Presentations 8 February - CCS Speed Dating - Capture

- Jørild Svalestuen, Gassnova
- Jan Gabor, Mo Industripark
- Bjørn Hølaas, Statkraft
- Tiril Fjeld, Haugaland Industrial Park
- Kjetil Bergmann, Returkraft
- Kristian L. Aas, SINTEF
- Guro Nereng, Borg CO_2
- De Chen, NTNU
- Thijs Peters, SINTEF
- Mona Mølnvik, SINTEF Energy Research
- Hanne Kvamsdal, SINTEF
- Zuoan Li, SINTEF
- Mario Ditaranto, SINTEF
- Ragnhild Skagestad, SINTEF
- Øyvind Langørgen, SINTEF Energy Research

Jørild Svalestuen

MODERATOR

The CLIMIT program provides financial support for development of carbon capture and storage (CCS) technology and consists of two support schemes; CLIMIT R&D and CLIMIT Demo. It is run by the Research Council of Norway and Gassnova respectively where Gassnova has the overall coordination responsibility and heads the program secretariat.

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7–9 February

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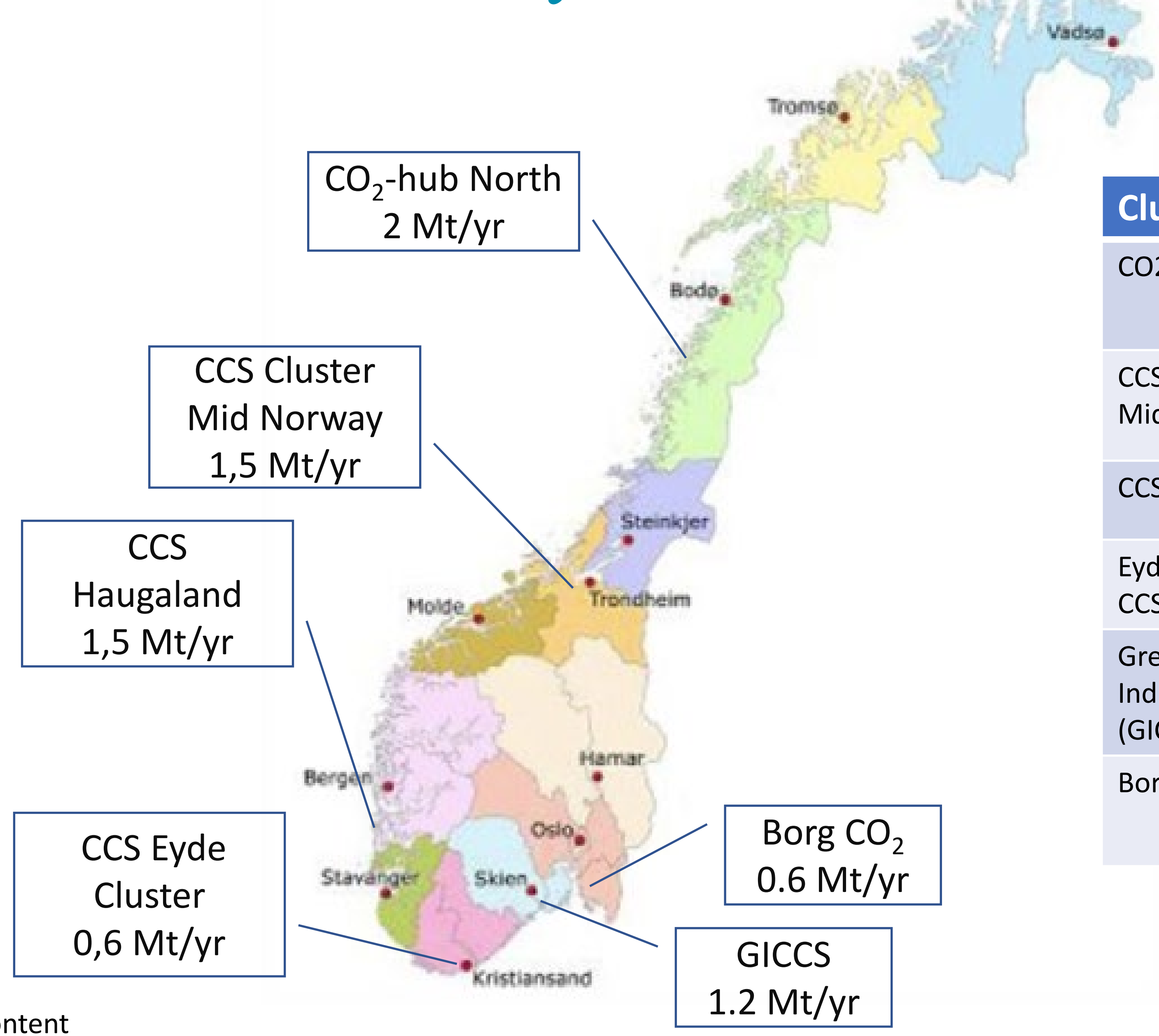
CCUS Industry Clusters in Norway



Cluster	Industry
CO2-Hub North	Alcoa (Mosjøen), Celsa, Elkem (Rana), Elkem (Salten) Ferroglobe, Mo Industrial Park, Norcem (Kjøpsvik), NorfraKalk, , SMA Mineral
CCS Cluster Mid-Norway	Elkem (Thamshavn), Equinor (Tjeldbergodden), Statkraft Varme (Heimdal), Franzefoss (Verdalskalk og NorFraKalk), Wacker Chemicals (Holla Metal)
CCS Haugaland	Equinor, Eramet (Sauda), Gasco, Haugaland Industrial Park, Hydro Karmøy
Eyde-Cluster CCS	Alcoa (Lista), Elkem, Eramet, Eyde Cluster, Fiven, Returkraft
Grenland Industrial CCS (GICCS)	Ineos, Inovyn, Eramet (Porsgrunn), Norcem (Brevik)
Borg CO2	Norske Skog Saugsbrugs, FREVAR, Sarpsborg Avfallsenergi, Kvitebjørn Bio-El og Borregaard, (Borg Havn)

Content

CLIMIT

Jan Gabor

VP BUSINESS & PROPERTY DEVELOPMENT

CO_2 HUB Nord, pilot CO_2 capture in Mo Industrial park

Educated at BI Norwegian Business School, worked for more than 35 yrs in construction and industry. Leading positions focusing on business development. Currently also a member of the CLIMIT Programme Board.

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CO_2 HUB NORD

Jan I. Gabor
CLIMIT Summit, 8/2-2023

Mo Industripark as

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CO_2 Hub Nord

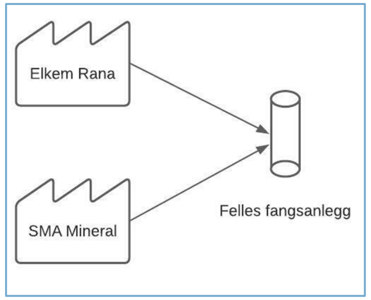
Roadmap for industry in Nordland 2017 Industri, SINTEF, NFK

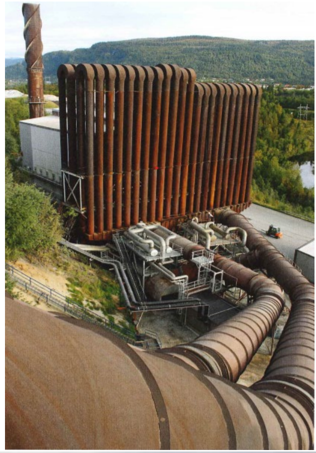
CO2 Hub Nordland Evaluation of Technologies 2018-2021 Industri, SINTEF, Gassnova

CO2 Hub Nord Demonstration of technology 2021-2023 Industri, SINTEF, Gassnova

Development of fullscale CO_2-capture 2024-

- The world's first test of CO_2-capture in ferroalloy industry
- Capture from two different sources + combination
- Optimising of integration solutions and further development of CO_2-capture technology
- Integration of energy systems and flue gas conditioning
- Case studies and LCA-calculations
- Benchmarking of technologies





Mo Industripark as

AKER CARBON CAPTURE

Elkem

sma mineral

Ferroglobe

CLIMIT

NORCEM HEIDELBERGCEMENT Group

celsa nordic

NorFraKalk

ALCOA

ACT ARCTIC CLUSTER TEAM

SINTEF

Content

CO_2 Hub Nord

- Six industrial sectors gathered in one project
- Duration of project, 2 years
- MTU from ACC is now running
- Pilot testing for 6 months

Content

20/1-2023

WORLD'S FIRST CARBON CAPTURE PILOT FOR SMELTERS INAUGURATED IN MO INDUSTRIAL PARK

20 January, 2023 12:33 Del Del Del

Today, the world's first carbon capture pilot for smelters has been officially inaugurated. The Mobile Test Unit (MTU), delivered by Aker Carbon Capture, is now connected to Elkem's plant in Mo Industrial Park, Mo i Rana, Norway, which produces high-purity ferrosilicon and microsilica.

The carbon capture pilot testing is a collaboration between Elkem, Mo Industrial Park (Mo Industripark), SMA Mineral , SINTEF, Alcoa, Celsa Group, Ferroglobe PLC, Norcem AS, NorFraKalk AS, ACT Cluster and Aker Carbon Capture. With full-scale implementation, 1.5 million tonnes of CO2 can be captured from their combined emissions. In a couple of months, testing will commence at SMA Mineral.

Joined by more than 60 invitees, Amund Vik, State Secretary at the Norwegian Ministry of Petroleum and Energy, spoke at the ceremony:

"There is no doubt that we need CCUS to reach our climate targets. We need CCS in hard-to-abate industries to keep industrial jobs in Europe. This pilot will provide important learning related to CO2-capture in metal industries, and will be an important hub for other companies in the Industrial Park to test CO2-capture technology," says Deputy Minister Amund Vik.

Mo Industrial Park's CEO Arve Ulriksen says carbon capture is a perfect fit for Mo Industrial Park's vision of being a green industrial park of world class.

"Mo Industrial Park is one of Norway's largest industrial areas with a range of industrial actors. This makes it possible for the industry here to benefit from synergy effects and be a part of a circular economic cluster. This pilot, where carbon will be captured from two different locations simultaneously, is a good example of the possibilities in an industrial cluster like Mo Industrial Park", says Mo Industrial Park's CEO Arve Ulriksen

Content

Bjørn Hølaas

VP/DIRECTOR CCS

Mid Norway CCS Cluster

Previous role; 24 years within energy utilities.
Trondheim Energy; EVP retail and trading, EVP staff functions, CEO.
Statkraft; SVP district heating, VP leadership support and shared services
Education:
Batchelor communication and risk management.
MBA strategic management

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CCS cluster mid-Norway
- findings and further plans

BJØRN HØLAAS, LEADER OF STEERCO

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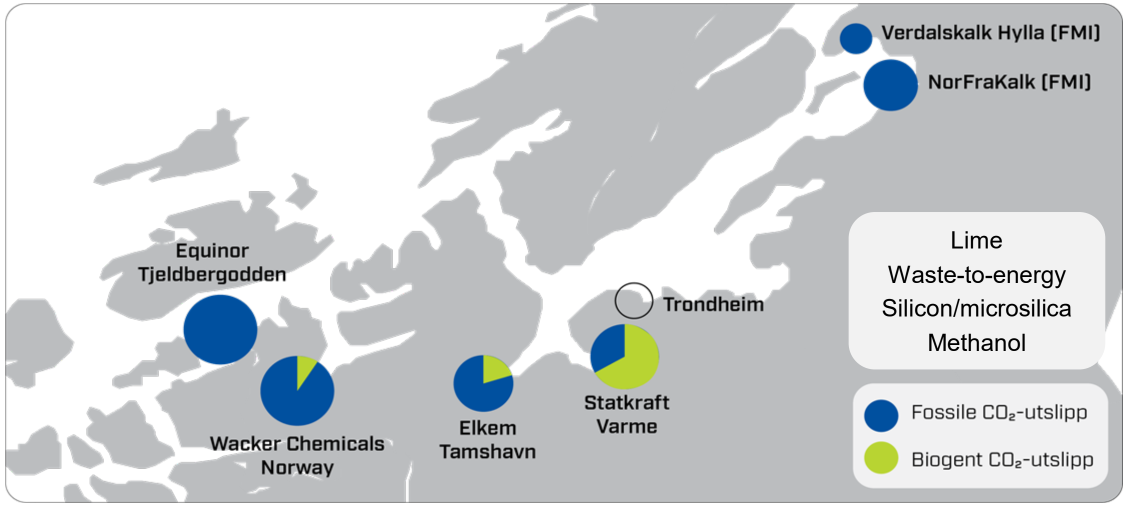
Supported by;

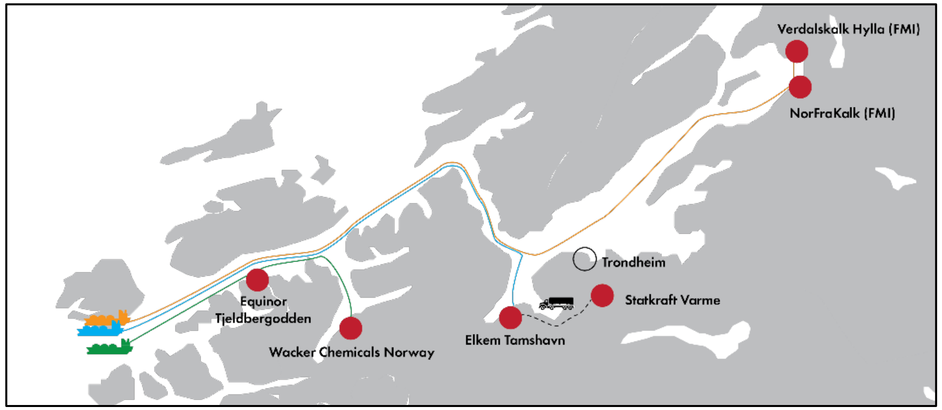
CCS cluster mid-Norway



- Project owner: Statkraft Varme
- Project lead; Sintef
- Time; March 2021 – February 2023
- 1515 kton CO_2/y whereof 290 kton biogenic CO_2

