Northern Lights

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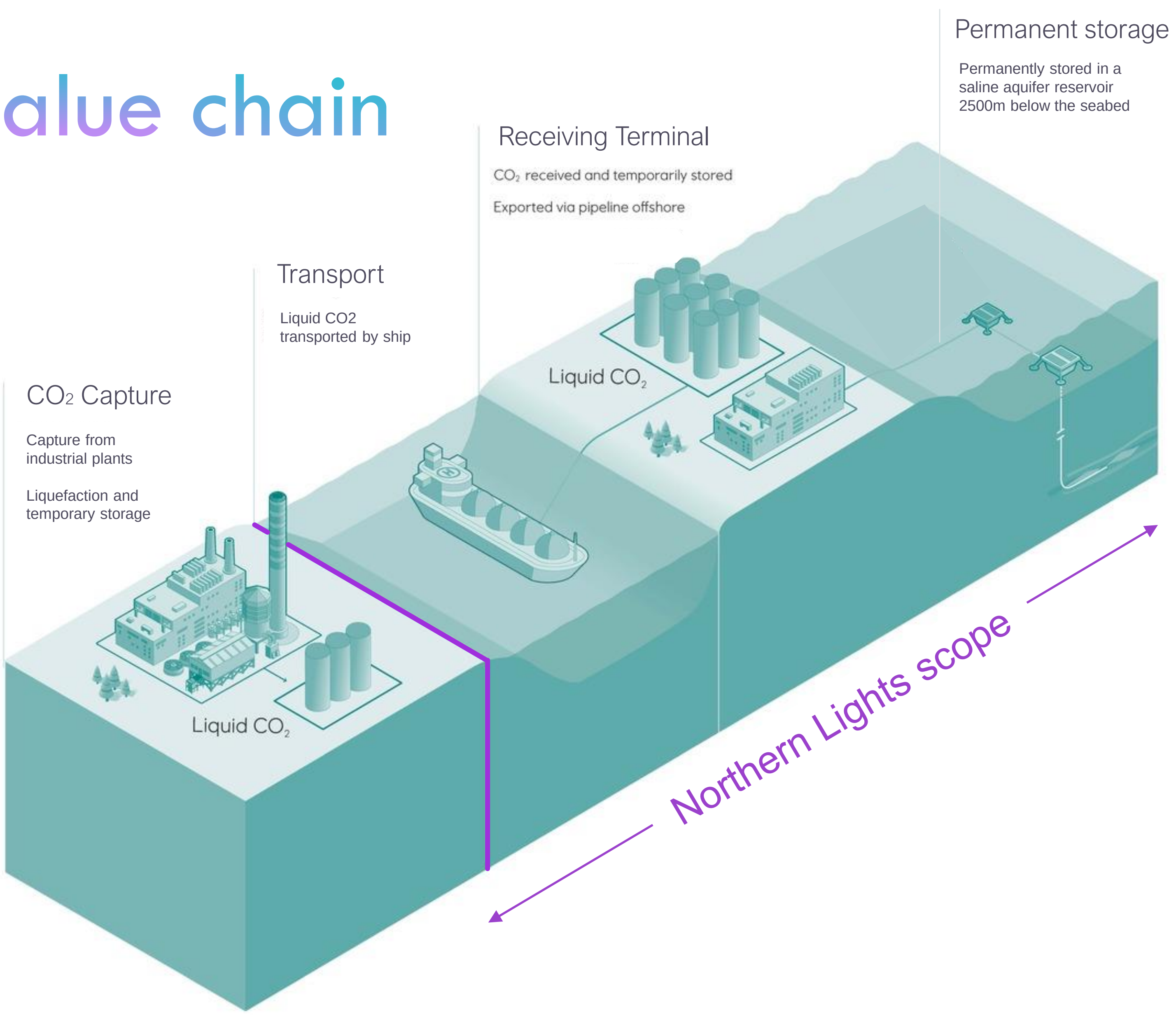
Northern Lights

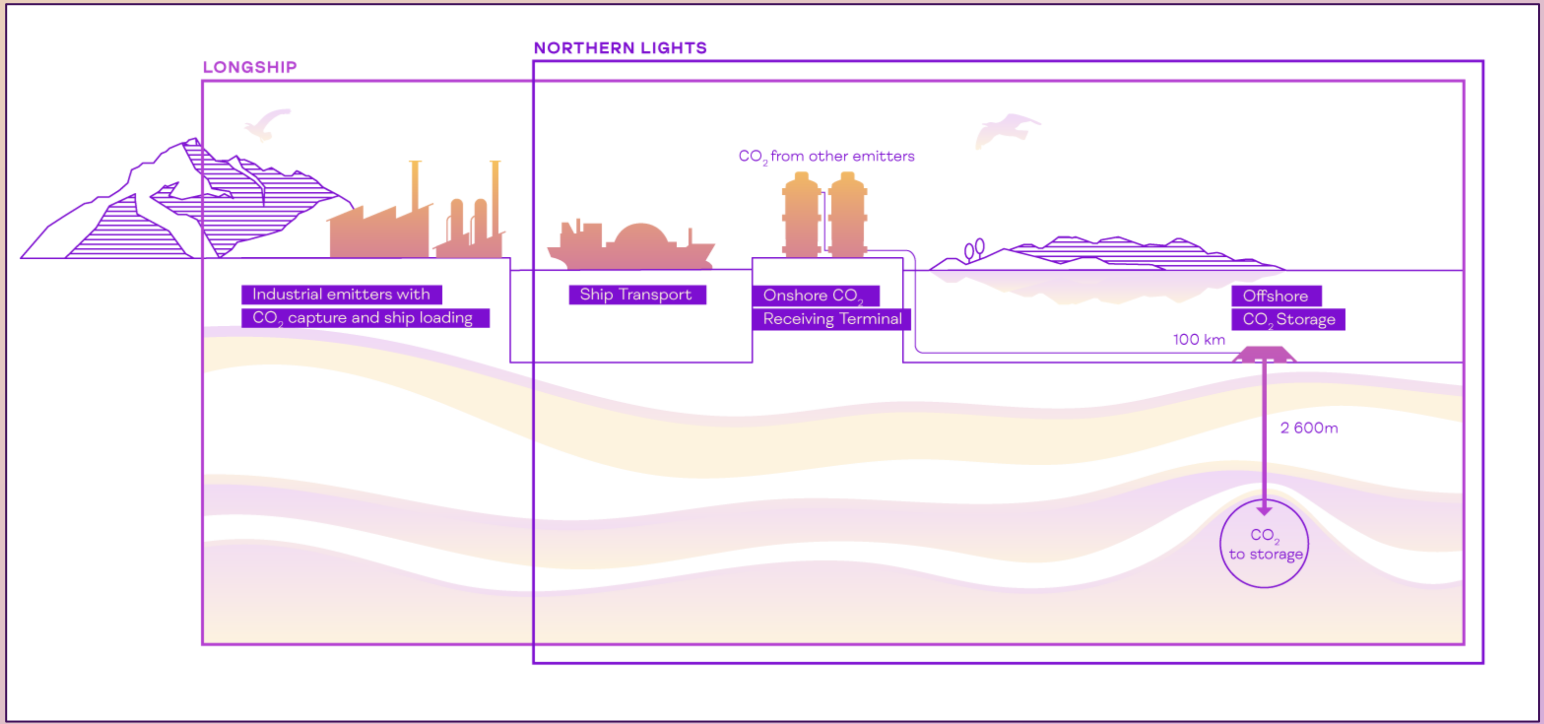
- The Northern Lights project passed FID 1,5 years ago
- Since then, we have started construction as the world's first open-source CCS project
- In June 2021 the Northern Lights JV was formally established
    - Owned by Equinor, Shell and TotalEnergies
- The Norwegian state contributes with considerable funding for the first phase

The CCS value chain



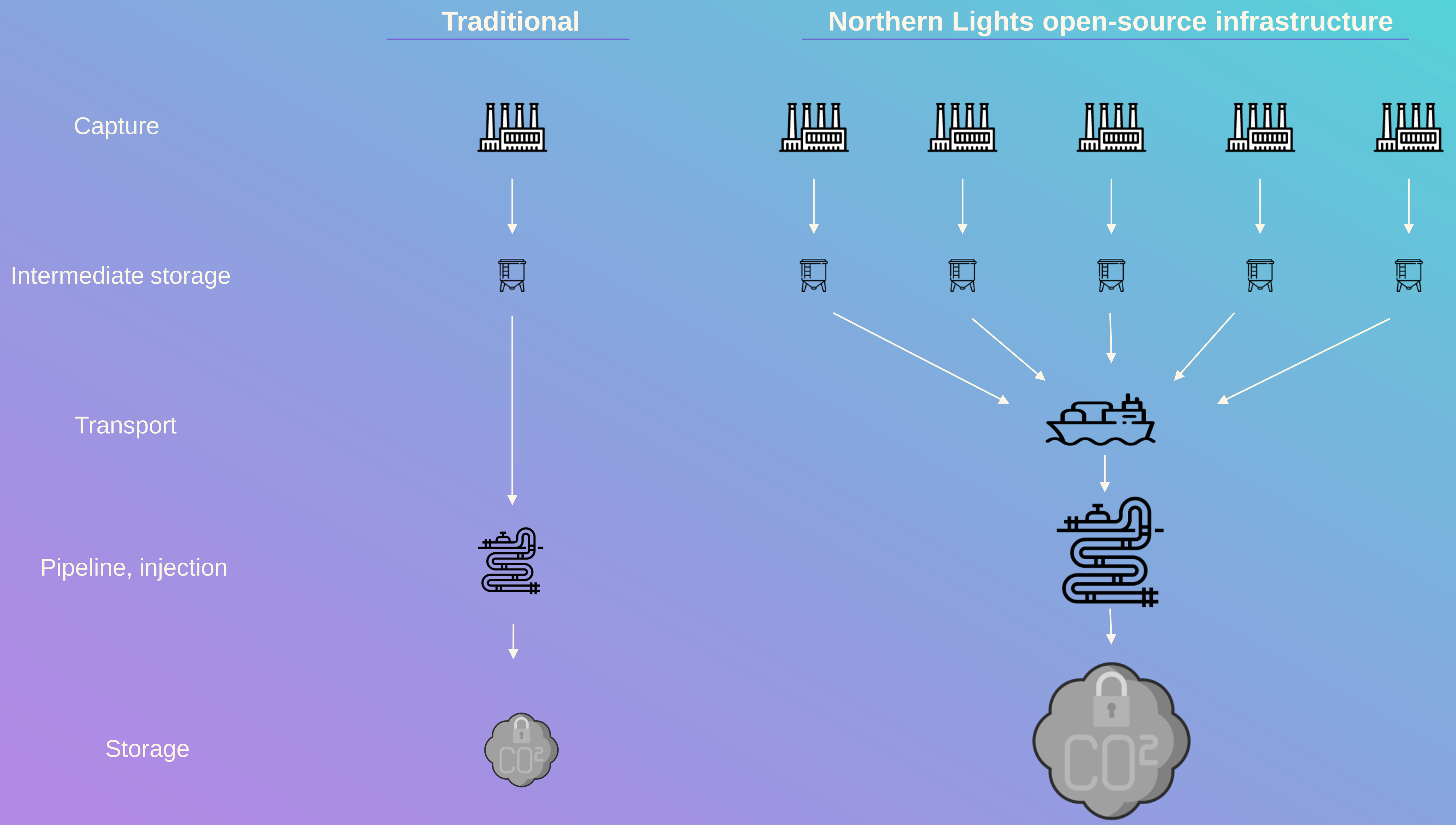
Longship

- Norwegian government's demonstration project of full-scale CCS value chain by 2024
- Full support to Norcem cement factory, and partial support to Fortum Oslo Varme waste to energy facility – both on the Norwegian east coast
- Includes CAPEX and OPEX support for the first 10 years
- Unlocking the "chicken and egg" dilemma



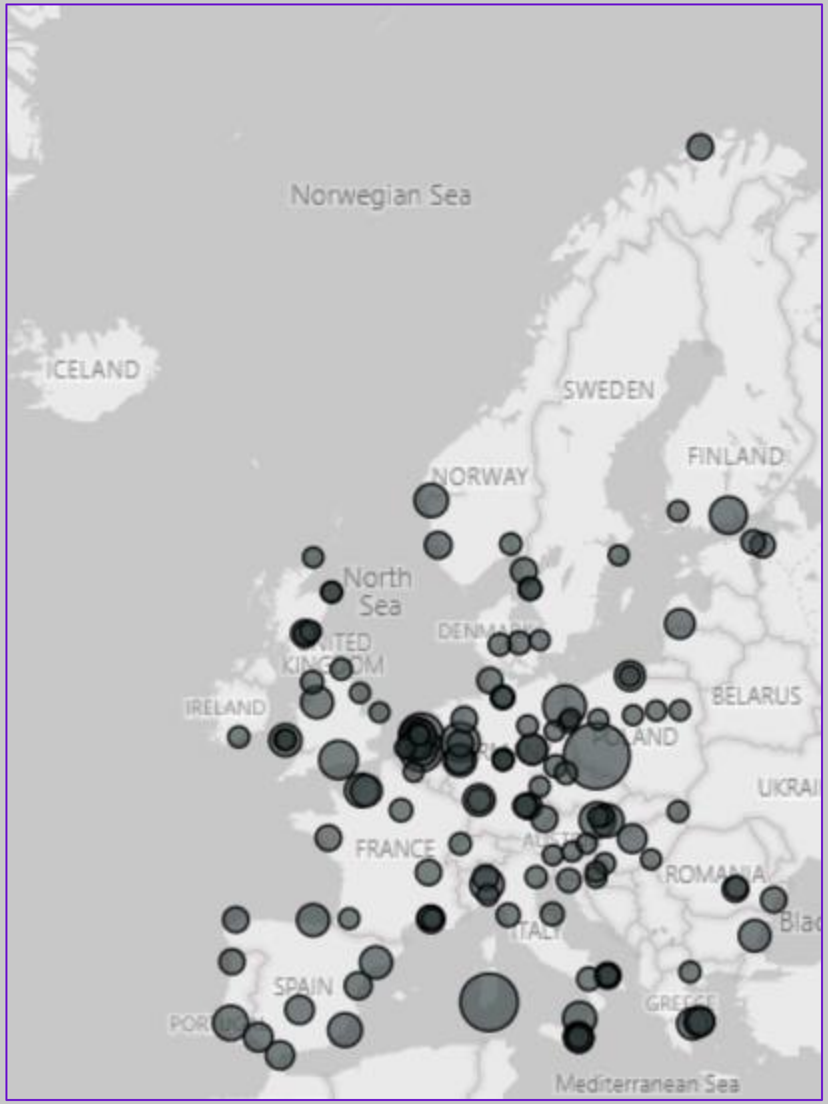
" Longship is a milestone in the Government's industry and climate efforts. The project will lead to emission cuts, and facilitate development of new technology and thus new jobs "

- Former Prime Minister Erna Solberg


Traditional
Northern Lights open-source infrastructure
Capture
Intermediate storage
Transport
Pipeline, injection
Storage

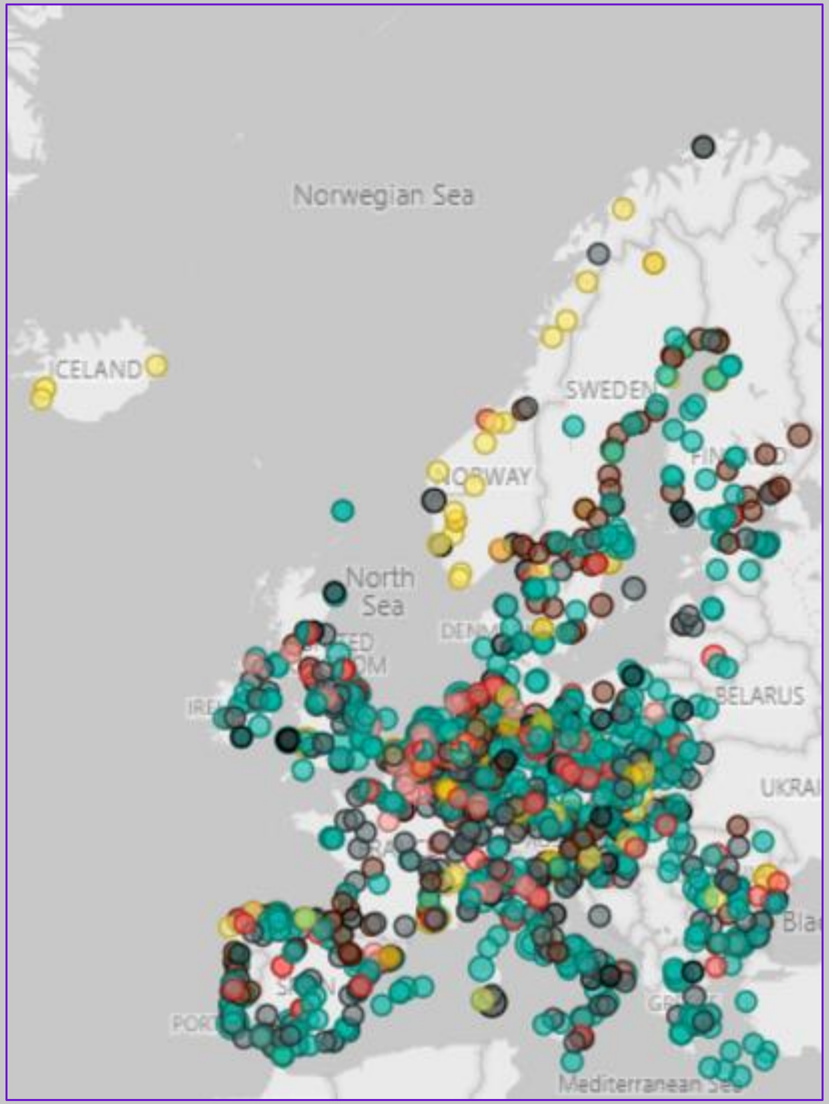
Traditional

Northern Lights open-source infrastructure



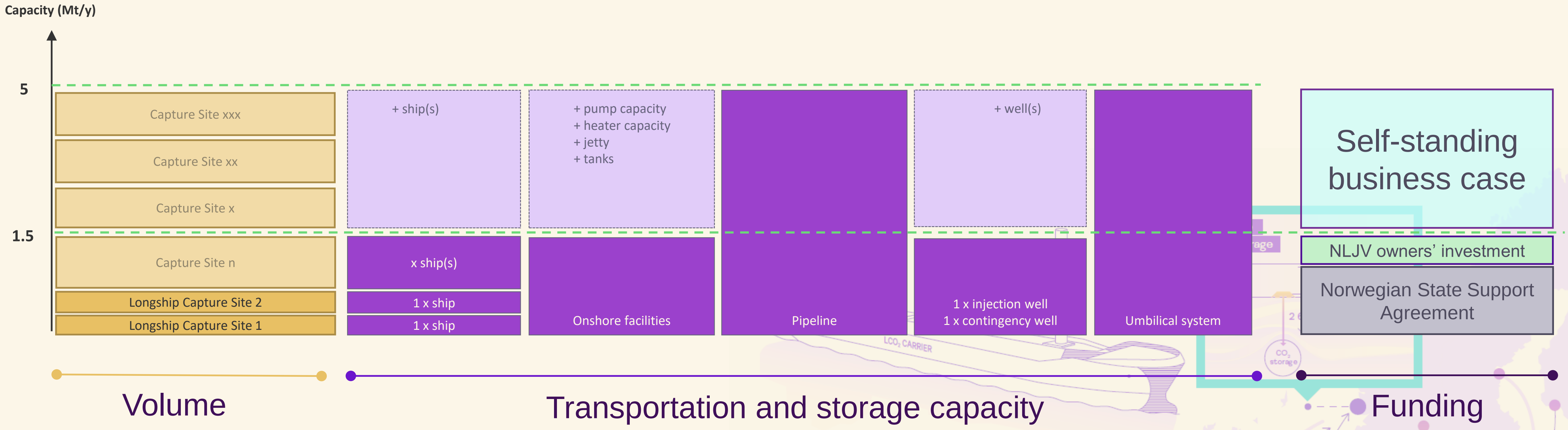
Emissions from oil and gas operators with potential access to reservoirs

135	facilities	2 200
149	MTPA (Million tonnes per annum)	1 687



Industrial emissions less then 300km from port

Volume and future ramp-up



→ **Demand and funding capabilities** will bring the 5 MTPA and potential future phases forward in time

Key factors for Norwegian development of CCS

- Geology on the Norwegian Continental Shelf (NCS)
  - Favorable storage conditions
- Political drive and ambition
  - Public-private collaboration
- Oil and gas competence
  - Long history of offshore oil and gas operations
  - High level of trust among the public

Impact of CCS on Norwegian industry

Securing existing jobs and industry

- The hard to abate sectors have a solution even with increasing carbon taxation

Enabling the development of new industry

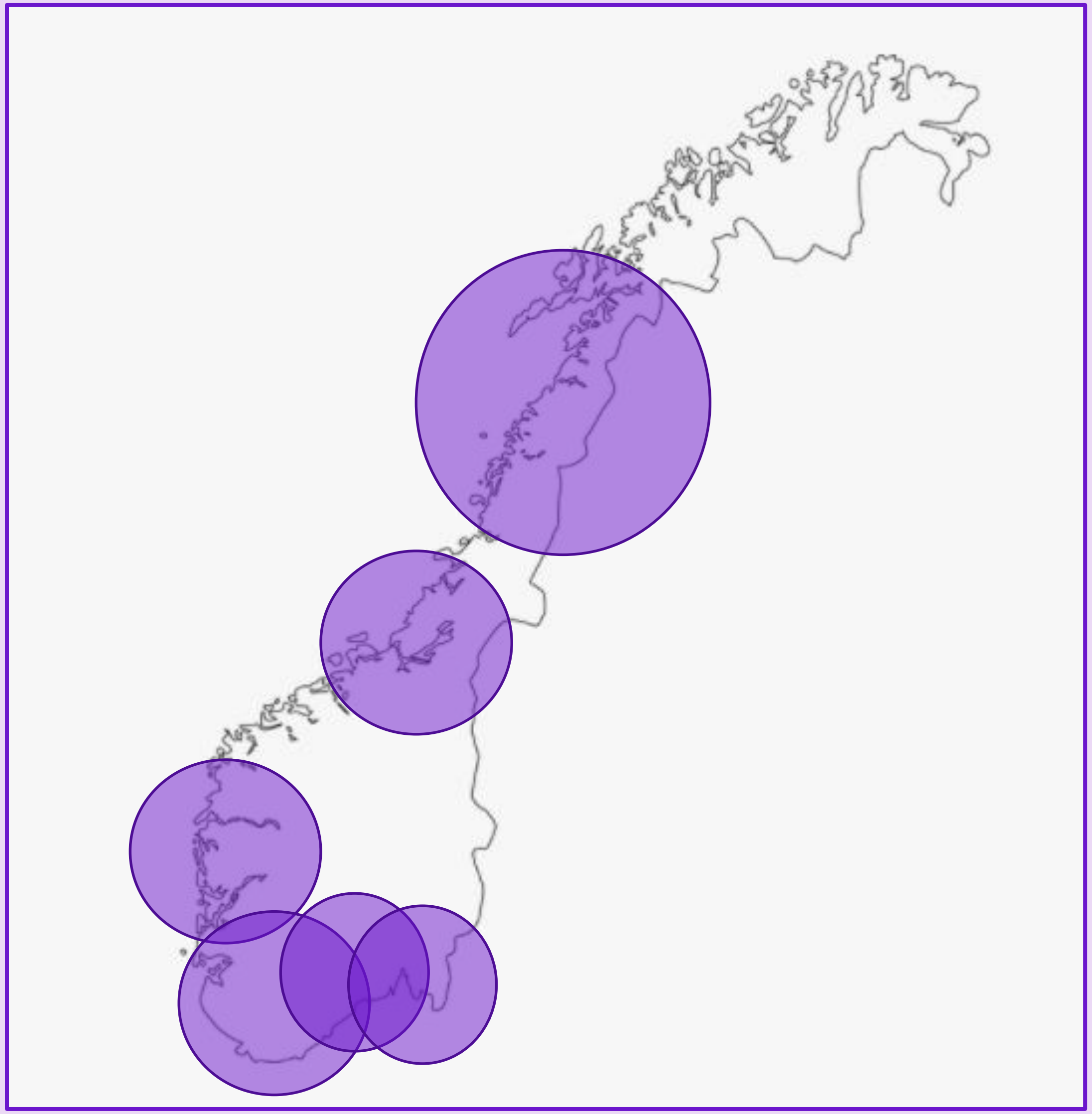
- Access to CO2 storage becoming a competitive advantage

Gaining experience in all parts of the value chain

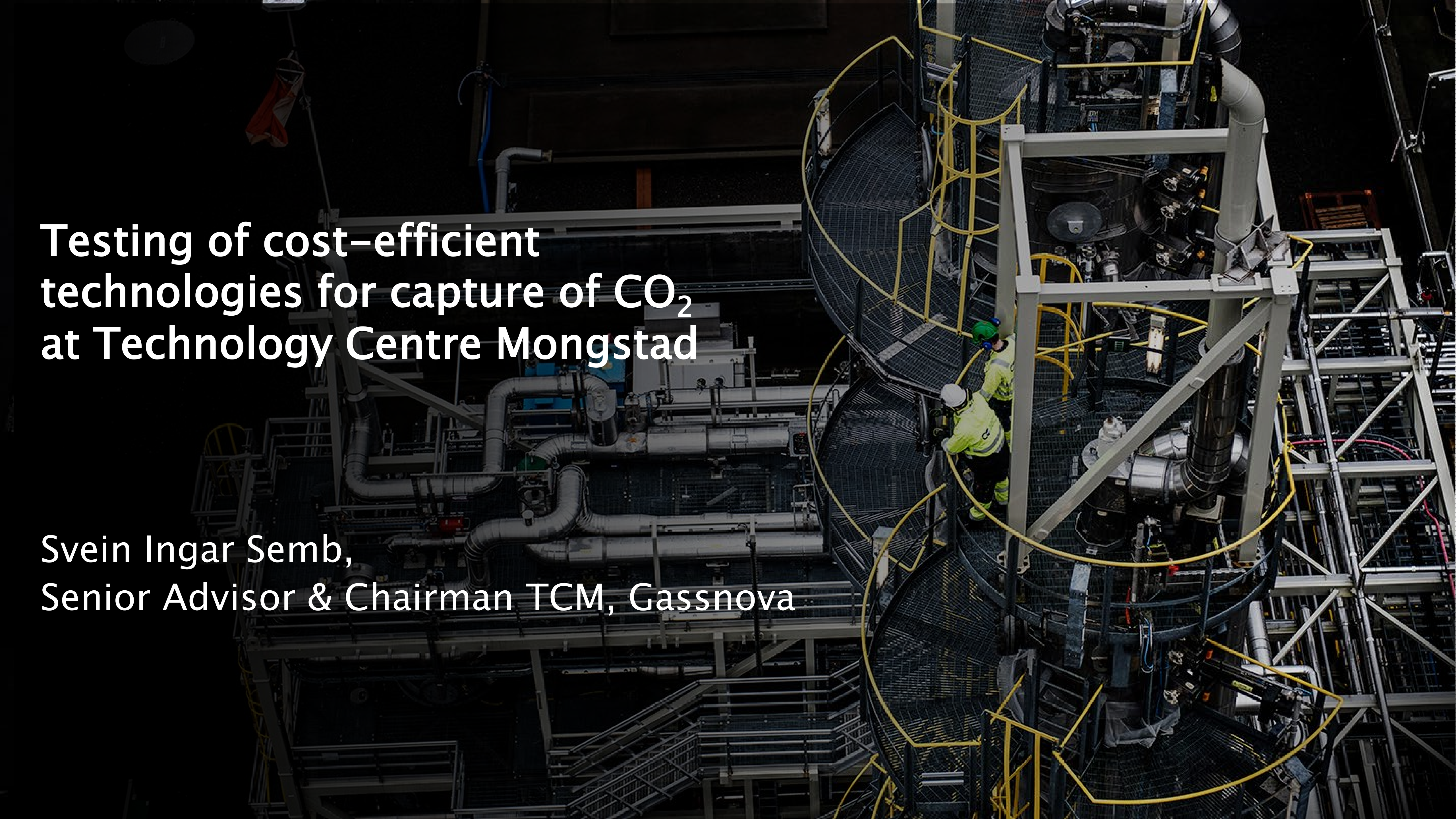
- Northern Lights and

Clustering

- Longstanding tradition to build economies of scale



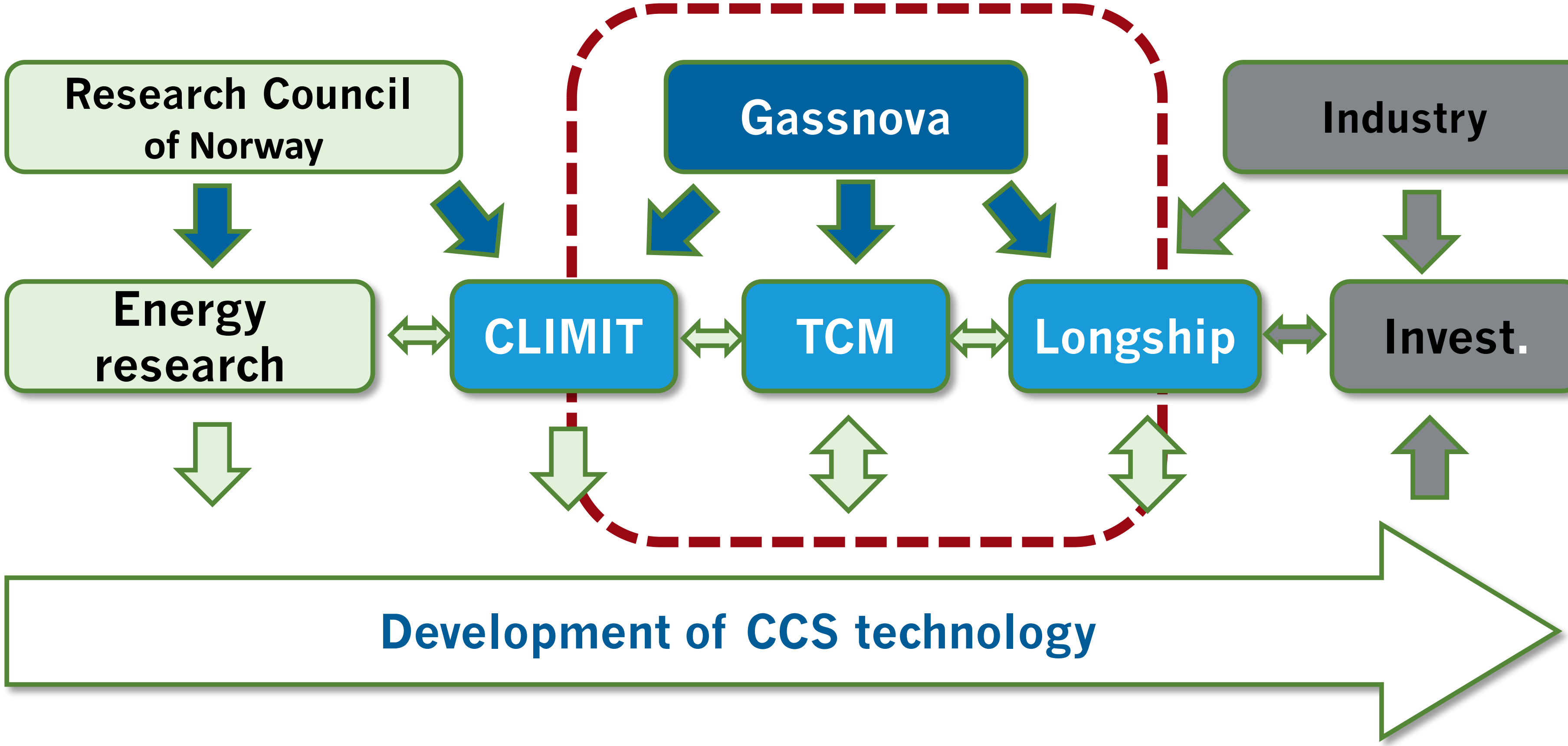
CCUS clusters



Testing of cost-efficient technologies for capture of CO_2 at Technology Centre Mongstad

Svein Ingar Semb,
Senior Advisor & Chairman TCM, Gassnova

Innovation chain for CCS in Norway



Technology Centre Mongstad (TCM)

- Large scale and fleksible CO_2 capture test facility
- A recognized global competence center
- Continuous operation since 2012
- An arena for training, problem-solving and development
- Seconded technical personnel from owners

GASSNOVA equinor TotalEnergies

Conducted Test Campaigns

Proprietary Campaigns

Technology Vendors perform tests with their own proprietary technology

2012 → **2023**

2012 - 2014	2014 - 2015	2015 - 2016	2016	2016 - 2017	2019	2021
Aker Solutions, ALSTOM	Cansolv 1st campaign	Carbon Clean Solutions	Cansolv 2nd campaign	ION Clean Energy	FLUOR	Mitsubishi Heavy Industries, MTR, TDA

Open and Public Campaigns

Extensive list of open scientific test campaigns with non-proprietary technology in cooperation with universities, research institutes, U.S. Department of Energy and the European Union

DoE & EU prosjekter: Aerosolve[1], DOCPCC[2], CCSI2[3], Align-CCUS[4]

2013 → **2023**

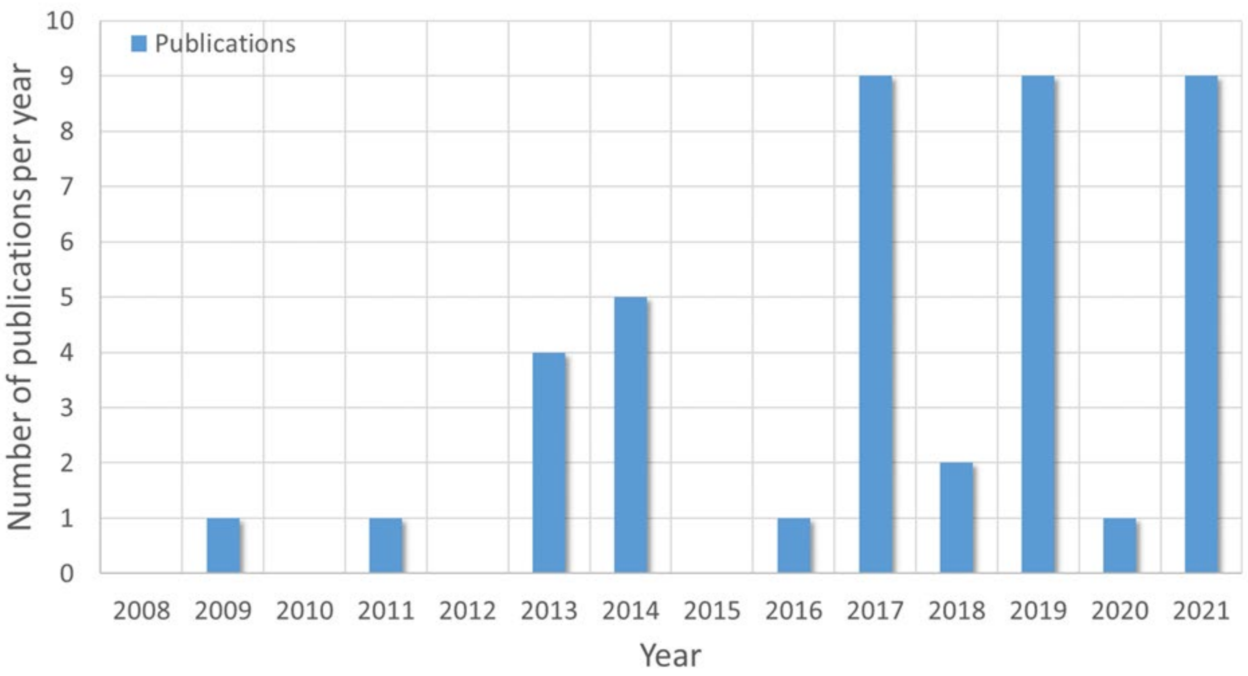
Open Campaigns: MEA-1, MEA-2, MEA-3, MEA-4, MEA-5, CESAR-1

TECHNOLOGY CENTRE MONGSTAD

HSE studies for Full-scale Mongstad (CCM), Norway

- Technology qualification program (TQP) for a CO_2 capture project for gas-powered heat and power (2009 – 2013)
- Special focus on amine emission to air
- CSIRO commissioned for studies (8 reports):
  - Sampling and analysis
  - Process and atmospheric chemistry
- Library with alle TQP (60) reports can be found at:
  - https://ccsnorway.com/hse-studies/

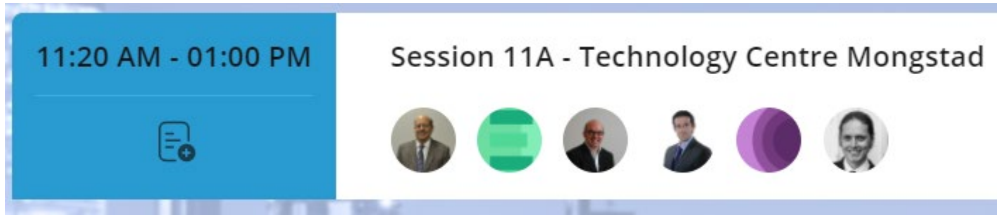
- The dispersion modelling tool TAPM (CSIRO) is used for the dispersion permit for Technology Centre Mongstad (TCM)



Scientific publications:

TCM with owners and partners

~50 publications with peer-review



Advisory Services

OGCI – OIL AND GAS CLIMATE INITIATIVE

sse

Statkraft

HEIDELBERG CEMENT

fortum Oslo Varme

TDA

中英（广东）CCUS 中心
UK–China (Guangdong) CCUS Centre

HÖEGH LNG

Net Zero Teesside

vallourec

RTI INTERNATIONAL

WÄRTSILÄ


History of TCM

How to get access to test at TCM?

