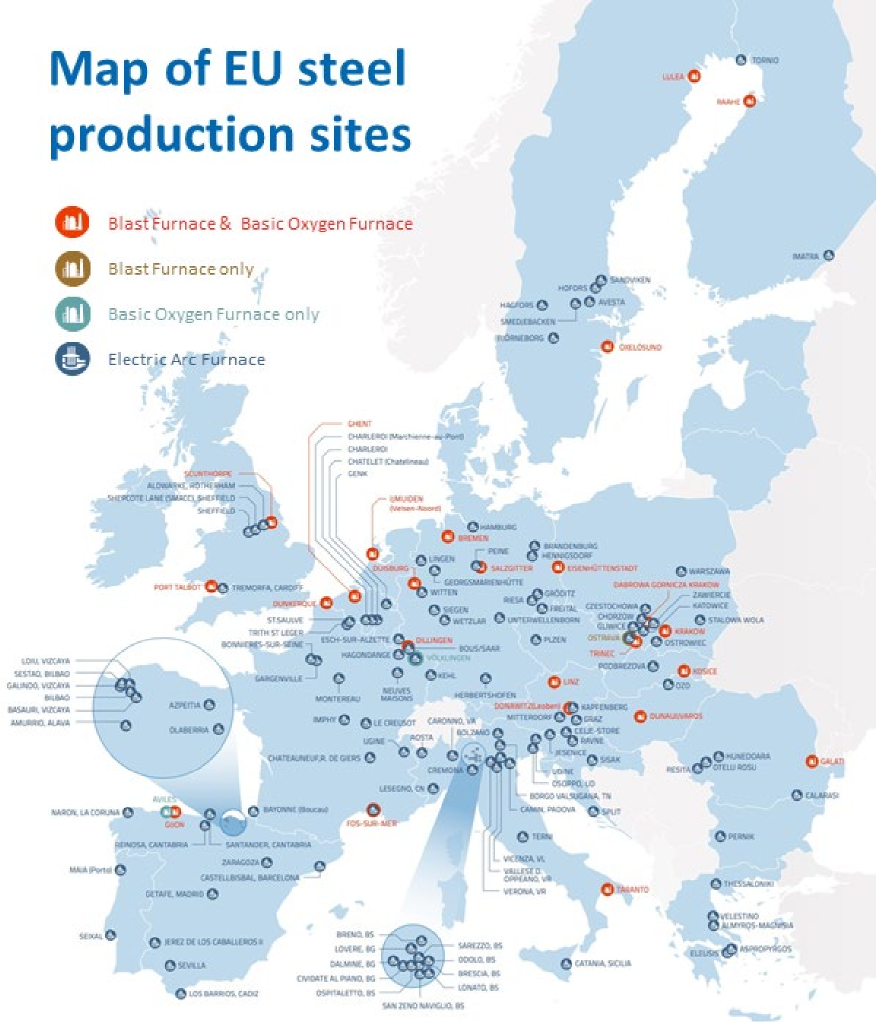
➢ Avoiding problems related to lack of available energy for CO_2 transport networks

Assessment of CCS infrastructure both for domestic CO_2 and imported CO_2

Example case study (ongoing work): Decarbonising the European steel sector

- Production of iron and steel responsible for **7 % of the emissions** from the energy system
- Large **production in Europe** and specifically in regions close to the **North Sea**
- **Hydrogen**, **Electricity**, and **CCS** relevant for the **decarbonization** of the steel sector

Eurofer.eu



Norway's resources are relevant for all technologies.
How can Norway contribute?

Thank you!

Technology for a better society

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Technology for a better society

Frank Wettland

PROJECT MANAGER

Stella Maris CCS – A large scale maritime solution

M.Sc from the Norwegian Technical University (NTNU) 1983.
Experience from E&P Company, Engineering, Consulting, Brownfield operations and modifications, New-build FPSO projects. Engaged within CCS from 2019 with the Stella Maris CCS project, Altera Infrastructure.

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Stella Maris CCS

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C
- Technical aspects squeezed

O
- VOLUME of CO_2

S
- Large Scale

T
- Stella Maris CCS

Stella Maris CCS

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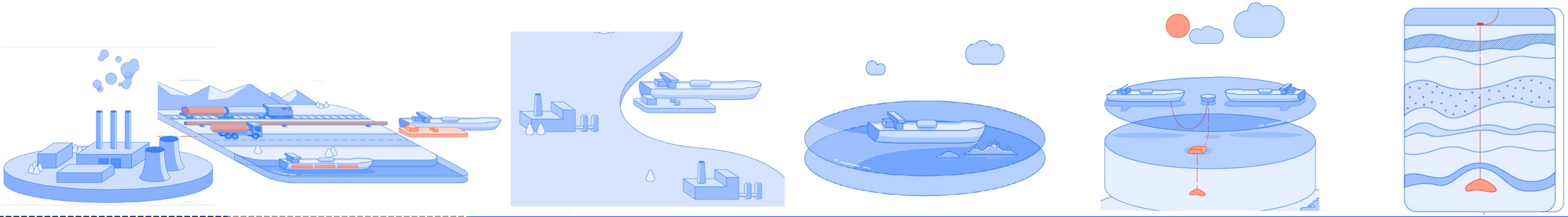
Infrastructure design capacity 10 mtpa



Capturing Technology
In cooperation with and specific per emitter

Transport CO_2 from Emitter to CO_2T
In cooperation with emitter (pipeline, truck, rail, barge, etc)