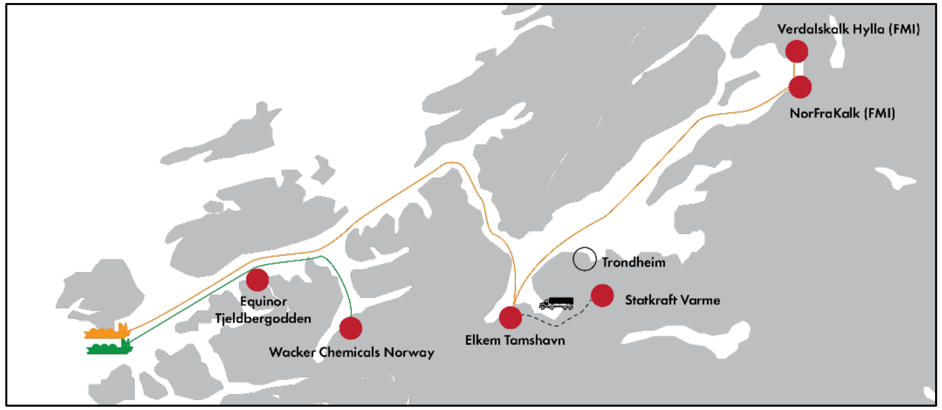
- Concept(s) for transport and intermediate storage
- Possible regional business models
- Contribute to realistic perception of CCUS in mid-Norway

Content



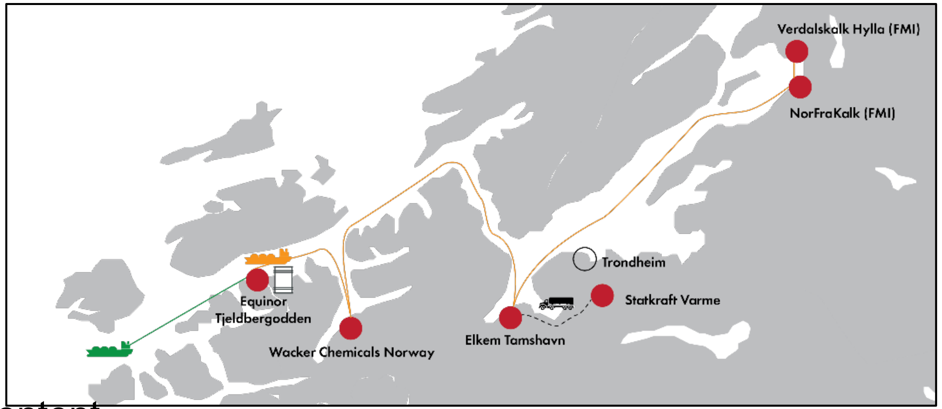
3 ships

- 1. Verdalskalk/NorFraKalk
- 2. Elkem/Statkraft common intermediate storage
- 3. Wacker + Equinor



2 ships

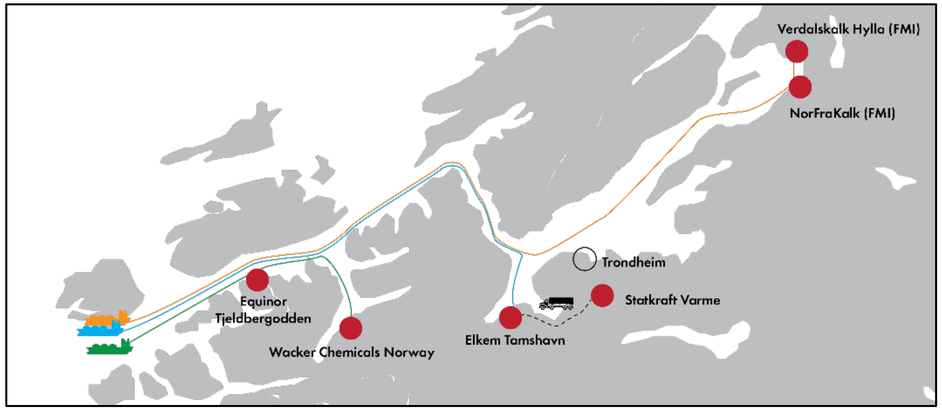
- 1. Verdalskalk/NorFraKalk + Elkem/Statkraft
- 2. Wacker + Equinor



2 ships

- 1. Verdalskalk/NorFraKalk + Elkem/Statkraft + Wacker
- 2. From intermediate storage nr. 2 + Equinor

- **Mapped existing infrastructure as aviable area, quay, utilities etc**
- **Developed alternatives for transport to Northern Lights**
  - **pipeline vs trucks, alternative routes, ship size, frequency, 7 bar vs. 15 bar etc**
- **Technological and economic analysis for comparison of alternatives**
  - **tool; iCCS (Sintef)**



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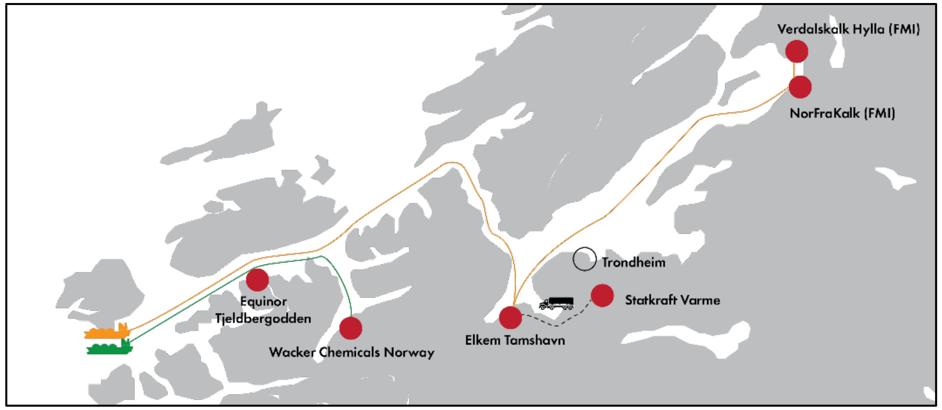

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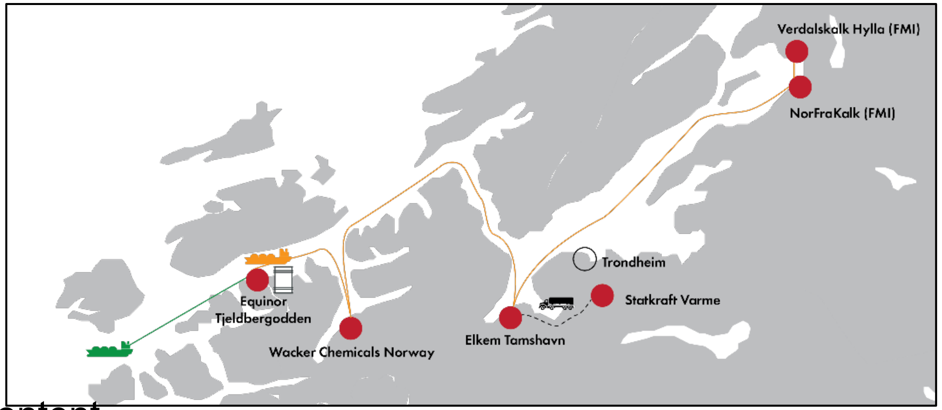

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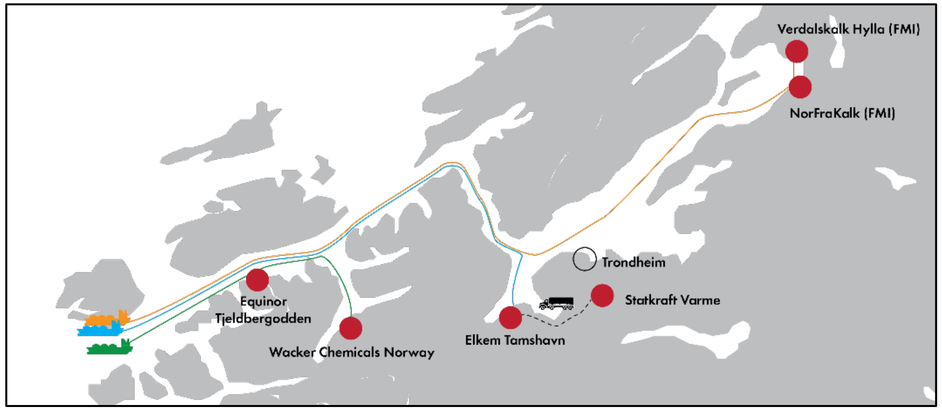

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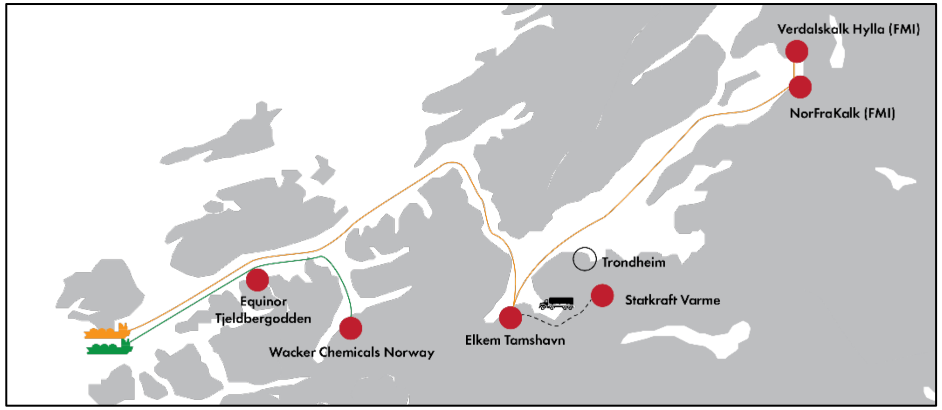

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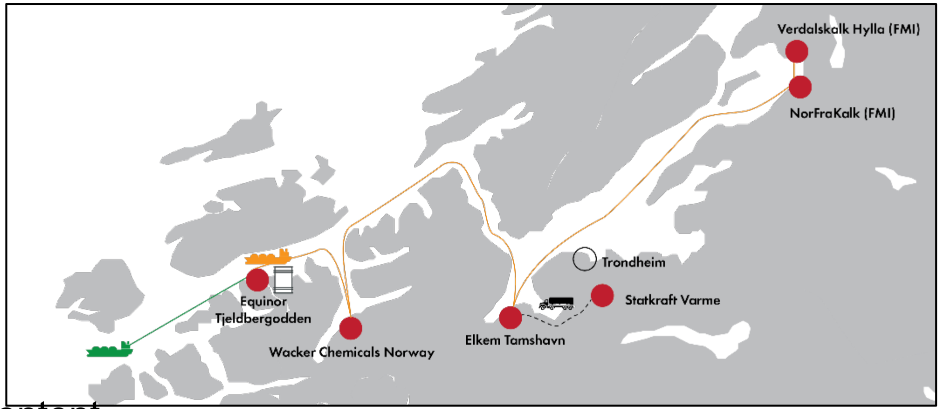

2 ships
- 1. Verdalskalk/NorFrakalk + Elkem/Statkraft + Wacker
- 2. From intermediate storage nr. 2 + Equinor

Key findings
- Potential of approx. 35% cost reduction with shared solutions
- Optimizing ship size/storage
  - Size of CO_2 carrier and buffertank need to be based on shipping plan (distance and stops)
- CO_2 volume
  - «Critical» volume allows larger ships or a fleet of ships, and potential economy of scale
- Shared infrastructure/ intermediate storage
  - Reduced cost and risk
- Trucks more cost-efficient than pipeline

Option
- Increased CO_2 volume from Sweden (by train) and others emission points

Challenges
- Different timeline for decision
- Binding legal framework/contracts between partners
- Viable business model/financing
- Agreement/access to permanent storage

Statkraft

Work packages next phase (tentative)

WP1: Cross-Industry Collaboration

- Mapping and sharing of company plans and relevant surveys
- Contact with/knowledge gathering from other CC(U)S hubs (CinfraCap, UK, Antwerp, Rotterdam…)
- Aligned partners decision Gates

WP2: Concept Evaluation

Transport & Storage

- Logistics – explore/gather and evaluate concepts from CO_2 transport operators
- Contact with storage operators, - aviability, timeline,
- Evaluation of storage sites

WP3: Business and legal framework

- Evaluation of actual costs along the chain
- Valid legal framework
- Contracts along the chain
- Cost distribution
- Risks and mitigation actions
- Roles and responsibilities along the chain (e.g. ownership and operation)

WP4: Stakeholder involvement and communication

- Contact, information and cooperation with NGO`s, authorities, public actors, etc.
- Participation in events/-relevant conferences

WP5: Concept description along the value chain

Statkraft

Statkraft

statkraft.no

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Tiril Fjeld

CEO

CCS Haugalandet

Tiril has been CEO of Haugaland Industrial Park since 2019 and previous she had 20 years' experience from the technology industry. She has experience as board member from i.e. energy industry.