- The technology must be sufficiently mature for testing in scale relevant at TCM.
- Testing at Site 3 for emerging technologies, can accommodate less mature technologies, but require the technology developer to bring own equipment
- Prerequisite that the technology can perform within the limits set in the emission permit
- TCM business development team assists and advice about testing at facility.

TECHNOLOGY CENTRE MONGSTAD


TECHNOLOGY
CENTRE
MONGSTAD
www.tcmda.com

NORWEGIAN ENERGY SYMPOSIUM - AUSTRALIA
9 – 10.11.2021

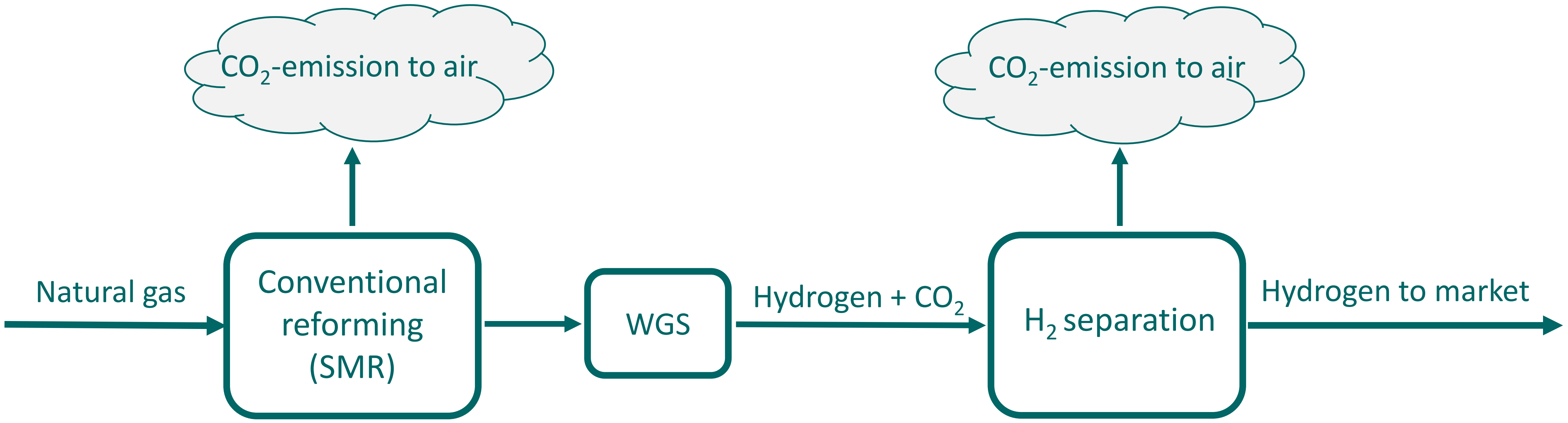
Blue Hydrogen and Ammonia – Emission-free production, efficient transportation and decarbonization

Torkild R. Reinertsen, PhD
President
REINERTSEN New Energy AS

REINERTSEN
NEW ENERGY

.... Developing Clean Energy Solutions

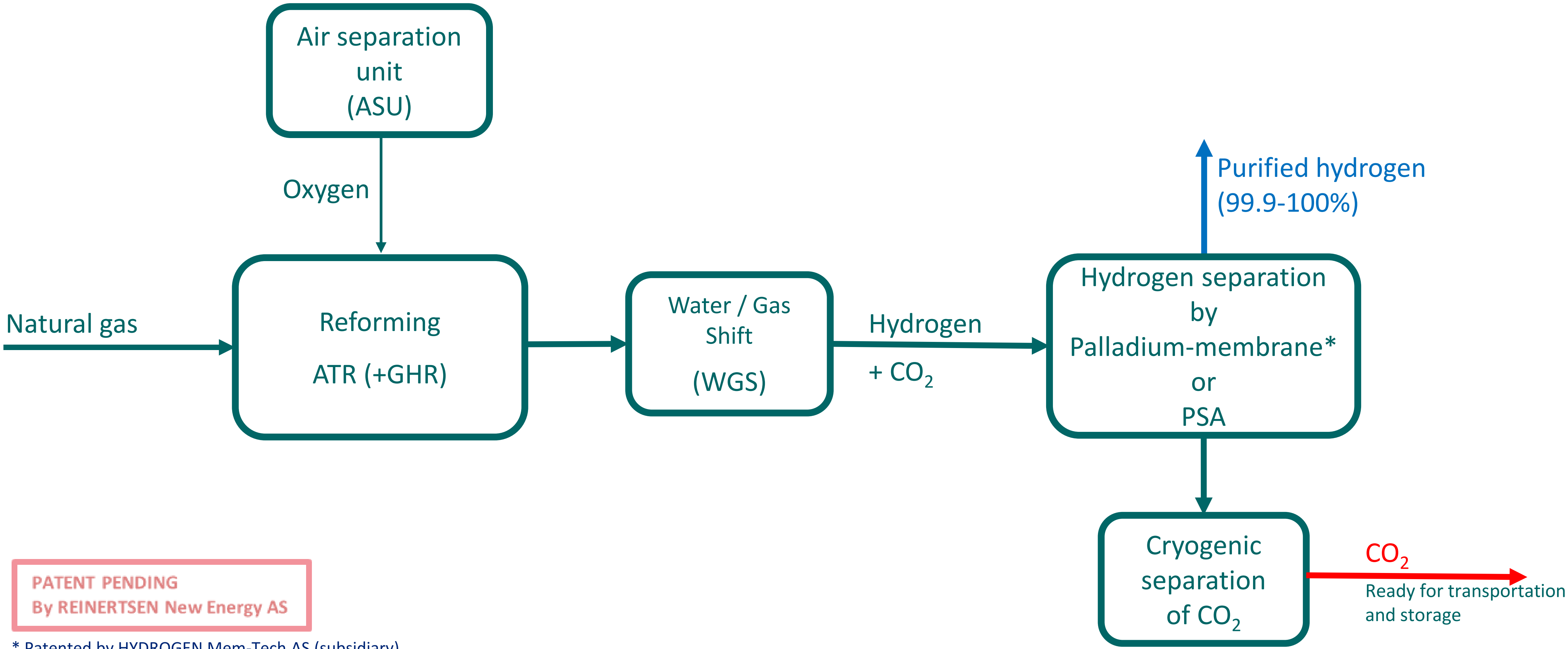
Conventional production of grey hydrogen - Unacceptable CO_2 emissions!



Overall Carbon Capture Rate: 0%
CO_2 emission: 8-9 kg CO_2/kg H_2
Typical hydrogen production cost: 1€/kg

Large scale, emission-free production of hydrogen – **HyPro-Zero™**

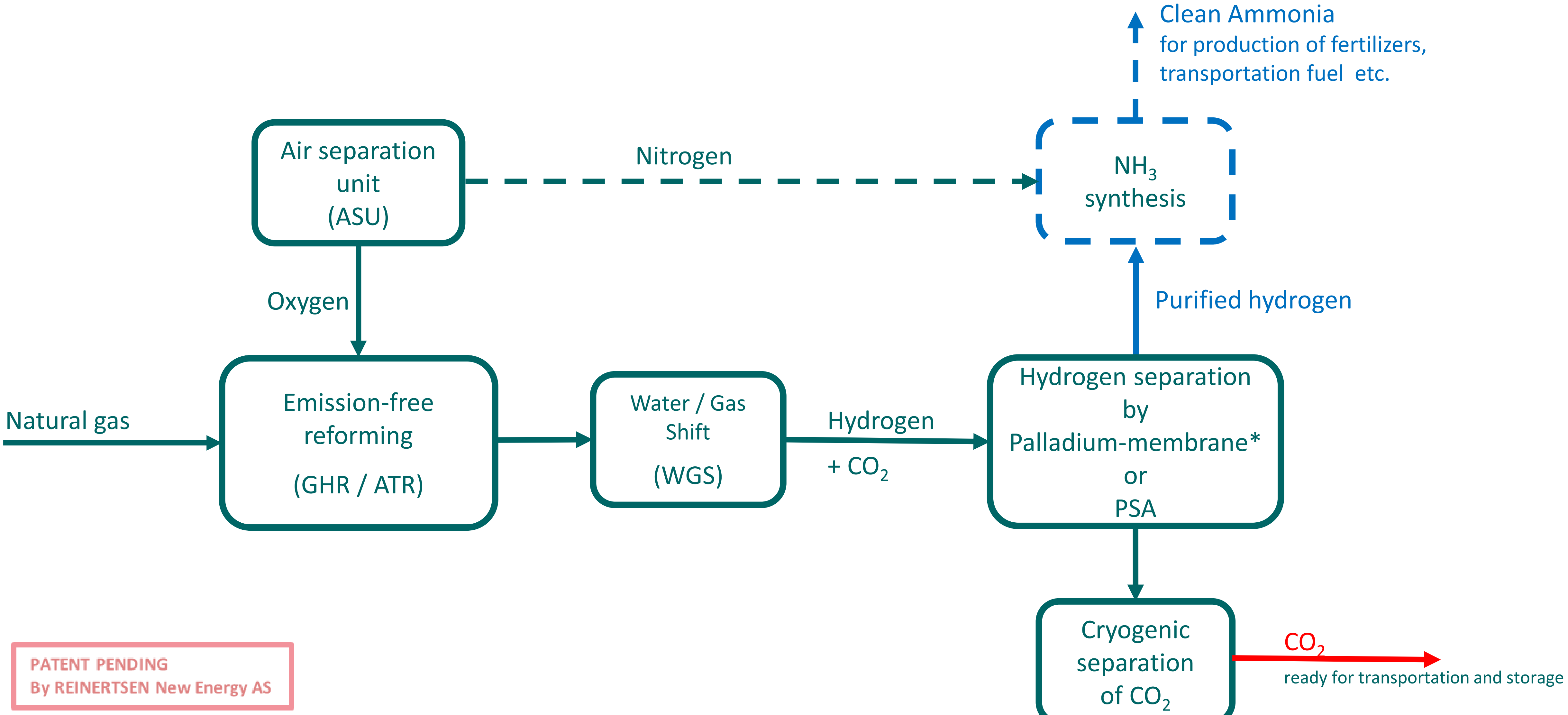
Existing technology in a new combination!
Clean and affordable!



PATENT PENDING
By REINERTSEN New Energy AS

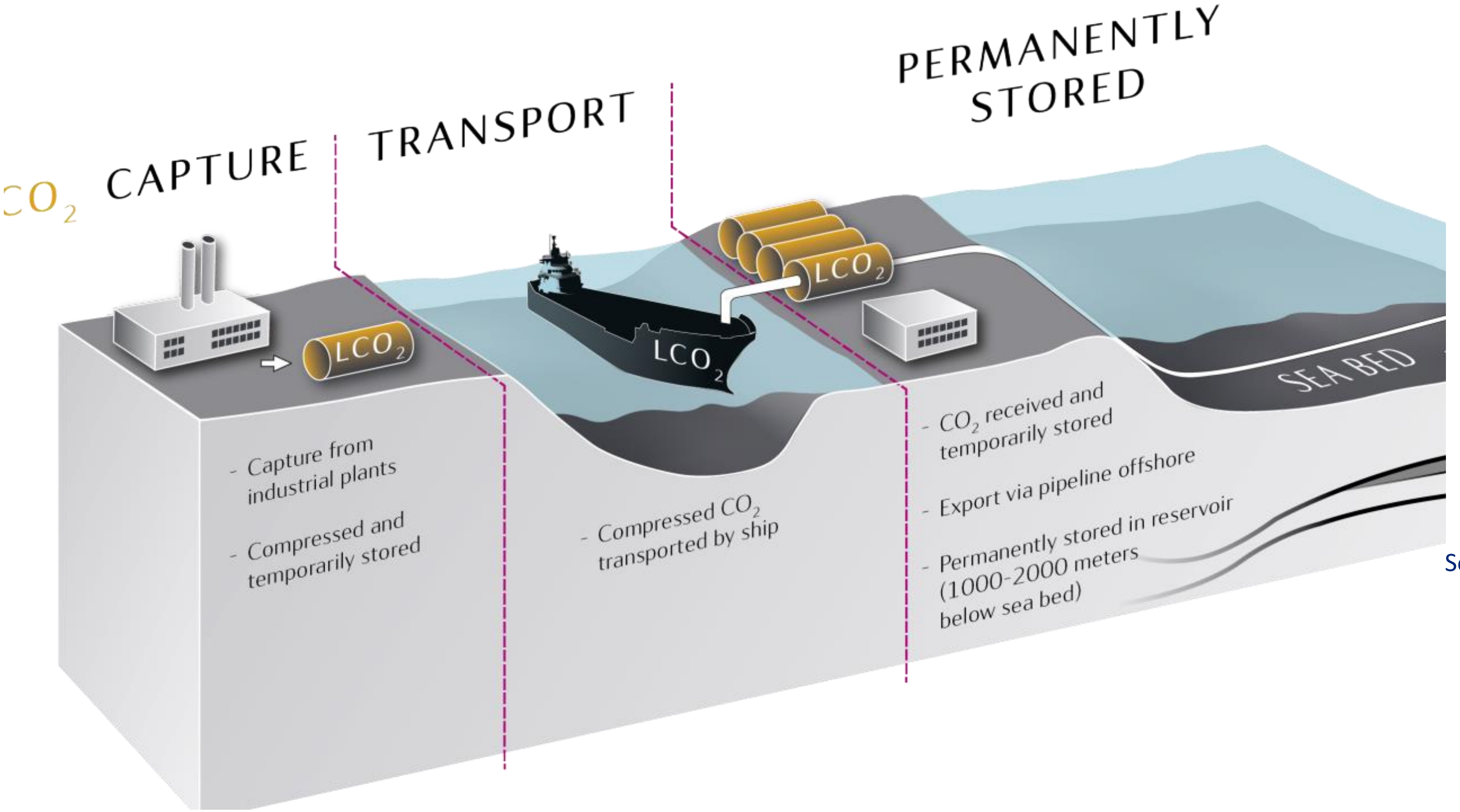
* Patented by HYDROGEN Mem-Tech AS (subsidiary)

Emission-free production of ammonia with "HyPro-Zero"



* Palladium membrane patented by HYDROGEN Mem-Tech AS (subsidiary of REINERTSEN New Energy)

Northern Lights CCS Project

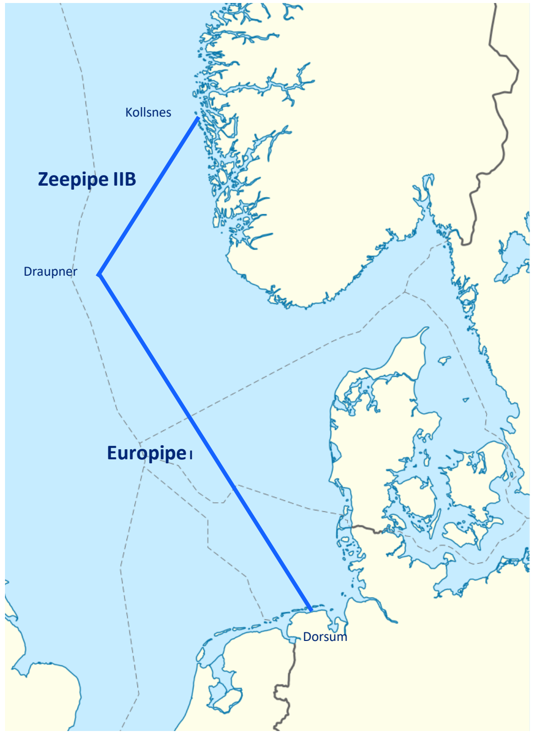


Source: Equinor

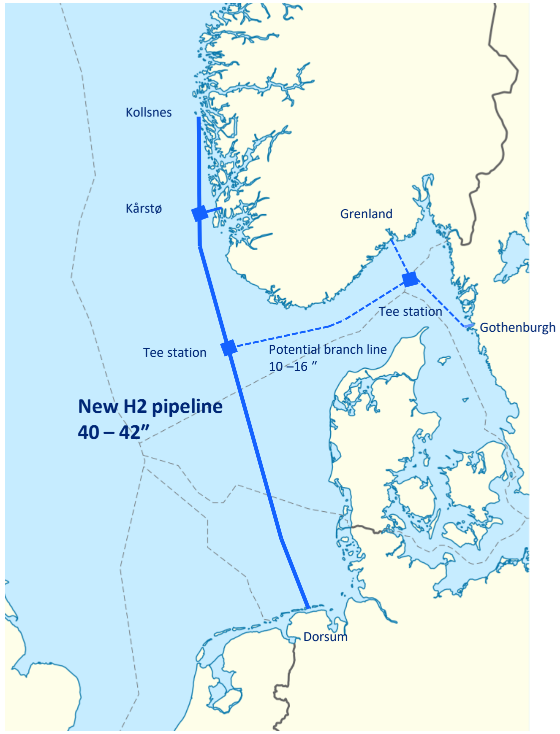
REINERTSEN NEW ENERGY

Gas pipelines for efficient hydrogen transportation
Example: Norway to Netherlands/Germany

Existing gas pipeline converted to hydrogen service, 40”/924km



New hydrogen pipeline
42”/800km
(3.5 million ton H_2/year)



Cost of hydrogen transportation:
~ 0.10 €/kgH_2*

*Net cost, excl. financing etc.

Palladium membranes – from innovation to market

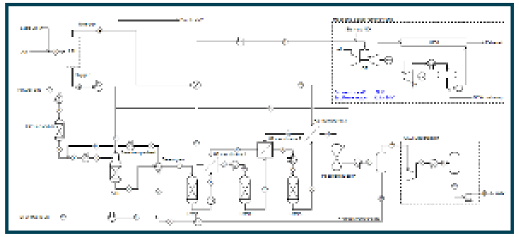
CLIMIT

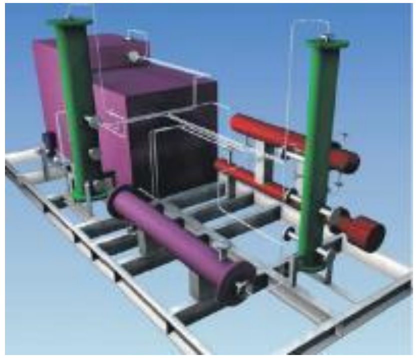
Innovasjon Norge

The Research Council of Norway

SINTEF

H M T
HYDROGEN MEM-TECH





2011 — 2012 — 2013 — 2014 — 2015 — 2016 — 2017 — 2018

Feasibility study → Concept phase → FEED-study → Test-rig at Equinor's methanol plant → Testing

Large scale, competitive, blue hydrogen production and transportation

Hydrogen production cost (incl. CO_2 capture)*:	1.2-1.6 €/kgH_2
+ CO_2 transport and storage cost:	0.3-0.5 €/kgH_2
Total production cost:	1.5-2.1 €/kgH_2
+	
Hydrogen transportation Norway – Germany/Netherlands:	0.10 €/kgH_2
=	
Total production and transportation cost:**	**~ 1.9 €/kgH_2**

* Natural gas price assumption: 0.12 €/SM^3

** Net cost, excl. financing, etc.

REINERTSEN NEW ENERGY

Decarbonization by hydrogen

Feed	Energy carrier	Distribution	Markets	Technology / Readiness	Decarbonization
Renewable power	Green Hydrogen	**Compressed hydrogen** transported in pipelines and gas networks	Industry	**Feedstock and energy / Available**	High
			Heat / Power	**Burners and small fuelcells / Available**	High
Natural Gas / LNG	Blue Hydrogen		Light & heavy vehicles and trains	**Fuelcells / Available**	High
			Power generation	**Turbines and Fuelcells / 3-5 years**	Low / Medium
		Liquid hydrogen transported by ships and road tankers	Ferries, high-speed vessels	**Turbines and Fuelcells / 3-5 years**	Low / Medium
	H_2, N_2 → Clean ammonia	**Clean ammonia** transported by existing infrastructure	Power generation	**Turbines and Fuelcells / 3-5 years**	Low / Medium
			Large airplanes	**Turbines + new airplane design / 3-5 years**	High
			Large ships	**Internal Combustion engines (ICE) / 3-5 years**	High
Sustainable energy crops, biomass, waste	H_2 → Bio fuel	Biofuel / Synthetic fuel transported by road tankers	Local filling stations and airports	Limited raw materials	Low / Medium
GHG-neutral CO2: • Direct air capture • Co2 from biomass	H_2 → Synthetic fuel				

Thank you for your attention!

Reinertsen New Energy has the technology to refine natural gas to hydrogen, without CO2 emissions. With more than 40 years of experience, we stand ready to start a new and clean industrial adventure here and now - for those that come after us and the world they will live in.

REINERTSEN
NEW ENERGY

Z·E·G

Providing solutions for clean hydrogen from gas

Kathrine K Ryengen, ZEG Power AS

October 2021

Z·E·G

ZEG delivers solutions for **clean hydrogen** production using the novel ZEG ICC™ Technology

Sustainability is the core of ZEG Power

The UN Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all

- ZEG unlocks the energy of natural gas with integrated capture of CO_2
- ZEG uses natural sorbent to capture CO_2 with no toxic emissions to air or water
- ZEG works to achieve carbon removal through bio-hydrogen w/CCS

7 – affordable and clean energy
9 – Industry, innovation and infrastructure
12 – Responsible consumption and production
13 – Climate action

Z • E • G is a pure-play clean hydrogen company

Vision: To empower the world with clean energy

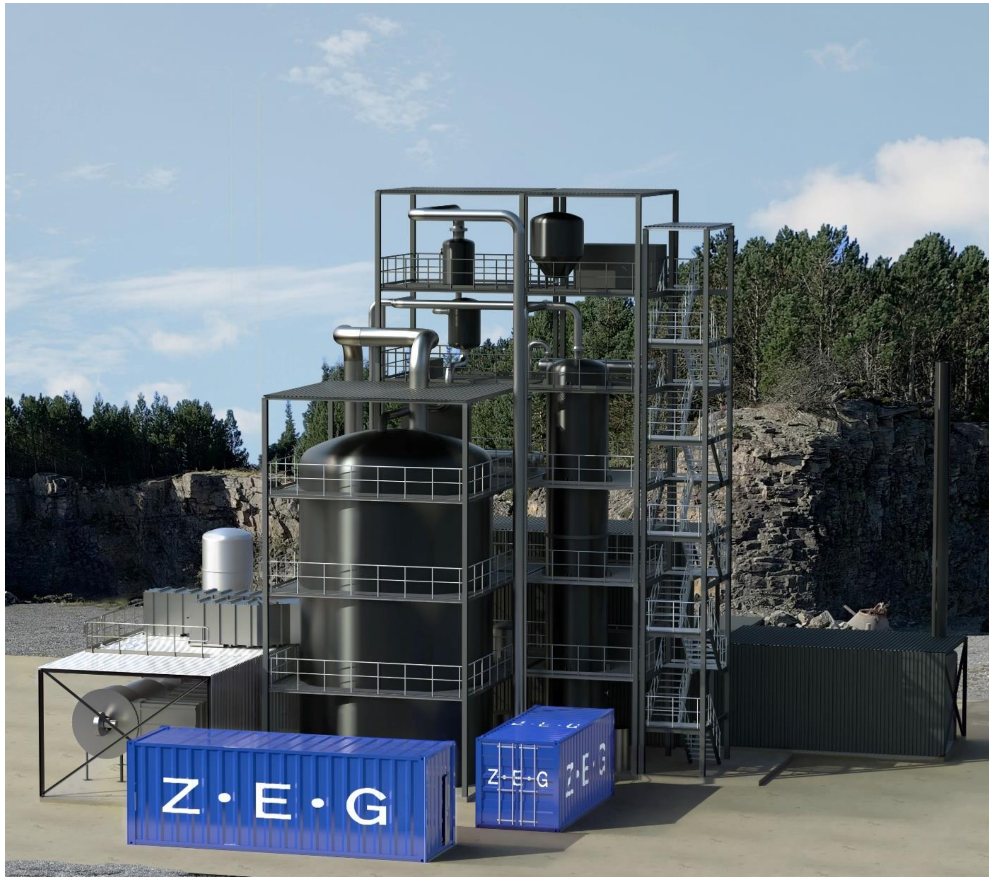
- ZEG provides systems to produce clean hydrogen from gas with proprietary integrated carbon capture technology, **ZEG ICC™ Technology**
  - high thermal efficiency
  - verified in pilot plants
- First commercial sale is secured, roadmap to industrial scale established
- ZEG holds a global approved patent portfolio spanning 7 patent families
- ZEG was founded from the Norwegian research institute IFE in 2008, has 16 employees and is growing fast from its headquarters in Oslo, Norway
- ZEG is backed by solid owners who are global frontrunners in financing the energy transition

90-99%
CO_2 capture[1]

<$1,5/kg
levelized cost of hydrogen[2]

NOK 175m
R&D since 2001

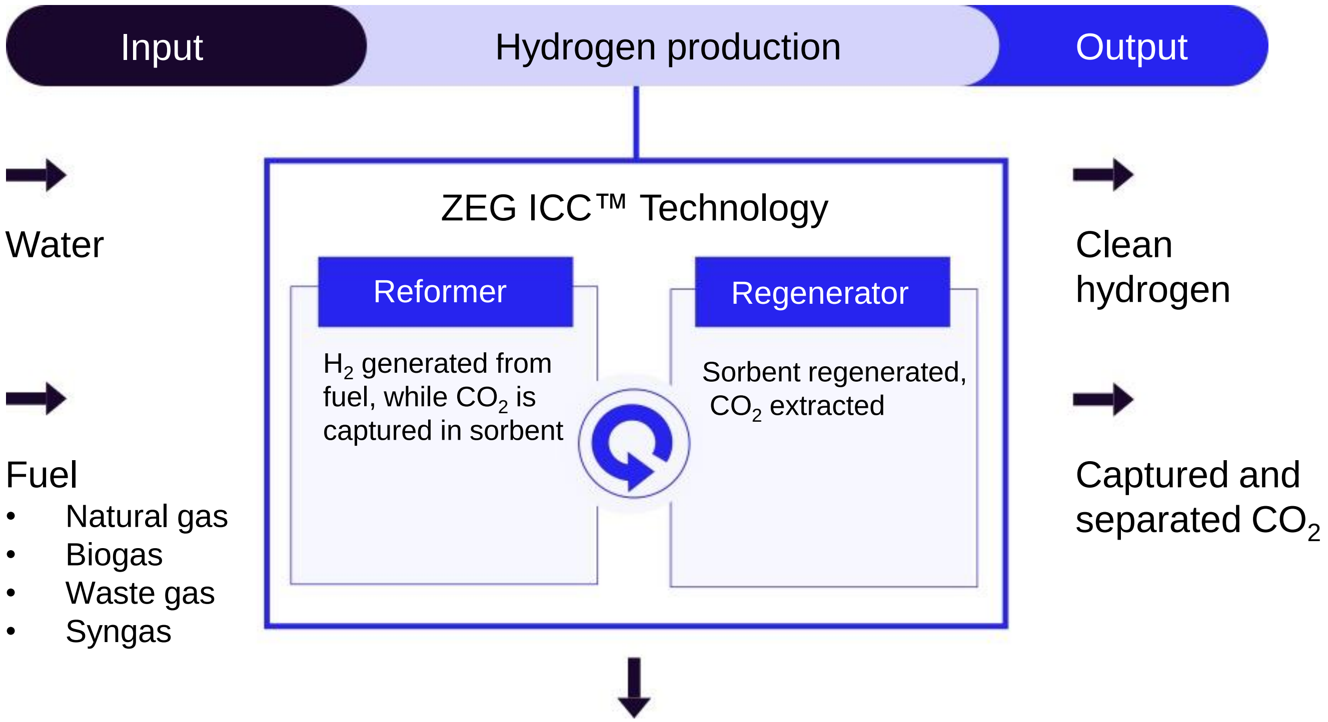
APVentures ADVANCE & PIONEER · SPARX · nysnø Climate Investments · IFE · STATKRAFT · Nordea ASSET MANAGEMENT · Danske Invest



[1] Dependent on plant configuration.
[2] At industrial scale, gas price USD 0.15 / kg (USD 4.0 / Mmbtu), electricity USD 60 / MWh, CO_2 transport and storage USD 25 / metric tonne,

ZEG Power offers an efficient technology

High yield clean hydrogen production with integrated CO_2 capture



Based on a sorption enhanced reforming technology for high-efficient hydrogen production where the key innovation is the introduction of a solid sorbent that allows for integrated CO_2 capture and separation

ZEG ICC™ Technology vs. conventional blue hydrogen

Eliminates four process steps compared with steam methane reforming with amine-based carbon capture

Process flow

Steam methane reforming w/carbon capture

Treated feedstock including fuel and water

1 Pre-reformer – Any hydrocarbons present in feedstock converted to methane

2 Reformer – Gas reformed at high temp. to produce hydrogen and mixture of CO, CO_2 and H_2O

3 HT shift reactor – High temperature shift to convert CO to CO_2 and hydrogen by excess steam

4 LT shift reactor – Low temperature shift to convert remaining CO to CO_2 and hydrogen

5 CO_2 absorber (MDEA)[1] – CO_2 capture using amine-based solvent

6 CO_2 stripper – CO_2 release and amine regeneration

7 Pressure swing absorber – Hydrogen purification to 99.999% hydrogen

Hydrogen

CO_2

ZEG ICC™ Technology

Treated feedstock including fuel and water

1 Reformer – Hydrogen production with Integrated carbon capture enhancing hydrogen yield

2 Regenerator – CO_2 release and solid sorbent regeneration

3 Pressure swing absorber – Hydrogen purification to 99.999% hydrogen

Hydrogen

CO_2

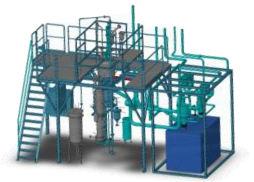
ZEG upscaling and development pipeline

On a clear path towards larger-scale plant realisation

→ 2020

ZEG Pilot Plant

22 kg H2/day



Partners:
Equinor • IFE • Innovation Norway • Climit • The Research Council of Norway

2021/22

ZEG H1 Plant

1 tonne H2/day

Partners:
CCB Energy Holding • H2 Production • Enova • Norsk Energi • GEXCON • Zeton

2023/24

ZEG H15 Plant

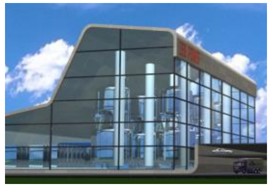
15 tonnes H2/day

Partners:
CCB Energy Holding • H2 Production
EPCI partner to be concluded

2025 →

ZEG H600 Plant

600 tonnes H2/day

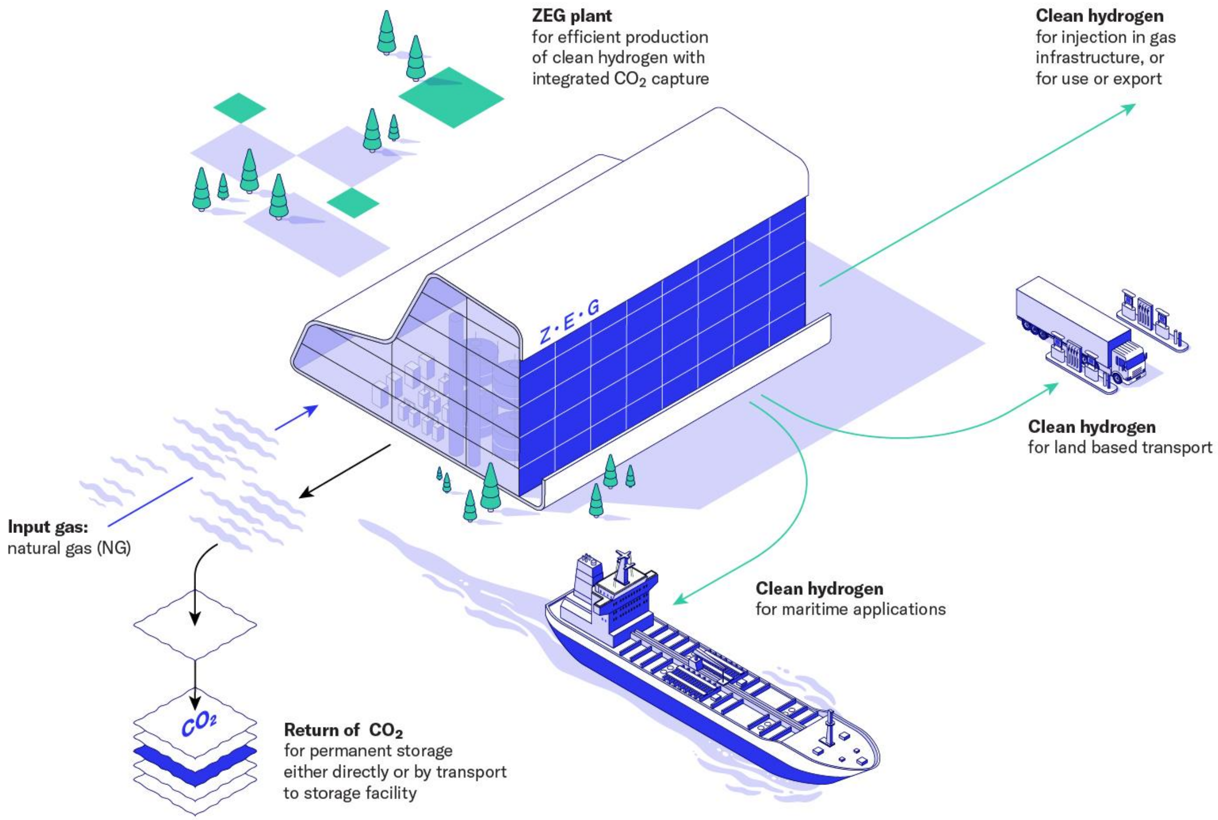


Partnership model to be investigated and concluded

Typical target market / hydrogen users:	Refueling station/1.000 hydrogen cars	Trucks or maritime/15 mid-distance ferries	Typical ammonia plant / industrial users
CO_2 captured :	6 ton/day ~ CO_2 emissions 1.000 cars	100 ton/day ~ CO_2 emissions 15.000 cars	5.000 ton/day ~ 600.000 cars

ZEG Clean Hydrogen Solution

Sustainably unlocking the value of natural gas

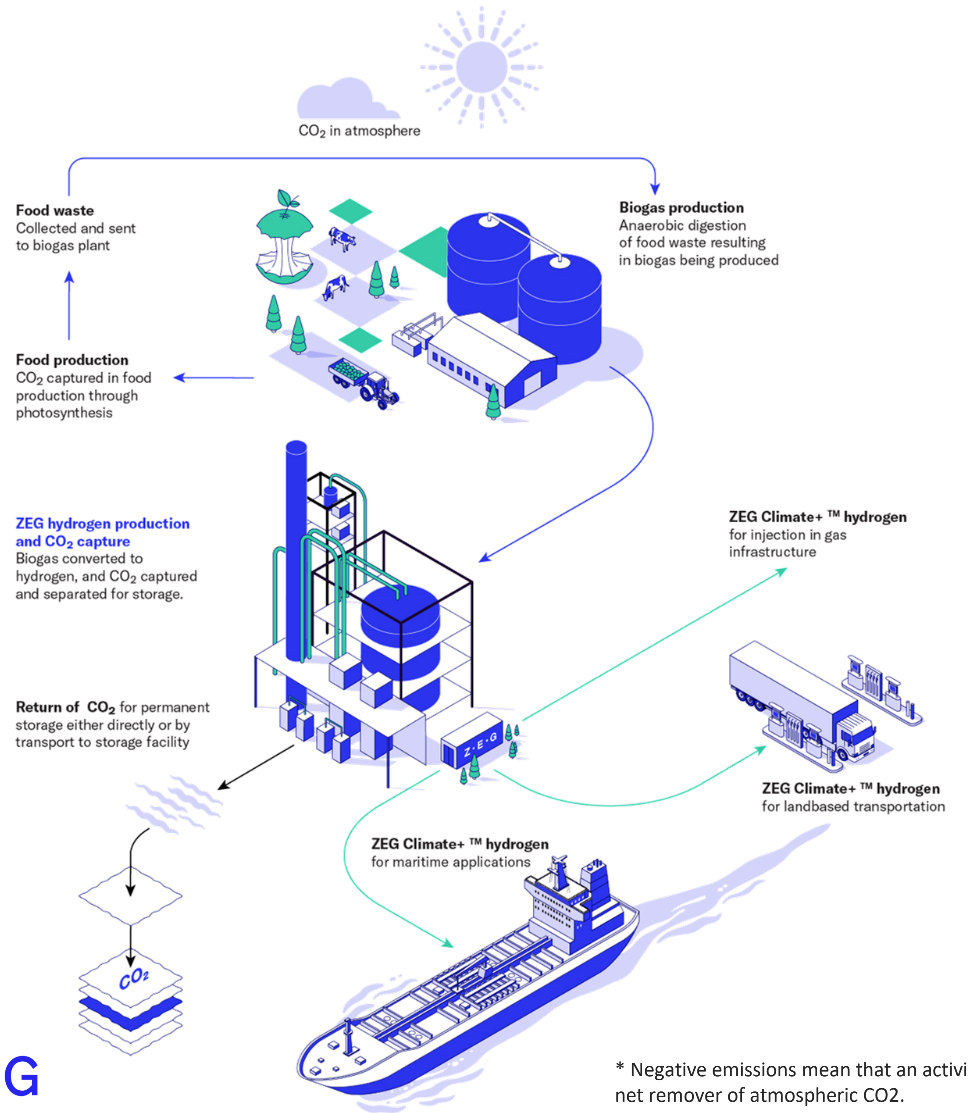


- increased CO_2 capture rate
- increased overall efficiency
- non-toxic CO_2 capture sorbent
- reduced plant footprint
- low cost of hydrogen

Z·E·G

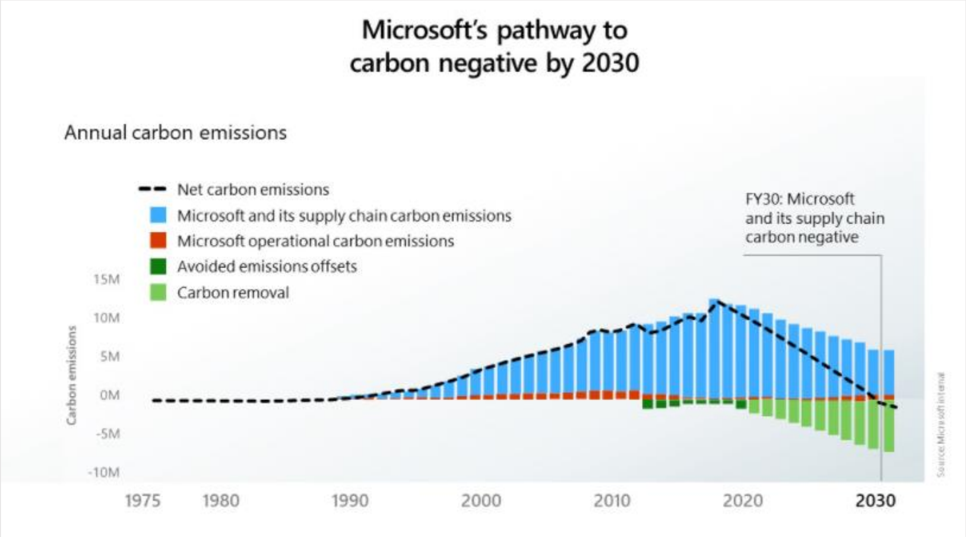
ZEG Climate+ Solution

Using biogas enables negative emissions*



Approaches to remove CO2 as defined by Microsoft:

- Forestry and soil-based projects, 100 years, short-term solution
- CO2 utilization, 100 - 1,000 years, medium-term solution
- Direct air capture w/CO2 geological storage, **long-term solution**



ZEG Climate+ Solution w/bio-CO2 geological storage
- a **long-term solution** for CO2 removal

Z·E·G

* Negative emissions mean that an activity is a net remover of atmospheric CO2.