Collection

CO_2 Terminal (CO_2T)

Transportation

CO_2-shuttle carriers

Injection of CO_2

Floating Injection Unit

Offshore Storage Reservoir

Havstjerne Application

Emitter capture, liquify and store in own CO_2 tanks
Stella Marris can collect CO_2 and transport to CO_2T or directly to injection location

Havstjerne Partnership

One Stop Shop

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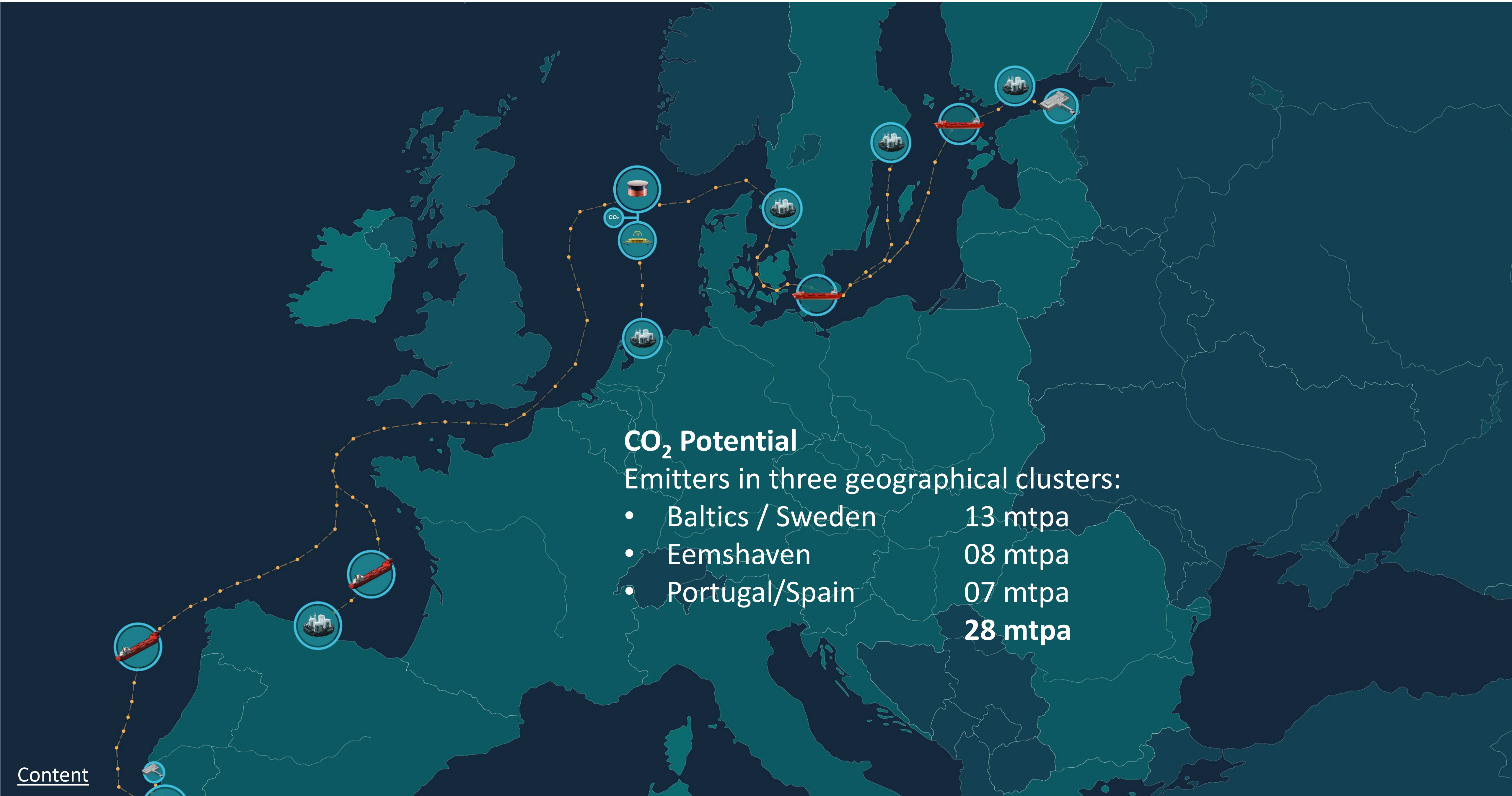

CO_2 Potential

Emitters in three geographical clusters:

• Baltics / Sweden	13 mtpa
• Eemshaven	08 mtpa
• Portugal/Spain	07 mtpa
	28 mtpa

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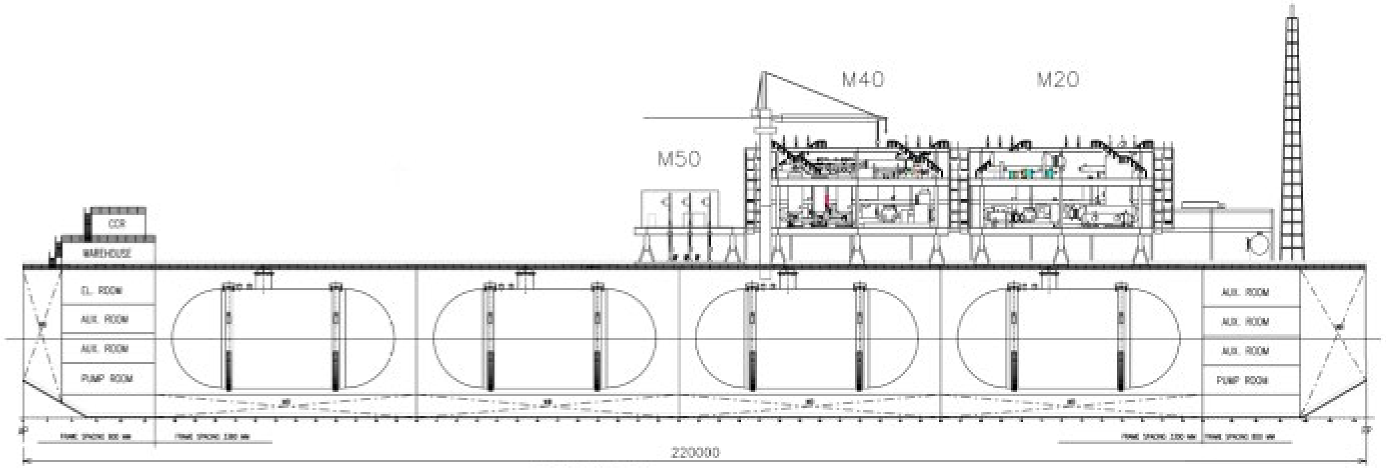
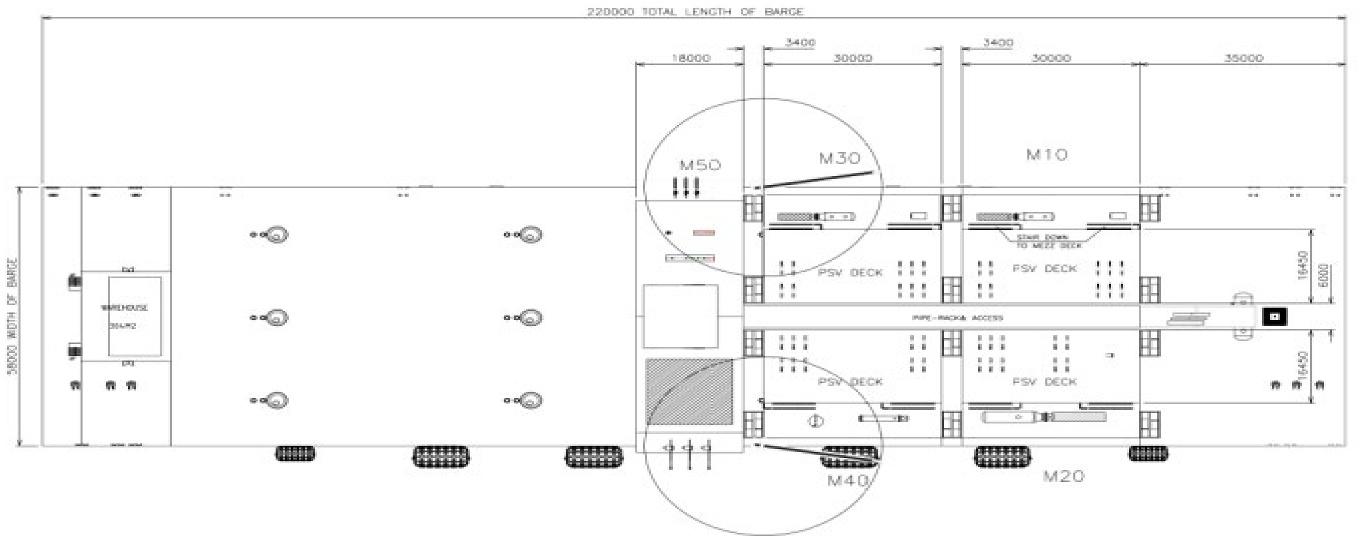
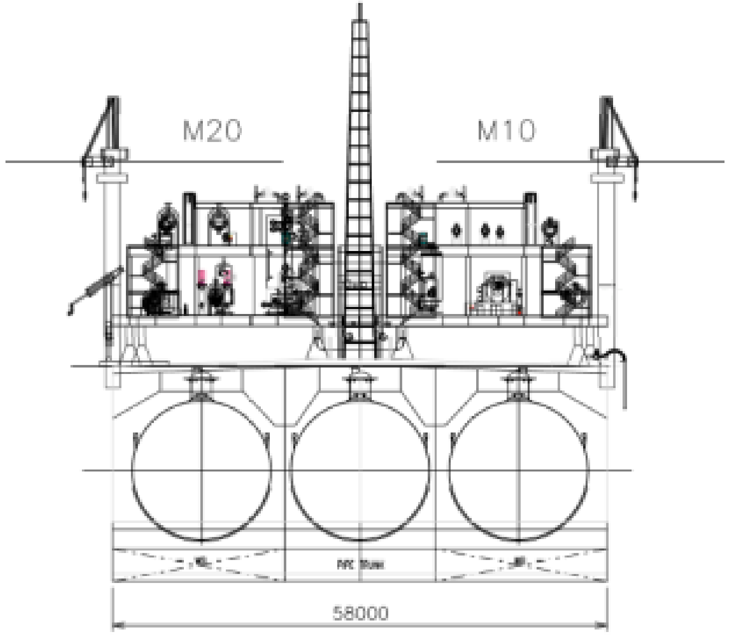
CO_2 Collection, Processing, Storage and Offloading Terminal (CO_2T)



SIDE VIEW
LOOKING STARBORD





END VIEW
LOOKING AFT

PRINCIPAL DIMENSIONS :