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CCS Haugalandet

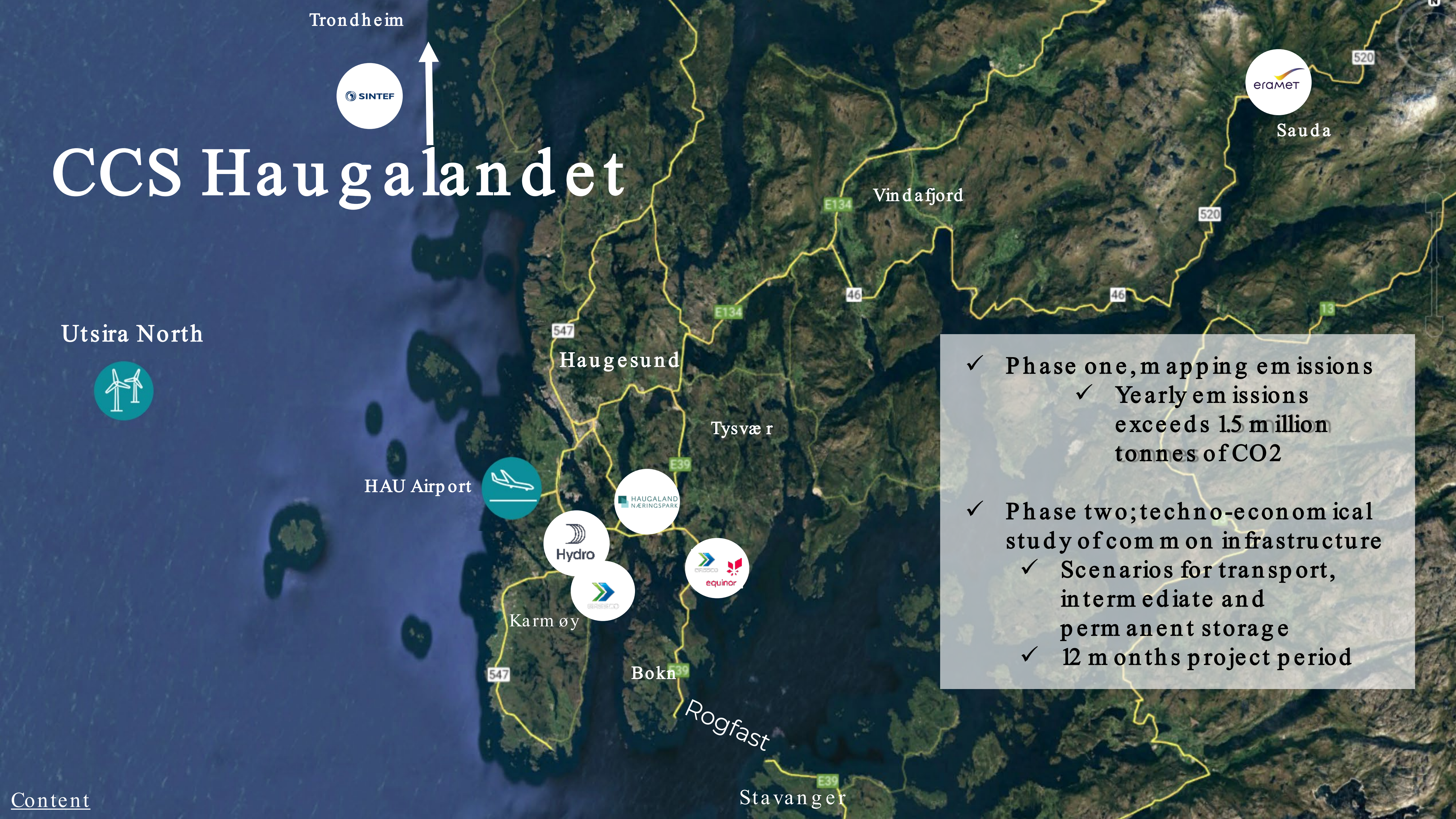
CLIMIT SUMMIT, February 2023

By Tiril Fjeld

CEO Haugaland Næringspark

Tiril.fjeld@haugaland-park.no

CCS Haugalandet



- ✓ Phase one, mapping emissions
  - ✓ Yearly emissions exceeds 1.5 million tonnes of CO_2
- ✓ Phase two; techno-economical study of common infrastructure
  - ✓ Scenarios for transport, intermediate and permanent storage
  - ✓ 12 months project period

Content

Kjetil Bergmann

PROJECT MANAGER CCS

Eyde-Klyngen – Ongoing CCS projects at Returkraft

Educated in the Norwegian Navy with 25 years of service in the Navy including positions as Commanding officer and project management in several large procurement projects. Have been working in the Waste to Energy sector for the last 10 years with focus on environment and quality. Started first CCU projects at Returkraft in 2018 and have been working with CCS 100 percent from 2021, with the aim of establishing a full-scale CCS chain at Returkraft in 2030.

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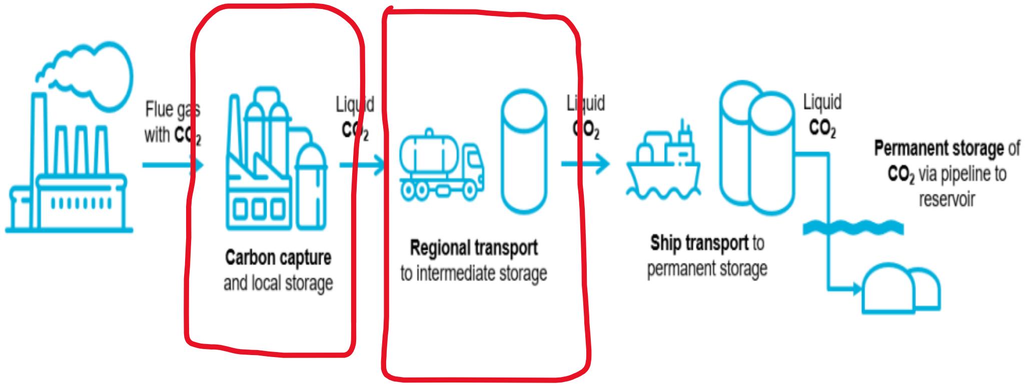
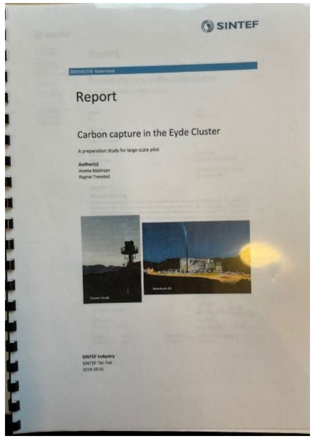
Eyde-Cluster – Ongoing CCS projects at Returkraft

- Our goal is to establish a full scale CCS chain by 2030



- Studies
  - A study on feasebillity for capture within the Eyde-cluster members started in 2018.
  - Two pilots
    - Returkraft and Eramet.
  - Air Products chosen as partner for Returkraft.
    - Membrane pilot

  - Logistics – how and where to move the captured CO_2 - Local HUB



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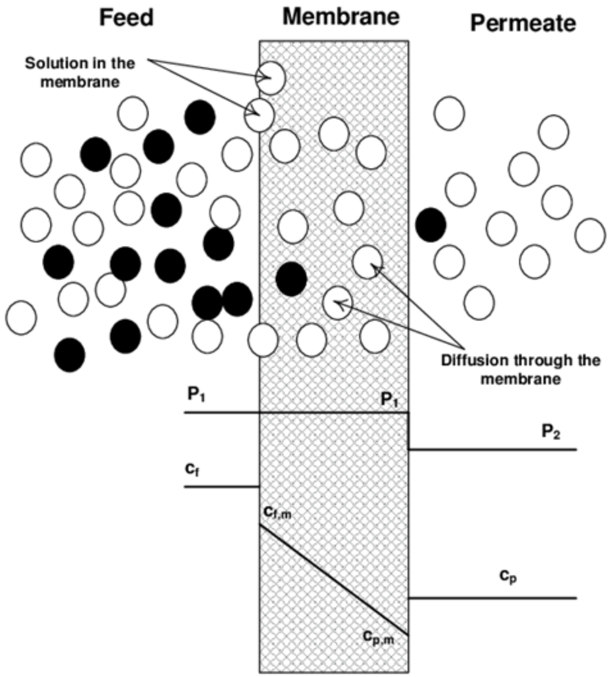
Returkraft CO_2 capture pilot project

• Gas separation in Polymer Membranes

- Membrane is a selective barrier
- Gases permeate at different rates through the polymer material.
- Permeability is the combined solubility and diffusability of a gas component

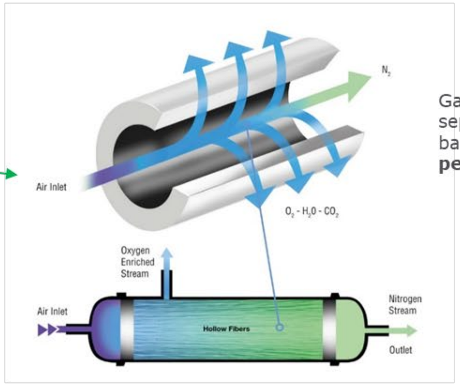


• CO_2 capture with PRISM Membranes

- Flue gas is cooled and pressurized and flows inside the hollow fibers
- CO_2 permeates faster than N_2 and O_2 to the low pressure side

Membrane separators can be arranged in series or parallel depending on application requirements

Hundreds of **hollow polymer fibers** make a separator



Gas mixtures are separated in the fibers based on the principle of **permeation**

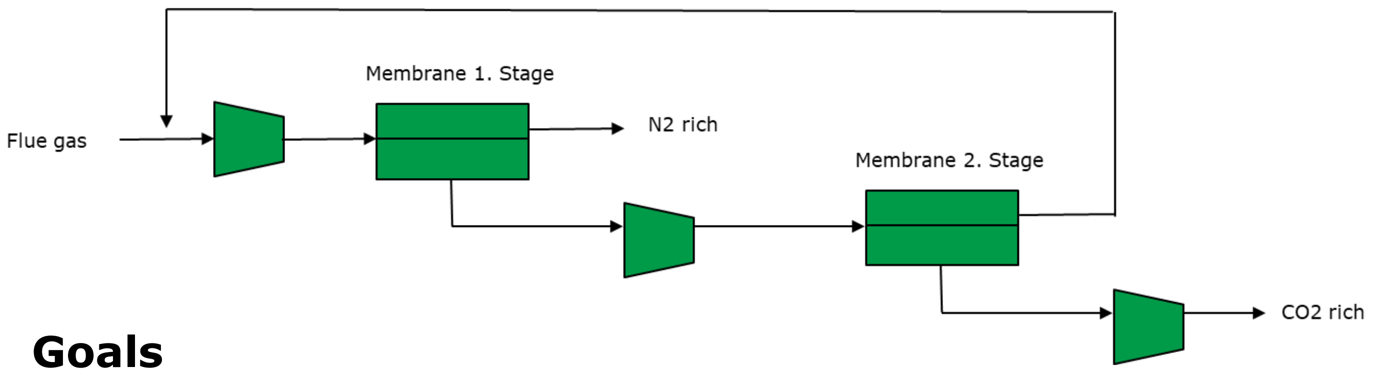
Content

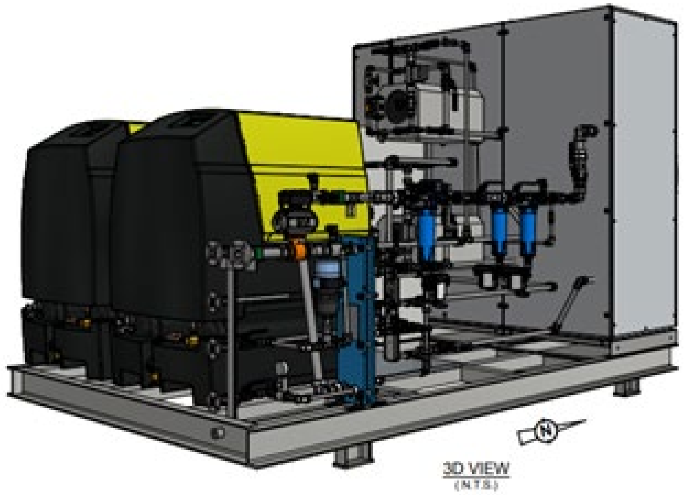
Returkraft CO_2 capture pilot project

Returkraft

Project scope

- Small-sized pilot; demonstrating one full scale membrane unit
- Flexible pilot able to operate with different capture modes:
    - 55% capture rate (Fossil based share of waste at Returkraft)
    - 90% capture rate (Enables Bio-CCS)





Goals

- Demonstrating PRISM membrane in flue gas.
- Membrane lifetime in exposure to SO_x, NO_x and other flue gas components
- Energy consumption at different capture rates and purity rates
- Demonstrating full scale process design

- Will be installed in march, with testing all through 2023.

Kristian L. Aas

SENIOR RESEARCH SCIENTIST

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GICCS – A Joint Solution Approach to CCS in Grenland

Has worked at SINTEF since 2017 when Tel-Tek became part of SINTEF. Works with energy and climate related projects in collaboration with the process industry in Grenland. Current topics are utilization of surplus heat and CO_2 capture.

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A Joint Solution Approach to CCS in Grenland

GICCS
Grenland Industrial CCS

- Owner: Powered by Telemark
- Industrial Partners:
  - Ineos
  - Inovyn
  - Eramet
  - Norcem
  - Herøya Industripark
  - Pipelife
  - Bluegreen Fusion
  - Nippon Gases
  - Nordic Electrofuel
  - Norsk E-fuel
  - Bouvet
- Research Partners:
  - SINTEF Industry
  - USN

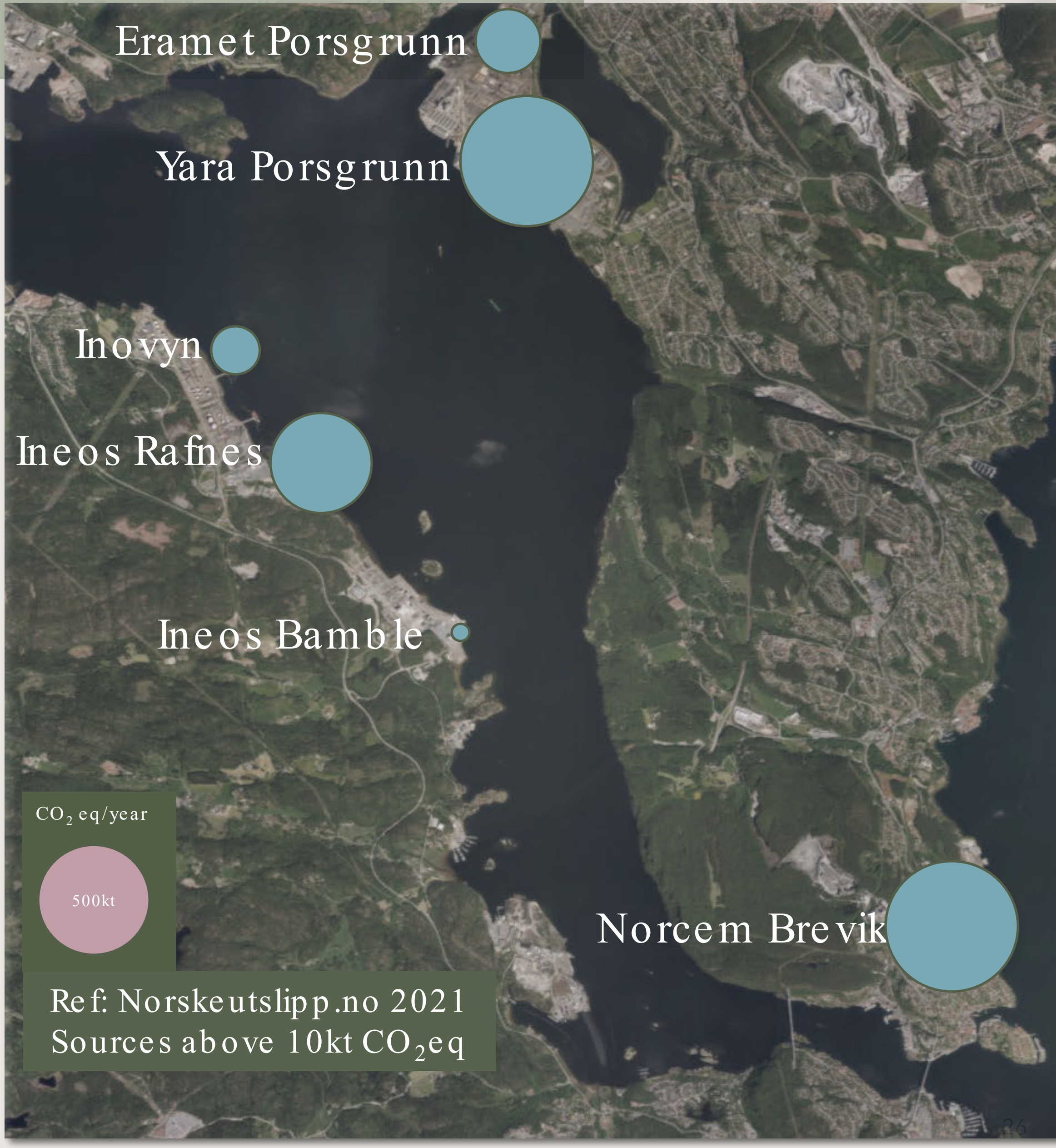
Total budget 11 375 kNOK												
Gassnova - Climit 50%						Industry 50%						
Year	21	2022				2023				2024		
Quarter	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3