First commercial ZEG plant under construction

H2 Production AS Customer of first ZEG H1	**Q4 2022** Production ready
ZETON Signed EPC contract	**NOK 77m** Supported by Enova grant


ZEG Power and CCB enters into strategic cooperation to establish cost efficient, clean hydrogen production from gas at Kollsnes

September 19, 2019 / in Aktuelt @en, News / by zegpower

[Bergen 19 September 2019] In accordance with a mutual desire to promote cost efficient, clean and sustainable energy, ZEG Power and CCB today announced the signing of a Letter of Intent (LoI).

Photo: Morten Wanvik

Finansavisen

Får 77 Enova-millioner til karbonfangst

ENOVA

ZEG Power og CBB får tildelt støtte fra Enova til utslippsfri hydrogenproduksjon og karbonfangst.

LAGER NYTT ANLEGG: Hydrogenproduksjonen skal gjøres ved CCB Energy Park.

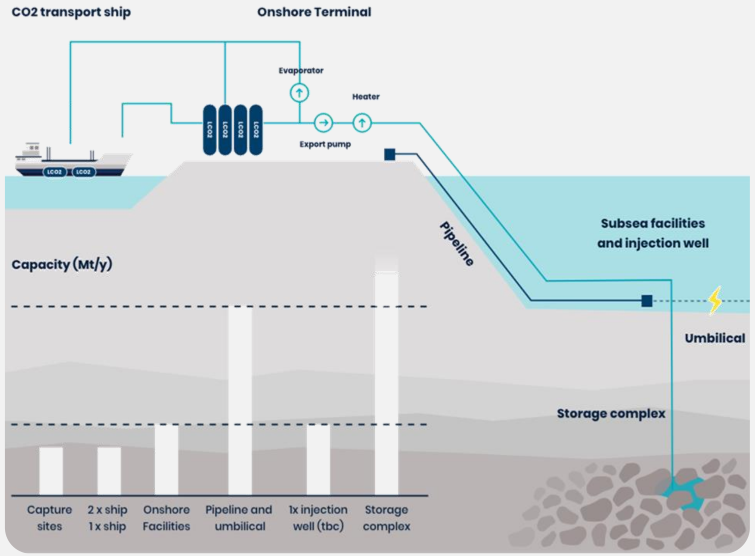
ccb energy holding

Z·E·G

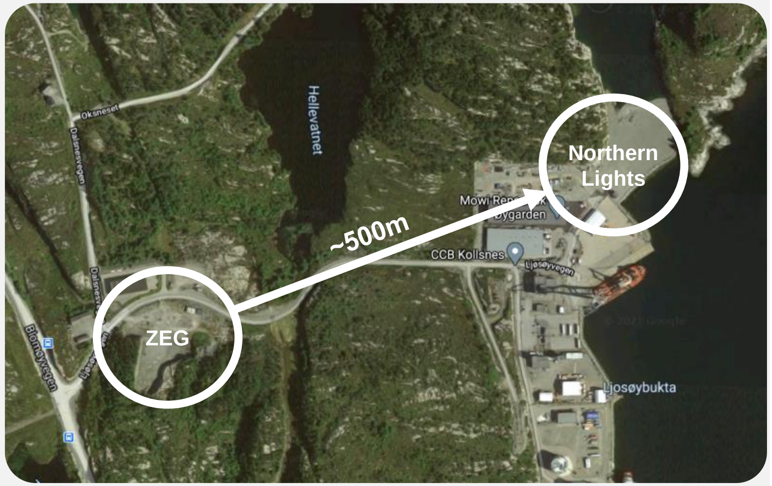
First plant to be co-located with Northern Lights

Northern Lights CO_2 terminal located 500m away from ZEG hydrogen production site, at CCB Energy Park

Northern lights project



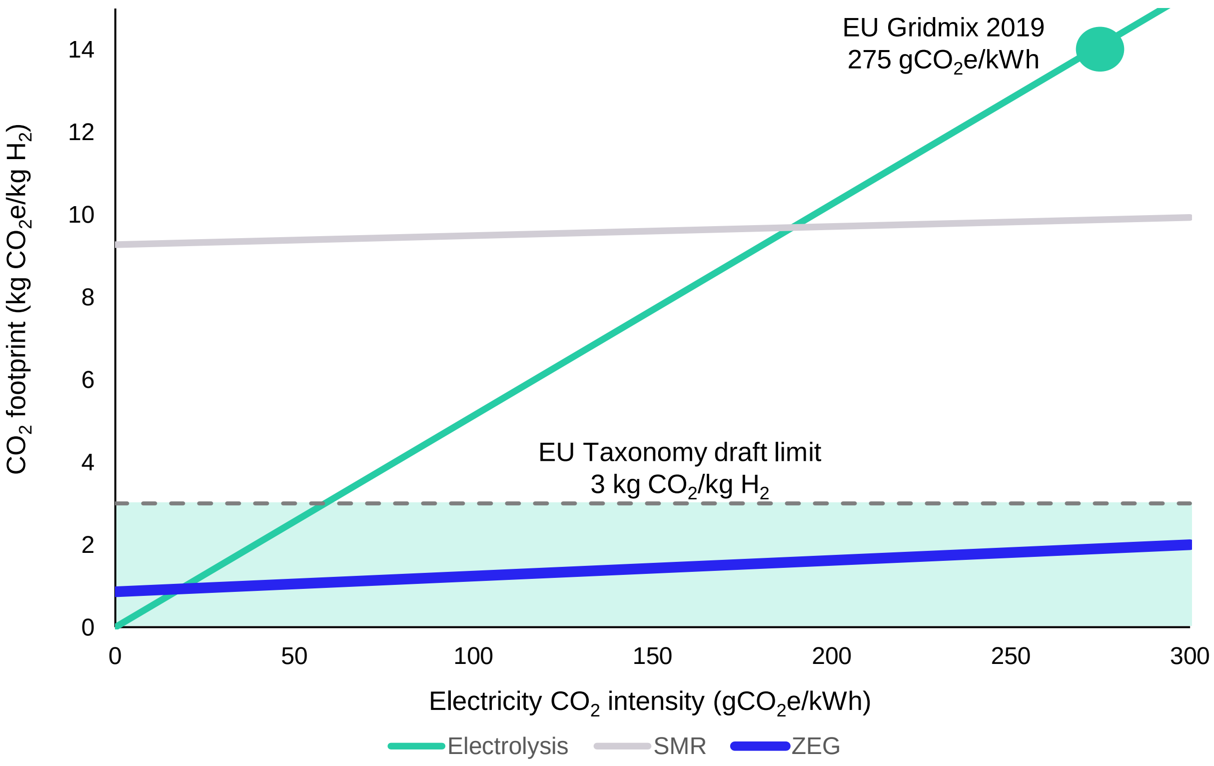
Proximity to CO_2 offtake



Strong local hydrogen market

ZEG provides clean hydrogen

CO_2 emissions well below draft limits in the EU Taxonomy



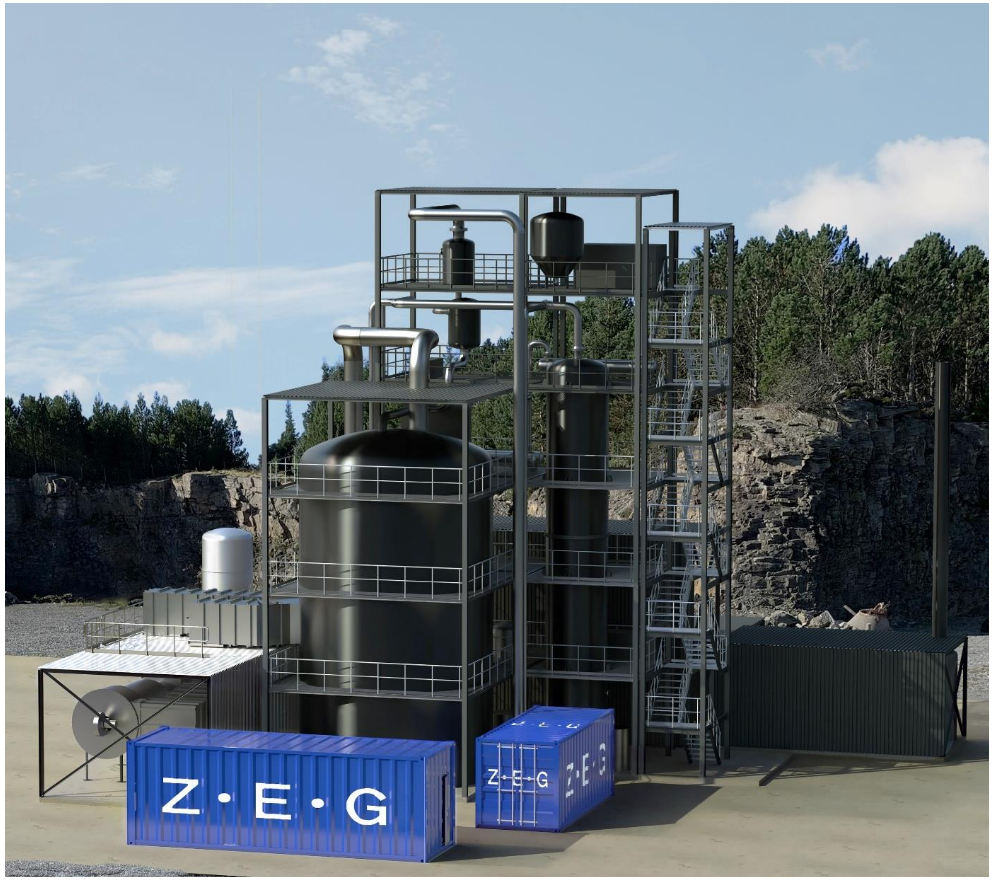
- The **EU taxonomy** is a classification system, establishing a list of environmentally sustainable economic activities
- The taxonomy will apply from January 2022 with limit of **3.0 kg CO_2e / kg H_2** for clean hydrogen production
- The CO_2 footprint of the ZEG technology is based on company estimates of well-to-gate emissions for an H15 plant using natural gas delivered to the UK.
- In general, the CO_2 intensity will depend on the exact specification of the plant and the source of the natural gas and electricity

Z•E•G

Sources: DNV GL: ZEG Power H2 technology comparison (2020). EU Grid mix 2019 from European Environmental Agency.
Key assumptions: Up, mid and downstream emissions from natural gas production 3000 g CO_2e / GJ Natural Gas. Statoil: Greenhouse gas emissions along the Norwegian gas value chain in 2016 (2016). Electrolysis 51 kWh / kg H2.
New version of the EU taxonomy is now available on the EU website: https://ec.europa.eu/info/publications/210421-sustainable-finance-communication_en

Summary

- ZEG enables clean hydrogen form natural gas due to pre-combustion carbon capture
- Technology developed over 20 years from the lab at IFE to commercialization now at CCB Energy Park, Kollsnes, and the roadmap to further scaleup is defined
- CCB Energy Park is a “sweet spot” location for ZEG plants, adjacent to gas terminal and Northern Lights CO2 storage
- Carbon removal an opportunity through ZEG Climate+ Solutions



Z•E•G

Now let's make a change

Baker Hughes

Compact Carbon Capture

A Baker Hughes Venture

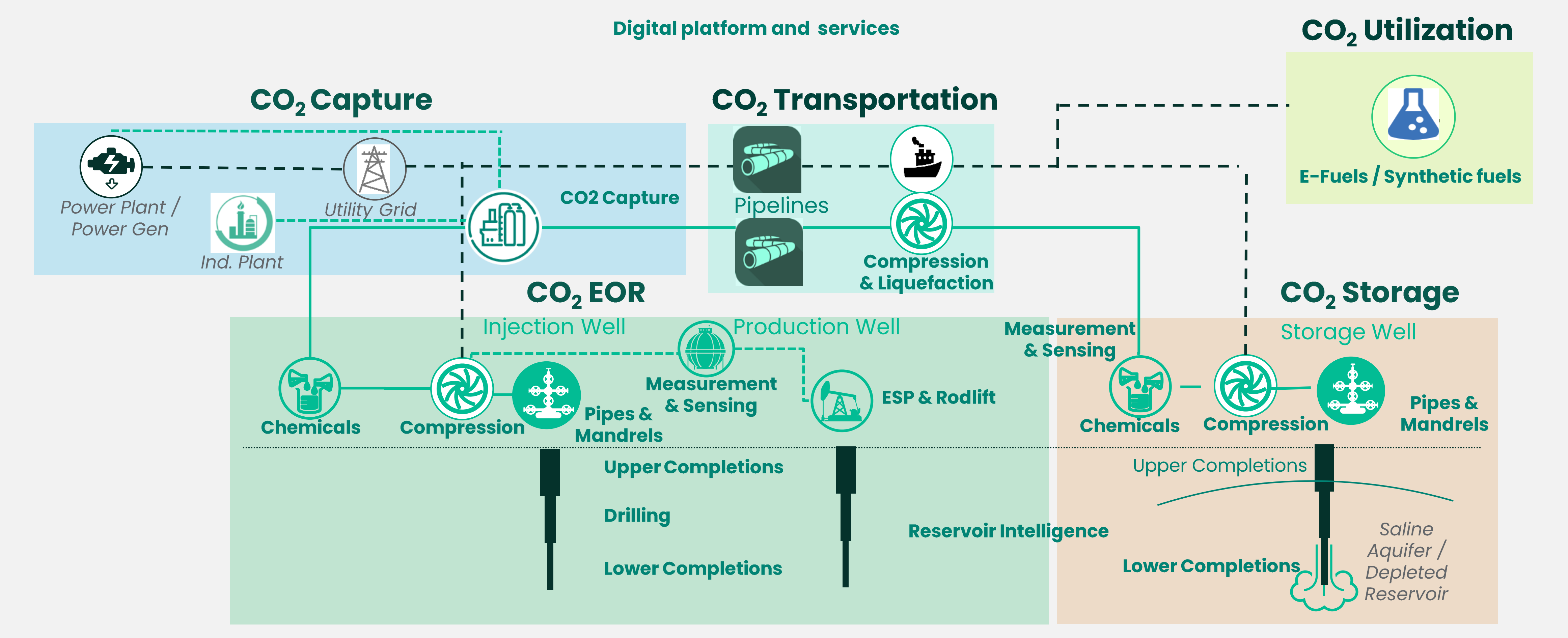
Norwep Presentation

Torleif Madsen

November 9th, 2021

Baker Hughes positioning in the CCUS value chain

A broad portfolio of technologies and expertise to unlock the CCUS market leveraging innovative solutions and business models across all or parts of its value chain



Baker Hughes

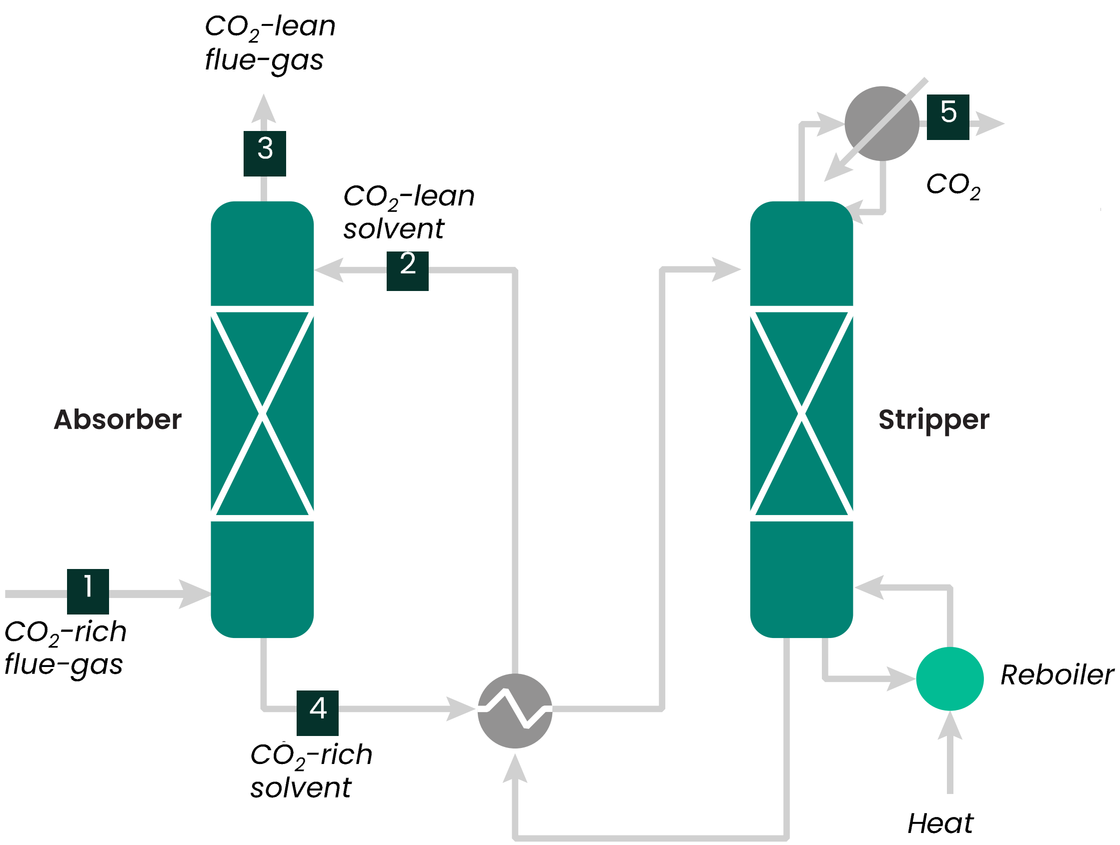
Three CO_2 capture technologies

Process technology		Readiness level	Key features
Chilled Ammonia Process (CAP) Solvent: ammonia-based		1 2 3 4 5 6 7 (green) 8 9 (dark)	Releasing CO_2 at high pressure: • Reducing compression needs • Allows for direct liquefaction Sustainable solvent: • Widely available/commodity • No thermal and oxidative degradation • Environmentally friendly effluents Controllable emissions to atmosphere Tolerant to flue-gas contaminants (NOx, O_2, etc.)
Mixed Salt Process (MSP) Solvent: potassium-based with ammonia		1 2 3 4 (green) 5 6 7 8 9 (dark)	

* ongoing

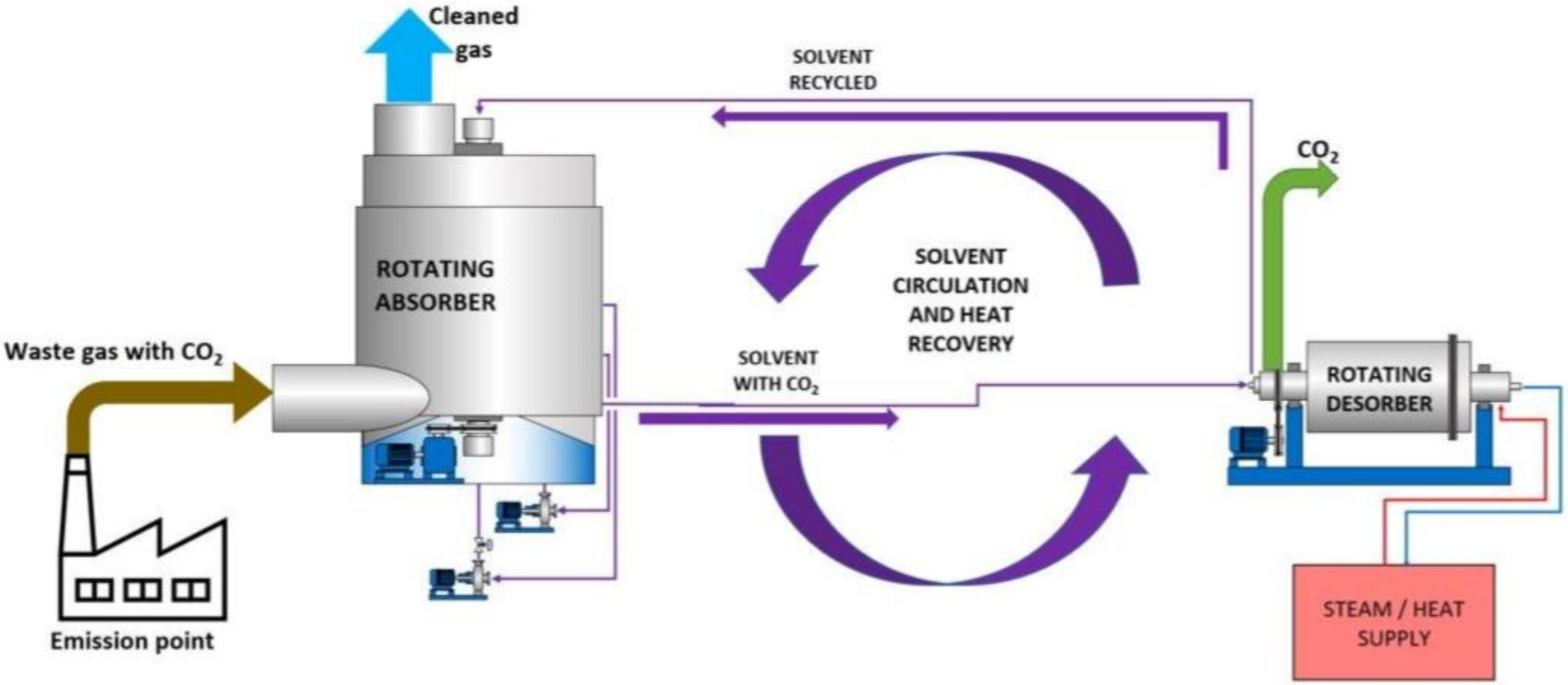
Solvent-based post-combustion carbon capture

- Cyclic and continuous absorption/ desorption process using an aqueous solvent (e.g. MEA)
- In the absorber, CO_2 rich flue gas is treated by a CO_2-lean solvent that has the ability of capturing CO_2
- The CO_2-lean solvent, after being enriched in CO_2, is discharged as CO2-rich solvent from the Absorber
- The CO_2-rich solvent is regenerated into CO_2-lean solvent in the Stripper while releasing CO_2



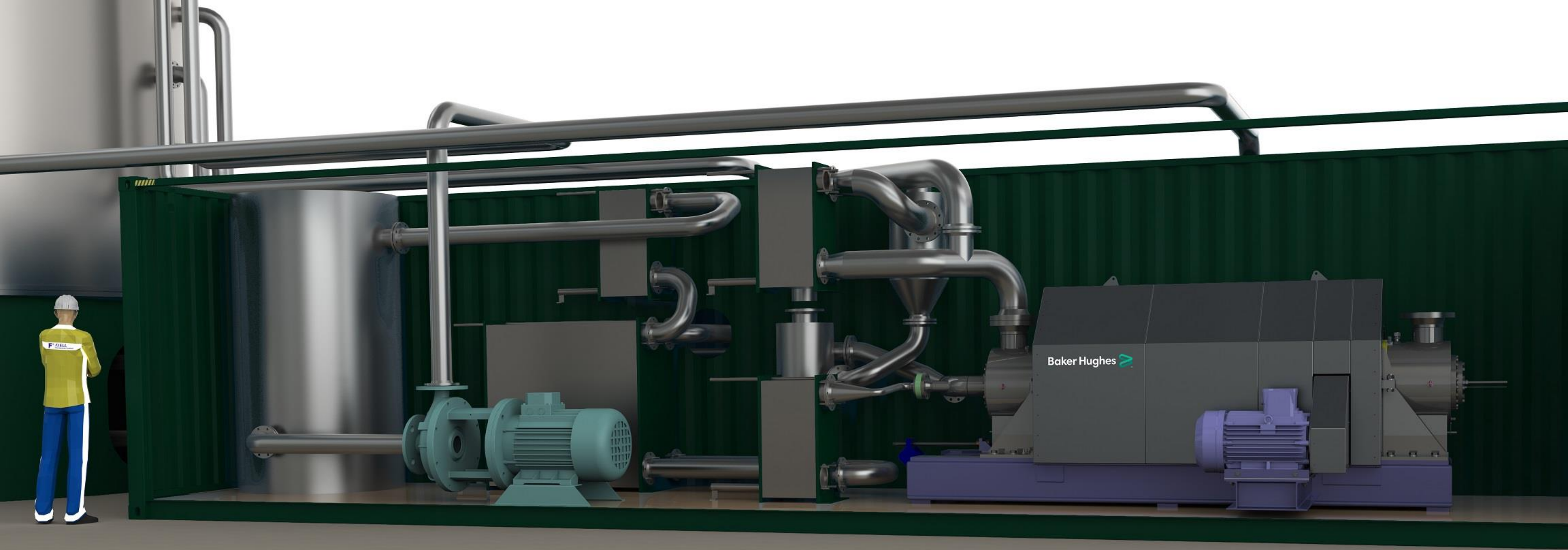
Baker Hughes

Process intensification by high speed rotation



Baker Hughes

Baker Hughes



3C tech differentiation vs traditional carbon capture solutions

- Centrifugal force replaces the gravity force for the gas/liquid contact by means of rotating beds
- Absorption and desorption columns are substantially smaller than traditional ones
- Can enable smaller footprint or a Modular and scalable configuration

7

Test facility

- Pilot test facility located in Porsgrunn, Norway
- Both absorption and desorption steps can be tested
- Testing is possible with simulated flue gas
- ca. 5tpd CO_2 capacity, depending on inlet 10%CO_2

Baker Hughes

The industrial plant is scalable through modularization

Baker Hughes

Enabling Large Scale CO^2 Capture by Solving the Transport & Storage Challenge

NORWEP Energy Symposium 2021 – H2/CCS

Digital, November 10th, 2021

Craig Harvey | Aker Solutions

Solving Challenges for 180 Years




1841 The ability to **transform** is in our DNA **2021**

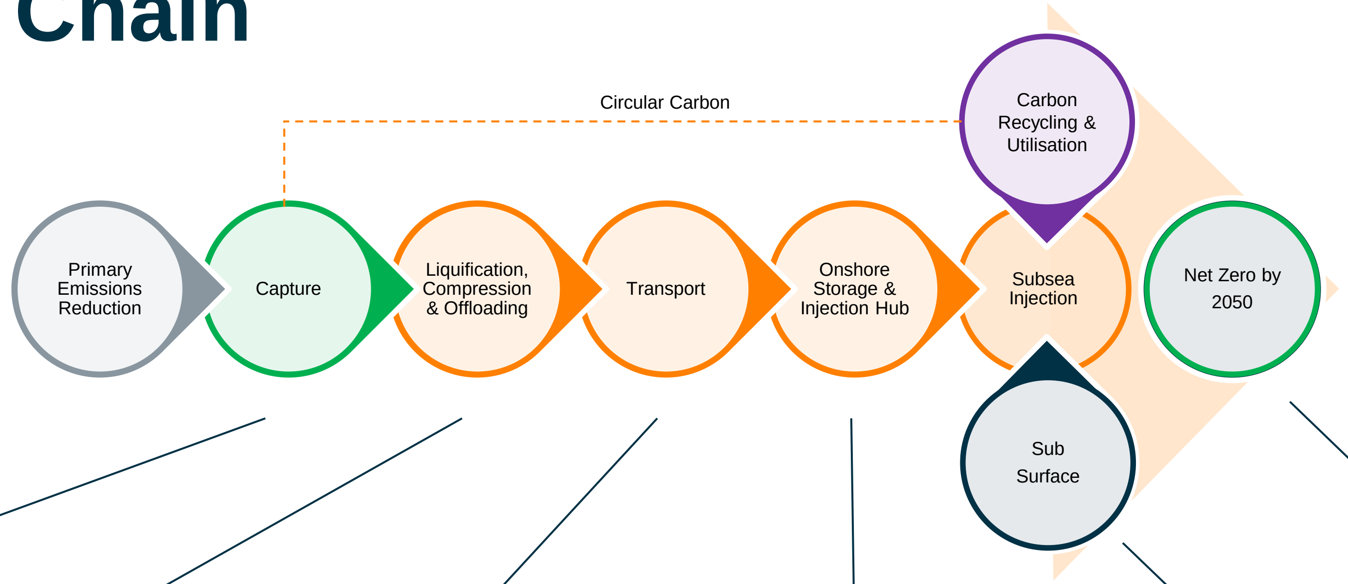

We solve global
energy challenges
for **future** generations
AkerSolutions

The CCS Challenge

Getting CO2 from **A to B** since **1996**

AkerSolutions

CCUS Value Chain



Integrate & Deliver EPC & BoP To Capture CO2 using selected Technology

Capture Technology

Prepare captured CO2 for transport

Transport CO2 from Capture hub to Storage hub

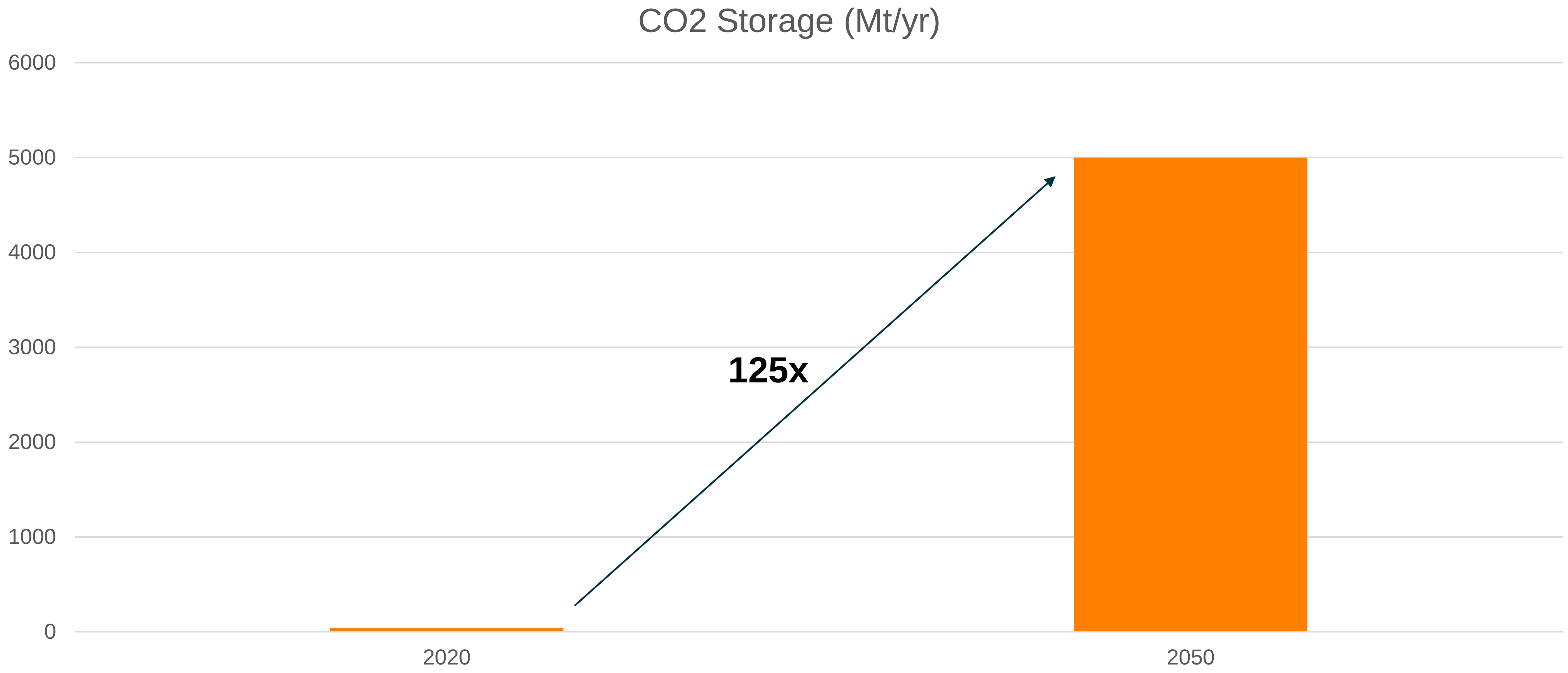
Prepare Large Volume CO2 for Permanent Storage

Inject & Store CO2 permanently offshore

Recycle CO2 to create sustainable value

Utilisation Technology

Global Need for CO2 Storage (Onshore & Offshore)



Drivers: Large Scale = Cost Down

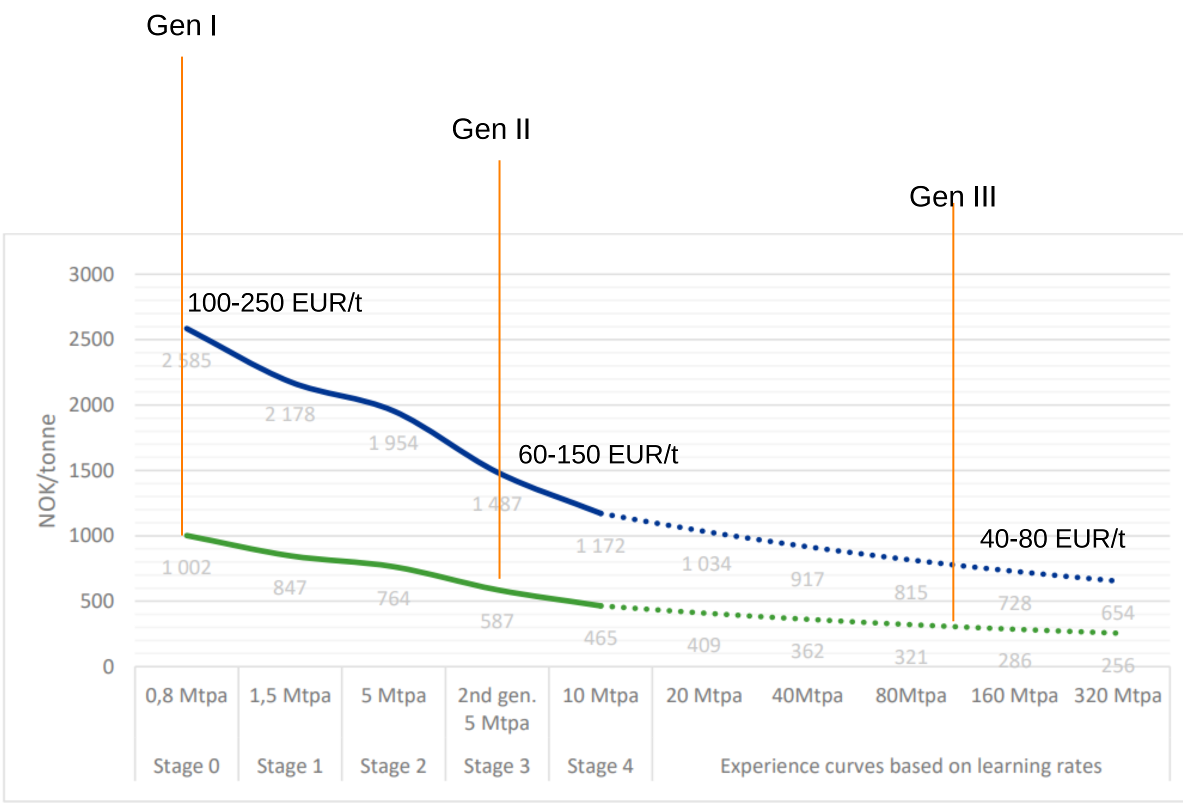
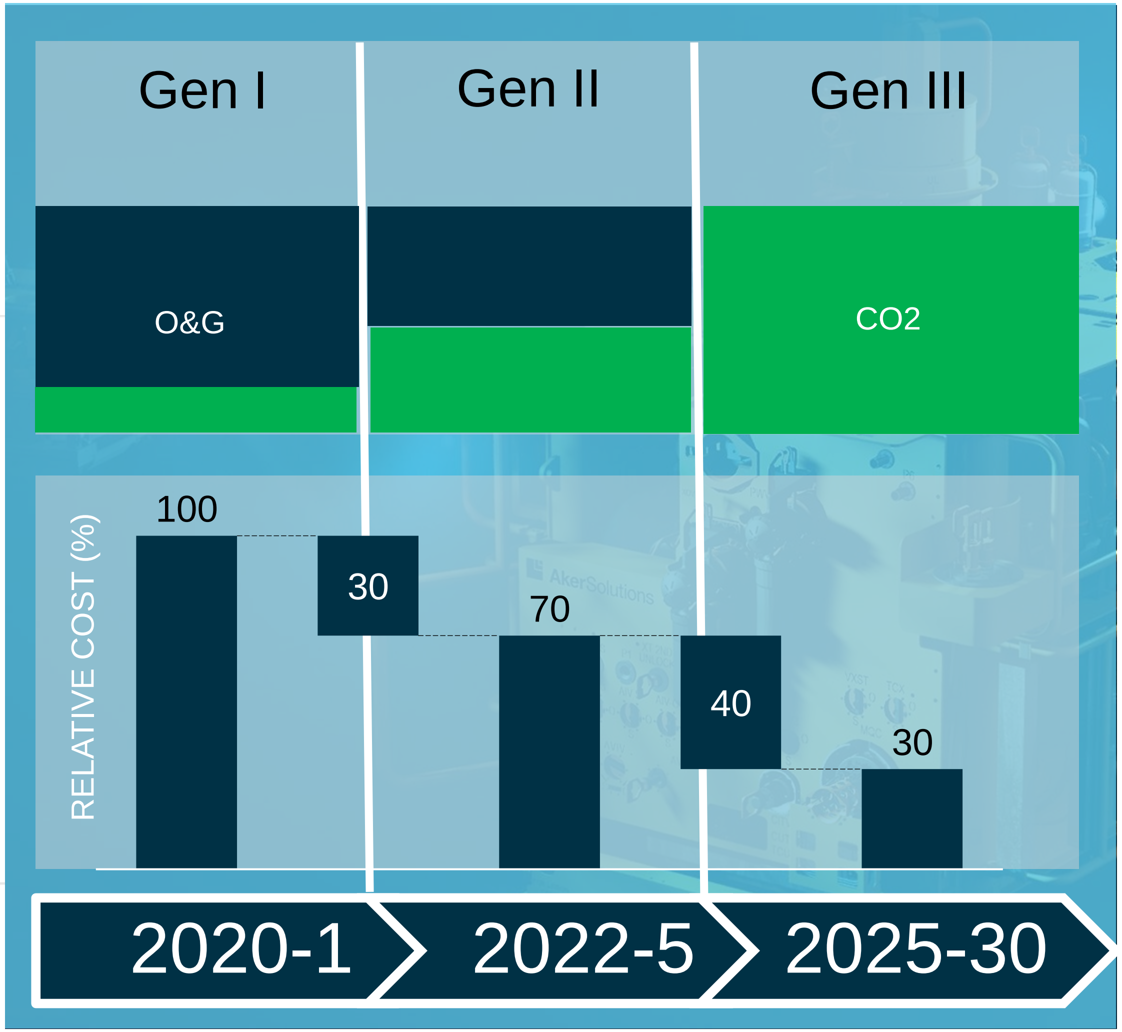


Figure 1 - Cost reductions estimates from capacity utilization increase, optimization and learning for increased CCS capacity. Investors perspective (high curve) and Norwegian Environment Agency method (low curve)



The CCS Challenge

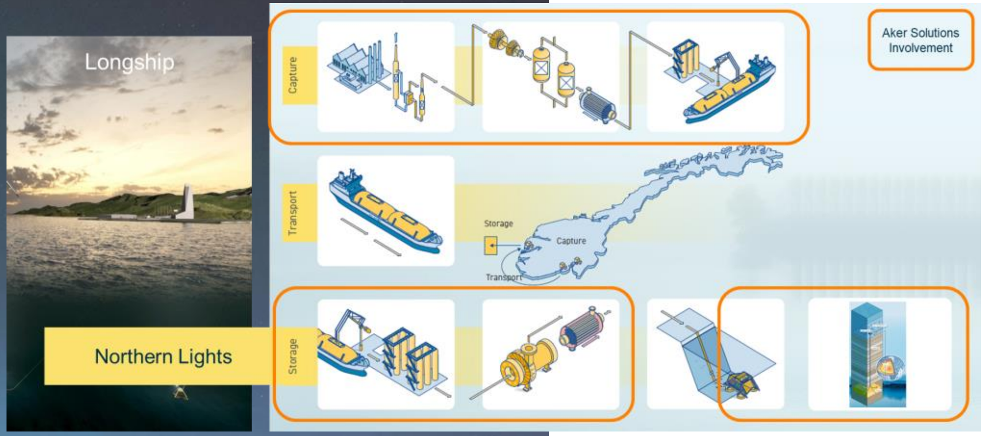
Getting CO2 from **A(1-N) to B**

Northern Lights: An international benchmark

What do we need to scale to 2050@2050

- Complete Source to Sink Offering
- A CO2 Offloading & Distribution Network
- All electric systems
- Cost effective direct injection offshore
- CO2 Permanent Storage Network

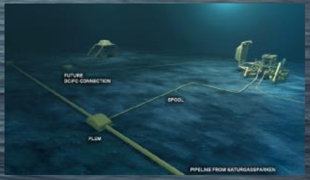
At a scale amounting to 1 Northern Lights equivalent per week!