LENGTH O.A.	app. 219.80m
BREATH(MOULDED)	57.80m
DEPTH (MOULDED)	24.30m
DESIGN DRAFT	~13.00m
CARGO CAPACITY TOTAL	80,000 m3

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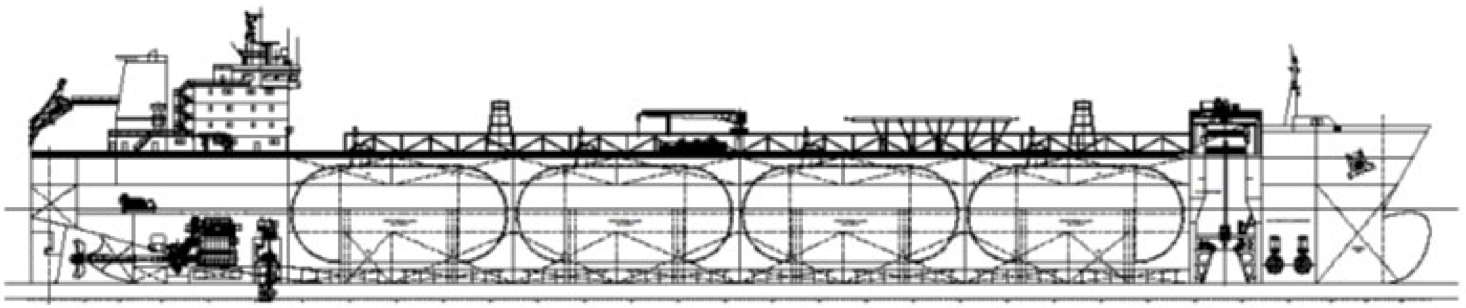
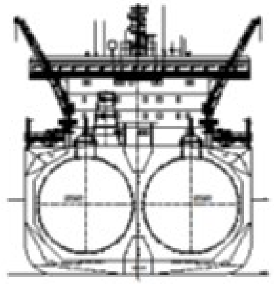
CO_2 Shuttle Carriers





Principal dimensions:

Length o.a:	238m
Breadth (M):	38m
Depth (M):	22m
Design draft:	13m
Cargo cap:	50k cbm

- New, state of the art CO_2 shuttle carrier design
- 50,000 cbm - low pressure tanks
- CO_2 stored and transported as liquid at 6,5 barg & -47°C
- Zero emission capable
- Electric Power distribution
- Battery hybrid installation
- LNG/Bio gas/NH_3 as fuel

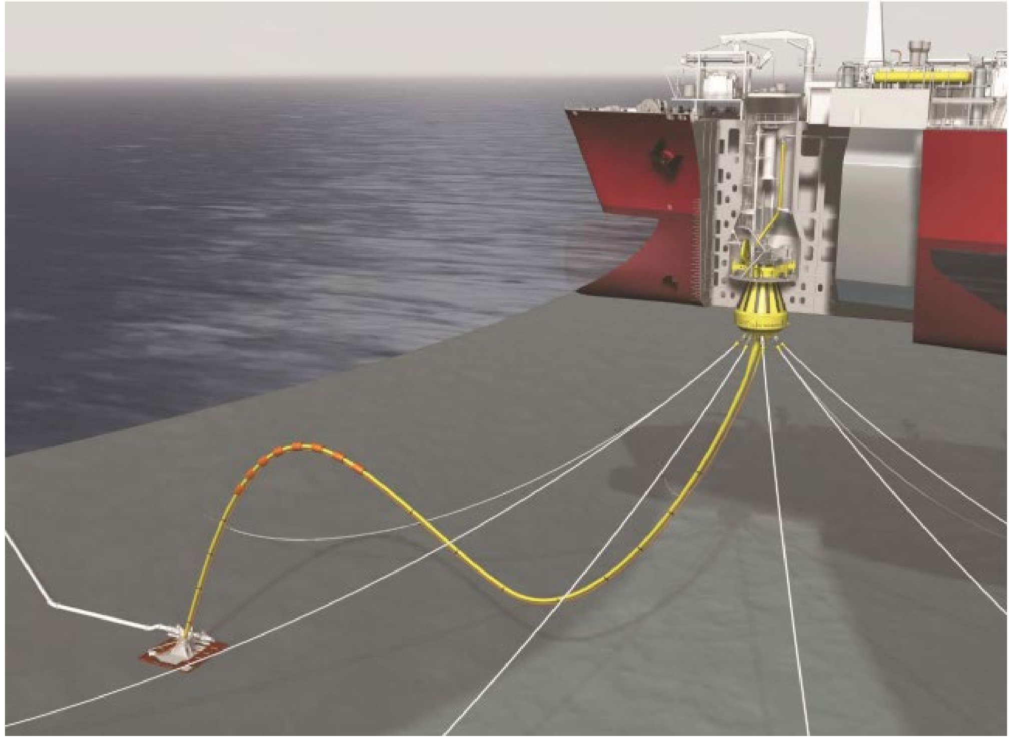
Optional:

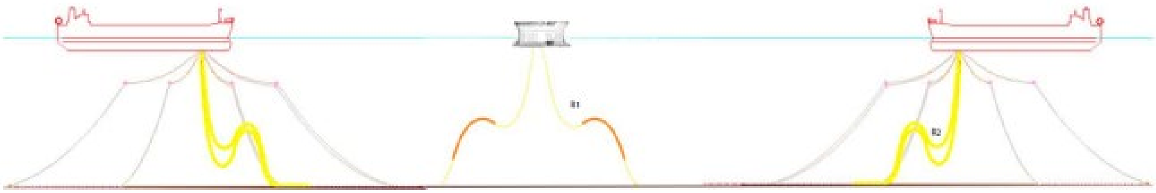
- Size to meet needs
- Direct injection capability

Key Innovations

- Low pressure CO_2 tanks
- Dynamically positioned CO_2 carrier
- Equipment for offshore un-loading of CO_2
- Power Source for injection unit

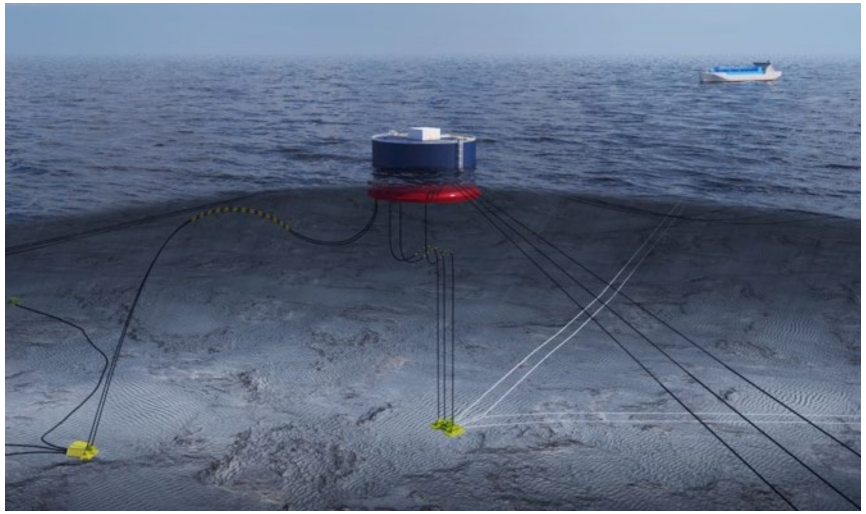
Offshore offloading

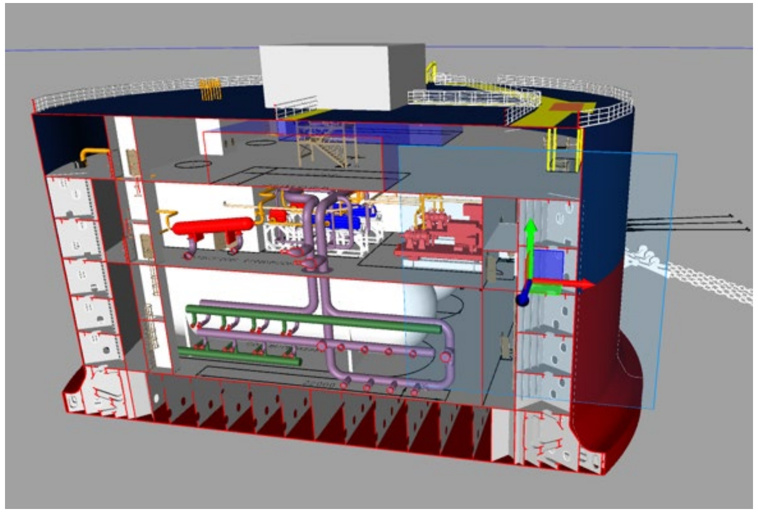




- Continious injection is ensured by always having one shuttle carrier at site
- 2nd shuttle connects and takes over before the 1st one leaves
- A Submerged Turret Loading (STL) system is used with two independent STL buoys
- Dry connection
- Electrical power cable in addition to the CO_2 offloading hose

Floating Injection Unit (FIU)





Principal dimensions:

Hull Diameter 50m	
Bilge Box diameter:	62m
Main Deck diameter	50m
Hull Depth:	22m
Design draft:	13m
Draft loaded	14m

Stella Maris CCS

- Allows continuous injection
- Heating and injection modules below deck
- Power from Shuttle carrier (+ battery back-up)
- Unmanned and operations from shore, communication via shuttle carrier
- CO2 heated and injected into reservoir in dense phase (>5°C & 65 -160 barg)

Alternatives:

- Injection facilities on an existing offshore installation or on new fixed offshore structure
- Direct injection from shuttle carrier

Key Innovations

- Power from CO_2 Shuttle Carrier
- Normally Unmanned
- Equipment for offshore loading of CO_2
- Zero emission capable

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Stella Maris CCS – one of the keys to “the tool box” to meet climate targets

Status and way forward

2021

- Concept selection
- Reservoir evaluation & identification
- Marketing and business development start-up

2022

- Establish partnership, joint organization
- Prepare & apply for exploration license

2023

- Secure offshore exploitation license
- MOUs & “firm” agreements with emitters
- Start FEED
- Funding

2024

Final yard orders

- FID
- CCSO
- CO2 Shuttle
- Offshore Injection Unit

Planning & start drilling wells

2025

Project execution

2027

Commissioning

Start operation

Stella Maris

The one-stop-shop provider of a cost-efficient CO_2 solution from collection to storage

Bente Helen Leinum

SENIOR PRINCIPAL ENGINEER,
PIPELINE OPERATIONS TECHNOLOGY

Design and Operation of Carbon Dioxide Pipelines – Key topics to be addressed

Bente has extensive experience within the field of failure analyses, materials technology and troubleshooting, project management and project sponsor role. Experience from general industry, process industry and oil and gas industry, research and development. The activities have been including project management & participation, RBI-analyses, pipeline integrity management (PIM) projects, verification projects, fabrication control, contact with authorities, hands on experience through field inspection, laboratory work and experiments.