POWERED BY TELEMARK

Green house gas in Grenland 2021

- More than 2,2 Mt CO_2 eq per year
- Projects ongoing
  - Brevik CCS – World's first CO_2-capture facility at a cement plant - part of "Longship". In operation 2024
  - Yara – Herøya Green Ammonia - Electrification - Pilot being build
  - Reduction through process changes
- GICCS – Concept study

A joint solution approach for existing and new companies in need for CCS - scale for up to approx. 1 Mt CO_2 per year



Main focus

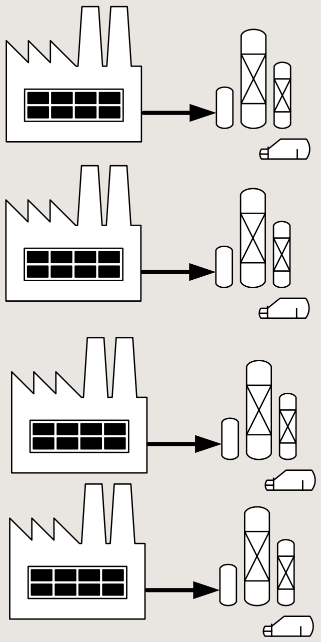
Capture	Energy supply	Joint Solutions
Base case CCS each site	Excess heat and alternatives	Capture, Integration, Pipeline, Digitalisation, Utilization, Transport and Storage

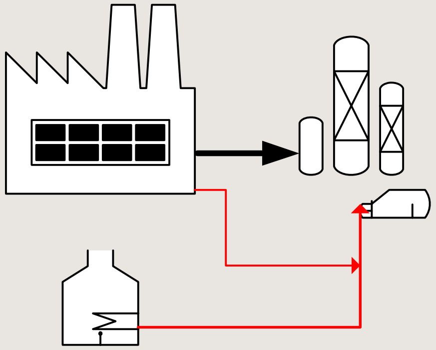
Ineos

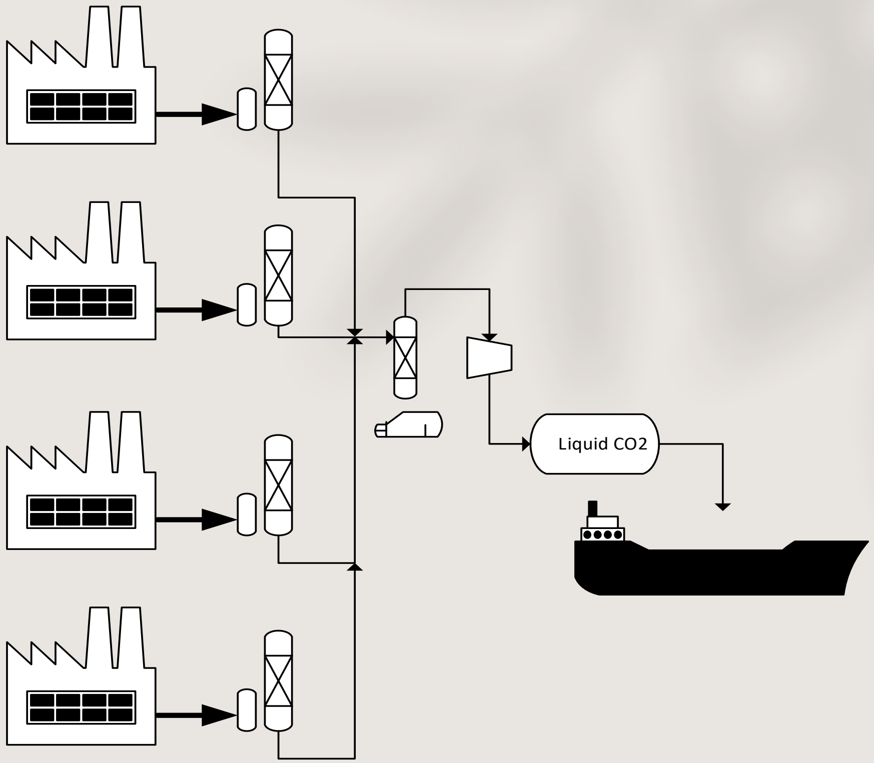
Inovyn

Eramet

Others



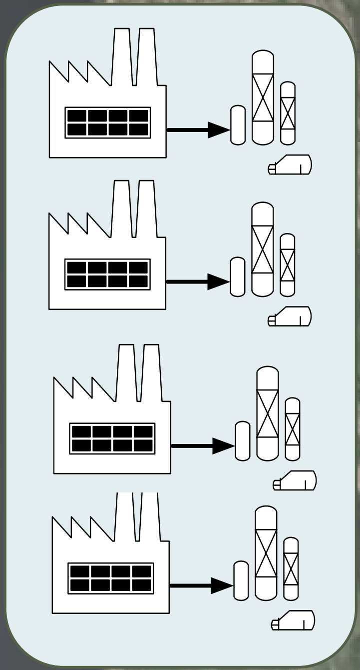


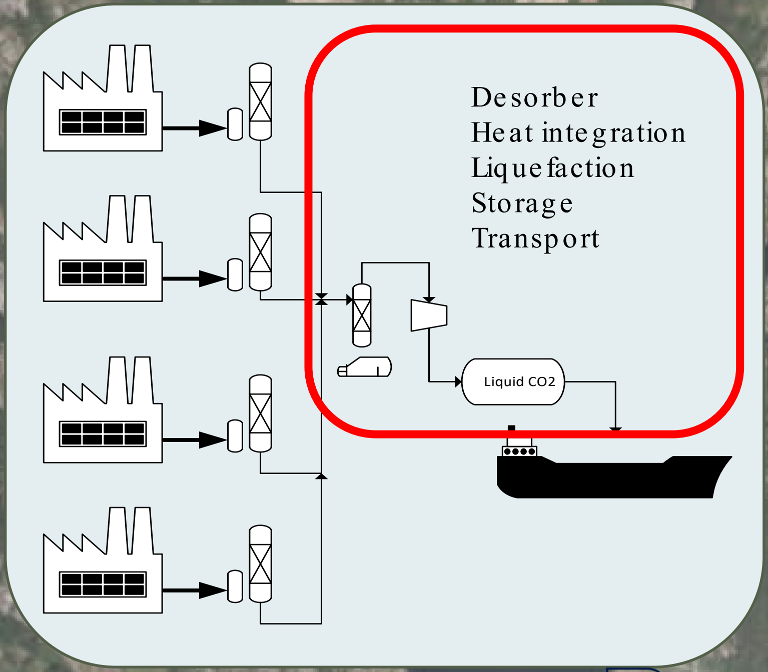


Techno-Economical Analysis
Tentative plan

Joint Solution – a better solution?

CCS each site ? or CCS in a Joint solution?





Guro Nereng

PUBLIC AFFAIRS MANAGER

Borg CO_2: Full-scale capture, storage and terminal

Guro Nereng has experience from the environmental NGOs Bellona and ZERO. There, she worked to promote better public instruments and framework for energy efficiency in buildings and for green public procurement.

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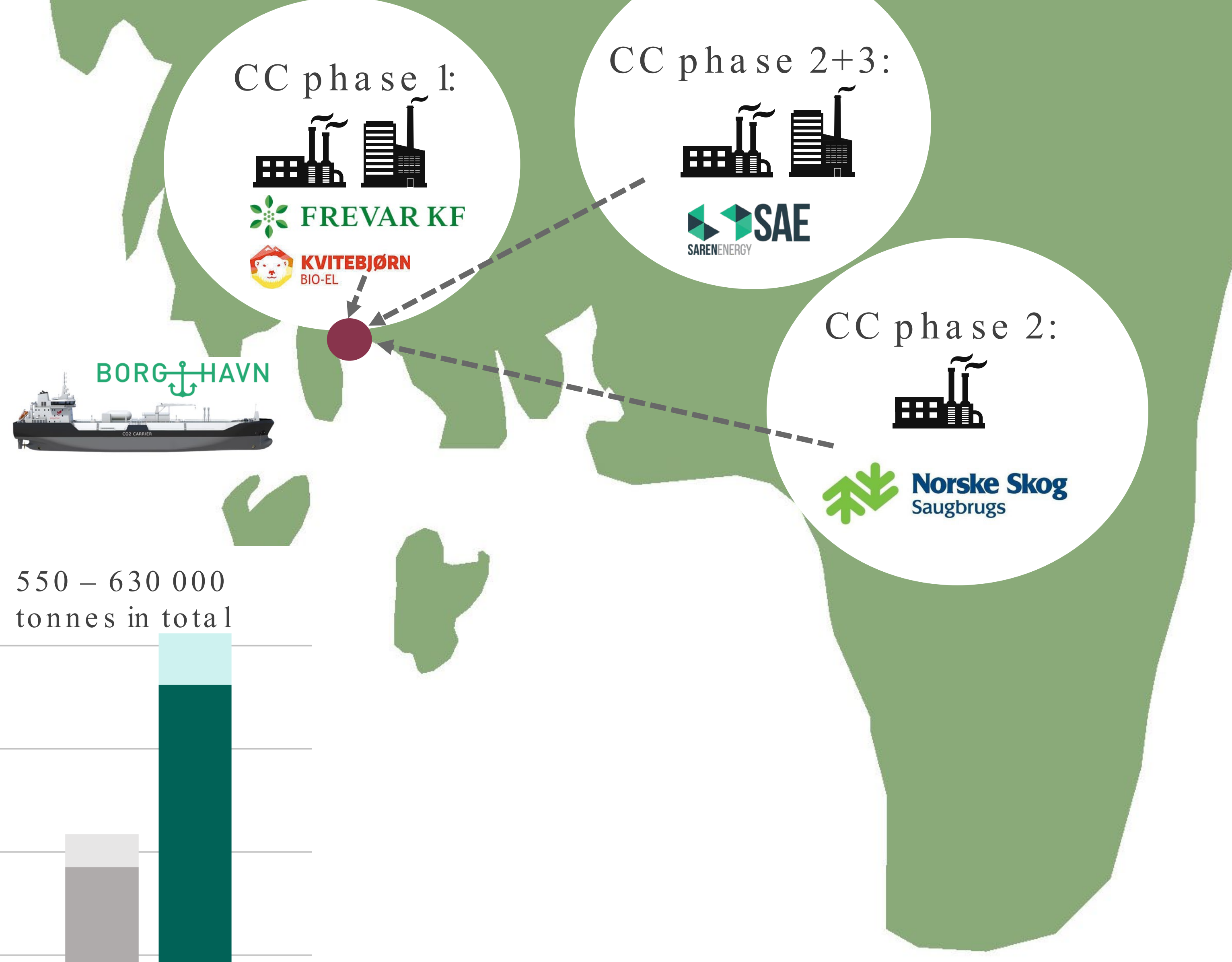
BORG CO_2:

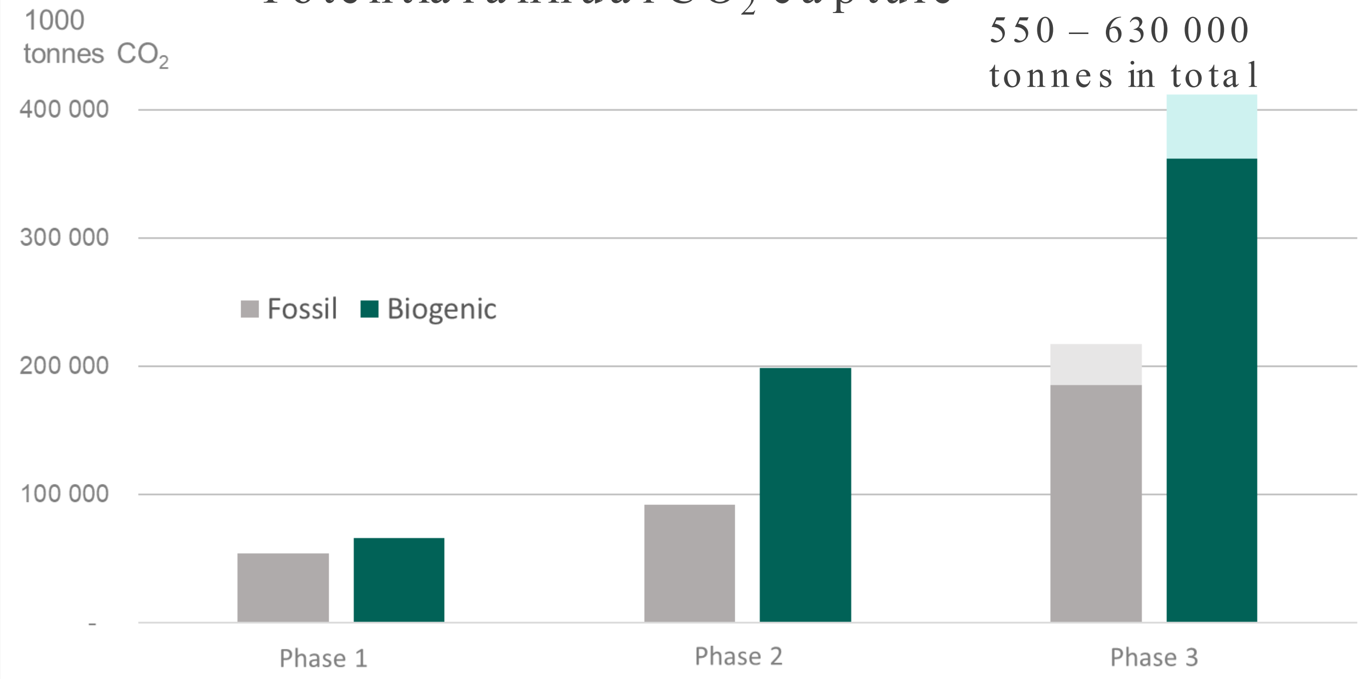
Full-scale capture, storage and terminal