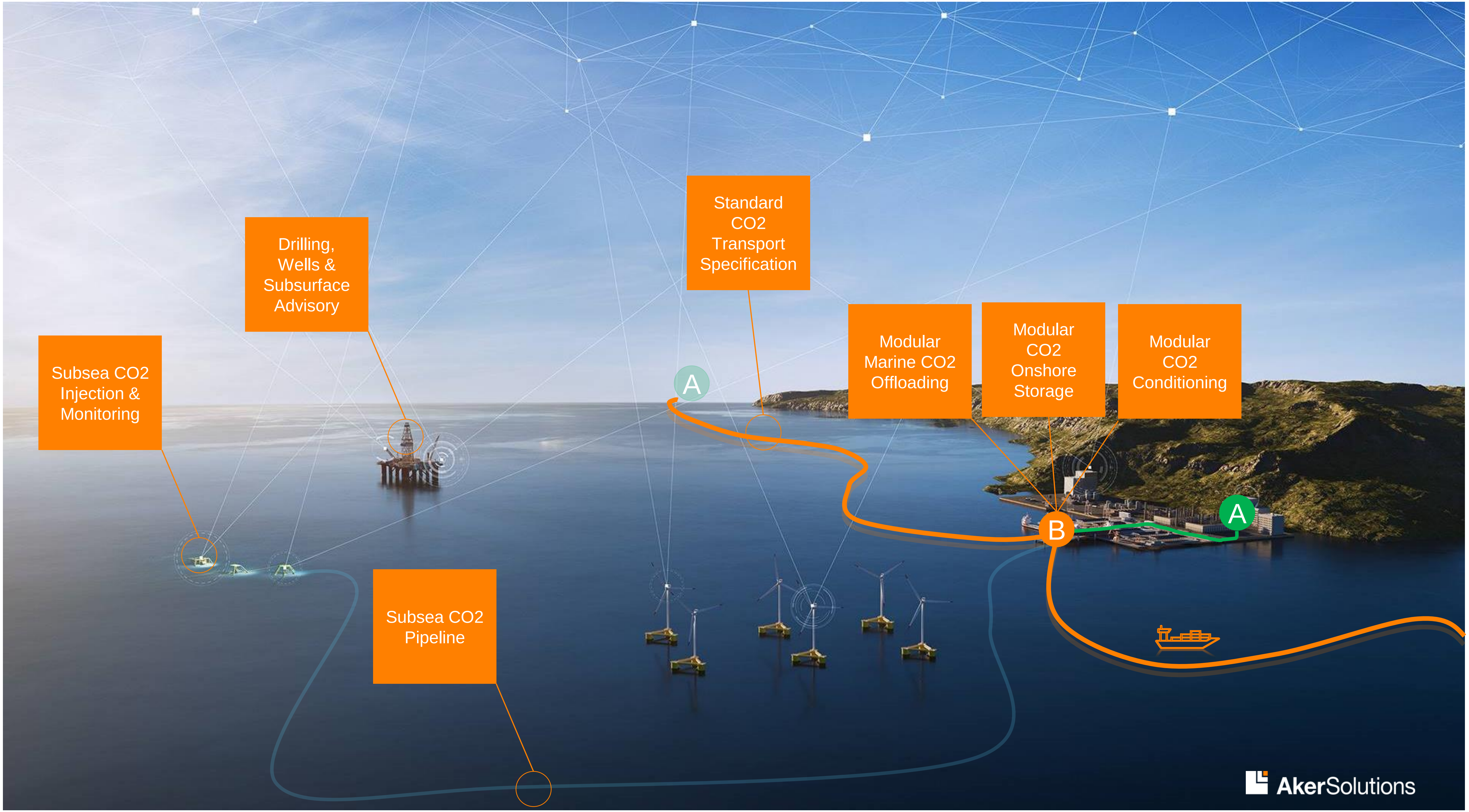


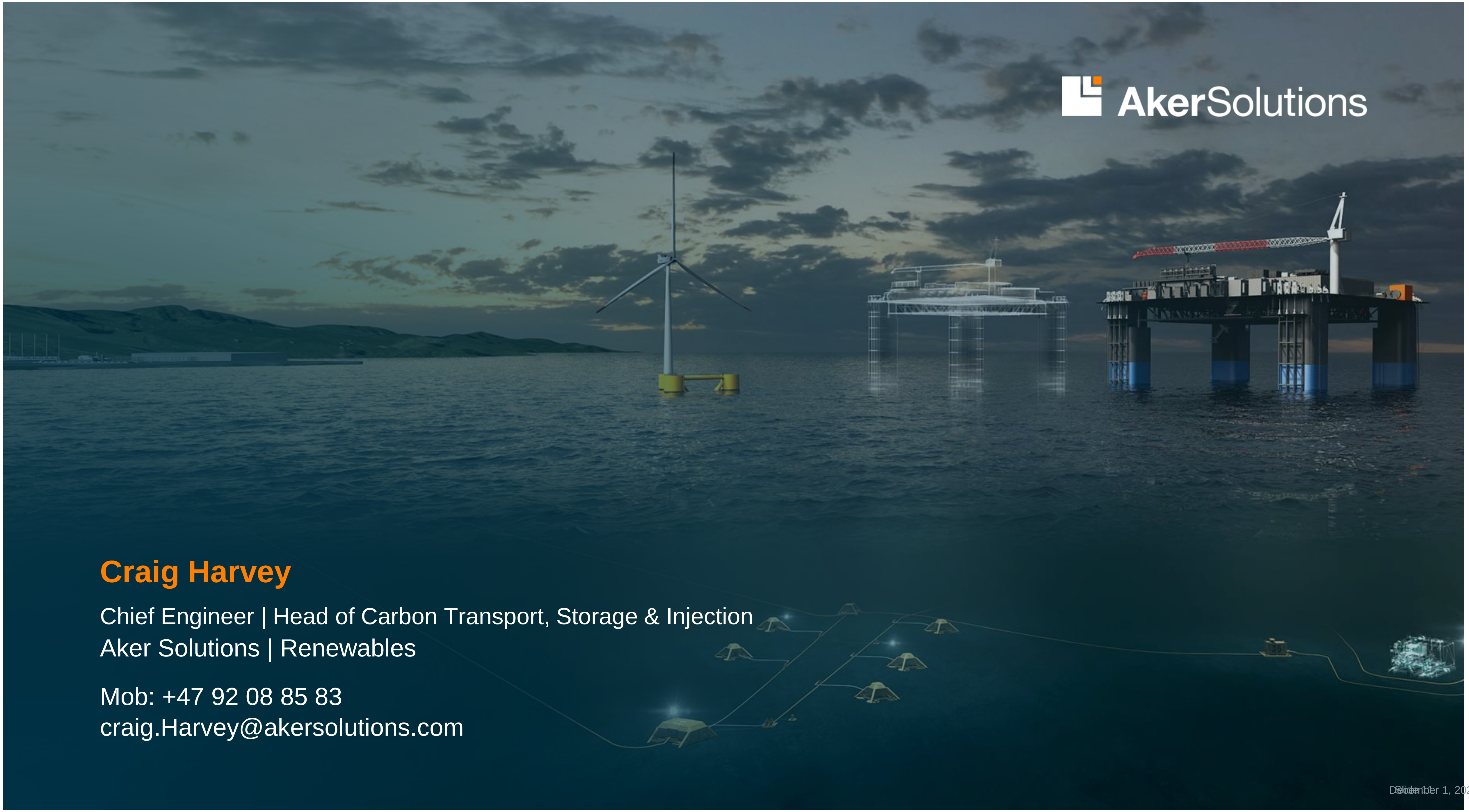
Transport Hub (Marine) → Monitoring → Intermediate Storage → Conditioning for Injection → Compression & Pumping → Metering → Pipeline Interface → Thermal Optimisation → Offshore Injection System → Well Monitoring → Injection Optimisation


Photo: Equinor

Source to Sink Optimisation
Downstream Capture to Subsurface Storage
Process Debottlenecking




Standard CO2 Transport Specification
Drilling, Wells & Subsurface Advisory
Subsea CO2 Injection & Monitoring
Modular Marine CO2 Offloading
Modular CO2 Onshore Storage
Modular CO2 Conditioning
A
B
A
Subsea CO2 Pipeline
AkerSolutions



Craig Harvey

Chief Engineer | Head of Carbon Transport, Storage & Injection
Aker Solutions | Renewables

Mob: +47 92 08 85 83
craig.Harvey@akersolutions.com

AkerSolutions

Copyright and Disclaimer

NOV: CCUS Offering

November 2021

NOV at a glance

579
Locations worldwide

$5.21B
Market capitalization

29,903
Employees

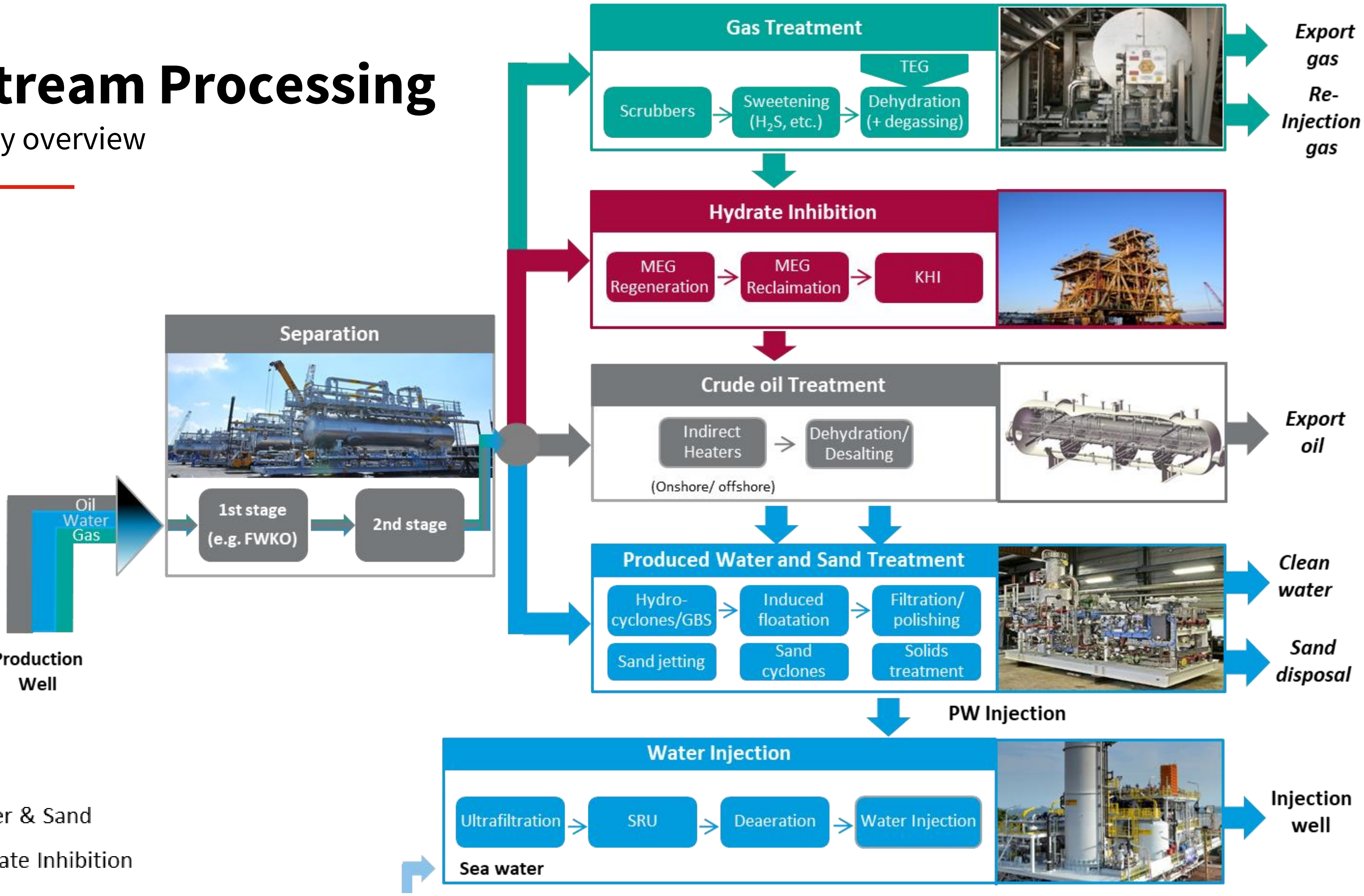
$7.04B
Annual revenue

61
Countries

200+
Acquisitions

Wellstream Processing

Technology overview



Gas

Oil

Water & Sand

Hydrate Inhibition

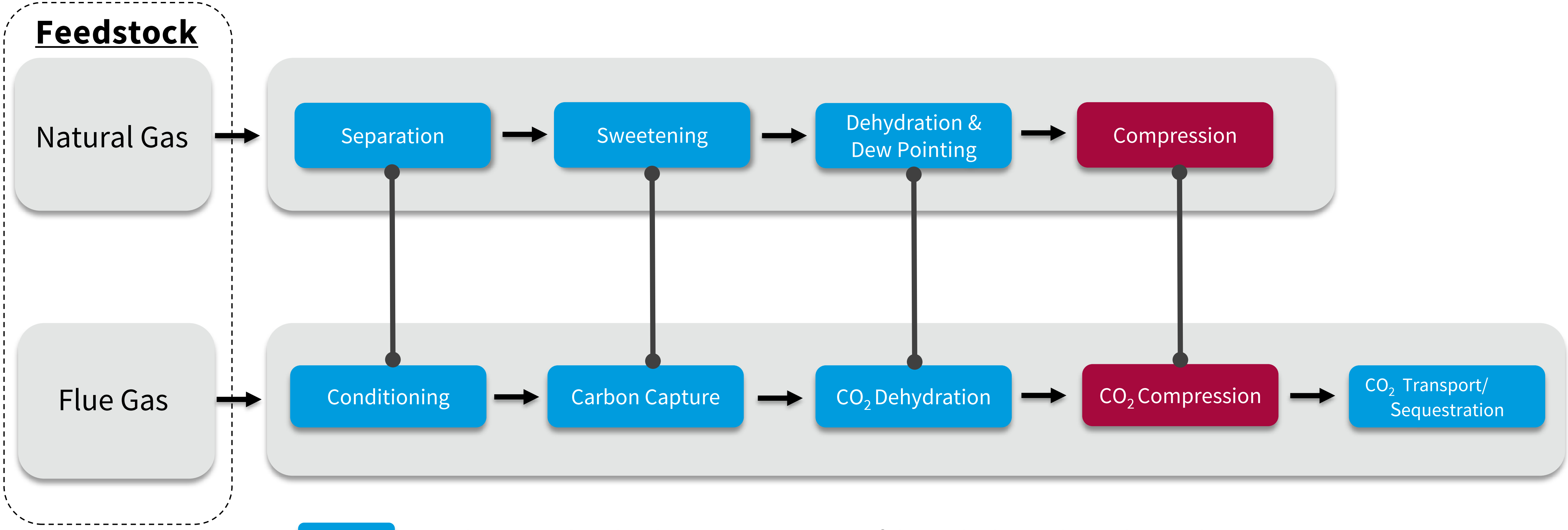
Wellstream Processing

Our History

- **1978** Kværner Process Systems is founded
- **1979** Merpro is founded
- **1989** First sale of TEG gas dehydration
- **1989** First PWT delivered
- **1990** Kværner acquires Paladon
- **1993** Tore™ sand handling technology is patented
- **1994** Petrex is founded
- **1997** First sale of MEG reclamation system
- **2000** First sale of Sulfate Removal Unit
- **2002** Kværner and Aker Merger
- **2011** NOV acquires Merpro
- **2012** NOV acquires Petrex
- **2013** Opus Maxim and Separation Specialists were acquired
- **2014** Aker Process Systems renamed Fjords Processing
- **2015** NOV acquires ProFab fabrication yard
- **2016** NOV acquires Fjords Processing

Carbon Capture Utilization and Storage (CCUS) Offering

Transferability of our natural gas processing portfolio for CCUS



NOV has critical technology / equipment portfolio and relevant know-how in-house

NOV has part of the offering in-house and is establishing partnerships to offer the complete solution

Carbon Capture

Experienced gas processing systems provider

- Extensive technology portfolio for post-combustion carbon capture from various emission sources.

- Strategic collaboration with critical technology suppliers for:
  - Chemical solvents
  - Novel technologies

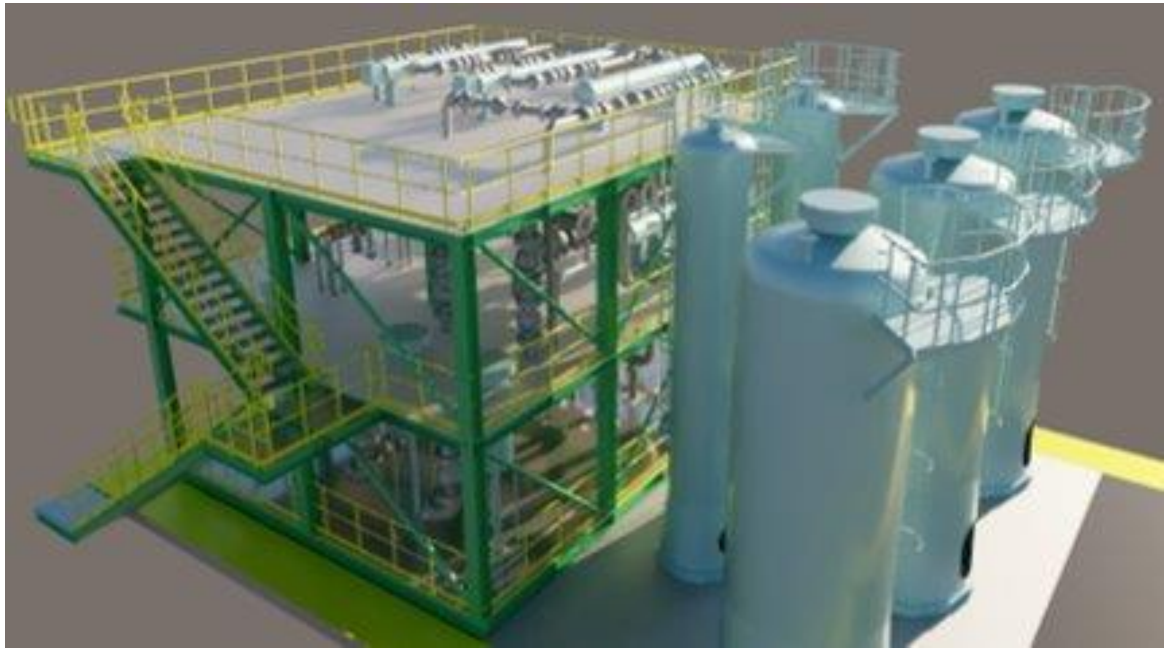
- Cost-efficient designs and effective execution models from process systems deliveries to the upstream oil and gas industry.

CO_2 Dehydration

Extensive technology portfolio

- TEG, molecular sieves, and silica gel
  - Industry-leading references for TEG dehydration systems
- 100 + projects executed – standardized design and cost-efficient execution model
- Optimized designs resulting in systems with lower CAPEX and OPEX costs.
- Technical studies to resolve challenges related to CO_2 drying in intermittent systems based on renewable energy sources.

Molecular sieves unit



TEG units

Composite Solutions

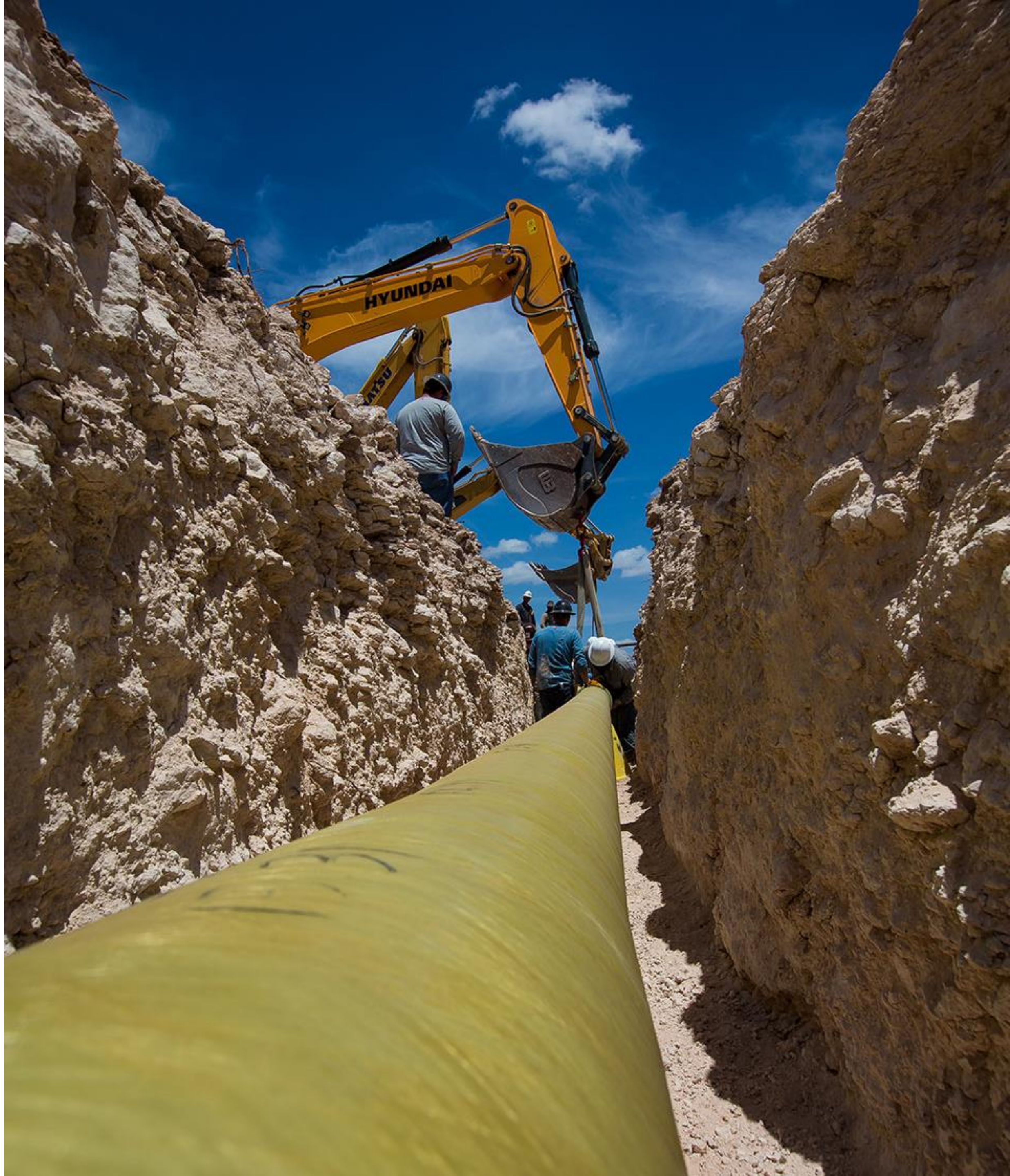
NOV offering for CO_2 transport

Advantages for CO_2 transport

- Excellent corrosion resistance—handles up to 100% concentrations of CO_2
- Require less energy to produce than carbon steel
- Superior smoothness compared to steel results in meaningful lower energy requirements
- GRE pipe has 50 years of proven use in CO_2 applications

Why can you trust us?

- Installation of millions of feet of composite pipe for CO_2 handling across the United States
- Largest global provider of GRE pipe in the world



CO_2 Offloading and Storage

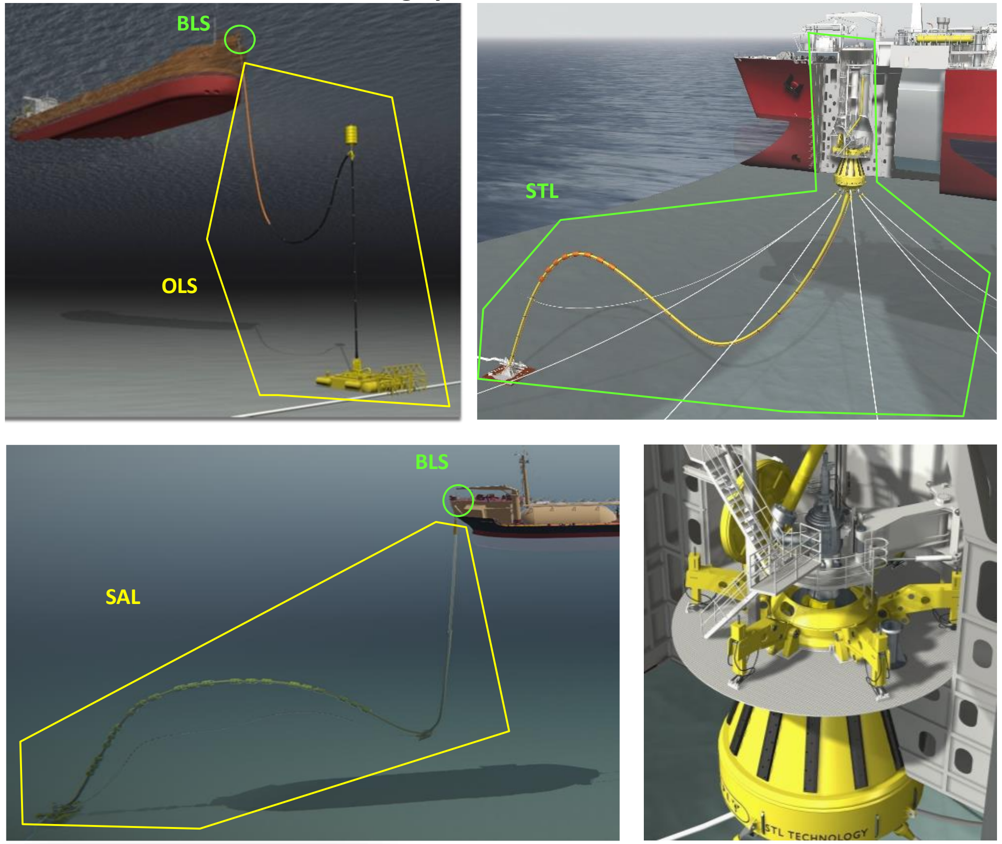
NOV offering for transport, injection and storage

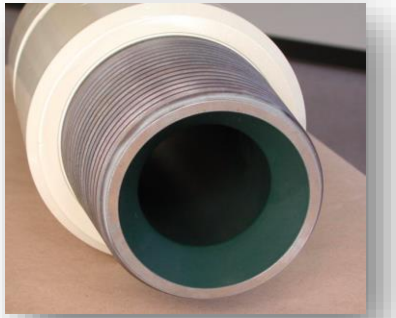
For the oil and gas production NOV delivers equipment for every aspect of the drilling process, and the same now applies to CO_2 injection and storage offering.

A sampling of our solutions for CCUS includes:

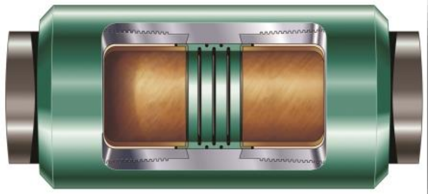
- For offshore applications: CO_2 static and dynamic high pressure flexible pipes, Offshore Loading System (OLS), Submerged Turret Loading (STL), Bow Loading System (BLS), Single Anchor Loading (SAL)
- Surface equipment: valves, actuators, separators, closures, oil in water monitoring
- Downhole drilling tools including full suite of BHA components
- Full drilling optimization services
- Max ™ data acquisition and visualization

Mooring systems and umbilicals





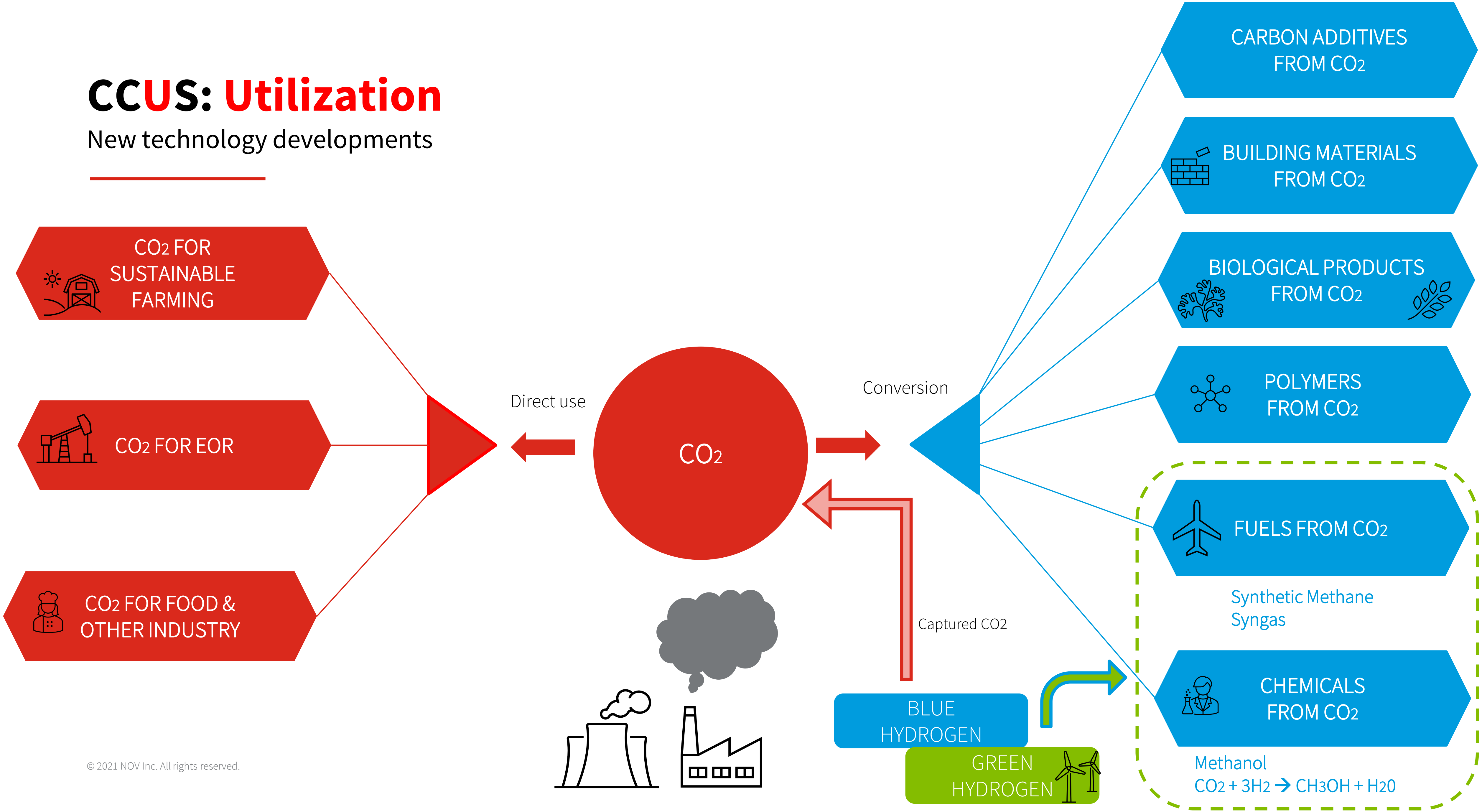
Drill Pipe Coating



TK Ring

CCUS: Utilization

New technology developments

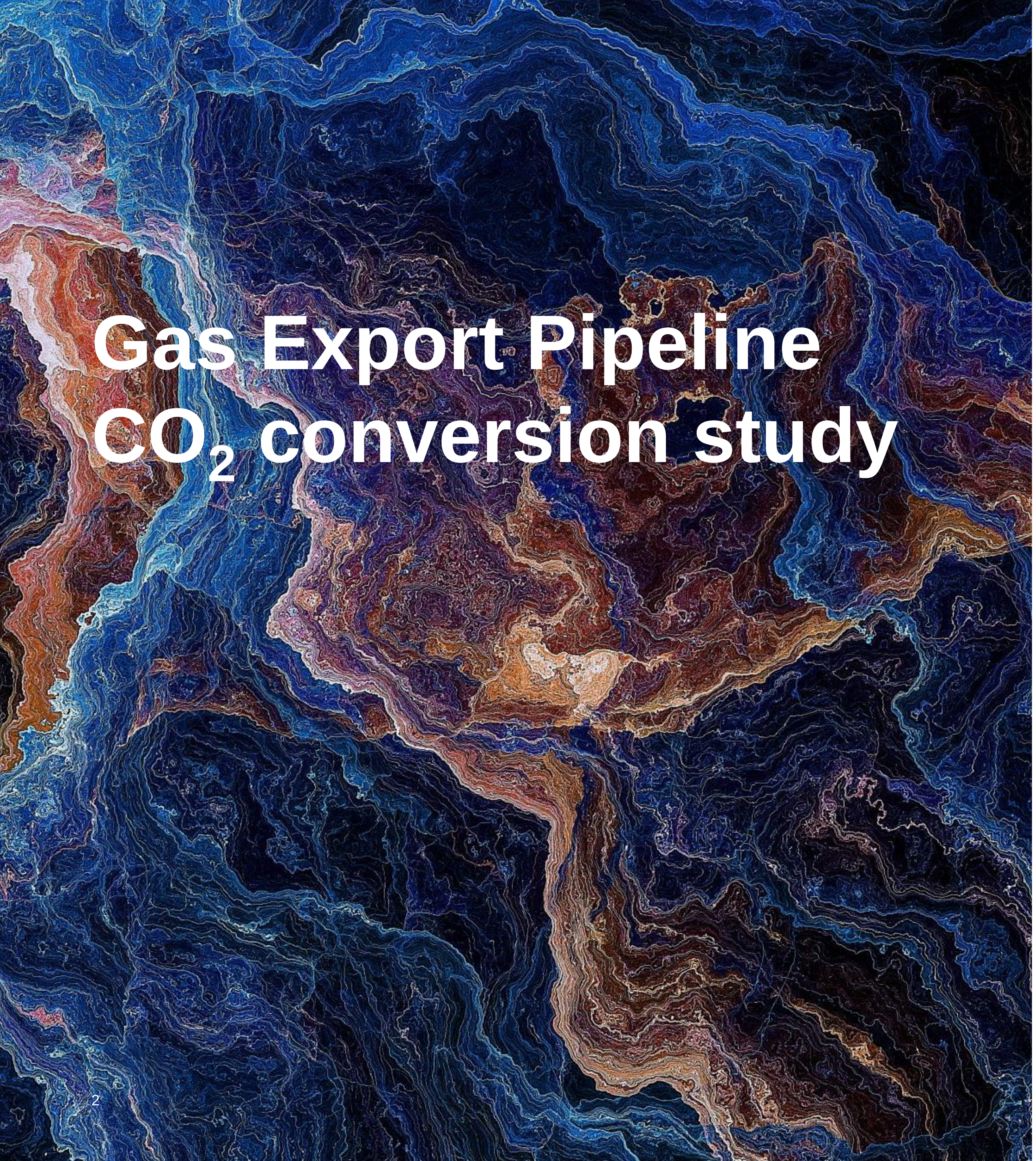


WHEN TRUST MATTERS

Gas Export Pipeline CO_2 conversion

Olivier Royet

10 November 2021



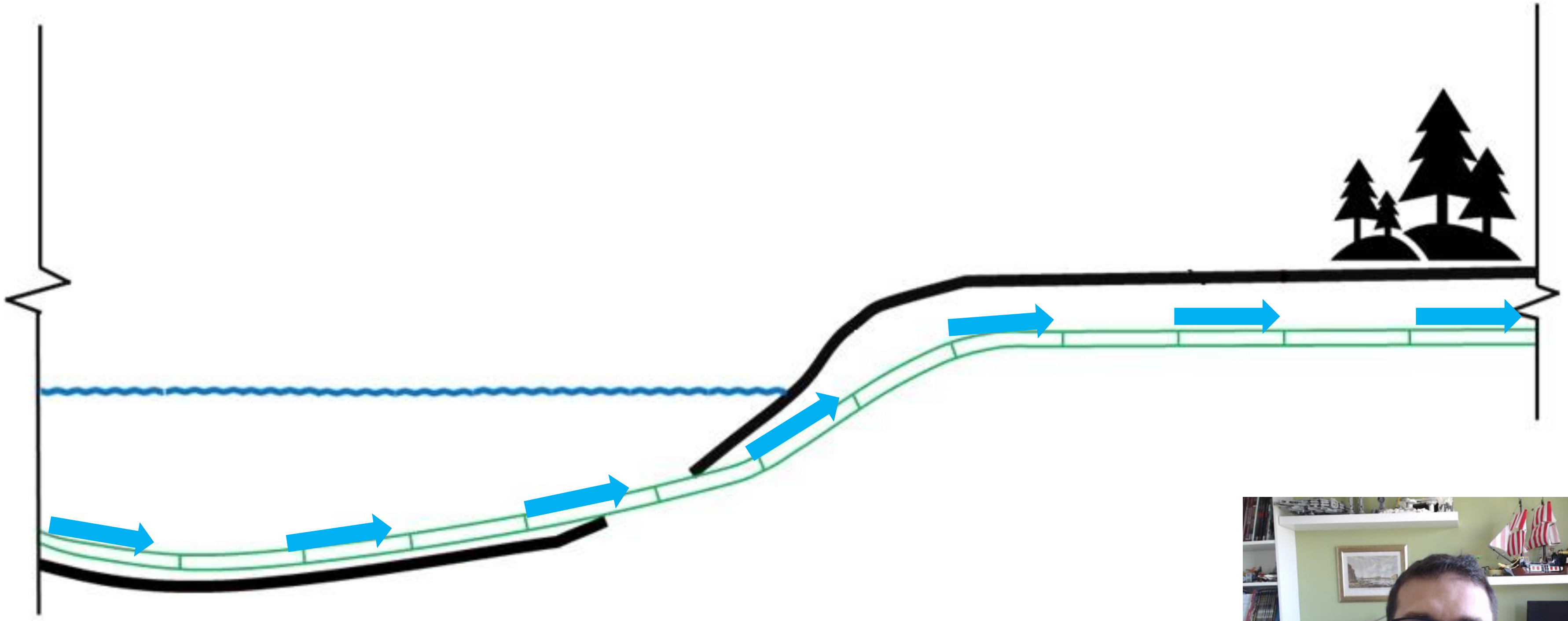
Gas Export Pipeline CO_2 conversion study