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WHEN TRUST MATTERS

CLIMIT Summit 2023

Design & Operation of CO_2 pipelines – Key topics

9 February 2023

Bente Helen Leinum, DNV

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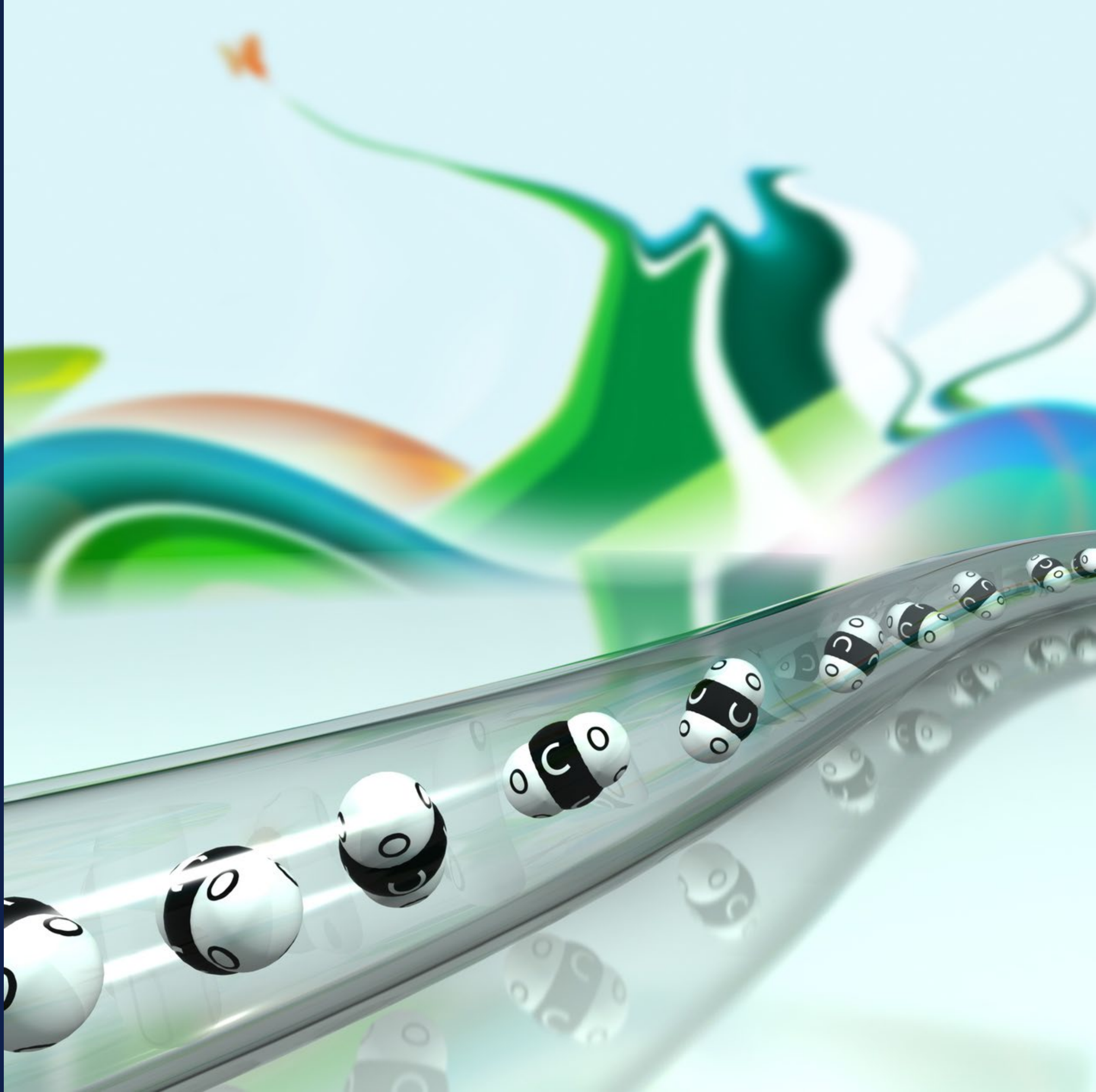


DNV's CCS ambition: enable the commercialisation of CCS value chains and deliver assurance to projects and stakeholders

We want to achieve this, by:

- Ensuring **safety** of CCS operations for people and environment through expert advice, testing, modelling and certification
- Developing new knowledge and practices required to maintain **integrity** of CCS infrastructure
- Driving **cost** efficiency through technology benchmarking, standardisation and qualification of purpose-fit solutions

DNV

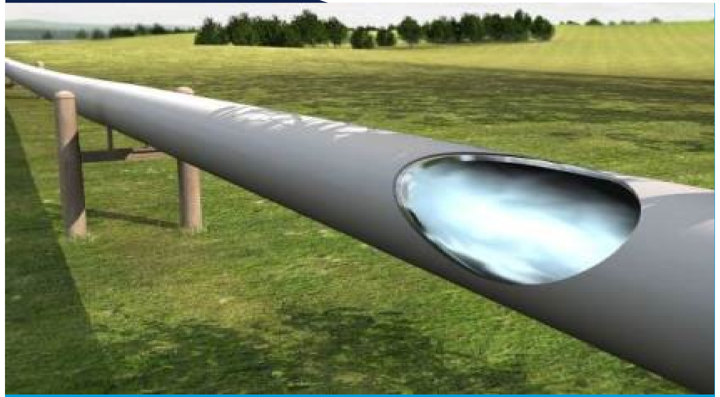
Helping scale CCS – 200+ projects in past 10 years