Guro Nereng

8. February, 2023



Potential annual CO_2 capture



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BORG CO_2 AS

Borg CO_2 owners

Shareholder	% Ownership
Borg Havn IKS	24,3 %
Baker Hughes	20,9 %
Stormkast Utvikling As	7,8 %
Beform AS	7,8 %
Norske Skog Saugbrugs AS	7,8 %
Hafslund Oslo Celsio	7,8 %
Acinor AS	7,8 %
CO_2 Capsol AS	7,8 %
FREVAR KF	7,8 %

Planned progress

Carbon capture, Phase 1:

4Q22 Funding discussions

2Q23 FEED Start

1Q24 FEED end

3Q24 FID

2027 Operation start

Terminal:

4Q22 QRA

2Q23 Pre-FEED end

3Q23 FEED start

2Q24 FEED end

3Q24 FID

2026 Operation start

Dr. De Chen

PROFFESOR

Carbon capture by solid sorbents: Materials and process

Dr. De Chen is a professor in catalysis at the Department of Chemical Engineering, Norwegian University of Science and Technology (NTNU) since 2001 (associate professor 1998-2001). He earned his PhD in industrial catalysis at NTNU, Norway, in 1998. He was a visiting professor at the University of California at Berkeley (2009-2010) and East China University of Science and Technology (2017-2018). His research is mainly on a multiscale approach at the interface between catalysis science and industrial chemical processes.

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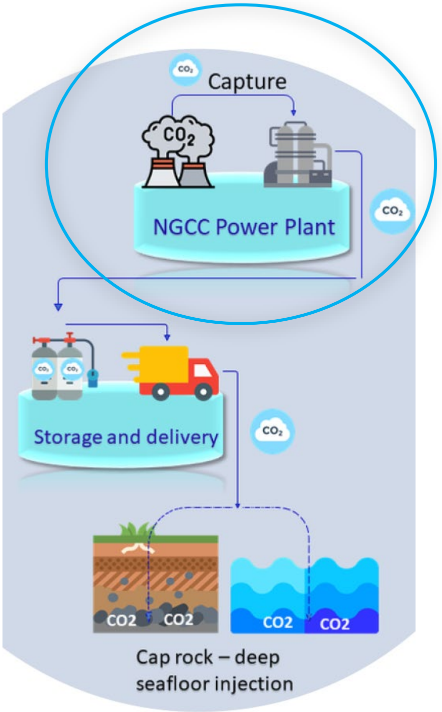
CO_2 capture process using low temperature sorbents: materials and process

De Chen

Department of Chemical Engineering, Norwegian University of Science and Technology, NTNU, Trondheim, Norway

Why solid sorbents

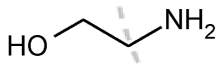
CO2 capture, utilization and storage (CCUS) came as a first agreement in the Conference of the Parties (COP), named Durban Agreement, followed by the Paris Agreement, with “zero net anthropogenic GHG emissions” by 2050



Low-temperature CO2 adsorbents

For Post-Combustion NGCC Power Plants

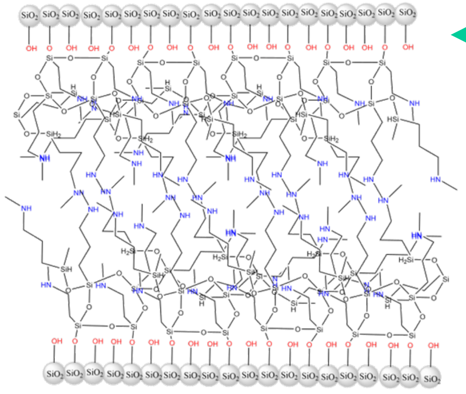
Liquid sorbent



MEA
30-40% in H_2O

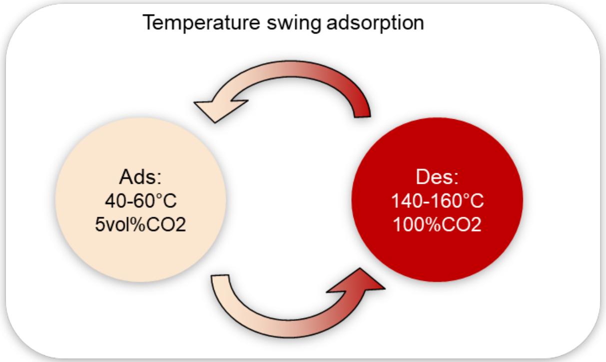
Why solid sorbent?

Pore wall

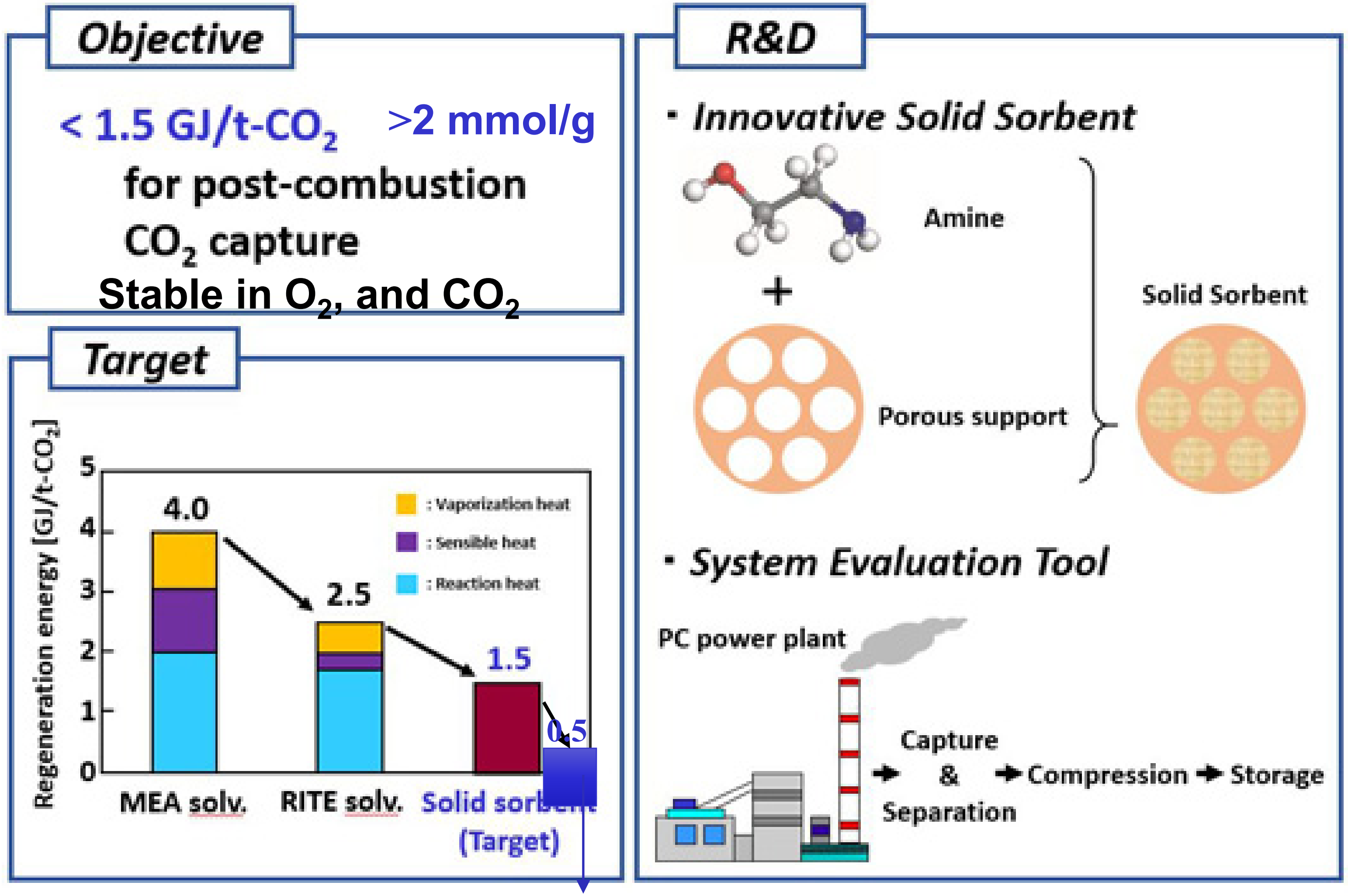


Pore wall

- No water (Energy efficiency)
- No corrosion (No expensive equipment)
- Limitted amine loss
- Desorption: steam or vacuum
- Desorption in CO_2 at atmospheric pressure



Development of low temperature sorbents



NTNU© super CO_2 sorbents

NTNU
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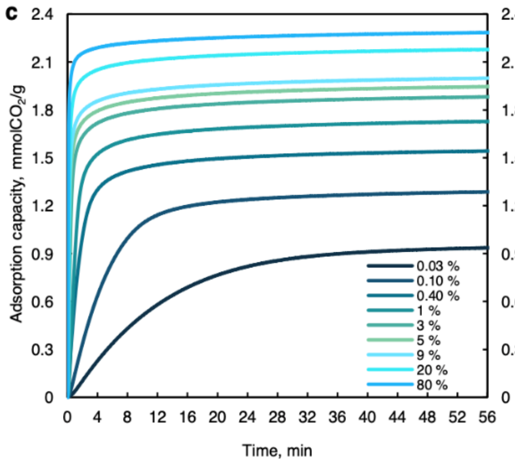
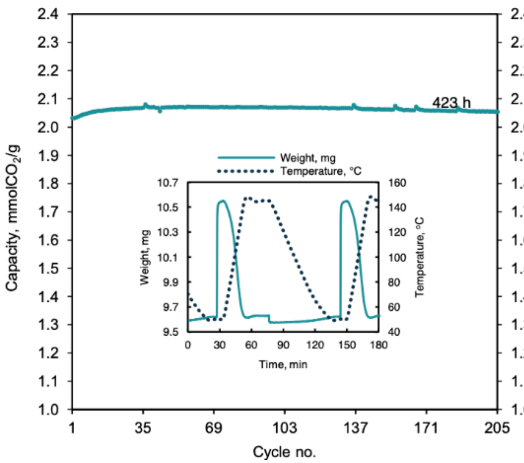
Advantages of NTNU/XPRUGO compared to other early-stage adsorbents

High capacity and fast kinetics



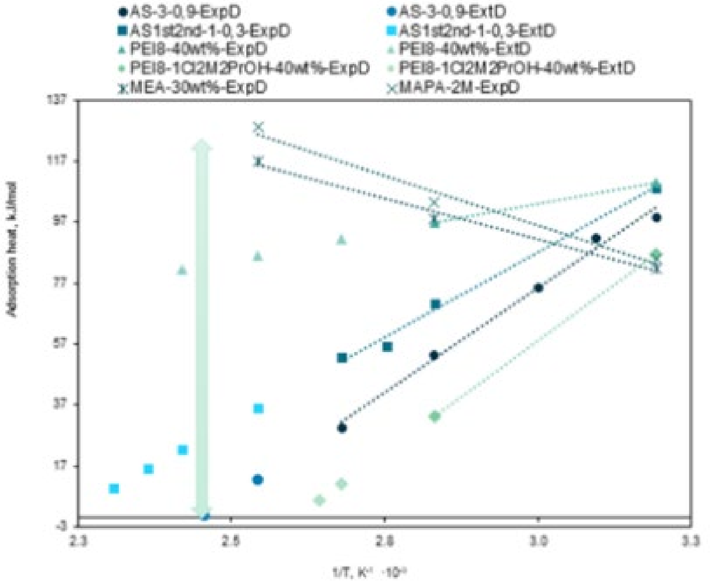
CO_2 capture capacity at 40 ^oC,

Highly stable in CO_2 at high temperatures



Stability of solid sorbent for multiple (205 cycles) adsorption/regeneration cycles, adsorption: 40C, 5 vol% CO_2, regeneration 140 ^oC, 80% CO_2, N_2 balance

Extremely low regeneration heat



Adsorption heat of solid sorbent, 5 vol% CO2, N2 balance

[Content](#)