Agenda

- Introduction
- Safety and CO_2
- Fracture
- Corrosion
- Conclusion

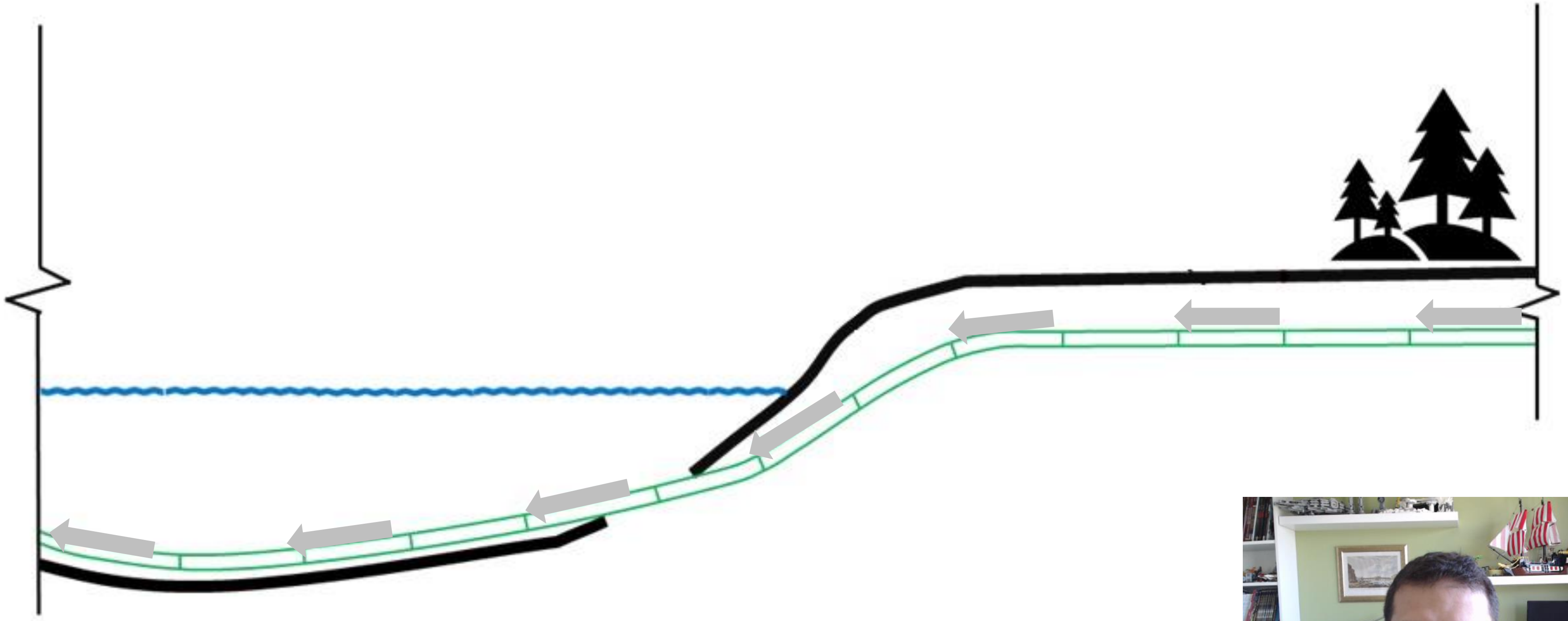
From hydrocarbon to CO_2 asset

- Gas trunkline
  - ✓ Natural Gas
  - ✓ Flow to shore



From hydrocarbon to CO_2 asset

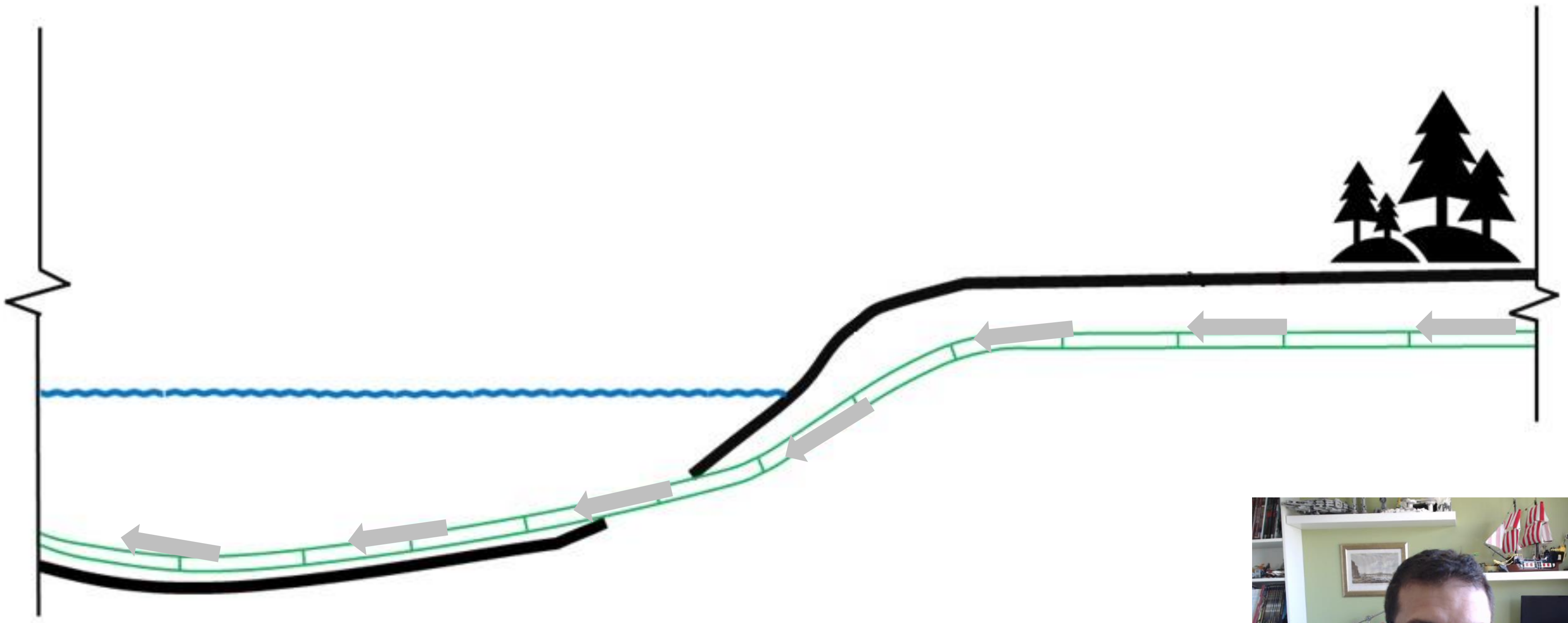
- Gas trunkline
  - ✓ Natural Gas
  - ✓ Flow to shore
- CO_2 trunkline
  - ✓ CO_2 multiphase
  - ✓ Flow to offshore
  - ✓ DNV-ST-F101



Suitability assessment

From hydrocarbon to CO_2 asset

- Assessment field
  1. Safety
  2. Environmental
  3. Integrity
  4. Transport Capacity
  5. Operability
  6. Availability
  7. Maintainability
  8. Regulatory



From hydrocarbon to CO_2 asset

- Assessment field
  1. **Safety**
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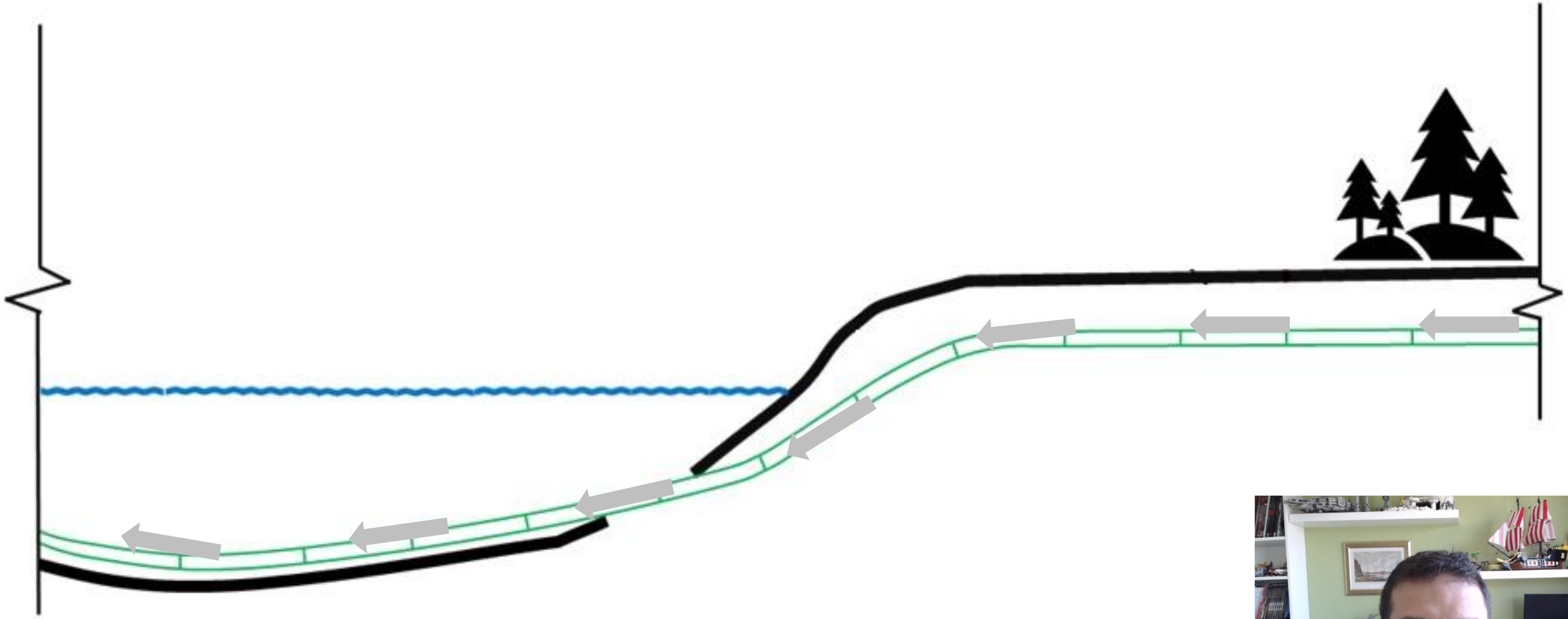


Safety and Environment

- New MAE definition
- Exposure of populated areas or near shore marine traffic

Table 3-4 Acute health effects of high concentrations of inhaled CO_2, see /13/

CO_2 concentration in air (% v/v)	*Exposure*	*Effects on humans*
17 – 30	Within 1 minute	Loss of controlled and purposeful activity, unconsciousness, convulsions, coma, death
>10 – 15	1 minute to several minutes	Dizziness, drowsiness, severe muscle twitching, unconsciousness
7 – 10	Few minutes	Unconsciousness, near unconsciousness
	1.5 minutes to 1 hour	Headache, increased heart rate, shortness of breath, dizziness, sweating, rapid breathing
6	1 – 2 minutes ≤ 16 minutes Several hours	Hearing and visual disturbances Headache, difficult breathing (dyspnoea) Tremors

DNV-RP-F104

LOCAL

'Foaming at the mouth': First responders describe scene after pipeline rupture, gas leak

Sarah Fowler The Clarion-Ledger

Published 11:23 a.m. CT Feb. 27, 2020

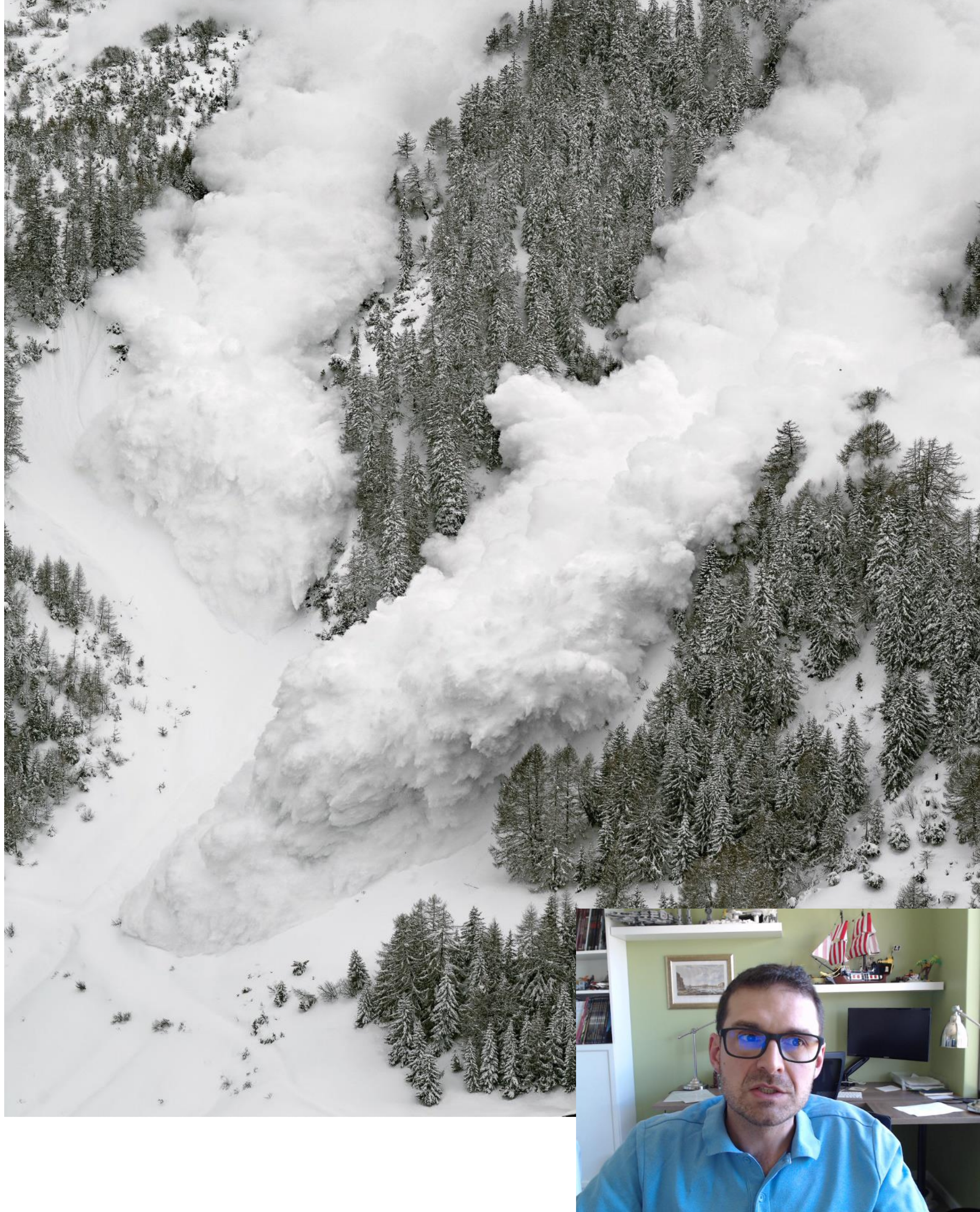
View Comments

Story Highlights

- Approximately 300 people were evacuated and 45 treated at area hospitals after a pipeline rupture.
- The pipeline, which ruptured Saturday in Yazoo County, belonged to Denbury Resources out of Texas.
- The pipleline released CO2 into the air, making people "act like zombies," said first responder.
- First responder rescued three people before he too was overtaken by the gas.

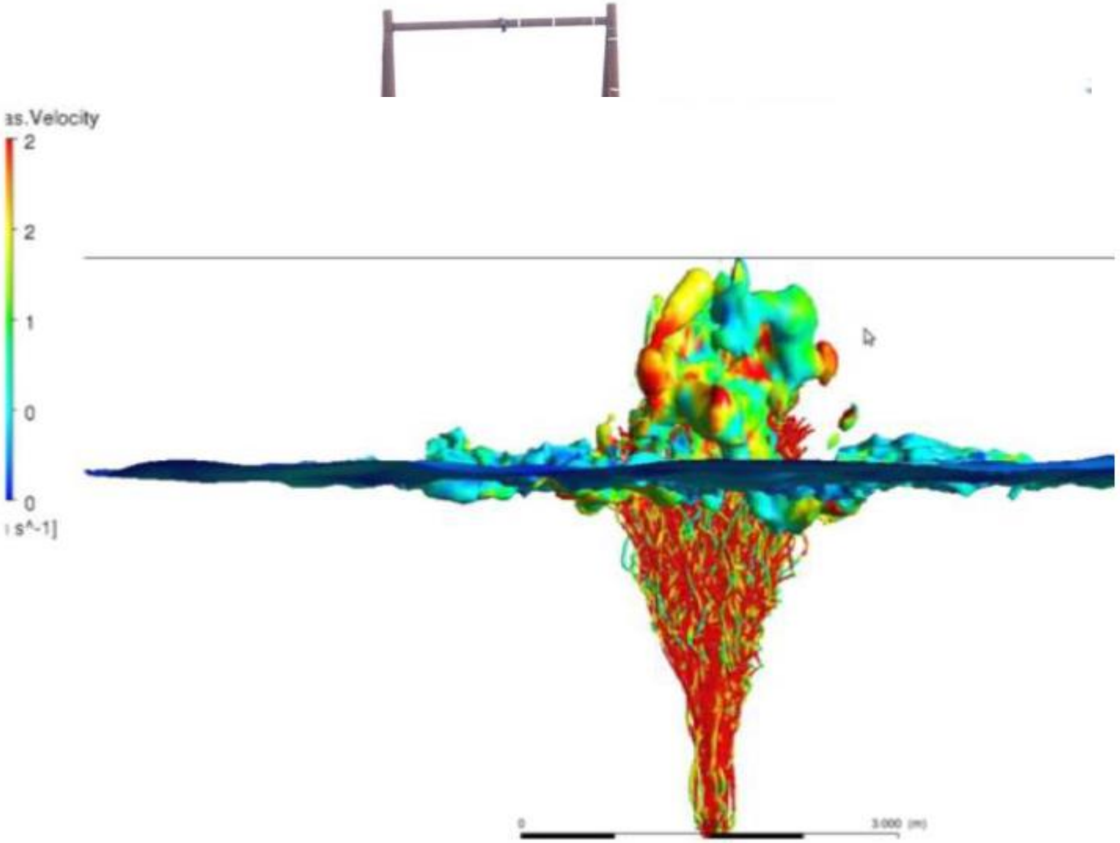
Safety and Environment

- New MAE definition
- Exposure of populated areas or near shore marine traffic
- CO_2 will be heavier than NG:
  - ✓Potentially larger near ground consequence radius;
  - ✓Concentration and flow.



Safety and Environment

- New MAE definition
- Exposure of populated areas or near shore marine traffic
- CO_2 will be heavier than NG:
  - ✓Potentially larger near ground consequence radius;
  - ✓Concentration and flow.
- Difference about leakage in sea
  - ✓Model in the water column is still uncertain.
  - ✓Consequence can be long term at sea i.e. PH change



From hydrocarbon to CO_2 asset

- Assessment field
  1. **Safety**
  2. **Environmental**
  3. **Integrity**
  4. Transport Capacity
  5. Operability
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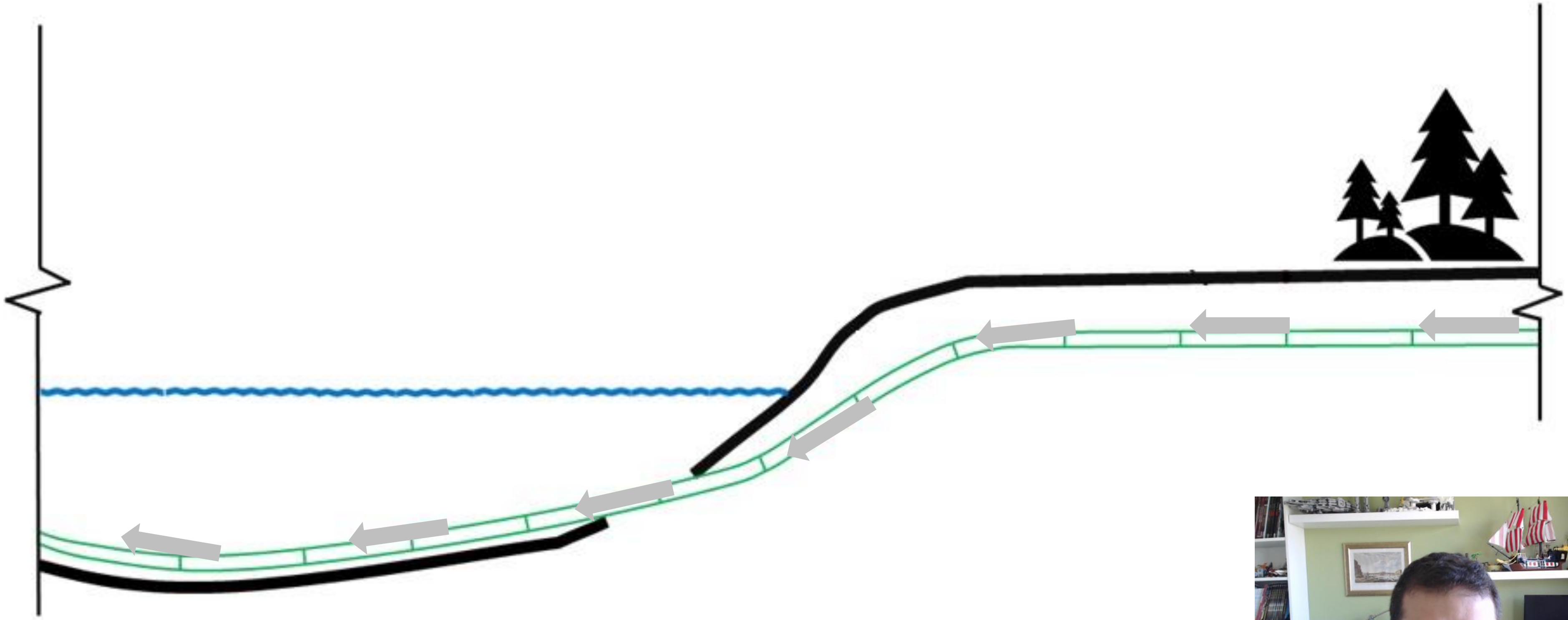
  8. Regulatory



CO_2 fluid properties

- CO_2 is normally in the liquid dense phase during normal operation of a pipeline.
- Actual CO_2 composition include impurities that affect the saturation line
- During decompressed, CO_2 will change phase from liquid to gas
- Liquid/supercritical fluid phase and vapour phase shall be considered as per DNV-ST-F101

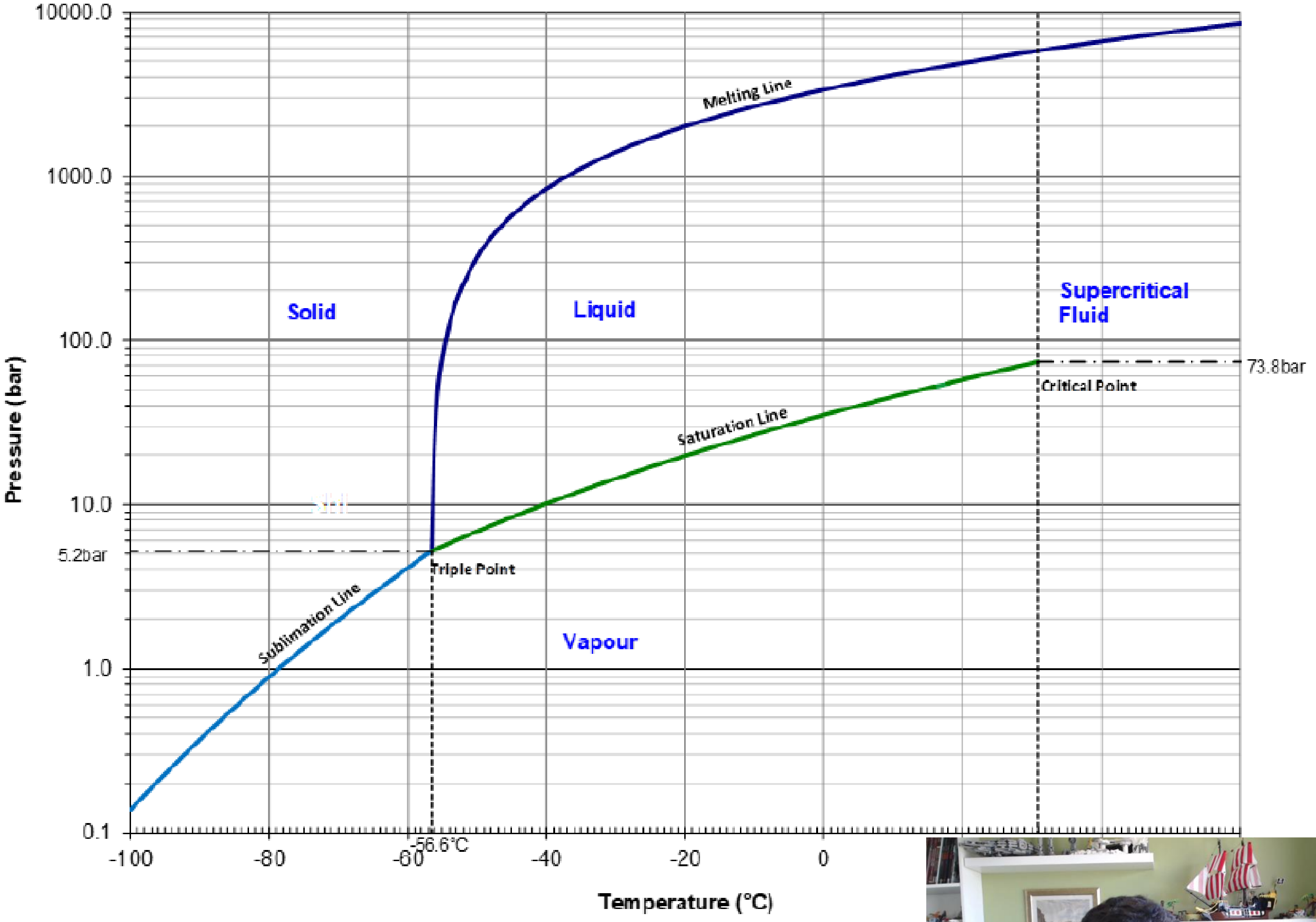


Figure 2-1 Phase diagram of pure CO_2 (based on ChemicaLogic Corpor

Integrity

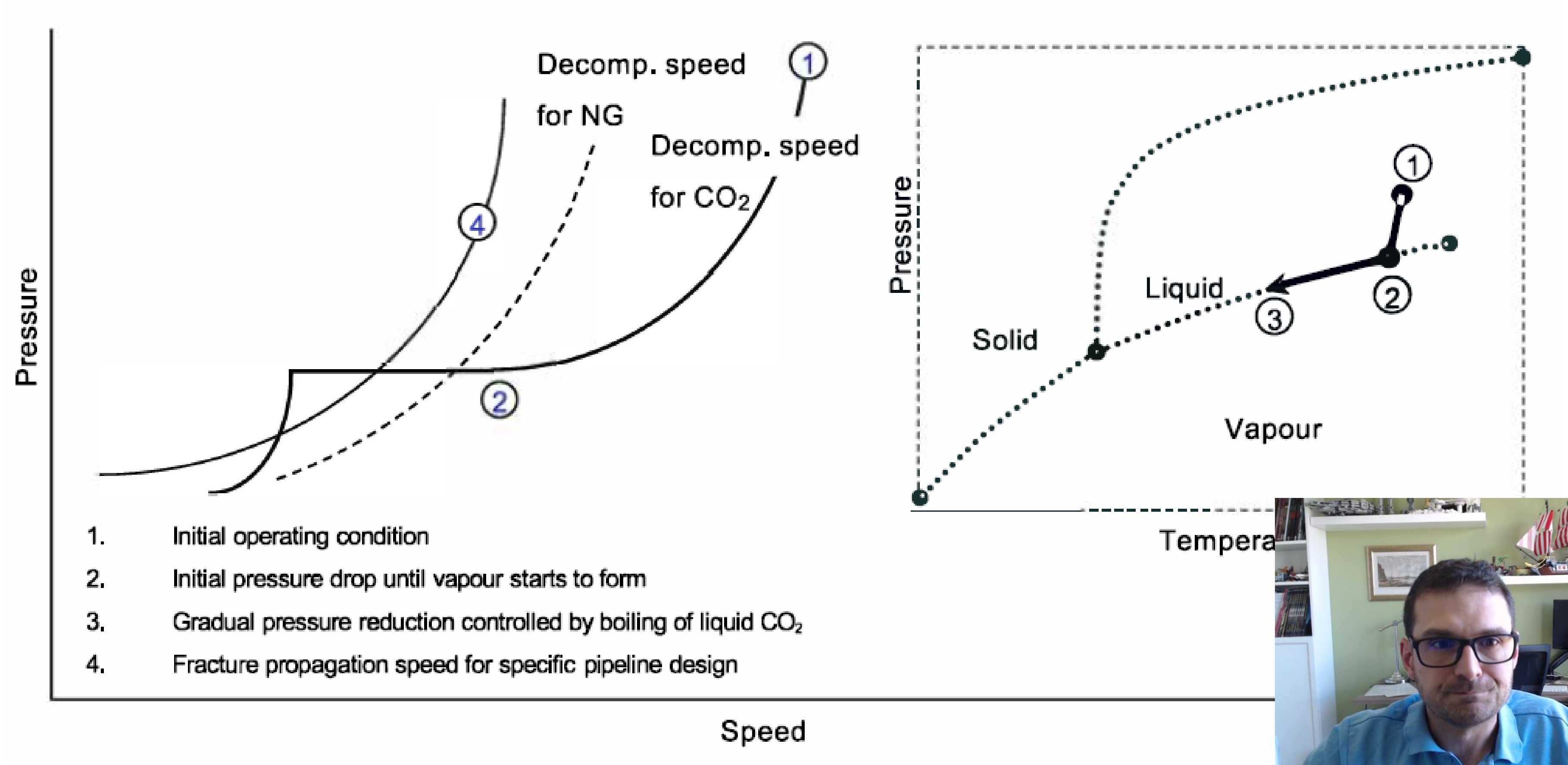
Retrospective design: Start with the end

- Fracture
- Corrosion
- Fatigue

Fracture

Fracture

- During decompression the CO_2 will change phase from liquid to gas
- This decompressi compared to natu running ductile fra conveying CO_2



DNV-RP-F104 – Fracture arrest model

- Linepipe characterization
  - ✓Use of existing records
  - ✓Re-test using spare
- Model limitation
  - ✓CVN>250J,
  - ✓OD:16” to 36”,
  - ✓WT: 10 to 26 mm
  - ✓Grade: X60 to X65
  - ✓Etc…

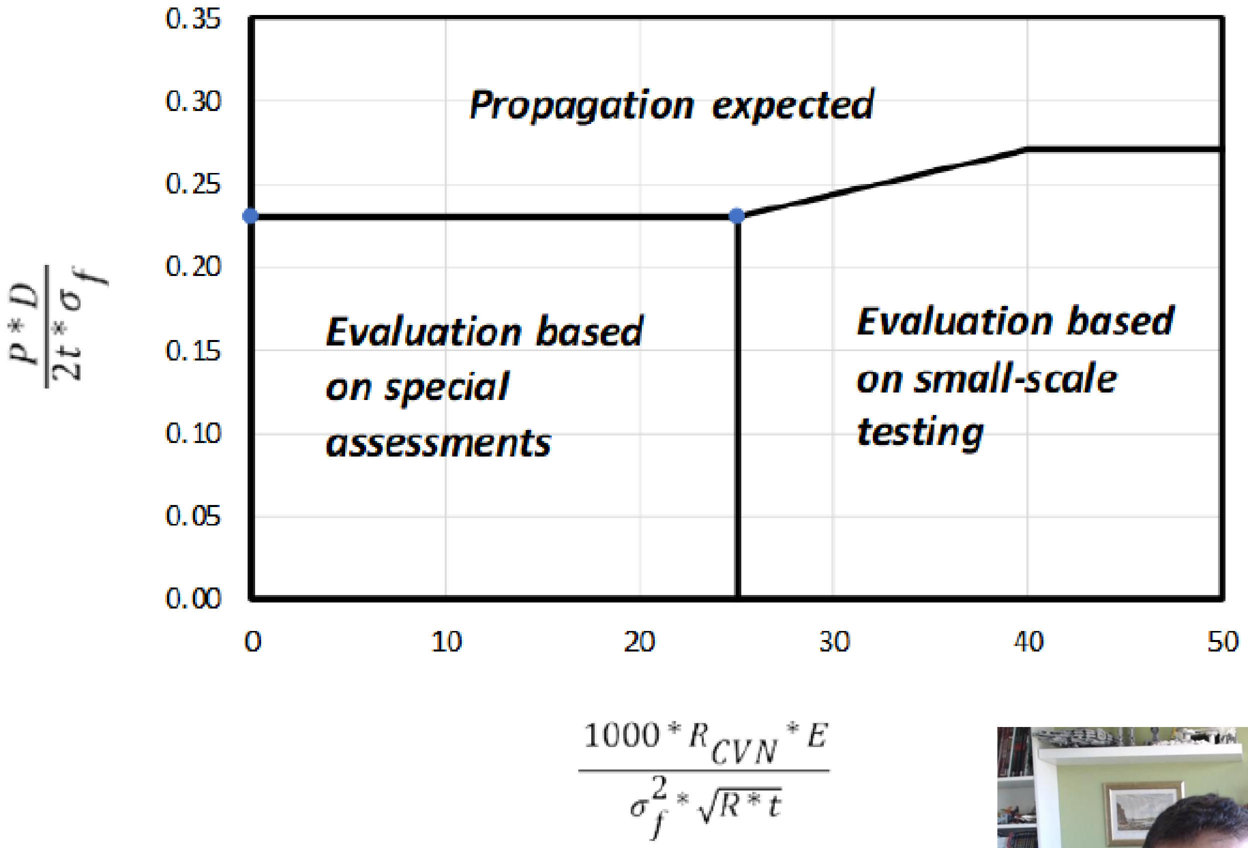


Figure 5-3 Scheme for evaluation of running ductile fracture arrest in

Internal and External corrosion

Internal and External corrosion for C-Mn Trunkline

- Internal corrosion
  - ✓Expected limited as Gas is exported dry
  - ✓Extra capacity available from corrosion allowance
  - ✓Inspection record: Intelligent pigging
- External corrosion:
  - ➢Loss of CP protection, anode consumption
  - ➢Coating / Field Joint Coating
- Pipeline history:
  - ➢Local external damage: gauge, dent, etc…
  - ➢Leak and repair (if any)