CAPTURE

- Fossil power plants
- Natural gas CO_2 reduction
- Other industrial processes

- Cost estimations
- Introduction of new technologies
- Technology review and benchmarking
- Up-scaling risk assessment
- HSE risk assessment
- Accidental release and dispersion
- Value of avoided CO_2

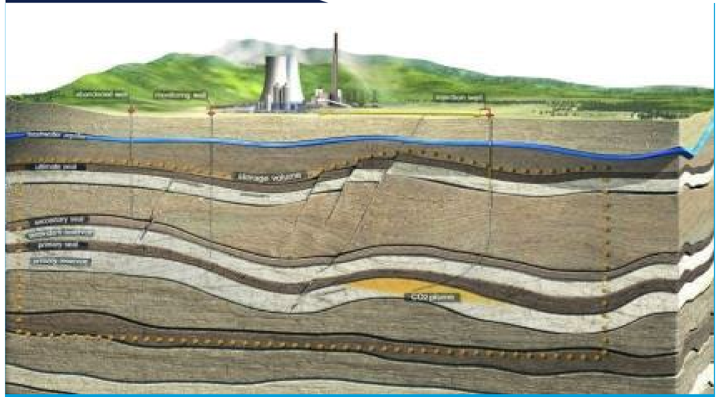
TRANSPORT



- **Pipelines**
- Ships
- (Motor trucks & Rail)

- Corrosion
- Material selection and structural design
- Flow assurance and operational issues
- Accidental release and dispersion
- CO_2 shipping insights
- Requalification of infrastructure

STORAGE



- Depleted oil or gas reservoirs
- Saline aquifers
- Enhanced oil recovery (EOR)

- Verification of storage sites
- Permanence of storage
- Risk management
- Monitoring and verification
- Public concern
- Transfer of responsibility

Available standards and guidelines for CO_2 pipelines

DNV-ST-F101 Submarine Pipeline Systems (2021)

DNV

DNV-RP-J201
Qualification procedures for carbon dioxide capture technology

First edition: 2010

DNV-RP-F104
Design and operation of carbon dioxide pipelines
First edition: 2010
Current edition: 2021
Next edition: 2024?

DNV-RP-J203
Geological storage of carbon dioxide

First edition: 2017

INTERNATIONAL STANDARD

ISO 27919-1
Carbon dioxide capture – Performance evaluation methods for post-combustion CO_2 capture integrated with a power plant

First edition: 2018

ISO 27913
Carbon dioxide capture, transportation and geological storage – Pipeline transportation system

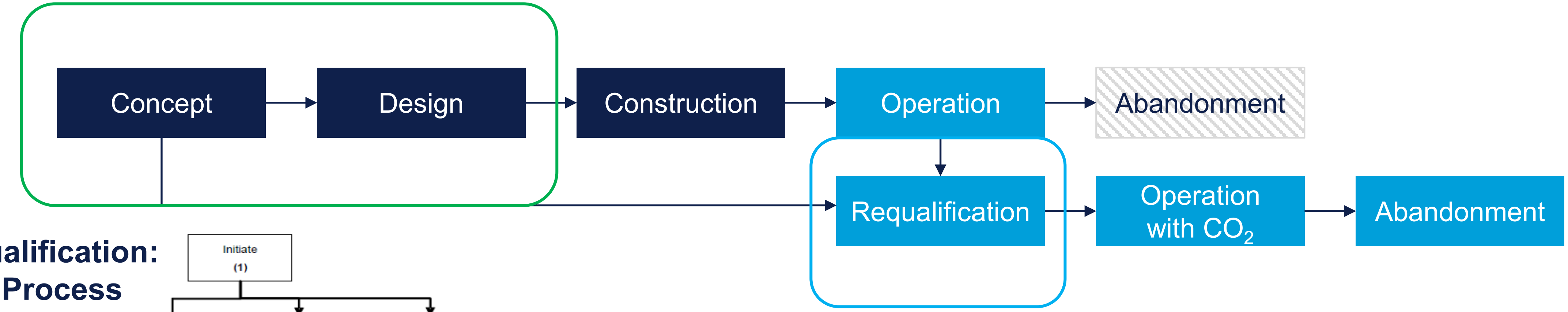
First edition: 2016

ISO 27914
Carbon dioxide capture, transportation and geological storage – Geological storage