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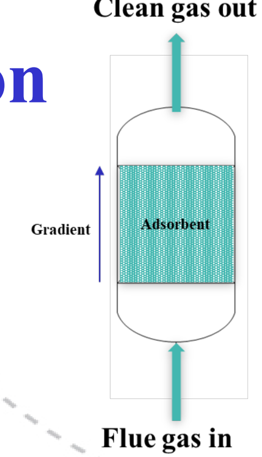
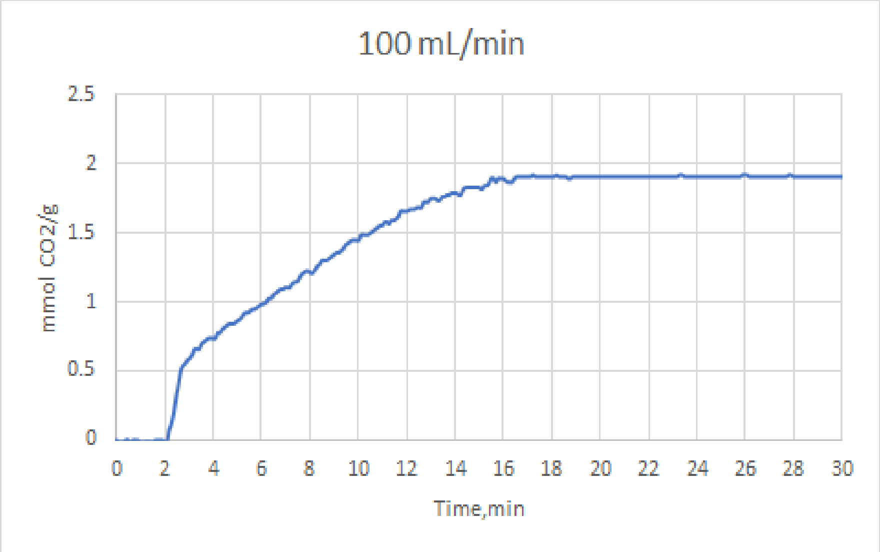
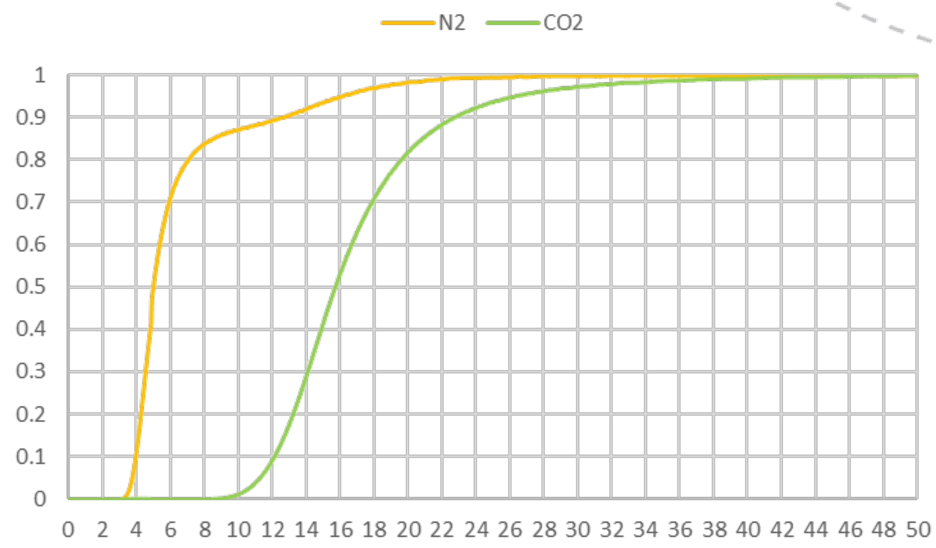
Breakthrough curve of CO_2 from the adsorption column



GHSV = Flow rate of flue gas / volume of adsorbent bed= 2211.57 h^{-1}

$$\tau = 0.027\ min$$





Minute 2 to minute 9 => 7 min

Almost 100% CO_2 removal efficiency

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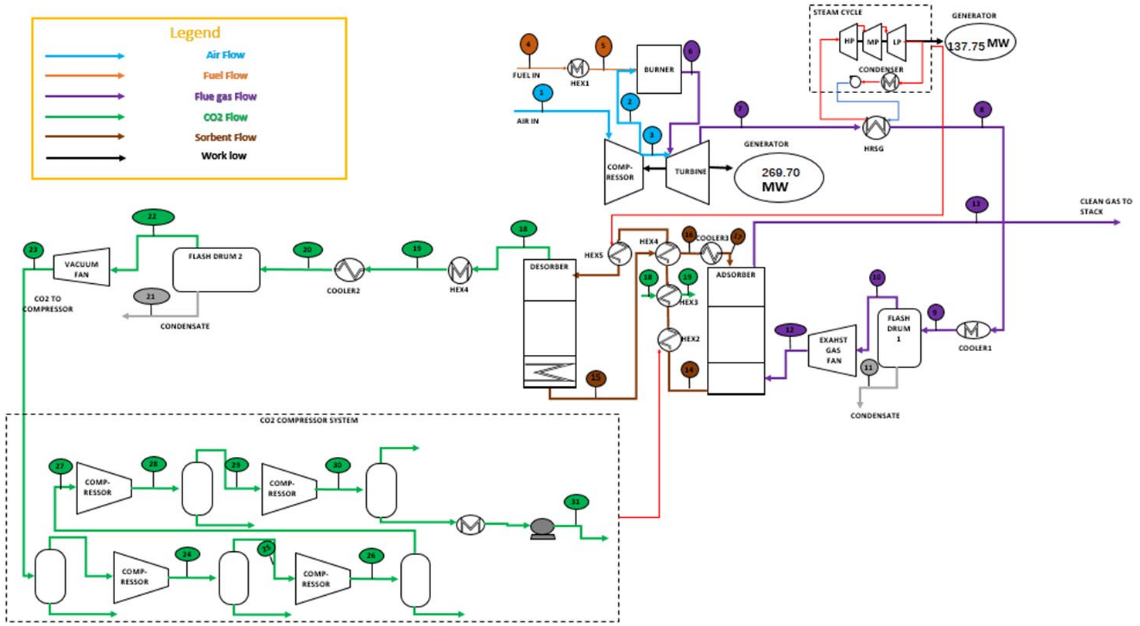
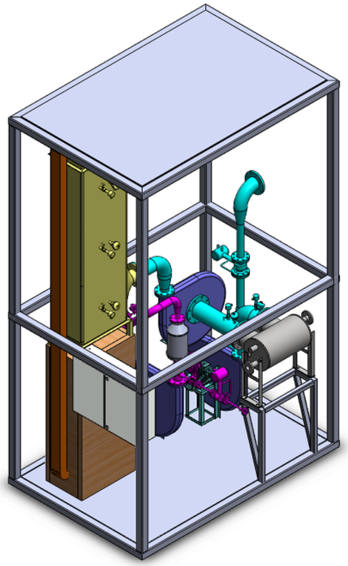
NTNU/XPURGO process





	No-retrofit solution	PCCC with MEA with CO2 compression	PCCC with solid sorbents With CO_2 Compression
Base reference	NGCC	NGCC	NGCC
Thermal input (MW)	711	711*	711
Power generation (MWe)	410	346*	383
Electrical efficiency (LHV basis)	57.7 %	48.7*	53.8%
Specific energy penalty of avoided CO_2 with CO_2 compression	-	9%*	3.8
Specific energy penalty of avoided CO_2 without CO_2 compression	-	3.62*	1.25
Net cost of CO2 avoided €/MT CO_2	-	51.3*	26.3

*Data for MEA is taken from DECARBit report and Berstad et. Al, 2014, IJGHGC, 24, 43-53

Comparison NGCC – 440 MW

Solvent based technology

– High footprint - 4000 m^2 (height > 50 m)
– CAPEX : 1007 Million kr
– OPEX : 290.66 Million kr
– Levelized cost : 308 kr/ton of CO_2 removal
– Desorption column regeneration heat duty 4.3 GJ/ton
– CO_2 capture efficiency < 70 % to 86% >
– Lower concentration CO_2 (below <4%) have consequences on higher energy consumption

NTNU/XPURGO Solid loop

– Low footprint : 1200 m^2 (hight < 10 m)
– CAPEX : 596.8 Million Kr
– OPEX : 181.7 Million Kr
– Levelized cost: 176 kr/ton of CO_2 removal
– Energy consumption with waste heat recovery 0.5 GJ/ton
– CO_2 capture efficiency 98 %
– Handling capability below < 4% near to 400 ppm level

CO_2 capture using solid sorbents saves about 40% CAPEX, OPEX, and levelized cost compared to solvent technology

NTNU
Innovation and Creativity

Thank you for your attention!

The Research Council of Norway

Prof. De Chen (NTNU)– chen@ntnu.no

Dumitrita Spinu (NTNU)

Dr. Kumar R. Rout (NTNU/SINTEF)

Reza Hezari, Inrigo AS

Dr. Rajesh Kempegowda, Inrigo AS

SINTEF

INRIGO

XPURGO

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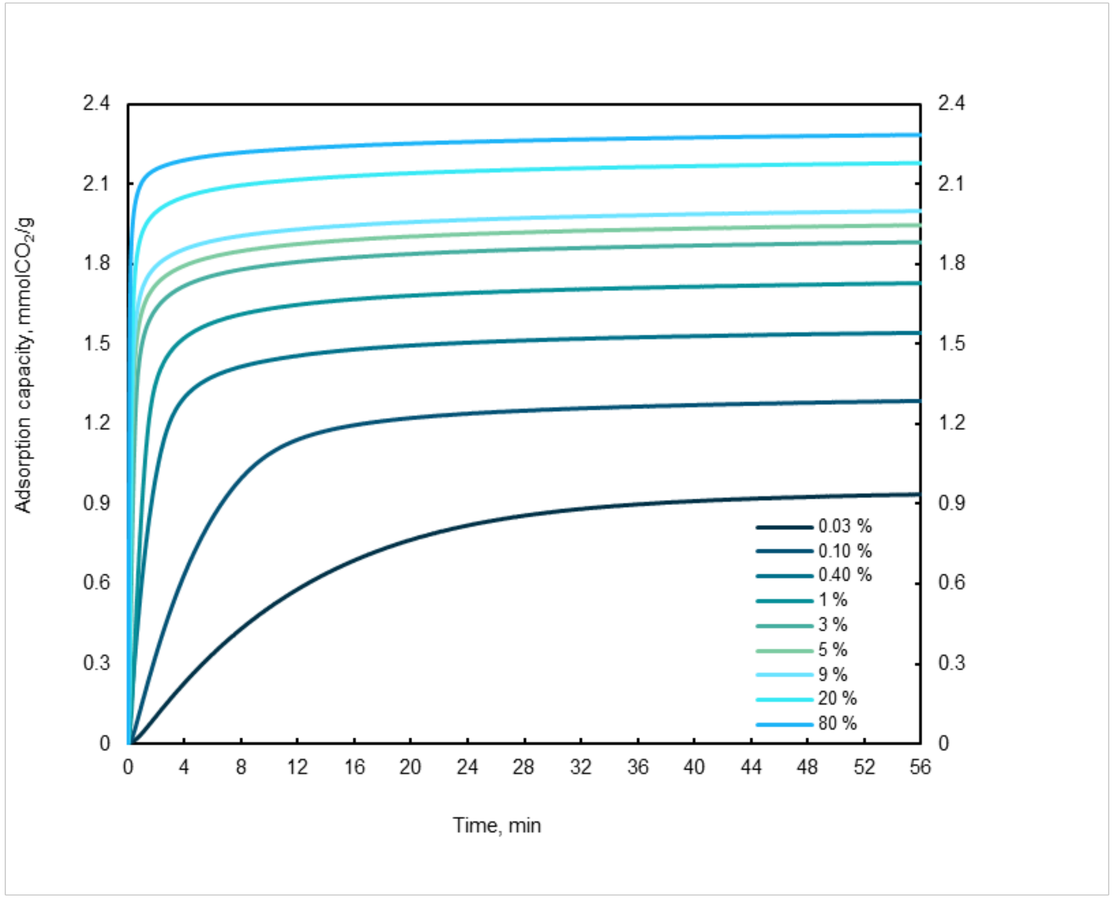
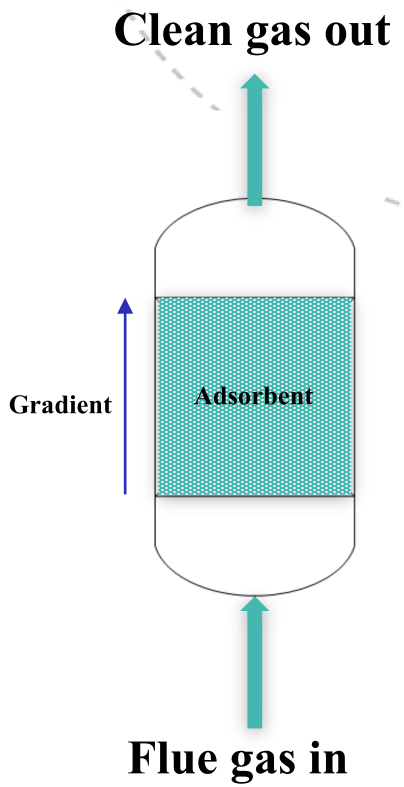
High CO_2 capacity and fast kinetics



CO_2 adsorption of NTNU/XPURGO solid sorbent. CO_2 adsorption profiles at 40 °C within a CO_2 pressure range of 0.03-80 kPa balance N_2, 101 kPa, 100 mL/min.