} Life extension for typical asset

Internal corrosion for C-Mn Trunkline with CO_2

- CO_2 dewatering
  - ➢No model to predict corrosion rate with free water
  - ➢Control free water i.e. before entering the line with shutdown procedure
- Impurities compounds reaction
  - ➢H2S: ISO15156 : qualification of linepipe for intended and non-intended exposure.
  - ➢SOx : Risk for formation of sulphuric acid with water.
  - ➢NOx : Risk for formation of Nitric acid with water.
  - ➢Etc…
- Chemical reaction
  - ➢$4O_2$+$8H_2S$ -> S_8 + $8H_2O$ (this reaction produces water)
  - ➢S_8 and H_2O S_8 (elemental sulphur) very corrosive to C-Mn steel
  - ➢Etc…

Fatigue

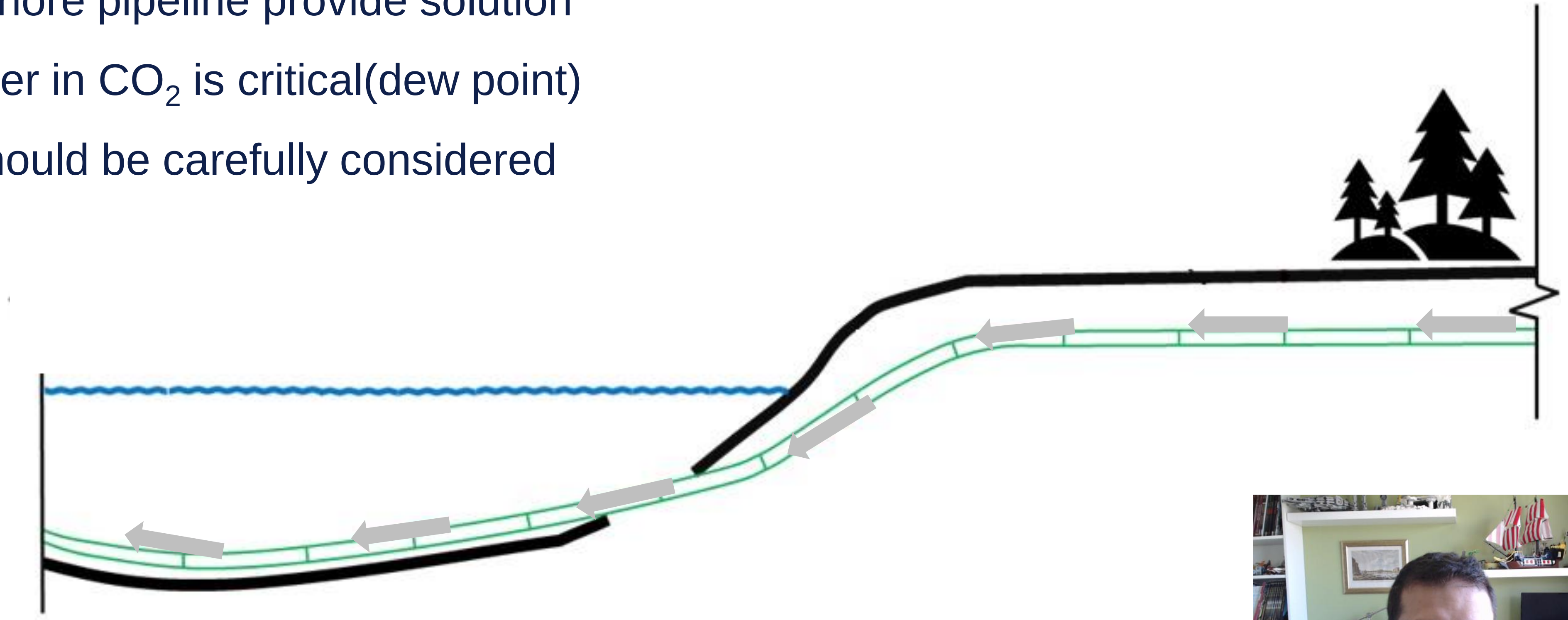
Fatigue

- Change in loading cycle
  - Change fluid density impact free span length and natural frequency
  - Change of flow direction impact walking and buckling.
- Fatigue curve
  - Standard fatigue design code still apply for CO_2 only
- In case of free water:
  - Project specific SN curve to be establish
  - H_2S and SO_2 : Corrosion assisted fatigue

Conclusion

From hydrocarbon to CO_2 asset

- Conversion of existing asset to transport CO_2 is possible
- DNV code for offshore pipeline provide solution
- The control of water in CO_2 is critical(dew point)
- Fluid impurities should be carefully considered



WHEN TRUST MATTERS

www.dnv.com

Large Scale CCS infrastructure

Norwegian Energy Symposeum – November 9th-10th 2021

The Stella Maris CCS Project

John Bateson
Head of Australian Operations– Altera Infrastructure

Ragnar Wisløff
SVP Clean Energy – Höegh LNG

altera

HÖEGH LNG

HÖEGH LNG

altera

The
Stella Maris CCS
Project

Höegh LNG and Altera at a glance

Altera

24 Shuttle Tankers | **9** FPSO & **3** FSO | **10** Towing Vessels

- Industry leader and pioneer in harsh weather FPSOs
- Industry leader and market segment developer of Dynamically Positioned Shuttle Tankers
- 30+ years of experience

Höegh

10 FSRU & **2** LNGC

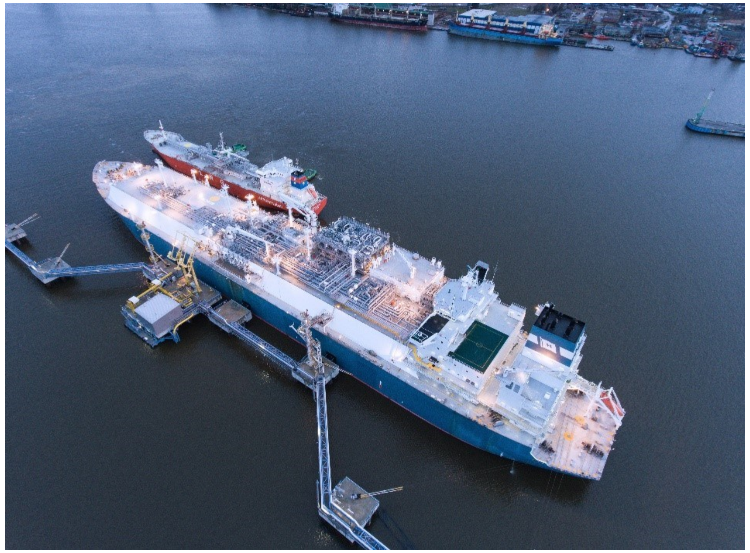
- Industry leader in the FSRU market
- 45+ years of gas handling experience
- Developend floating LNG import terminals worldwide
- Part owner & ship managgmment of small LNG carrier fleet

Our collective competence and experience in these three industry segments makes us unique and puts us in a stellar position to lead our industry to a sustainable CCS future.

Offshore CO2 transport, injection and storage - FPSO, shuttle and FSRU business “in reverse”

Offshore Production

DP loading and transport

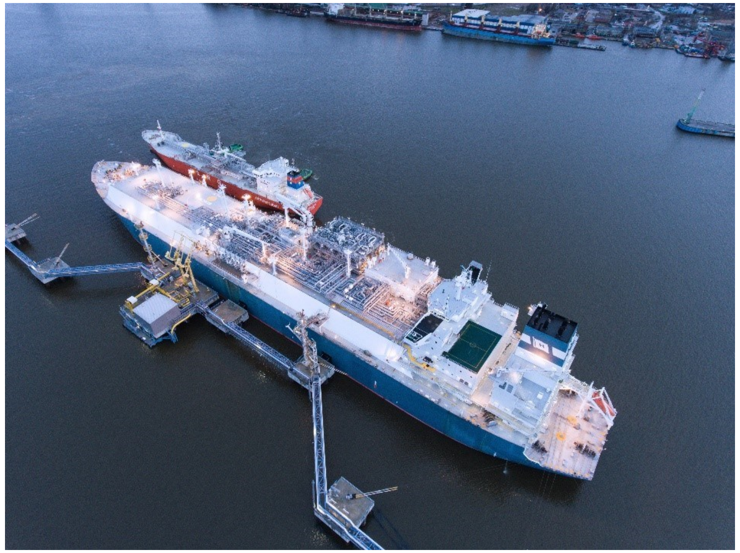


Import, Gas processing and Distribution

O&G related competence used to realize CCS

altera HÖEGH LNG

Offshore CO2 transport, injection and storage - FPSO, shuttle and FSRU business "in reverse"



Collection, Processing and Export

Transport and DP offloading

Offshore Injection and storage

O&G related competence used to realize CCS

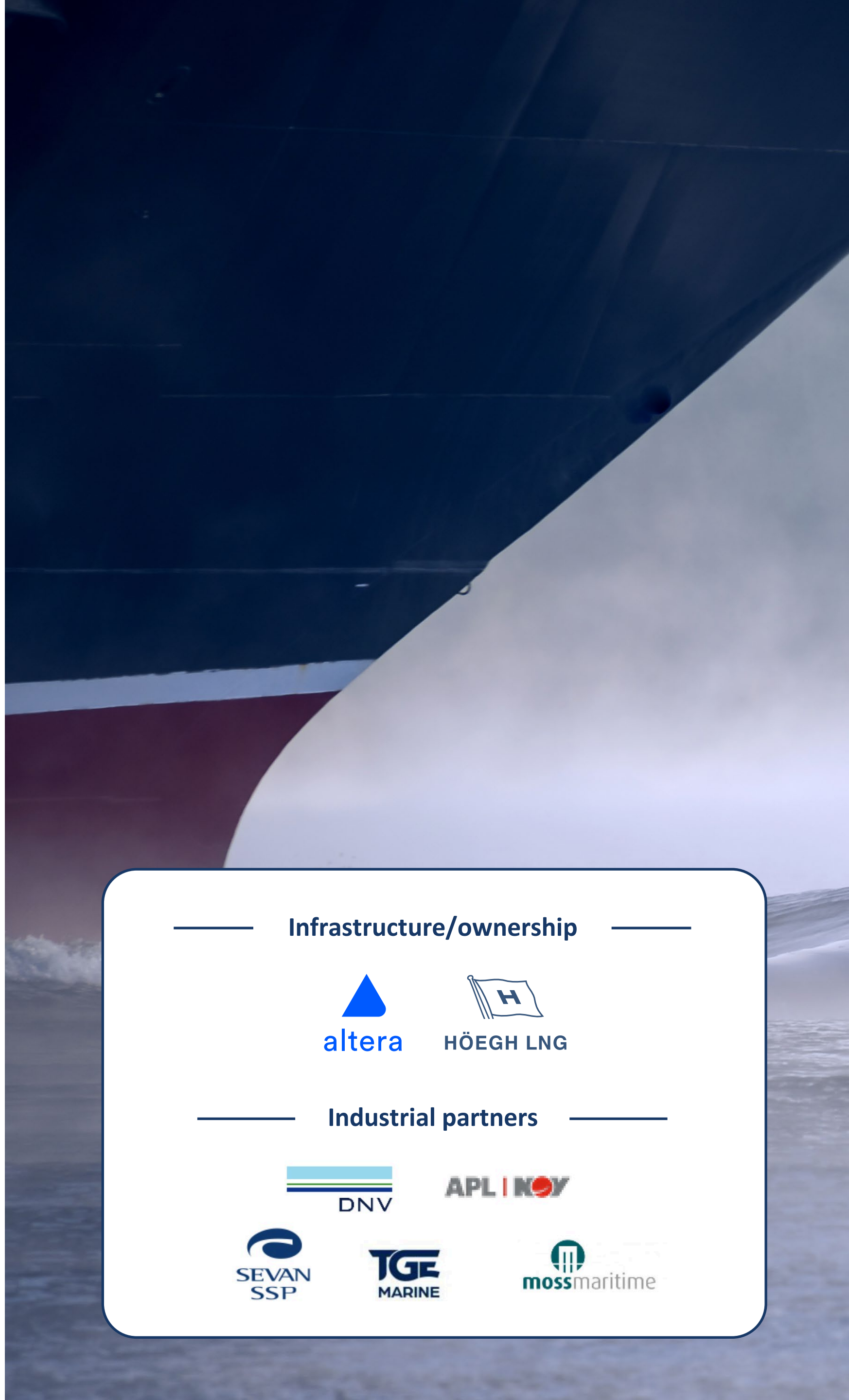
Stella Maris –Think Big

To get CCS costs down, large scale flexible solutions are required!

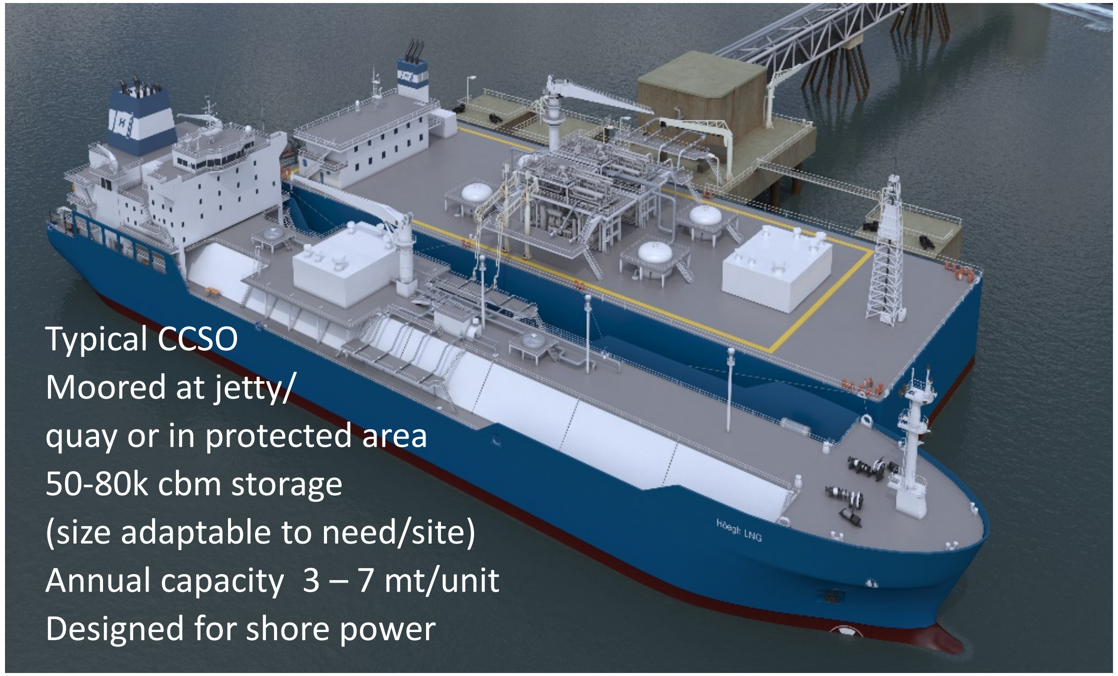
10 Mt CO_2 / year

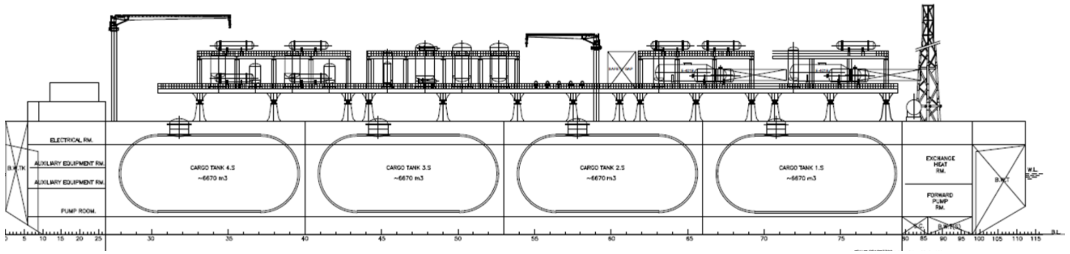
Infrastructure will include:

- Carbon Collection Storage Offloading units (2-3) to be located at key location(s) as export hubs
  - Capable of receiving various grades of CO2 from multiple emitters
- A fleet of large CO_2 shuttle carriers (3-4)
  - 50 000m3 – low pressure tanks
- Offloading and continuous injection of CO_2 offshore
- Zero emission capable
- Scalable Worldwide – design one – build many
- Solution deployed for large scale emitters, clusters and/or nation states in 2025
- One stop-shop from collection to storage
- Cooperate close with industry and policy makers nationally and internationally



Carbon Capture, Storage and Offloading Unit (CCSO)





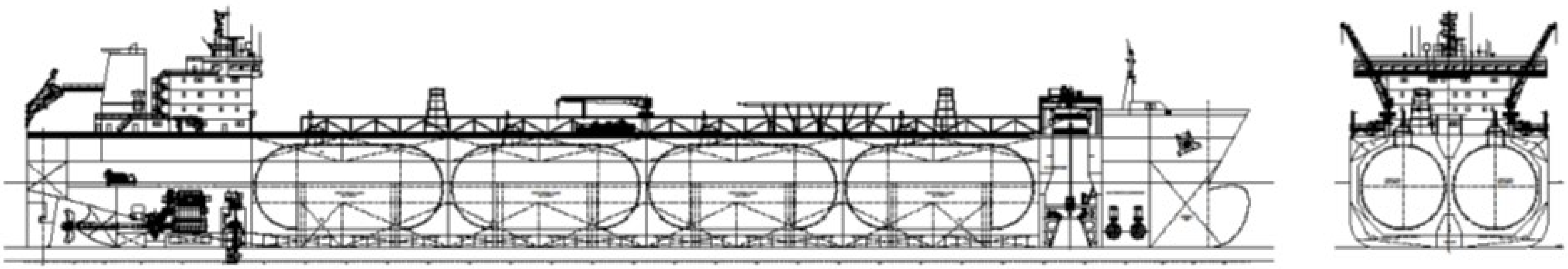
Designed to receive and process:

- High- & low-pressure gas from pipelines
- Medium & low-pressure liquid from trucks, rail, ships, barge
- Various qualities with different levels of impurity

Principal Dimensions (80k cbm design):

Length o.a.	220m
Breath (M)	58m
Depth (M)	24,5m
Design Draft	13m

CO2 Shuttle Carriers



Principal dimensions:

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

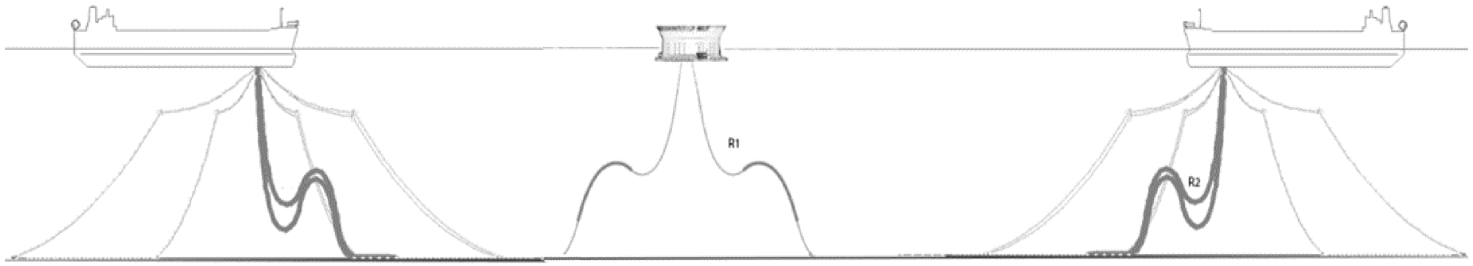
- New, state of the art CO2 shuttle carrier design
- 50,000 cbm - low pressure tanks
- CO2 stored and transported as liquid at 6,5 barg & -47°C
- Zero emission capable
- Electric Power distribution
- Battery hybrid installation
- LNG/Bio gas as fuel (base case)

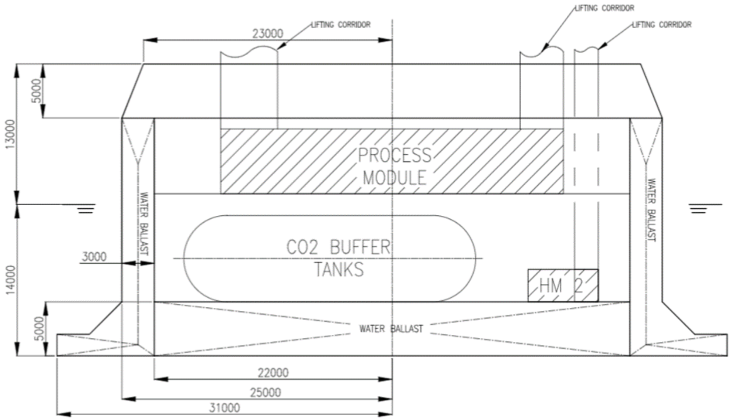
Optional:

- Size to meet needs
- Direct injection capability

Key Innovations
- Low pressure CO2 tanks
- Dynamically positioned CO2 carrier
- Equipment for offshore loading of CO2
- Power Source for injection unit

Floating Injection Unit (FIU)





- 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
- CO_2 heated and injected into reservoir in dense phase (>5°C & 65 -160 barg)

Principal dimensions:

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

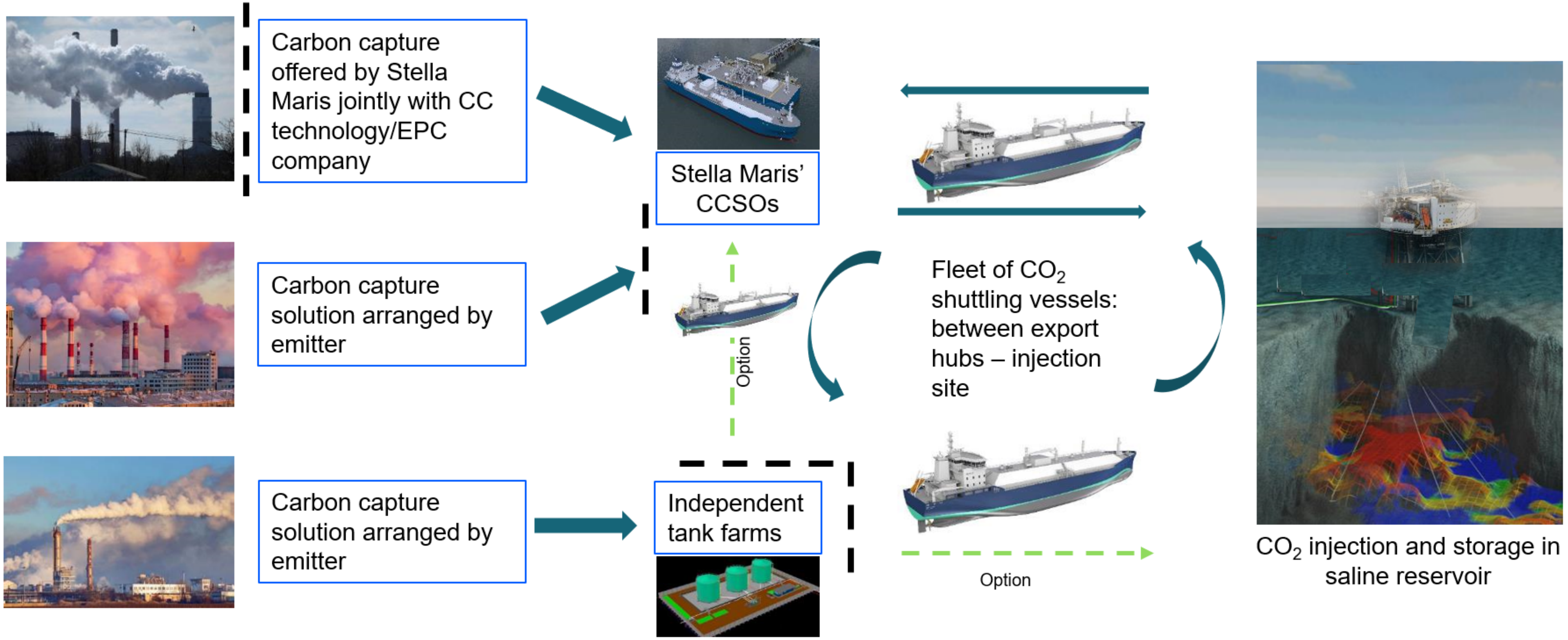
Alternatives:

- 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

Several models possible with different services and collection/transfer points

Flexible model with different collection/transfer points(— — —)



Stella Maris – Large Scale, Flexible, Scalable Maritime CO_2 Logistics Solution

The CCS industry challenge is best solved in partnership

During 2021 we will;

- finalize technical concept for the Stella Maris logistical solution
- establish cooperation & partnerships to deliver Stella Maris
- market our solution to individual companies, industry clusters and national authorities
- Become a one-shop-stop provider of a competitive and cost-efficient CO_2 solution from collection to storage.


The
Stella Maris
Project

LarvikShipping MOL
Your partner in transport of liquefied CO_2

LarvikShipping MOL

Your partner in transport of liquefied CO_2

Larvik Shipping AS + Mitsui O.S.K. Lines, Ltd.

LarvikShipping MOL
Your partner in transport of liquefied CO_2

- Larvik Shipping was founded in 1988, on the request of Norsk Hydro, to become a shipping management company for Hydro's new carbon dioxide business.
- Provides the expertise in CO_2 handling operation when new CO_2 terminals are built.
- In March 2021, Mitsui O.S.K. Lines, Ltd. acquired 25% shares in Larvik Shipping and became an official partner.

>30 Years

Liquid CO_2 transportation

SINTEF

Technical committee for liquid CO_2 transport

CO2 vessel "Froya"

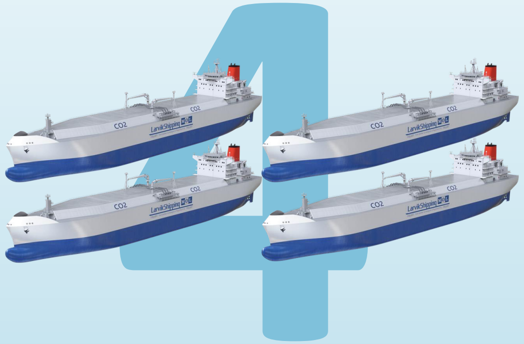
Cargo operation

Major Conversion in Turkey in 2016

DNV- DOC
for Gas Carrier

Larvik Shipping AS

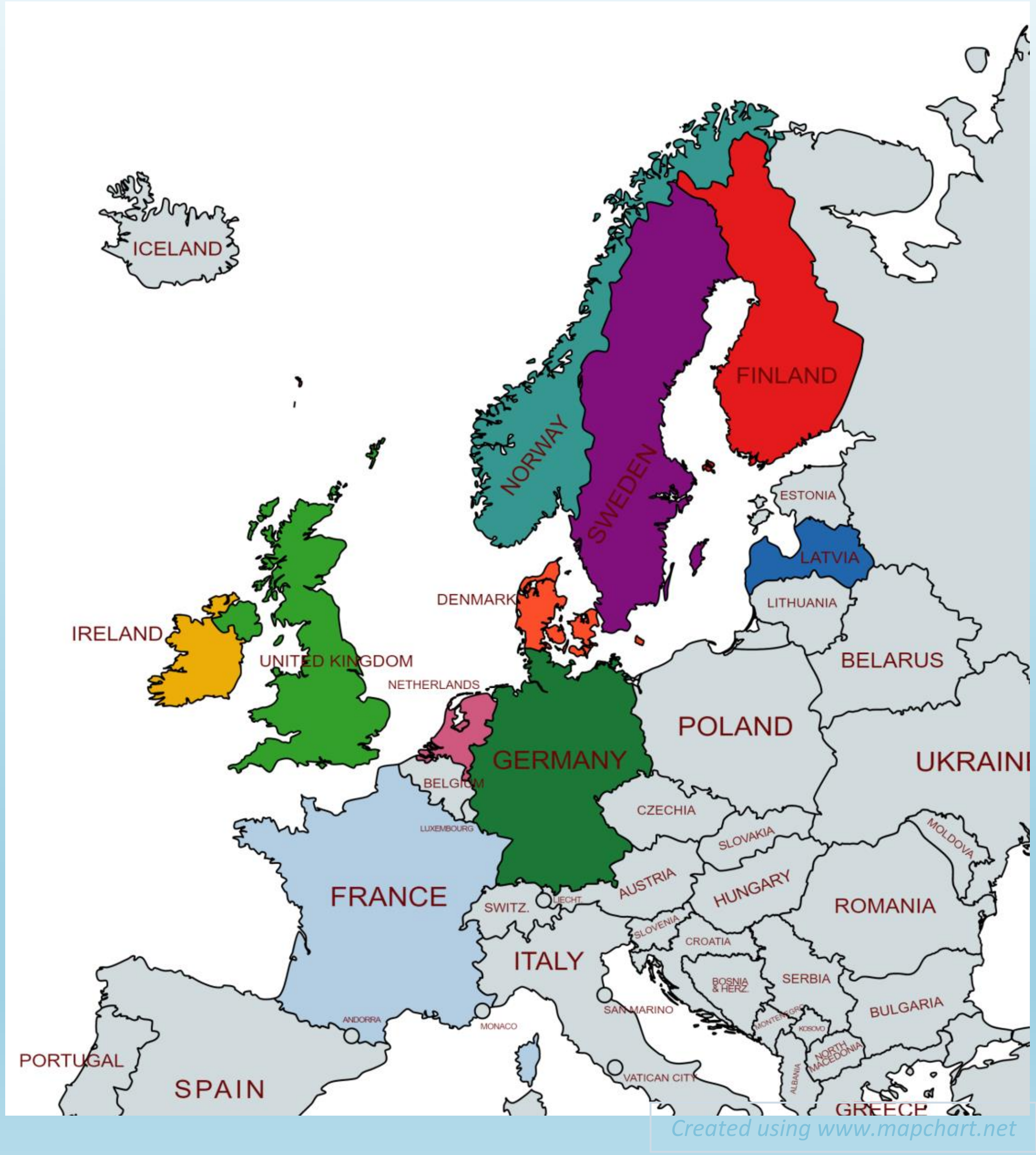
LarvikShipping MOL
Your partner in transport of liquefied CO_2



2020

225 Voyages

473 Cargo Operations



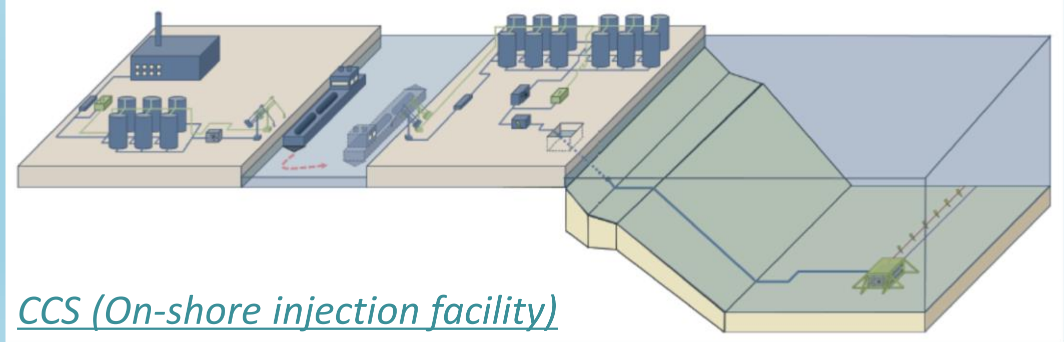
CCS Value chain at a glance

LarvikShipping MOL
Your partner in transport of liquefied CO_2

Carbon Capture and Storage (CCS) value chain by ship transportation

Emission → Capture → Interim storage → **Loading to ship** → **Transport-ation** → **Off-loading from ship** → Interim storage → Injection → Subsea storage

Emission → Seamless service is needed for the industry → Subsea storage


CCS (On-shore injection facility)

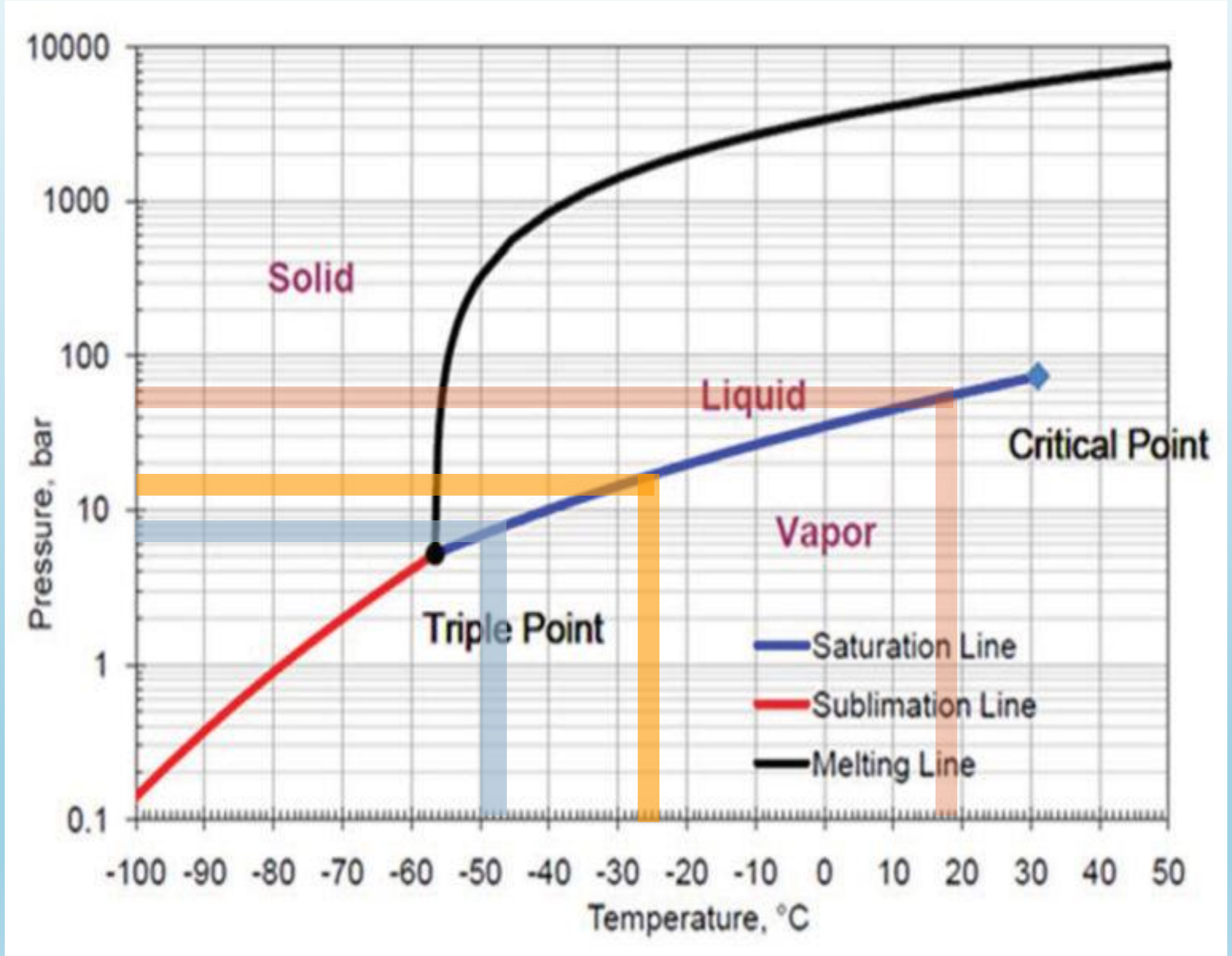
(Norway・Longship Project)

CCS (Off-shore injection facility)

(Australia・deepC Store Project)

CO_2 characteristics for sea transportation

LarvikShipping MOL
Your partner in transport of liquefied CO_2



Challenges

Dry ice formation / triple point

- Transportation always at pressurized conditions above triple point with safety margin.
- Always maintain sufficient temperature in containment

	Pressure	Temperature	Track record
Low	6-8 bar	- 50°C	No
Medium	15-18 bar	- 25°C	**Yes**
High	40-60 bar	+20°C	No

CO_2 transport by ship

- Pressure vessel design
  - Single cylinder
  - Bi-lobe
  - Tri-lobe
- Number of tanks
  - Single row
  - Side by side
  - Combination of above
- Cargo system
- Loading / Discharging

Way-Forward

LarvikShipping MOL
Your partner in transport of liquefied CO_2

- Larvik Shipping is involved in a study of Low Pressure CO_2 transportation with DNV (7-8 bar, -50 °C).
- Following illustrates the points to be considered when developing Low Pressure CO_2 transportation.
  - Ship/tank design, including tank material and support
  - Potential pressure loss
  - Flashing/Ice formation
  - Cargo handling system
  - Liquid loading/off-loading system
  - Pressure Relief Valve
  - ~~Stratification~~
  - Instrumentation and control system.