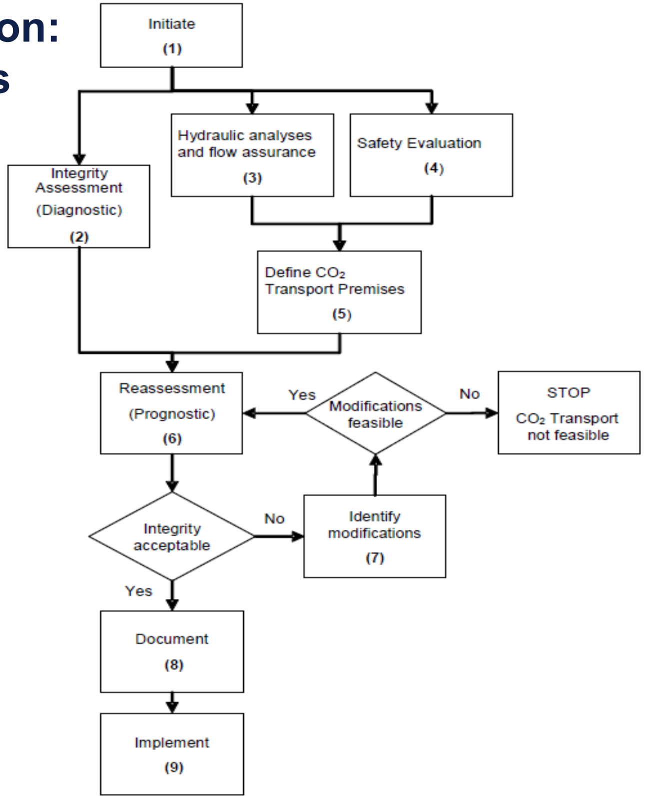
First edition: 2017

ISO 13623 Pipeline Transportation Systems (2009)

New pipelines vs repurposing existing pipelines



Re-qualification: Work Process



Basic principle:

- Re-qualification shall comply with the same requirements as for a pipeline designed especially for transportation of CO_2.
- Any deviations identified shall be thoroughly evaluated and concluded whether it is acceptable or not.

DNV

CO2SafeArrest – Fracture propagation testing

CLIMIT

Two full scale fracture arrest tests for validation of the numerical models at DNV's Spadeadam full scale test site during 2017/2018.

Full-scale fracture propagation testing to understand ductile fracture propagation/arrest behaviour of pipelines.

Improving safety and efficiency of CO_2 pipelines by developing and validating predictive models for CO_2 pipeline design.

SOLUTION

DNV's validation of fracture arrest models and design requirements will:

- Eliminate project-specific full scale fracture arrest tests
- Remove excessive conservatism (sufficient wall thickness and material properties identified)
- Reduce costs for new CO_2 pipeline projects

⇒ **Leading to update of DNV-RP-F104, 2021 version**

PROJECT DETAILS

Partners
DNV / **Climit** & Energy Pipelines CRC / Commonwealth

Location
UK + Norway + Australia

Date
2016-2020

DNV

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

Phase 2 extension

Contact: klas.solberg@dnv.com

Content

Full scale testing of Submerged CO_2 pipelines

DNV supports **Wintershall DEA** and the **OTH Regensburg University of Applied Sciences** to explore how existing natural gas pipelines in the southern North Sea can be used for future CO_2 transport.

A key activity is performing large-scale CO_2 pipeline testing of running fracture in air and in submerged (water) condition at DNV's Testing and Research Facility at Spadeadam in the UK

SOLUTION

Quantify the effect of the water surrounding the pipeline on the crack arrest behavior for a specific pipeline, and thus better define the model parameters used for different backfill types.

https://www.dnv.com/news/dnv-supports-world-first-large-scale-testing-of-submerged-co2-pipelines

PROJECT DETAILS

Customer
Wintershall Dea (Germany)

wintershall dea

Location
Germany + UK + Norway

OTH OSTBAYERISCHE TECHNISCHE HOCHSCHULE REGENSBURG

DNV

New build and repurposing of CO2 pipelines - DNV RP-F104

Motivation

CO_2 transport plays an essential role in the CCS value chain and the use of pipelines may have significant advantages transporting CO_2 from the capture site to the storage site depending on transport volumes and distance.

The current DNV-RP-F104 (2021) gives recommendations to the design and operation of pipelines transporting CO_2. However, it is recognised by the industry that the experience from recent research studies and upcoming new build and re-qualification projects has not been fully addressed in the current revision of the DNV-RP-F104. A Joint Industry project (JIP) will therefor be launched as a response to this feedback.

Selected topics to be addressed

- Description of dense phase vs gas phase, onshore and offshore
- CO2 stream composition from various sources
- Running ductile fracture (RDF) and fracture arrestors (solutions and spacing)
- Low temperature brittle fracture
- Environment & safety
- Requalification / repurposing
- Leak detection
- Pre-commissioning - Replace hydrotesting

Outcome and benefits

- The objective of the JIP is to provide clearer guidance based on the recent developments on relevant topics as identified to be crucial for the design and operation of CO_2 pipelines
- The guidelines and recommendations will be implemented in the next revision of DNV-RP-F104 'Design and Operation of carbon dioxide pipelines' with special focus on selected topics as described in the various work packages.
- Schedule: 12 months duration. Kick-off Q2 2023

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What to avoid ?

24” dense CO_2 pipeline failure – Satartia 2020

Incident:

- Pipeline failure on the Delhi 24” Transmission Line near Satartia, Mississippi.
- The failure (rupture) was reported to have occurred February 22, 2020.
- The carbon dioxide (CO_2) pipeline was operated by Denbury Gulf Coast Pipelines LLC (Denbury).
- The rupture followed heavy rains that resulted in a landslide in the area.

Failure Investigation Report - Denbury Gulf Coast Pipeline.pdf (dot.gov)

CO2SafeArrest:
Understanding Running Ductile Fracture

- Test02 Drone Footage 1x.mp4

- 4K North Turret.mp4

Content

WHEN TRUST MATTERS

Thank you for your attention

Bente H. Leinum,
DNV, Pipeline Operations Norway,

Content