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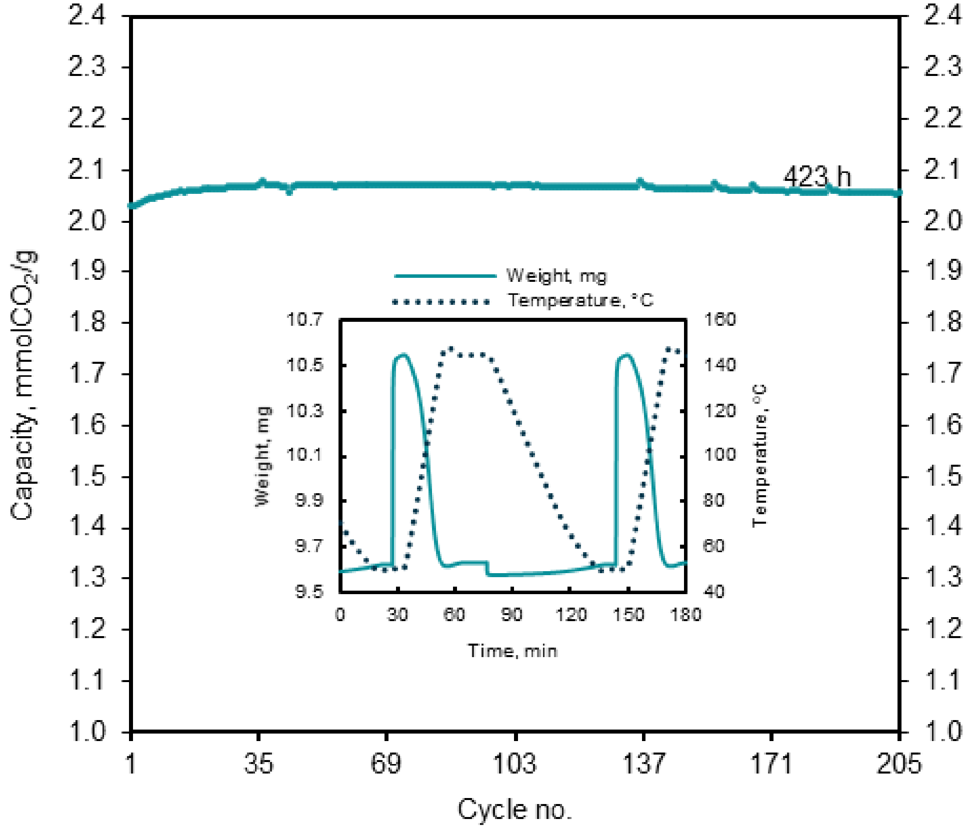
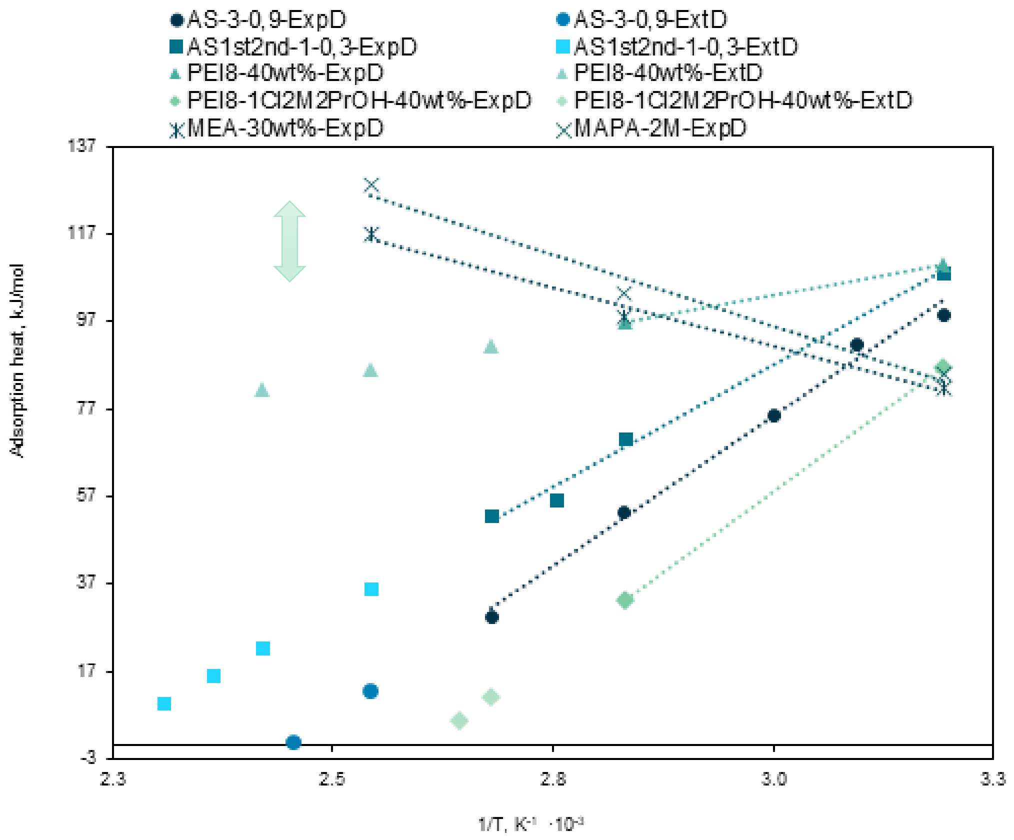
Highly stable in CO_2 at high temperatures



Long-term stability of NTNU/XPURGO sorbents over 205 TSA cycles. Adsorption: 50 °C, 80% CO_2 balance N_2. Desorption: 145 °C, 80% CO_2 balance N_2. Cooling down to adsorption temperature: N_2. Total run time: 423 h.

NTNU
Innovation and Creativity

Extremely low regeneration heat



Save 2.4-2.9 GJ/ton CO2

NTNU
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Thijs Peters

SENIOR SCIENTIST

A novel hybrid process for membrane-assisted hydrogen production with CO_2 capture through liquefaction

Thijs Peters is a senior research scientist and project manager at the Department of Sustainable Energy Technology at SINTEF Industry in Oslo since 2005. His research interests spans from process chemistry, membrane technology, hydrogen production, CO_2 capture, energy efficiency, to gas separation technologies. He has >80 publications in international peer-review journals and contributed to 12 book chapters and close to 200 conferences.

Content

CLIMIT SUMMIT

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SINTEF

MACH-2 project

A novel hybrid process for membrane-assisted hydrogen production with CO_2 capture through liquefaction

Thijs Peters – SINTEF Industry, Oslo, Norway

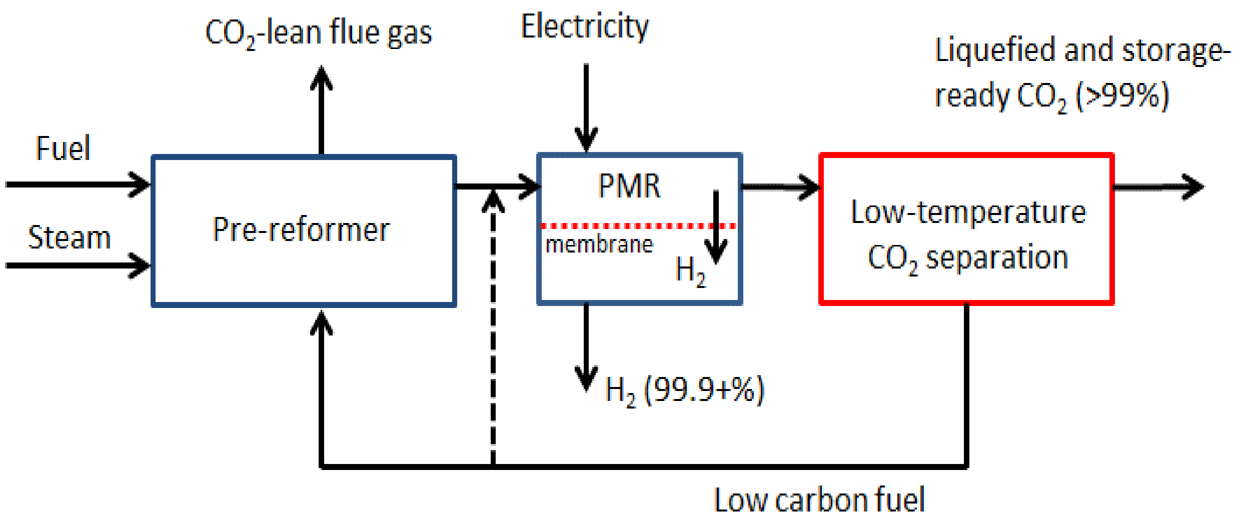
Teknologi for et bedre samfunn

Content

The MACH-2 project

- KPN project financed by CLIMIT
  - Duration: 2019-2024
  - Budget: 7.5 MNOK
  - Partners: SINTEF Industry, SINTEF Energy, and NTNU, CoorsTek Membrane Sciences AS
  - Co-financed by NCCS

- Objectives
  - Develop and optimize a hybrid process for membrane-assisted clean H_2 production with CO_2 capture through liquefaction
  - Combines H_2 extraction from syngas by membrane technology with subsequent low-temperature CO_2 capture from the retentate stream in an integrated process



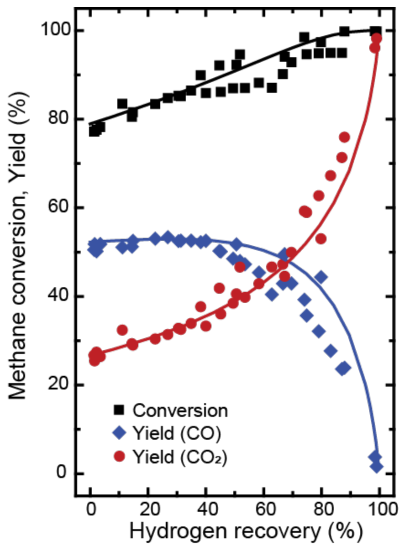
CoorsTek's PMR technology

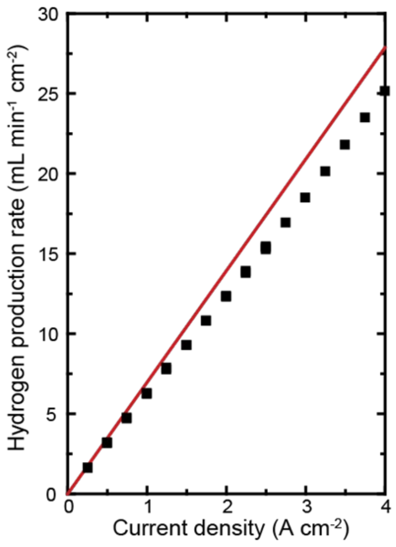
nature energy ARTICLES
https://doi.org/10.1038/s41560-017-0029-4

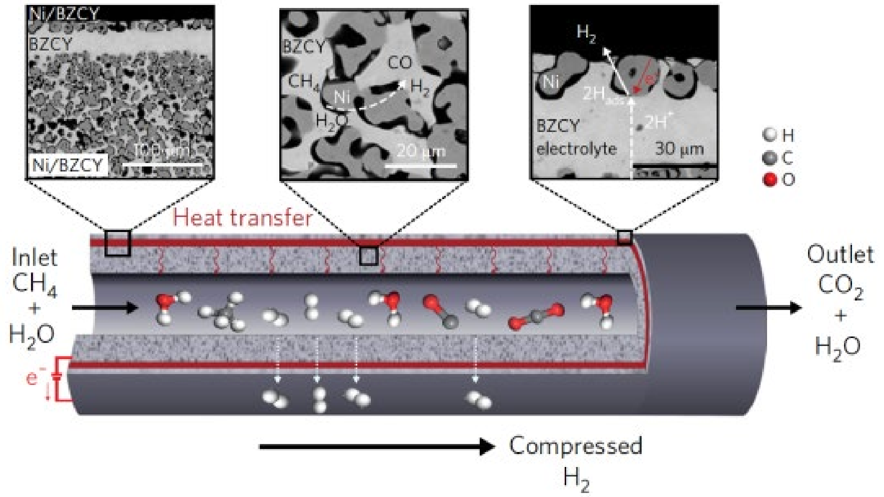
Thermo-electrochemical production of compressed hydrogen from methane with near-zero energy loss

Harald Malerød-Fjeld[1], Daniel Clark[1,2], Irene Yuste-Tirados[1], Raquel Zanón[3], David Catalán-Martinez[3], Dustin Beeaff[1], Selene H. Morejudo[1], Per K. Vestre[1], Truls Norby[2], Reidar Haugsrud[2], José M. Serra[3]* and Christian Kjølseth[1]*

- SMR with in-situ electrochemical H_2 separation and compression
  - Single step reforming and separation
  - Net endothermic chemical reaction is balanced with the heat evolved from the galvanic operation of the membrane
- High CO conversion requires a HRF close to 100%
  - Large membrane surface area, with economic penalties
  - Operation under higher current density at fixed area
    - Increases the heat flux evolving on the membrane beyond that would be needed for the reforming, which in turn may challenge the robustness of the membrane reactor
    - Increased polarization losses at electrodes; reduced efficiency at high HRF



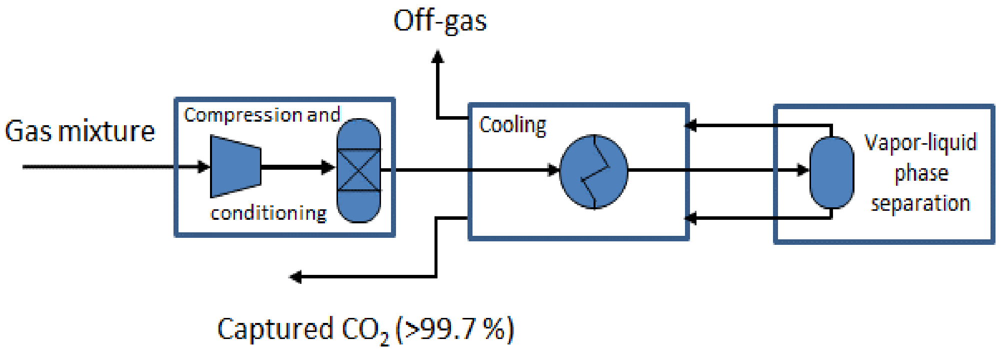


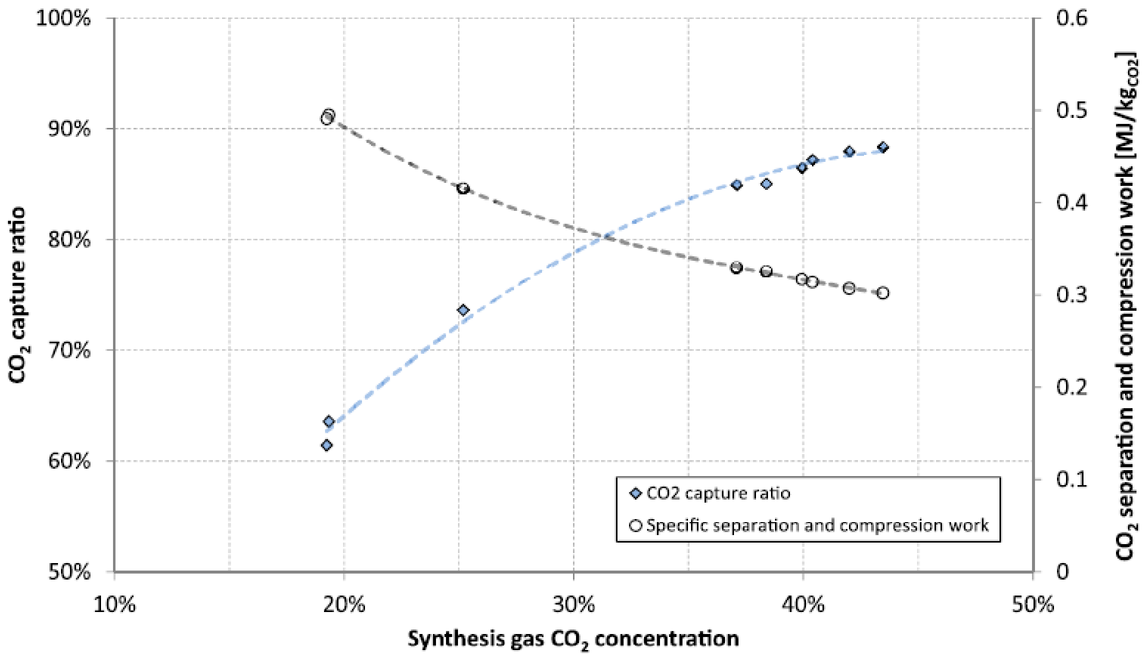


Content

CO_2 separation by liquefaction

- Vapor–liquid phase separation after compression and cooling of the gaseous mixture
  - Obtainable CO_2 capture rate, specific separation and compression work, and thus power consumption, are sensitive to the CO_2 concentration of the incoming flue- or syngas