Thank you

Stein Tollevik
stein@larvik-shipping.no

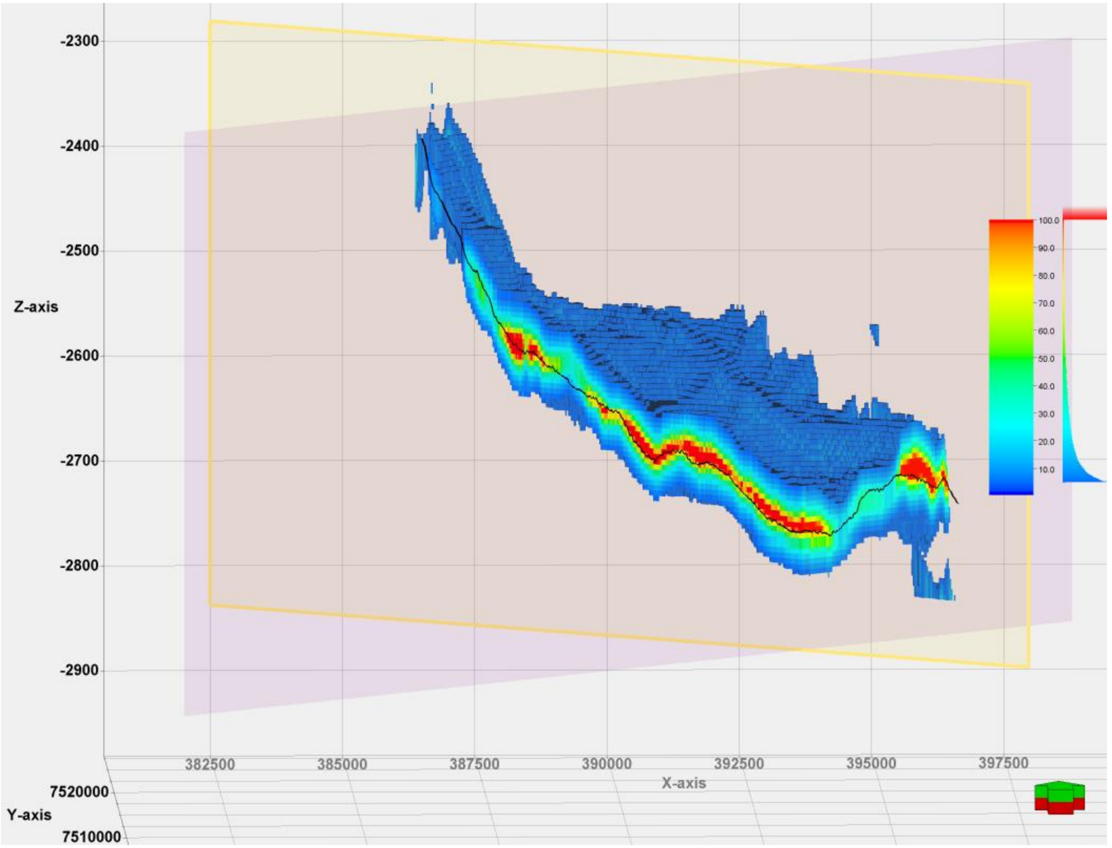
Increased security with CSEM for CO_2 storage

Norway/Australia Energy Symposium - H2/CCS

November 2021

Contents

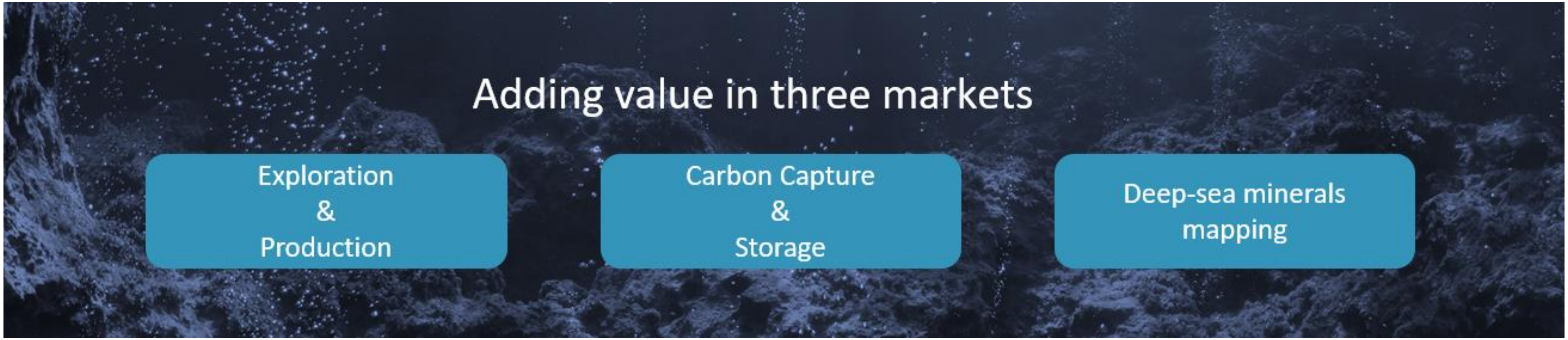
- Introduction and motivation
- CSEM principles
- CSEM for CO_2 monitoring
- Allton technical developments
- Safety in acquisition
- Allton R&D projects
- Conclusions



CSEM subsurface model

Who is Allton?

- Norwegian CSEM company with HQ Stavanger
- Mission: Advance CSEM state of the art
- 4D focused solution for monitoring applications
- Global reach:
    - Offices in Norway and Houston
    - Representation in Brazil, India and Malaysia



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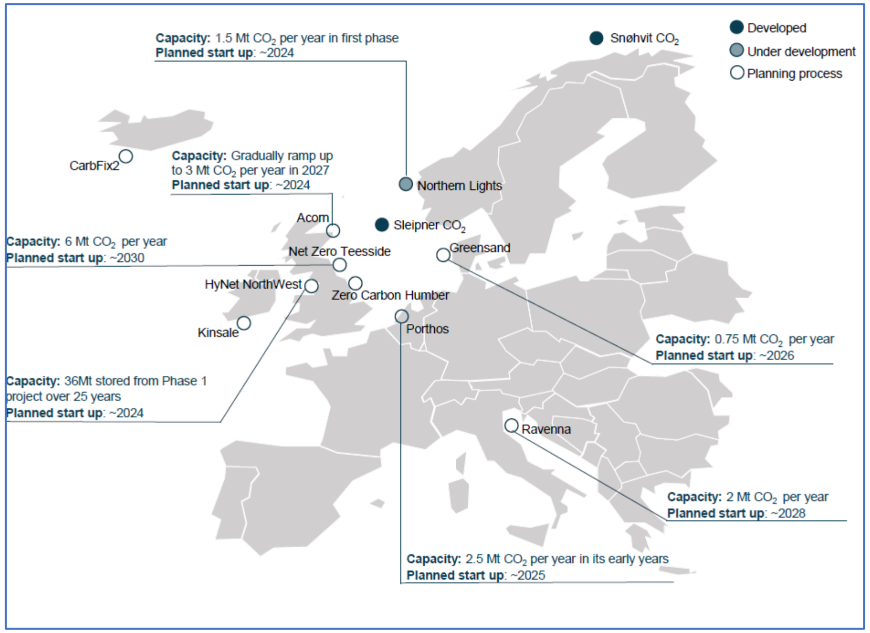
Introduction and motivation

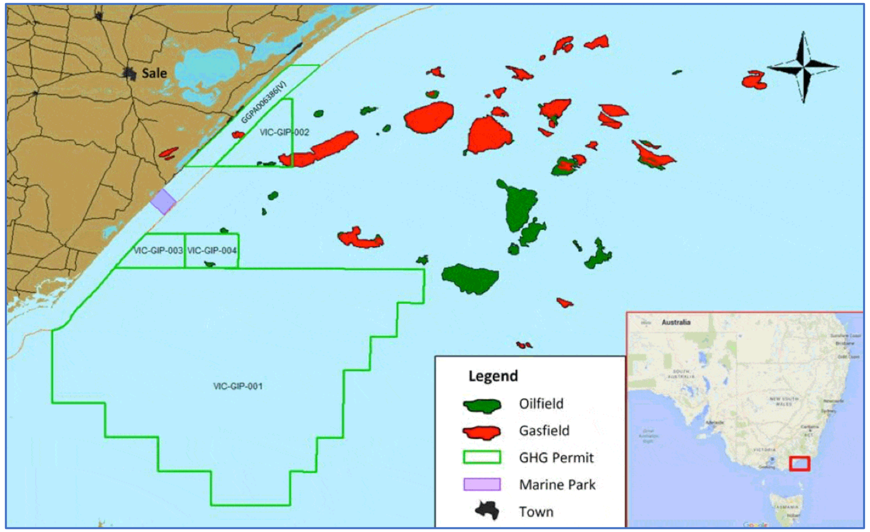
- Remote monitoring is essential for observing CO_2 during and after injection.
- Authorities require safe and secure solutions with low environmental impact
- Need to address **leak detection**, **monitoring** of plume migration and **verification** of stored volumes
- Electrical resistivity is well known to respond sharply to changing fluid type and saturation
- Controlled Source ElectroMagnetics allows for delineation and saturation estimates through resistivity imaging
- CSEM acquisition also provides a **safe alternative** in sensitive areas and areas with existing infrastructure

Requirements for monitoring

- Regulators and authorities require monitoring and verification plan prior to approval of any CCS project.
- Clear and accessible information to secure public confidence in CCS programs.
- Long term verification of CO_2 subsurface distribution and volumes.
- Timely detection of unpredicted behavior such as leakage to allow intervention.
- Geophysical monitoring solutions need to minimize environmental impact and risks associated with health and safety.
- Cost efficient monitoring solutions required to meet both environmental and financial objectives.
- Standardized best practice vs site specific solutions.



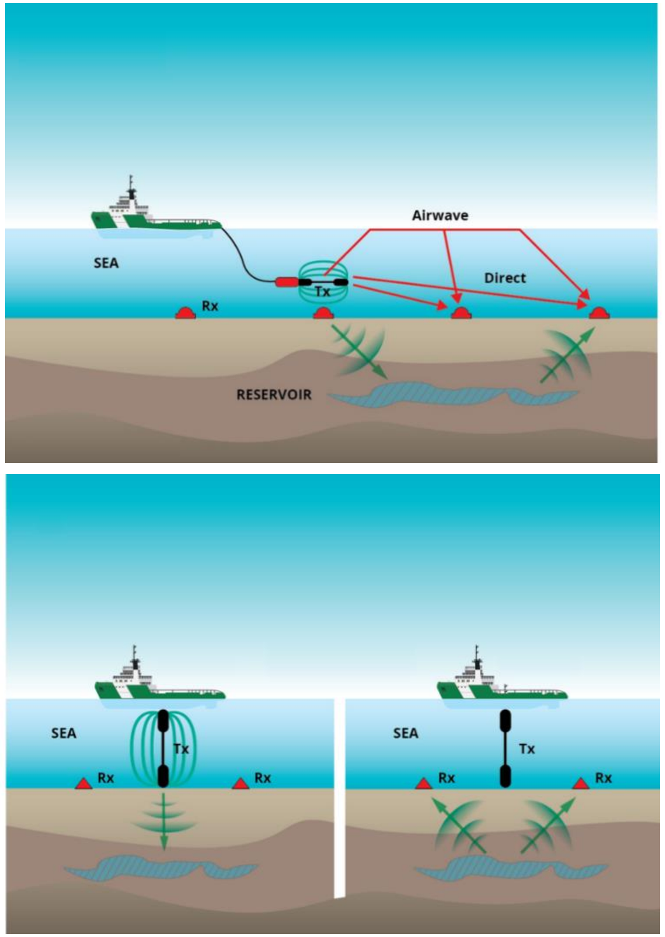
Geographical location of offshore European CCS projects



Gippsland Basin permits under CarboNet project

CSEM principles

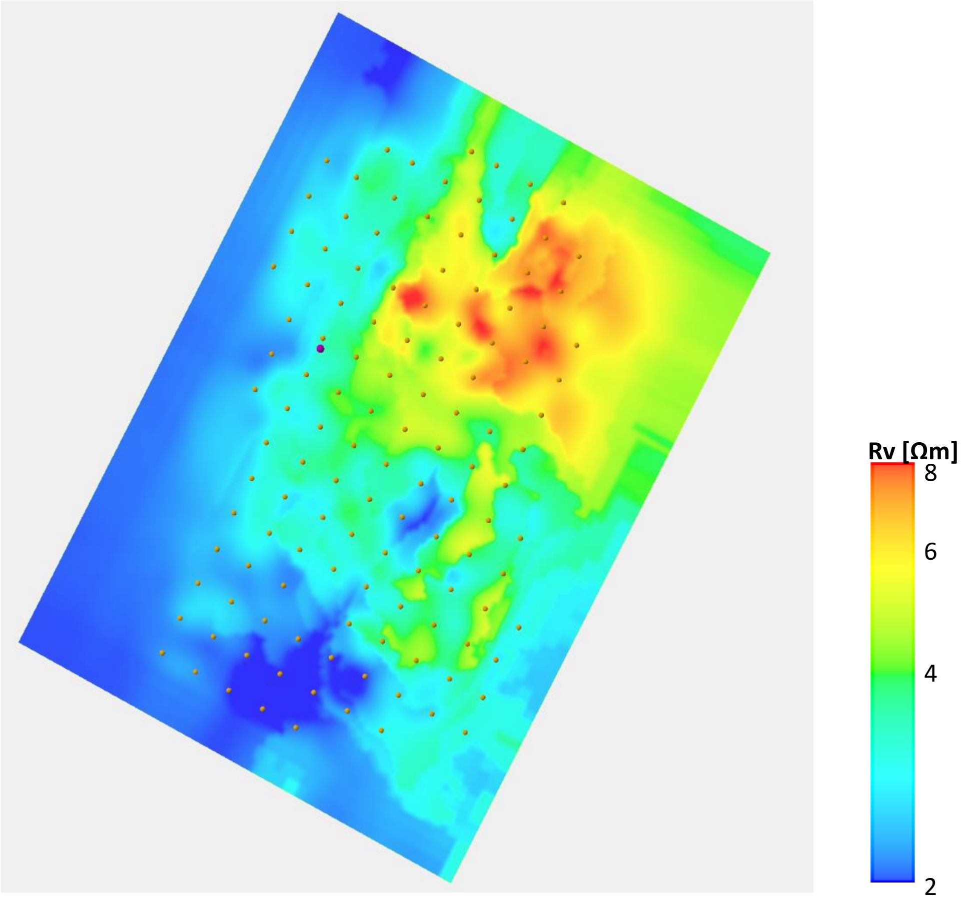
- CSEM measures the electromagnetic field distribution from an active source
- Sea bed node receivers combined with a stationary or towed source
- Primary tool for interpretation is numerical **inversion**, which allows imaging of the subsurface resistivity distribution from sea bed measurements
- CSEM has been used for hydrocarbon exploration since 2002.
- Technology has matured from 1D and 2D modes to full **3D**
- Increased accuracy through technological developments now allow **monitoring** applications
- Under appropriate conditions CSEM will provide sensitivity to **CO_2 saturation**



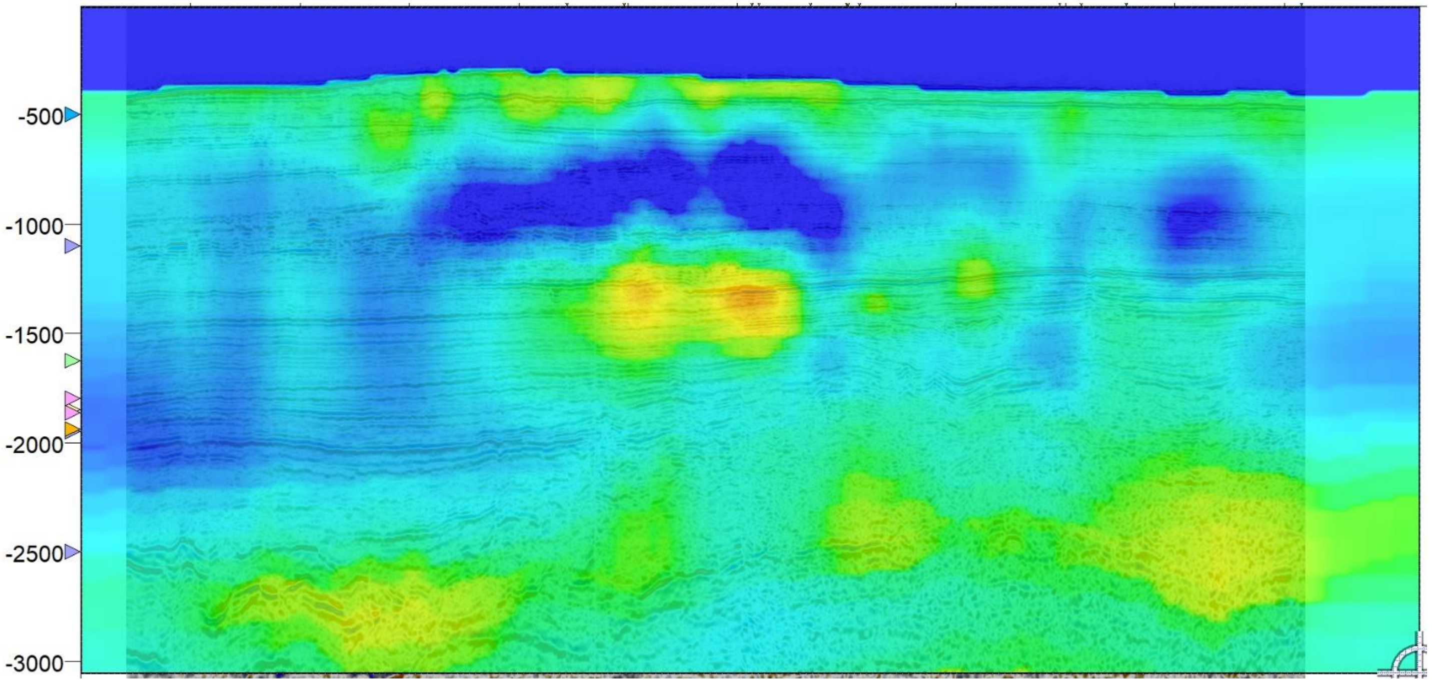
Visualization of different CSEM acquisition modes. Transmitter and receiver configuration is optimized for project specific conditions and objectives.

CSEM Principles: Subsurface Imaging Through Inversion

- Inversion of CSEM data provides resistivity volumes in depth
- 3D inversion of real data from acquisition in Norwegian Sea
- Guided inversion improves structural resolution



Resistivity map at depth 1850 m



Resistivity depth section co-rendered with seismic

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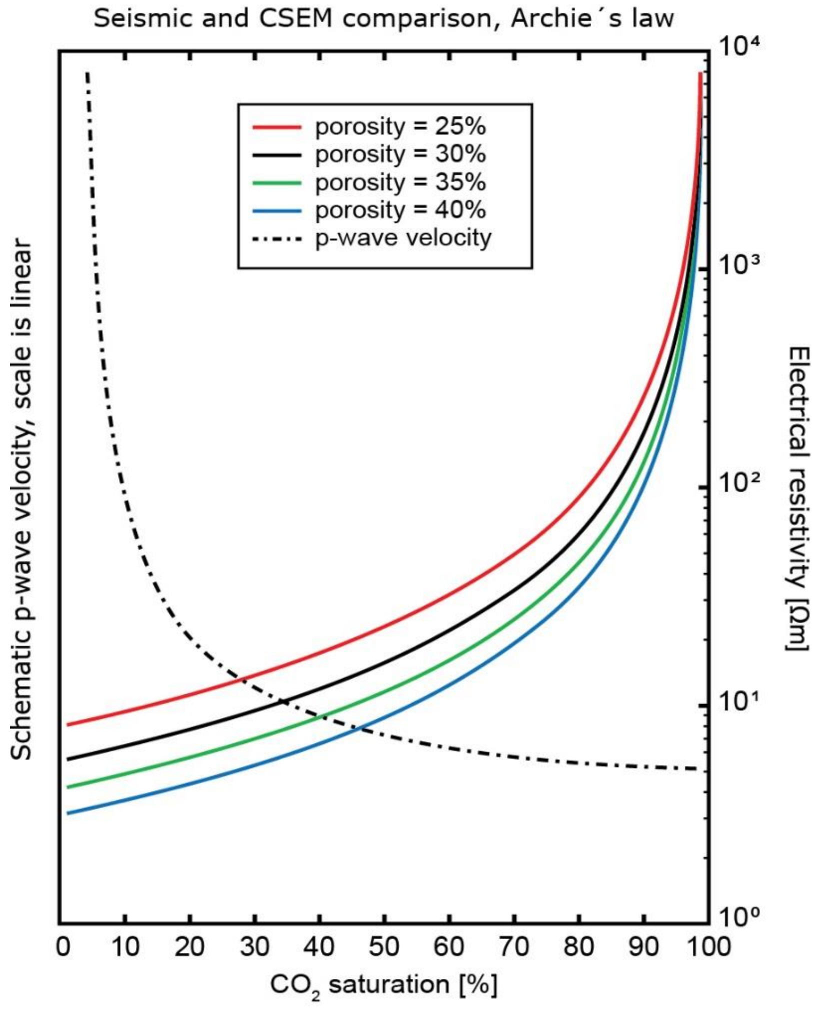
CSEM for CO_2 monitoring

- Formation resistivity from CO_2 saturation changes can span orders of magnitude.
- Detectable through remote sensing.
- Resistivity contrast caused by CO_2 will be dependent on local conditions, such as reservoir rock physics and plume geometry.
- CSEM applicability for CO_2 evaluated in several studies, demonstrating sensitivity.
- EM has high sensitivity in mid to high saturation range, unlike seismic which sees main sensitivity in low saturation range.
- CSEM acquisition has less environmental impact in sensitive areas.

- Allton offers feasibility modelling for CCS projects to evaluate the feasibility in specific settings.



Comparison of p-wave velocity and resistivity as function of CO2 saturation

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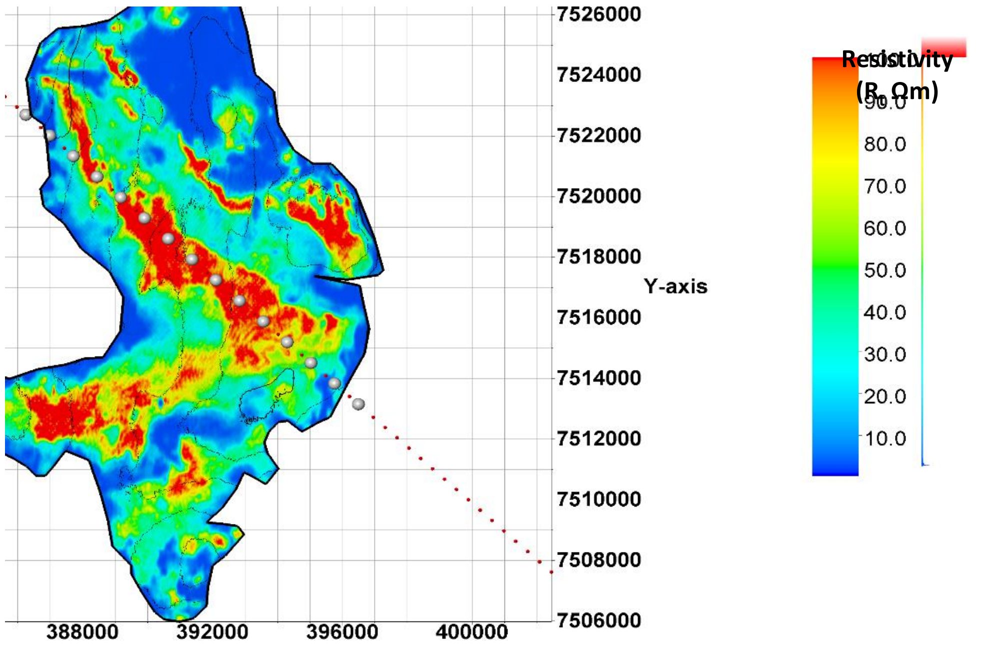
CSEM for safe CO_2 monitoring

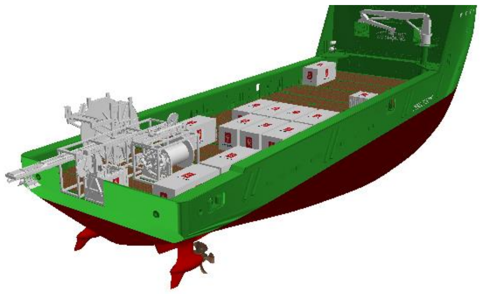
- Geological storage of CO_2 has several risks associated with containment, primarily related to leakage paths:
  - Failed caprock seal
  - Transmissive faults
  - Degraded or poorly sealed wells
- To mitigate such risks, a CSEM monitoring program can be aimed at detecting leakage, both vertically and laterally.
- Also provides feedback to injection management: verification and control of CO_2 volumes and movement.
- Inversion results for anomalous transverse resistance (ATR) can provide estimates for CO_2 volume in place.

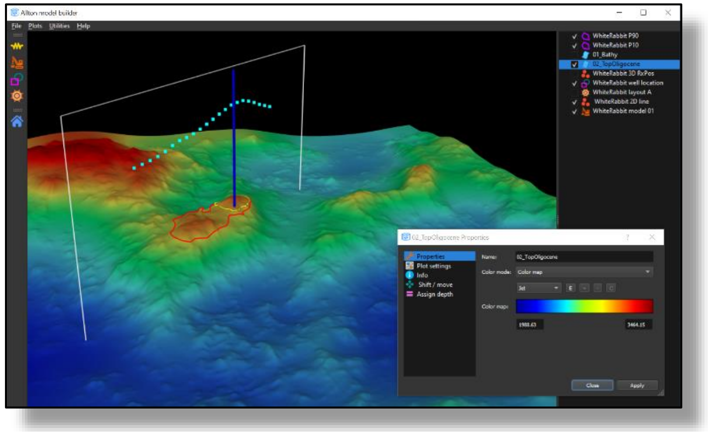
Resistivity map for a container reservoir (synthetic model).



Correa, J. L. et al. [2019], Marlim R3D: A realistic model for controlled-source electromagnetic simulations — Phase 2: The controlled-source electromagnetic data set. https://doi.org/10.1190/geo2018-0452.1

Allton Technical development





New seabed nodes

- Prototypes built and delivered
- Offshore testing this Autumn

New source solution

- 3 operational modes
  - Horizontal towed or stationary on sea floor
  - Vertical stationary
- Flexible installation on various vessel designs

Imaging & interpretation

- 2.5D inversion available now
- 2.5D & 3D modeling software available now
- 3D inversion available next year
- 4D inversion available 6-12 months after completion of 3D

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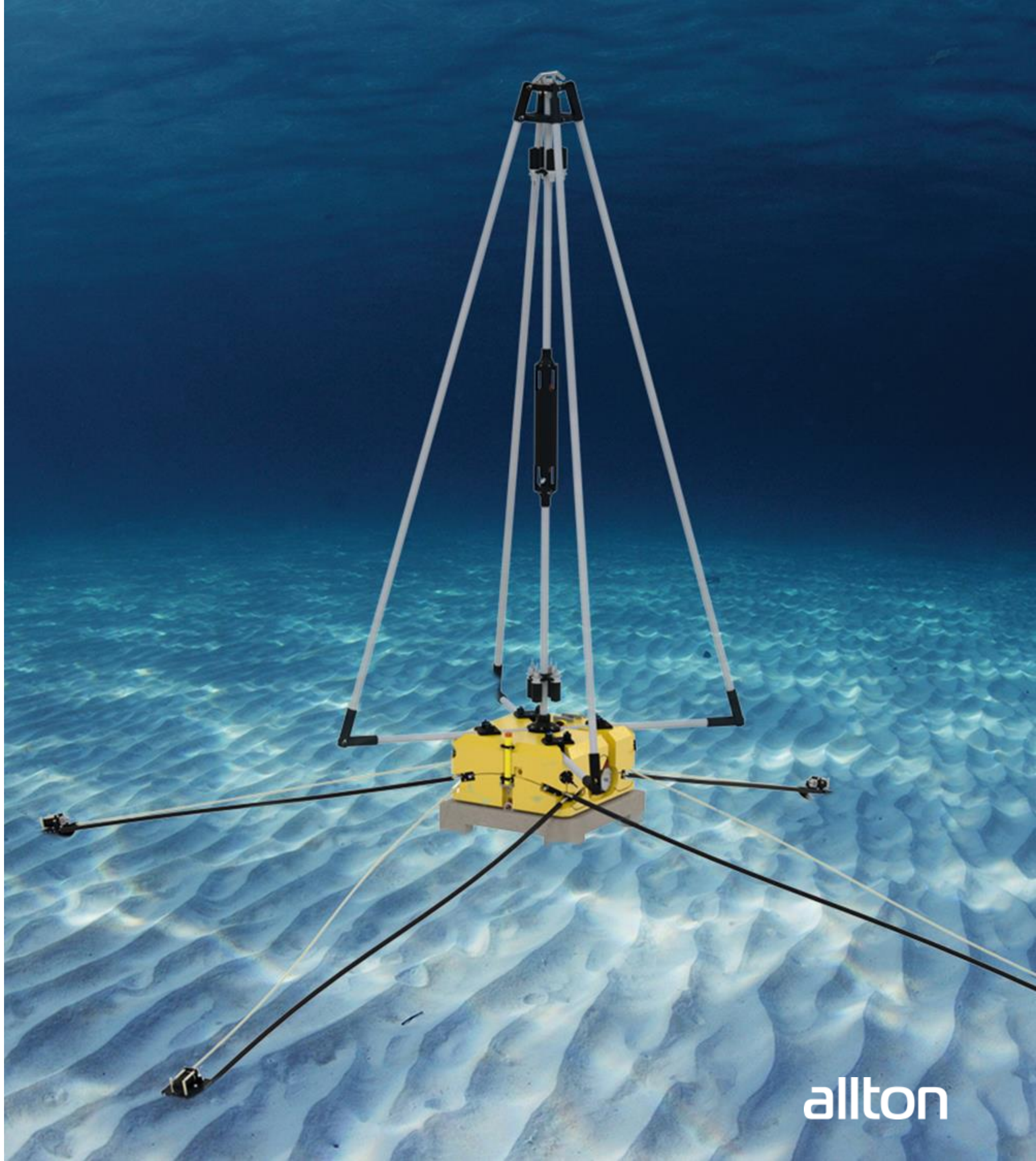
Safe and reliable acquisition solution

- Latest generation stationary receivers with horizontal and vertical measurements.
- Stationary horizontal source solution for maximum resolution and repeatability
  - Optional towed solution offered with same hardware.
- Accurate positioning of transmitter and receivers to
  - Ensure measurement repeatability.
  - Optimize acquisition to meet project specific objectives.
  - Minimize local environmental footprint from acquisition.



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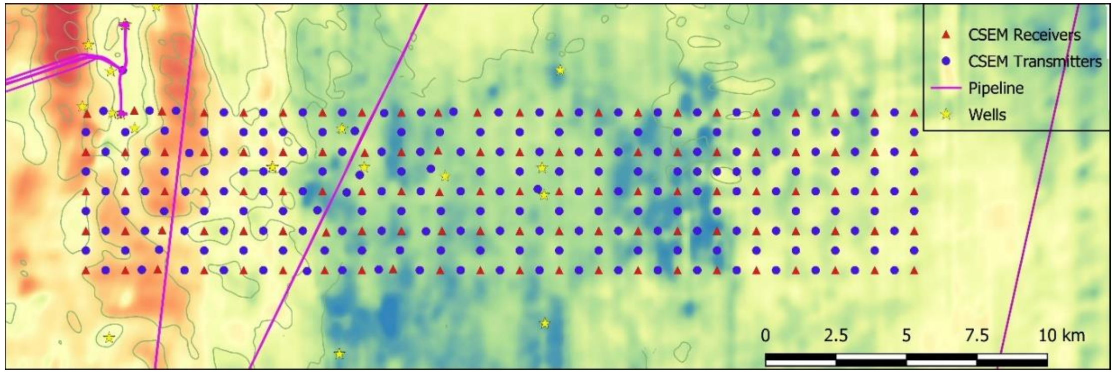
Safe and reliable acquisition solution

- Low to zero impact on sea life from Allton's operations
- Nothing left behind on survey site
- Safe operations in areas with dense infrastructure such as injection wells, pipelines, windfarms, platforms, shipping line etc.
- Stationary system allows accurate planning of acquisition layout.
- CSEM acquisition methodology avoids multi-streamer configuration required for high-res seismic 3D



Dense CSEM acquisition plan in area with existing infrastructure

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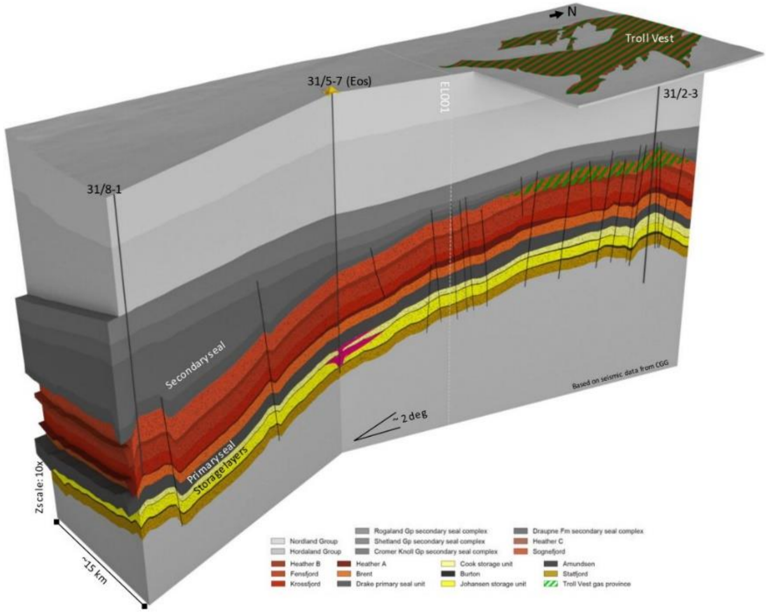
Selected R&D effort to improve safe storage using CSEM

- ***COSMOS*** *project (<u>**CO**</u>ntrolled <u>**S**</u>ource electromagnetic <u>**MO**</u>nitoring of CO2 <u>**S**</u>torage sites)*
- *Partner project with Total and SINTEF to demonstrate the value of EM for CCS* CO_2 monitoring
- *Accepted for funding by the Research Council of Norway*

SINTEF allton TotalEnergies

- Main objective of the ***COSMOS*** project is to assess the applicability of CSEM for monitoring of CO_2 storage sites offshore Norway
- Secondary objectives will be
  - Benchmark new CSEM software
  - Assess sensitivity of CSEM for potential storage sites
  - Develop software/methods for optimal survey design
  - Develop methods based on VOI concepts



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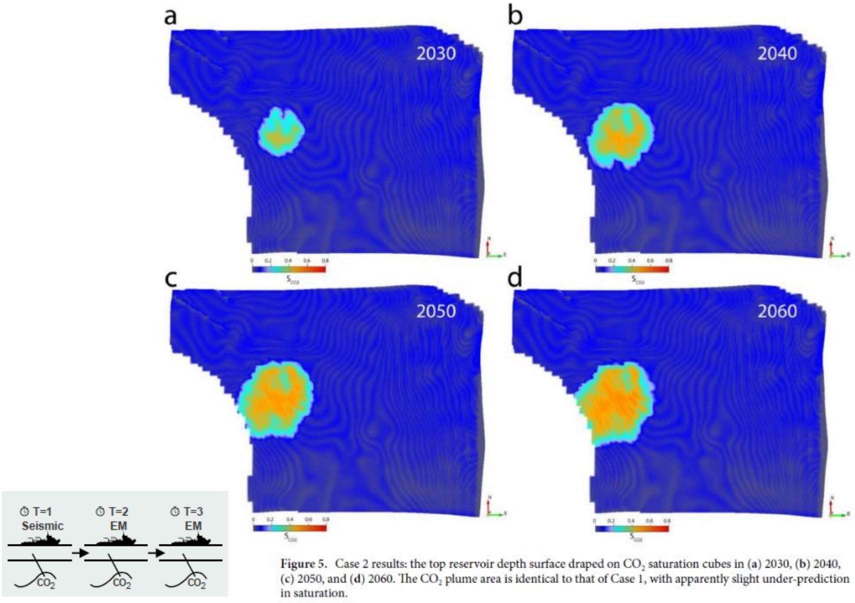
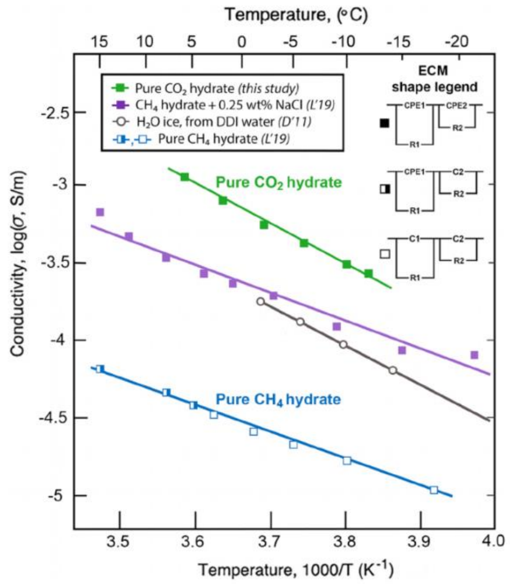
CSEM for CO_2 storage: an active field of research

Several recent publications in leading publications on the applicability of CSEM for CO_2 storage



Monitoring geological storage of CO_2: a new approach
Fawad & Mondol [2021] – Nature - Sci Rep **11,** 5942



Electrical Properties of Carbon Dioxide Hydrate: Implications for Monitoring CO_2 in the Gas Hydrate Stability Zone
Stern, Constable, Lu, Du Frane & Roberts [2021] - Geophysical Research Letters **48(15)**

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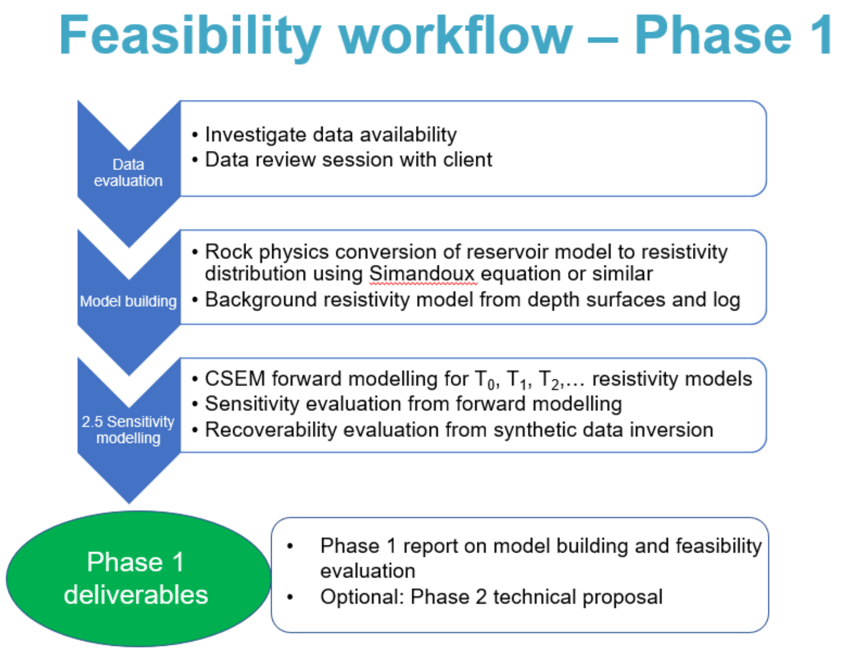
Allton project feasibility modelling

- Allton offers modelling to evaluate CSEM feasibility for CCS projects in cooperation with the stakeholders
- Modelling needs to address project specifics such as:
    - Existing data availability
    - CO_2 Injection process
    - Local rock physics
    - Project risks and challenges



Allton modelling workflow

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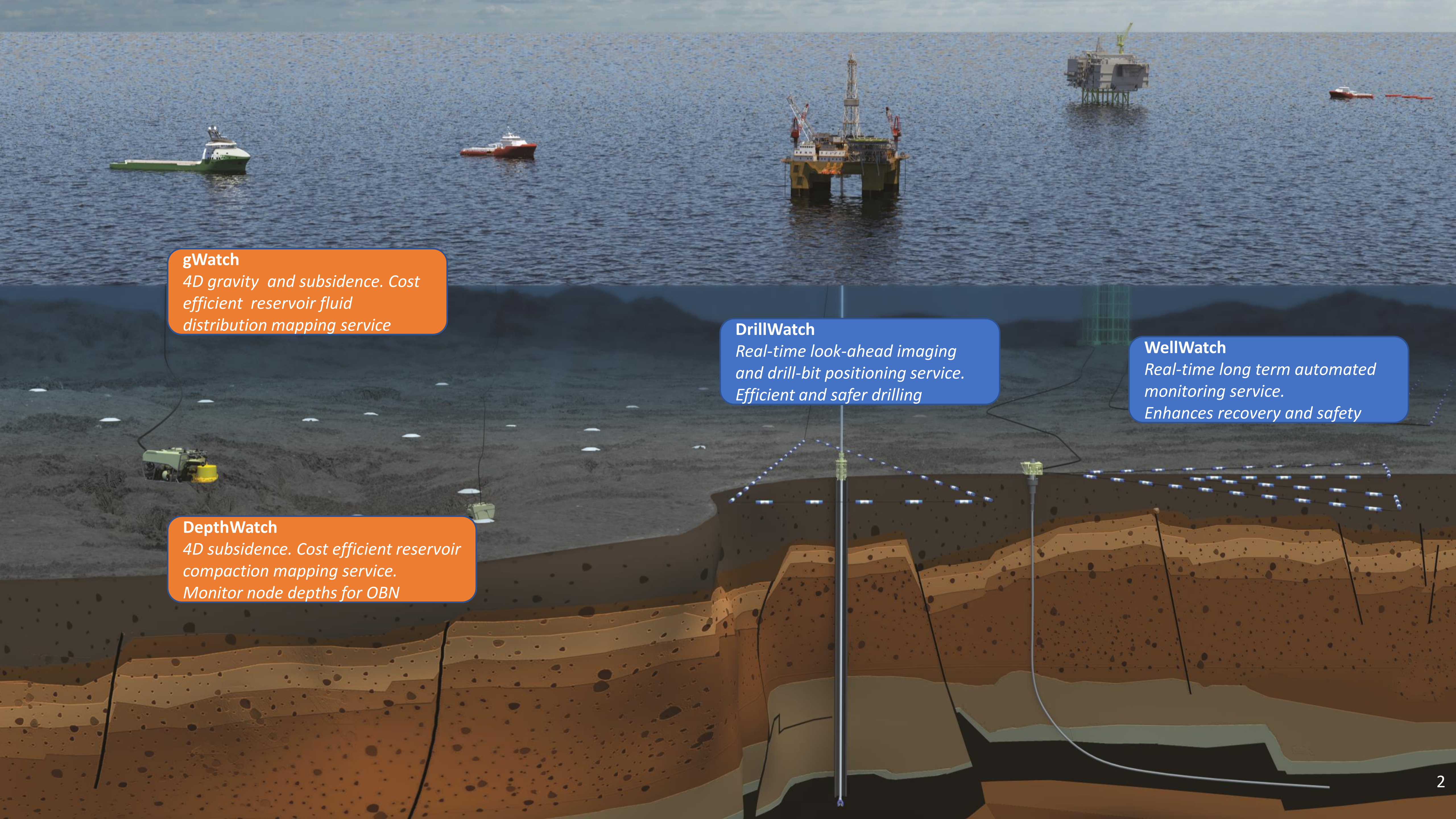
Conclusions

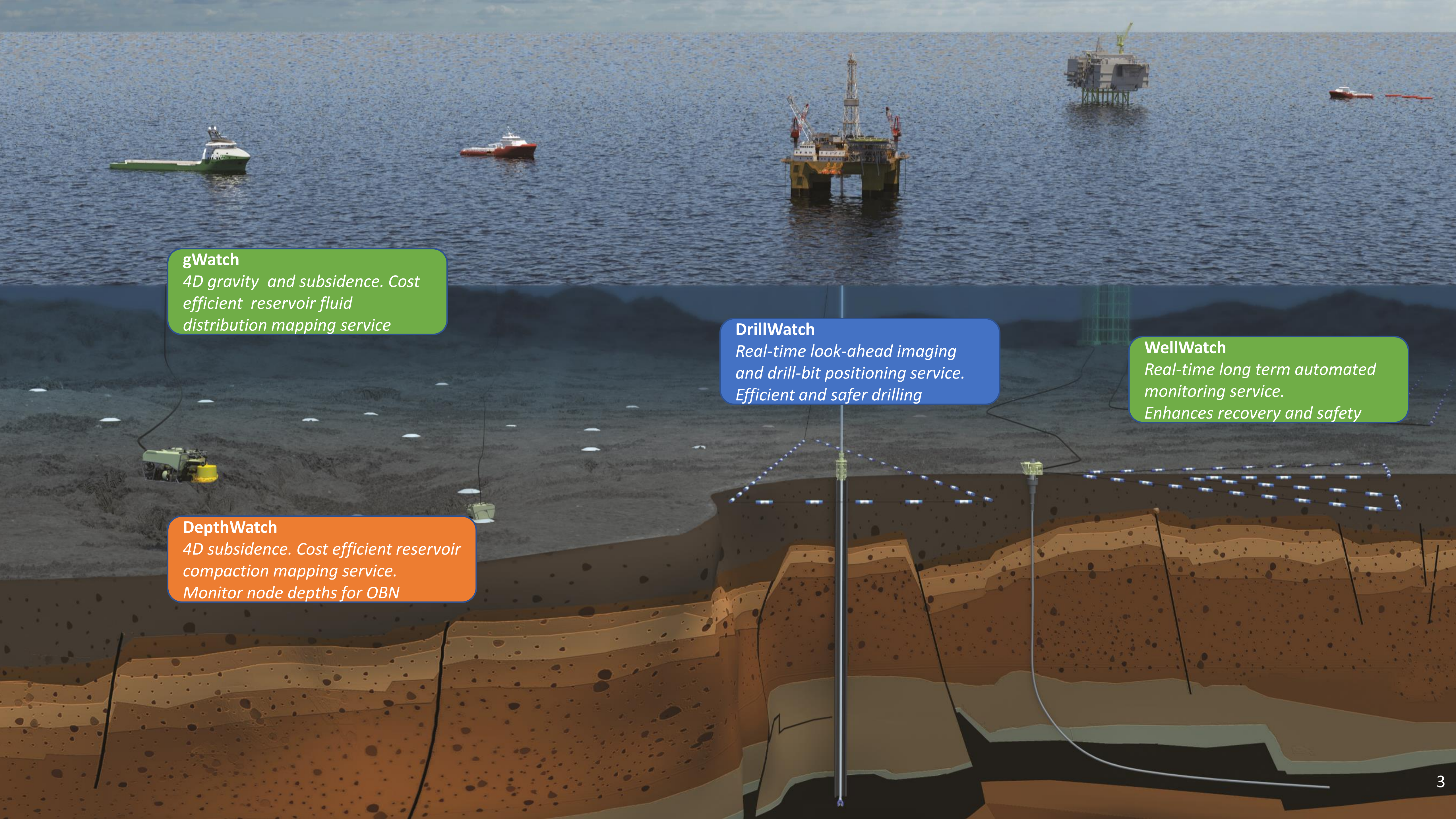
- There is a need for cost efficient monitoring solutions for CCS projects.
- Advances in CSEM technology allows for CO_2 monitoring applications aimed at leakage detection, plume mapping and volume estimation.
- CSEM acquisition can provide a safe alternative in sensitive or challenging areas.
- No monitoring solution will work everywhere – Allton encourages feasibility modelling to evaluate CSEM applicability for specific projects.

Thank you for your attention!

gWatch

A cost-effective holistic approach to monitoring of CO_2 storage


gWatch
4D gravity and subsidence. Cost efficient reservoir fluid distribution mapping service
DrillWatch
Real-time look-ahead imaging and drill-bit positioning service. Efficient and safer drilling
WellWatch
Real-time long term automated monitoring service.
Enhances recovery and safety
DepthWatch
4D subsidence. Cost efficient reservoir compaction mapping service.
Monitor node depths for OBN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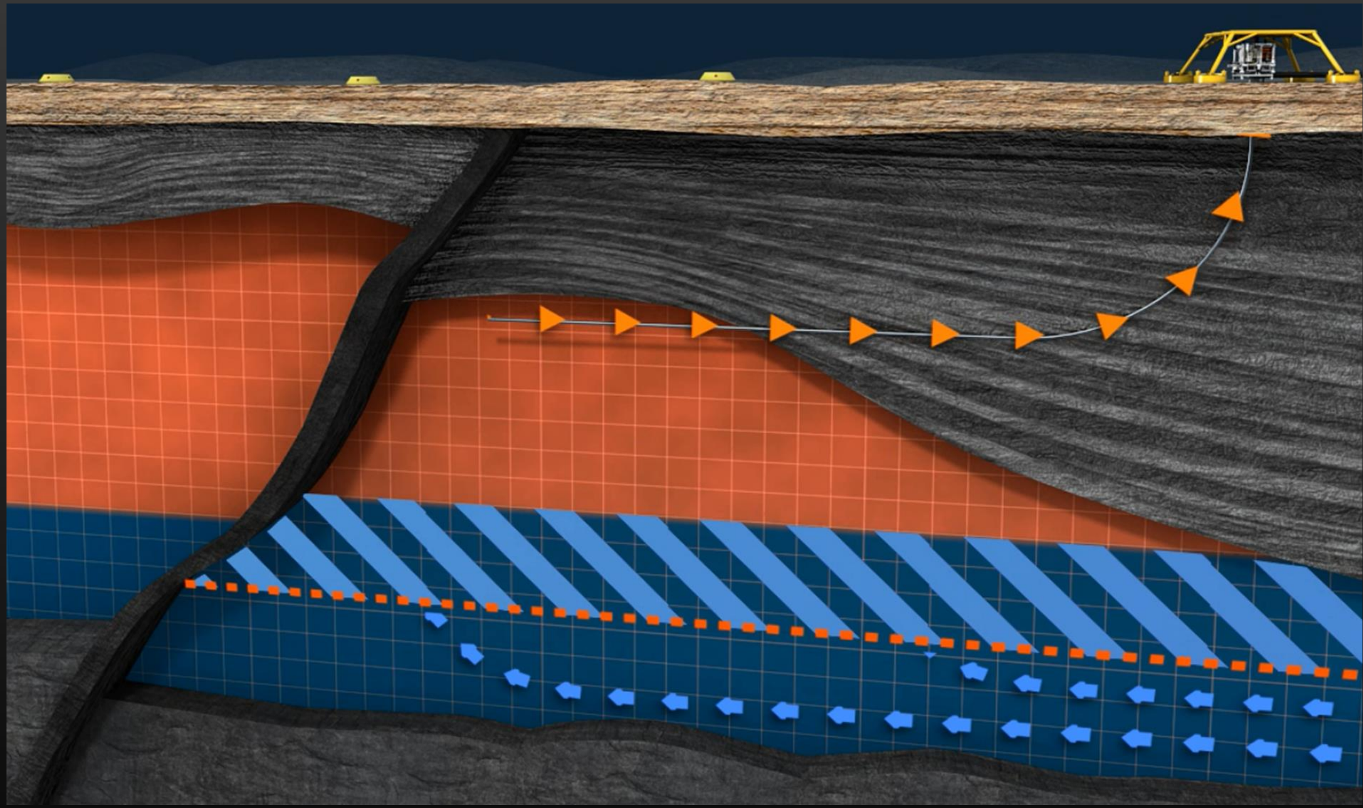
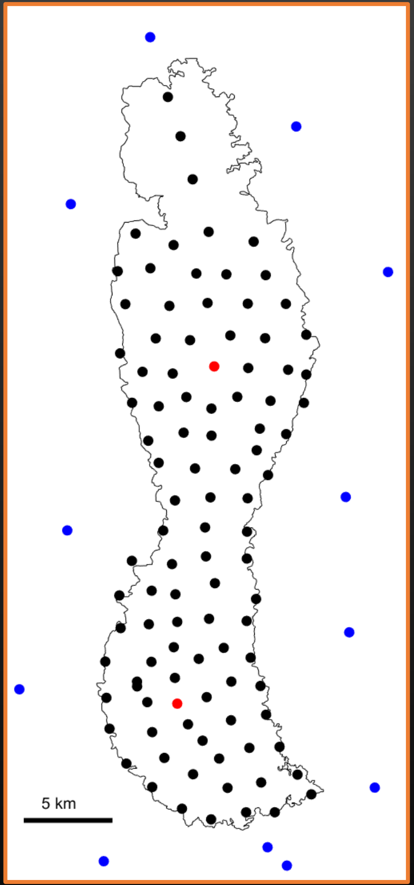
Enhances recovery and safety
DepthWatch
4D subsidence. Cost efficient reservoir compaction mapping service.
Monitor node depths for OBN

gWatch Technology in a nutshell

$$F = G\frac{Mm}{r^2}$$



gWatch Technology in a nutshell



Sensor frame with three relative gravimeters and three pressure sensors

gWatch

Two independent measurements

Gravity : Sensitive to mass changes

- Monitor fluid movements
- Maps hydrocarbon depletion
- Distinguishes drive mechanism

DepthWatch

Seafloor subsidence: Sensitive to reservoir compaction

- Pressure drop
- Pore compressibility

Ruiz, H., et al., 2016, Monitoring offshore reservoirs using 4D gravity and subsidence with improved tide corrections, SEG Annual Meeting, October 2016, Dallas, SEG-2016-13576781

OCTIO GRAVITUDE

Value proposition for CO_2 and H_2 storage

Efficient reservoir management
- Constrain uncertainties in volumetric expansion of the injection plume
- Reduce uncertainties in in-situ CO_2/H_2 density
- Pressure communication in the reservoir
- Detect vertical leakage of the CO_2/H_2 plume

Field development strategy
- Maintain injection rates below fracture pressure gradient
- Confirm long term containment and storage capacity

Cost effective
- 1/10 conventional 4D seismic
- Simplified operations and logistics

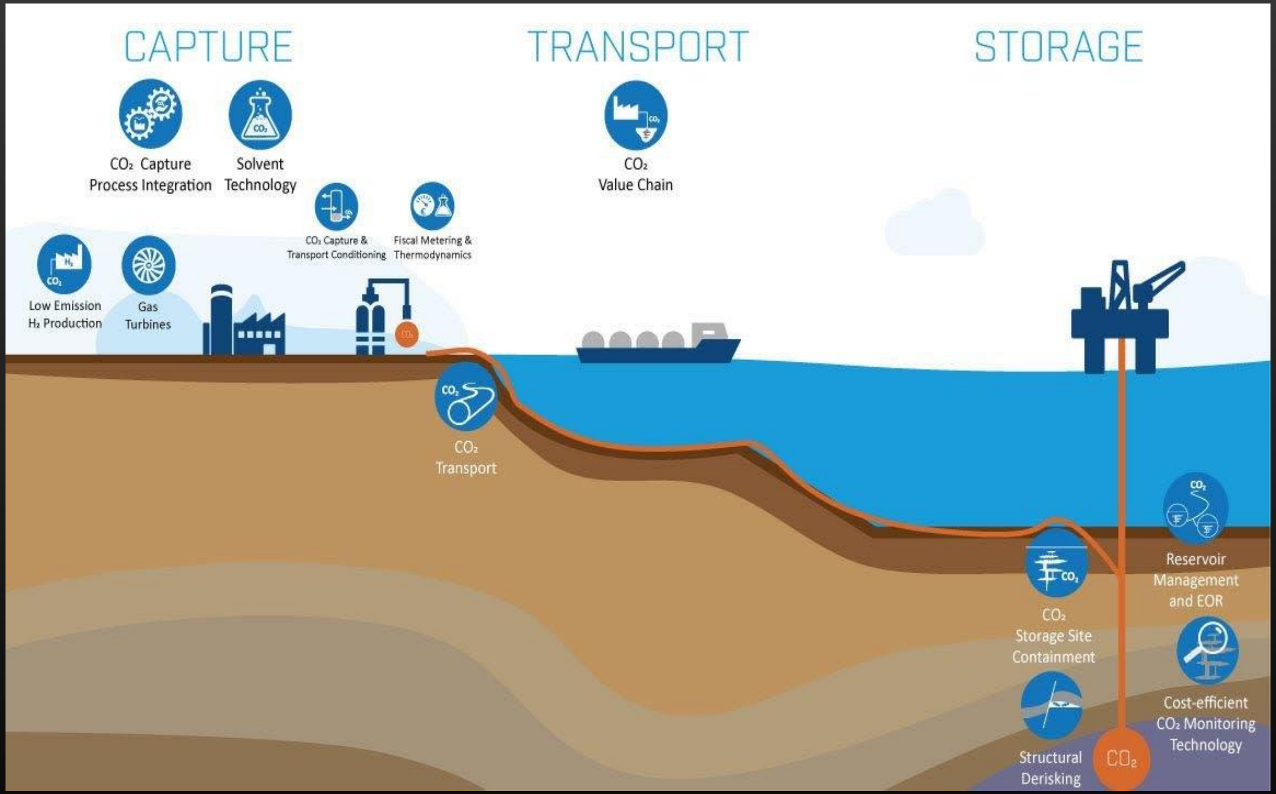


Illustration from Norwegian CCS Research centre

Gravity and subsidence: track record

Field	Since	No. surveys	Burial depth (m)	Concrete platforms	Main applications (Main contribution from: gravity, subsidence)
Troll	1998	7	1400	113	Compressibility Aquifer support, prediction of water break-through
Sleipner	2002	4	800/2350	50	Properties of injected CO_2
Mikkel*	2006	4	2500	21	Aquifer strength, volume of gas in place
Midgard	2006	5	2500	60	Identified undrained compartment: successful infill well Aquifer strength, prediction of water breakthrough
Snøhvit / Albatross	2007	3	2500	86	GIIP, prediction of water break-through
Ormen Lange	2007	7	2000	120	Aquifer influx, compartmentalization Reservoir compaction, pressure depletion
Statfjord (oil)	2012	2	2750	53	Subsidence, aquifer properties, reservoir compressibility Improved geomechanical for better 4D seismic
Aasta Hansteen*	2018	2	2300	31	Aquifer influx, optimize production
Three Oil Fields in the GoM	2018	1	2500		Node DepthWatch
Oil field in the GoM	2018	2	800 - 2000		DepthWatch at a water depth of 2800 m Client been trying alternative technologies
Oilfield in the GOM	2021	1	2000		Node DepthWatch

*: No-4D seismic at all

Sensitivity evolution

- Three gravity surveys to date at the Snøhvit field: 2007, 2011, 2019
  - 4D seismic acquired on a section of the field to monitor CO_2 injection

- Sensitivity in gravity over a decade:

	Average uncertainty	
Time-lapse	Subsidence (mm)	Δ Gravity (μGal)
2007-2011	4.6	3.7
2011-2019	2.8	1.6
Projected 2019-202x	1.9	0.64

Improvements in instrumentation and survey procedures

Factor of 5 improvement on gravity

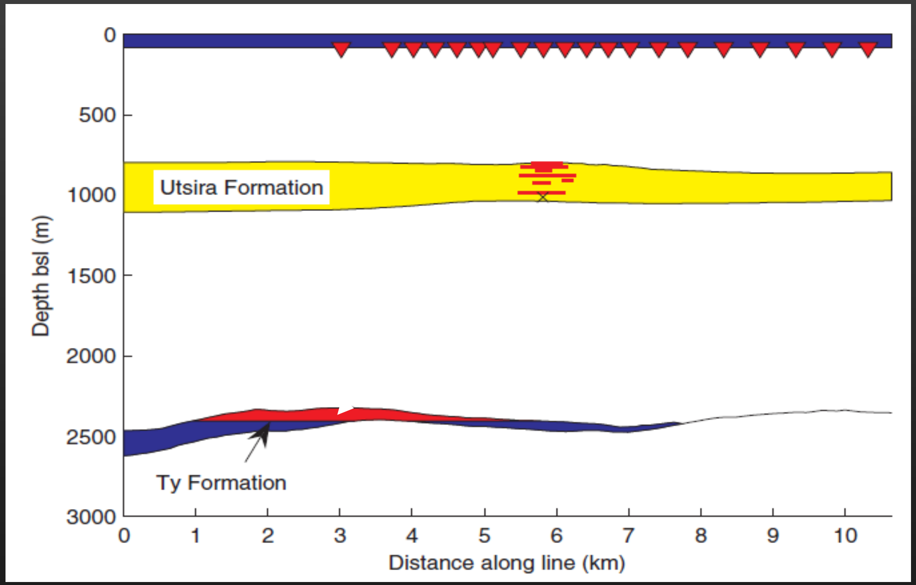
High sensitivity allow resolving smaller changes in the reservoir

OCTIO GRAVITUDE

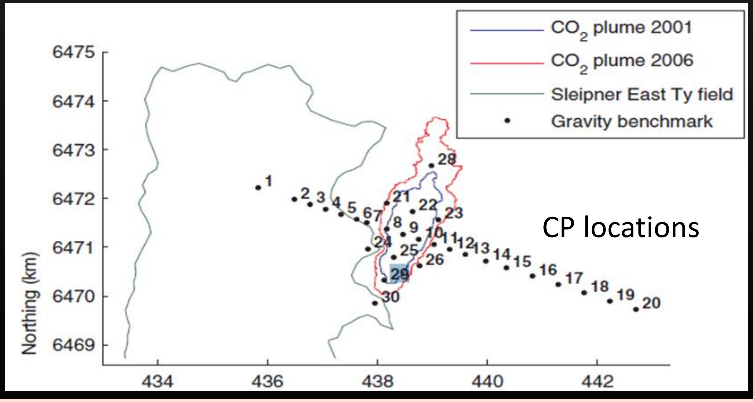
Field cases

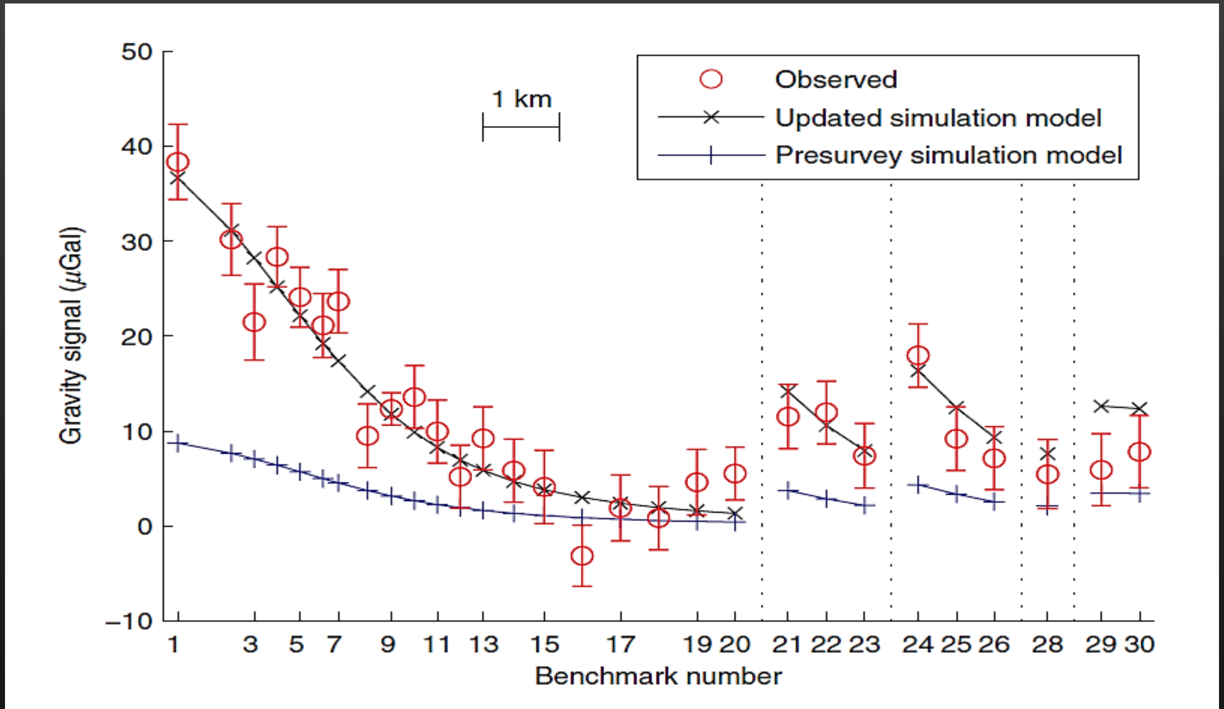
Alnes, H., et al., 2008, Monitoring gas production and CO2 injection at the Sleipner field using time-lapse gravimetry, Geophysics, 73, 155-161

Sleipner CO_2 monitoring



Layout design of the measurement monuments





- Learnings from gravity:
  - Production: data showed larger water influx than expected, later confirmed by well and 4D seismic data
  - CO_2 injection: gravity provided a lower bound on CO_2 density at 640 kg/m3 at 95% confidence

Alnes, H., et al., 2008, Monitoring gas production and CO2 injection at the Sleipner field using time-lapse gravimetry, Geophysics, 73, 155-161

Sleipner CO_2 monitoring

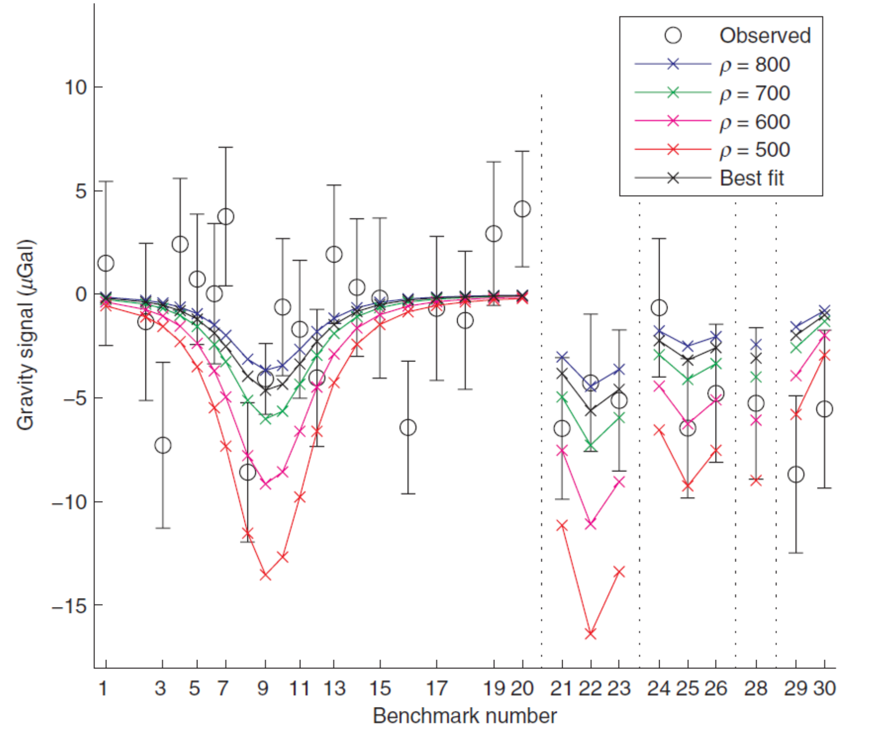
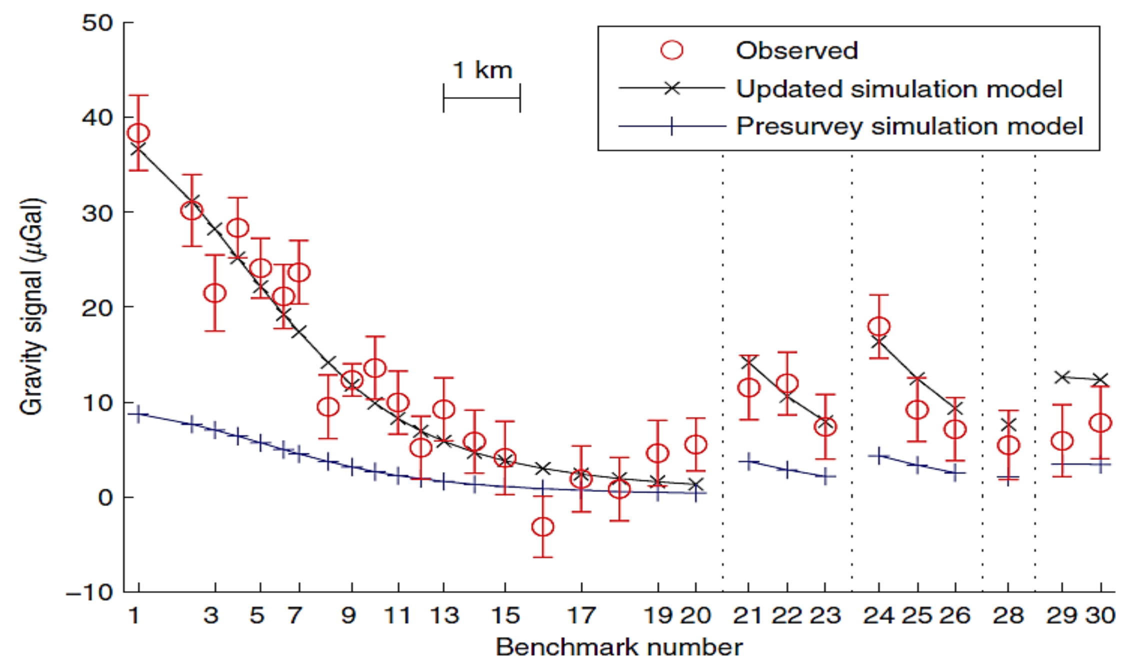


Figure 7. Gravity signal after contributions from the Ty reservoir and benchmark subsidence have been subtracted. The best-fit value for in situ CO_2 density is 760 kg/m^3.



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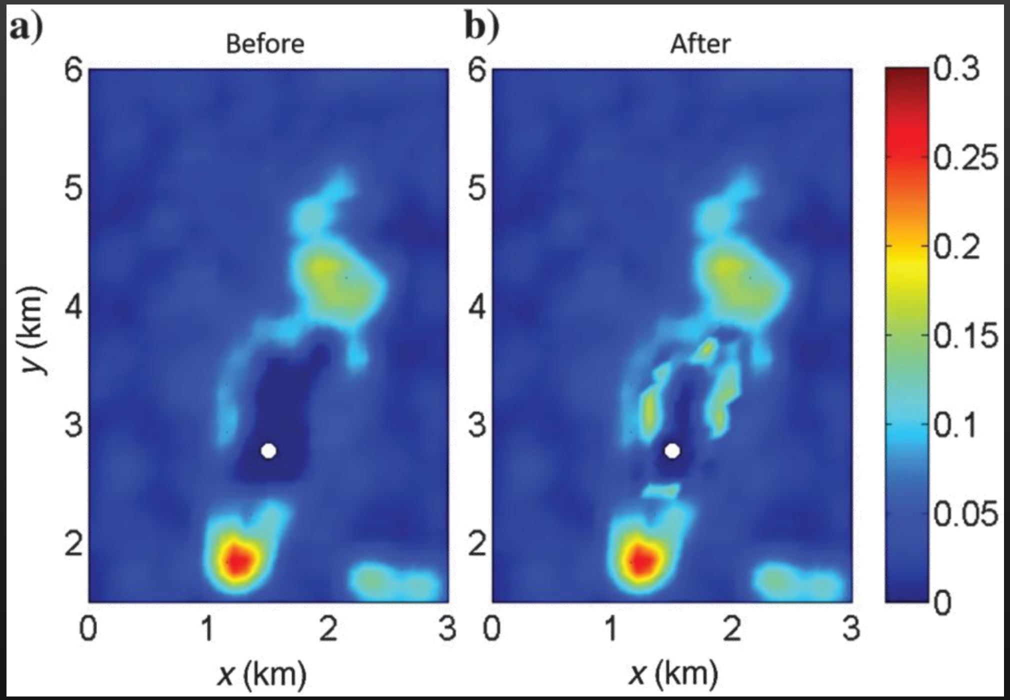
Landrø M. and Zumberge M., 2017, Estimating saturation and density changes caused by CO_2 injection at Sleipner – Using time-lapse seismic amplitude-variation-with-offset and time-lapse gravity, Interpretation, Vol 5 May Issue, T243-T257

Sleipner – Inversion of CO_2 saturation

- Challenges with seismic:
  - Seismic shadow effects under layers that had already been charged with CO_2
  - Limited velocity sensitivity to changes in saturation between $0.3 \rightarrow 1.0$
  - Velocity sensitivity exist between saturations in the range $0 \rightarrow 0.3$
  - Seismic inversions will have limited sensibility to changes in CO_2 saturations
- Combined seismic + gravity inversion
  - Use measured changes in gravity to constrain saturation changes in the inversion



Inverted saturation with and without including gravity changes in the inversion

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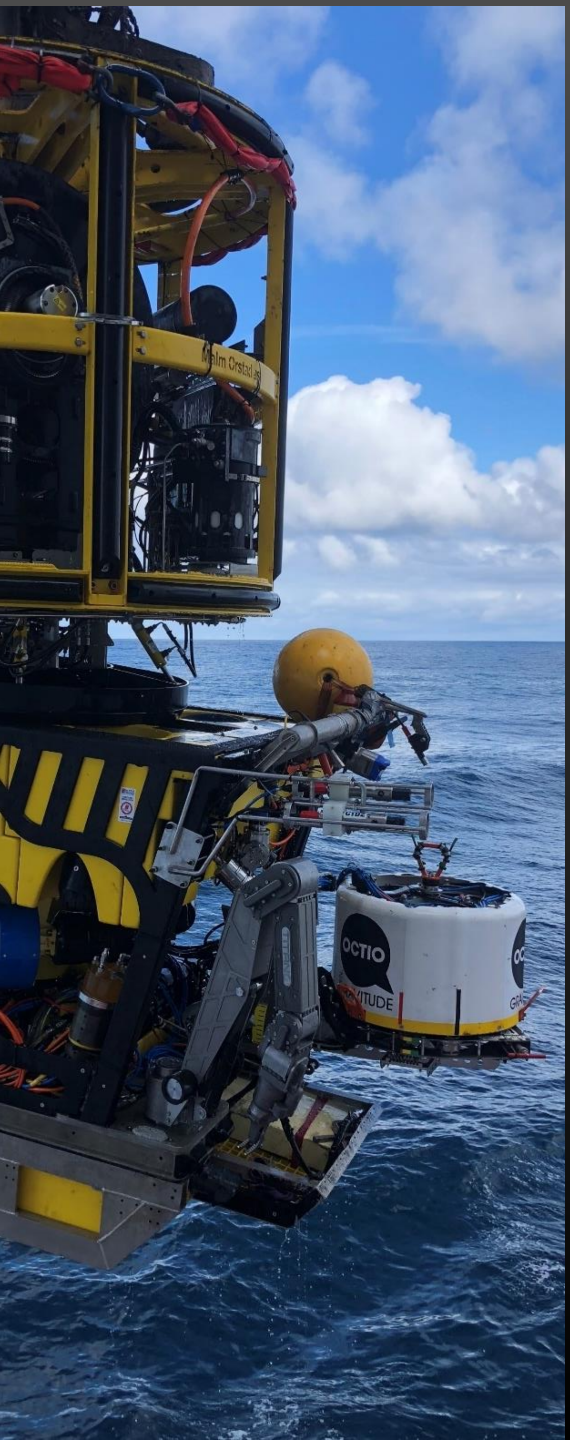

Conclusions and outlook

Field-wide mapping reservoir management:

- Constrain uncertainties in volumetric expansion of the injection plume
- Reduce uncertainties in in-situ CO_2 / H_2 density and mass distribution
- Pressure communication in the reservoir
- Detect vertical leakage of the injection plume

• Field development strategy

- Maintain injection rates below fracture pressure gradient
- Confirm long term containment and storage capacity

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