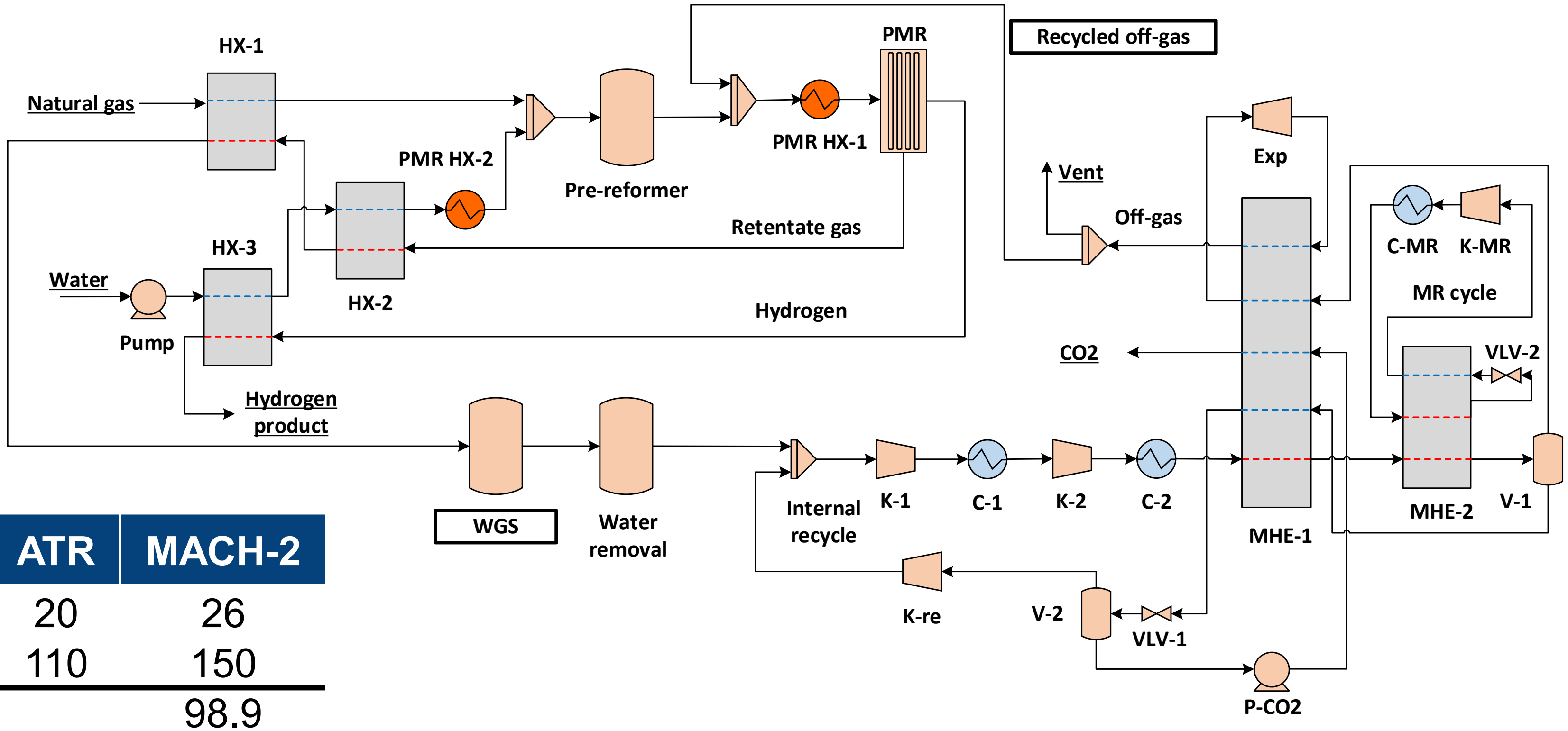




  - H_2-rich off-gas can be partially recycled to the reactor maximizing the overall HRF and CO conversion

Performance of the hybrid system

- Hybrid process details
  - Recycled off-gas allows to recover H_2 and unreacted methane
  - Water gas shift reactor downstream of the PMR to convert CO to CO_2 and H_2



	SMR + MEA	ATR	MACH-2
$P_{H2\ product}$ [bar]	22.3	20	26
$P_{captured\ CO2}$ [bar]	1.3	110	150
HRR_{system} [%]	87		98.9
CCR_{system} [%]	90	96.3	98.9
Energy conversion efficiency [-]	0.71	0.78	0.81

Content

Kim, et al., Design of a novel hybrid process for membrane assisted clean hydrogen production with CO_2 capture through liquefaction, *Computer Aided Chemical Engineering*, 49, 2022, 127-132.

Summary

- A novel technology that combines H_2 production by PMR with CCS is proposed.
  - Combines H_2 extraction from syngas by membrane technology with subsequent low-temperature CO_2 capture from the retentate stream
  - Both high recovery rate and purity of H_2 and CO_2 are achievable from the hybrid process.

- Hybrid process has higher energy conversion efficiency than conventional H_2 production processes
- Idealized PMR reactor heat integration assumed - updated PMR module model including heat exchange and integration in development
- Both membrane and liquefaction technology is experimentally investigated separately in the project
  - See CoorsTek presentation on PMR (Harald Malerød-Fjeld) tomorrow, 10.15, Bølgen 1
  - Results from GASSNOVA CLIMIT-demo on upscaling and demonstration

Acknowledgements

- This work was performed within the CLIMIT-KPN MACH-2 project (294629) with support from the NCCS Centre, performed under the Norwegian research program Centres for Environment-friendly Energy Research (FME). The authors acknowledge the following partners for their contributions: Aker Solutions, Ansaldo Energia, Baker Hughes, CoorsTek Membrane Sciences, EMGS, Equinor, Gassco, Krohne, Larvik Shipping, Lundin, Norcem, Norwegian Oil and Gas, Quad Geometrics, Total, Vår Energi, and the Research Council of Norway (257579).

Mona Mølnvik

DIRECTOR NORWEGIAN CCS RESEARCH CENTRE,
RESEARCH DIRECTOR

CCS for the process industry – an example from FME NCCS

Mølnvik is Research Director for gas technology in SINTEF Energy Research, heading a department of 60 researchers, and Director of the *Norwegian CCS Research Centre*, NCCS, a 600 MNOK centre of excellence funded by the Research Council of Norway and a strong industry cluster under the FME scheme.
Mølnvik has worked with SINTEF since 1997 and holds a doctoral degree in Mechanical Engineering from NTNU.

Content

NCCS
NORWEGIAN CCS RESEARCH CENTRE

CCS for the process industry – an example from FME NCCS

8th February 2023

Climit Summit, Larvik, Norway

FME

Content

users

GASSCO, vår energi, wintershall dea, eramet, Elkem, TotalEnergies, equinor, AkerBP, NORCEM HEIDELBERGCEMENTGroup, Hafslund Oslo Celsio, Oslo

research institutes

NGI, TNO, BGS British Geological Survey, NIST National Institute of Standards and Technology, SINTEF, Lawrence Livermore National Laboratory

university

NTNU, UiO: University of Oslo, RUHR UNIVERSITÄT BOCHUM RUB, UNIS, TUM, University of Zurich[UZH]

- CO_2 value chain and legal aspects
- Solvent technology – environmental issues
- Low emission H_2 production
- Conditioning through liquefaction
- Gas turbines
- CO_2 capture process integration
- CO_2 transport
- Fiscal metering and thermodynamics
- Structural derisking
- CO_2 storage site containment
- Reservoir management and EOR
- Cost-efficient CO_2 monitoring technology

associated partners

eccsel eric The European CCUS Research Infrastructure, University of Bergen, The University of Western Australia, NORCE, Seoul National University, Sandia National Laboratories, calix, Torvald Klaveness, WÄRTSILÄ, altera INFRASTRUCTURE, HÖEGH LNG, vallourec, OFFSHORE NORGE, University of Connecticut, U.S. DEPARTMENT OF ENERGY, UKCCS RESEARCH CENTRE

vendors

AKER CARBON CAPTURE, ANSALDO ENERGIA, STRATUM RESERVOIR, KROHNE, allton, Baker Hughes, LarvikShipping, CoorsTek, QUAD GEOMETRICS

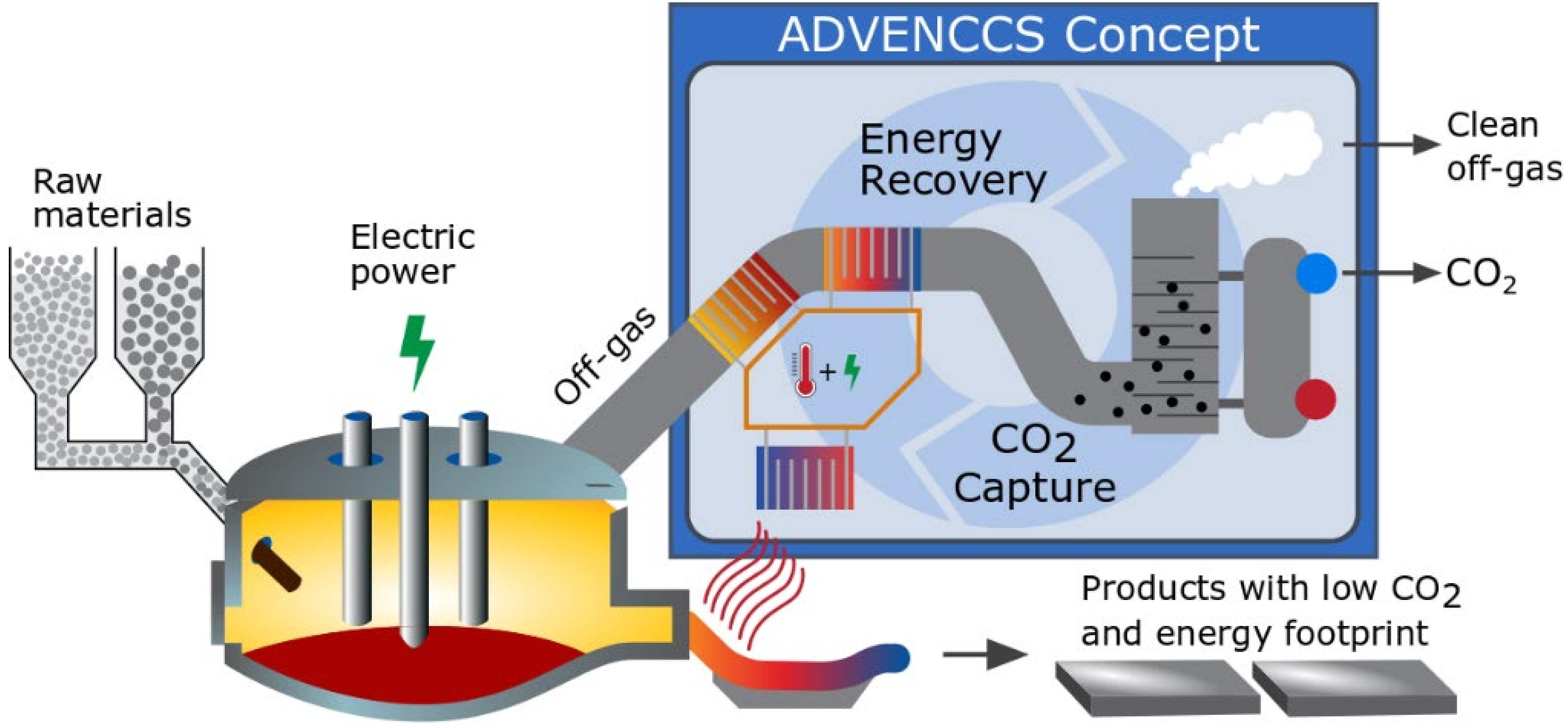
Content

CCS Momentum

Ricarda Lang, leader of the German party Bündnis 90/Die Grünen

German economics and climate minister Robert Habeck (l) and Norwegian Prime Minister Jonas Gahr Støre

ADVENCCS: *Advanced energy recovery and CO_2 capture systems for a decarbonised ferroalloy industry*



Content

Hanne Kvamsdal

SENIOR RESEARCH SCIENTIST

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

SCOPE - Sustainable OPEration of post-combustion Capture plants

Senior Research Scientist in SINTEF Industry with more than 20 years of experience with research related to CO_2 capture technologies. Background in chemical engineering at PhD level within process modelling, simulation and control and experience from offshore process engineering and refinery operation. Has managed various large research projects and has a large international network.

The Research Council of Norway

GASSNOVA

Project number 327341
ACT – Accelerating CCS Technologies

SCOPE - Sustainable OPEration of post-combustion Capture plants

Hanne Kvamsdal

SINTEF IND

08/02/2023

Content

SCOPE – Sustainable OPEration of post-combustion Capture plants

Building upon ACT 1: ALIGN-CCUS and ACT2: LAUNCH: Follow the continuous path of the treated gas from source to recipient and ensure a sustainable and environmentally safe operation of the capture plant

Flue gas impurities and pre-treatment, impact of load and fuel variations

Emissions control and mitigation, minimizing aerosol emissons

Emissions monitoring and measurements of component and whole effluent

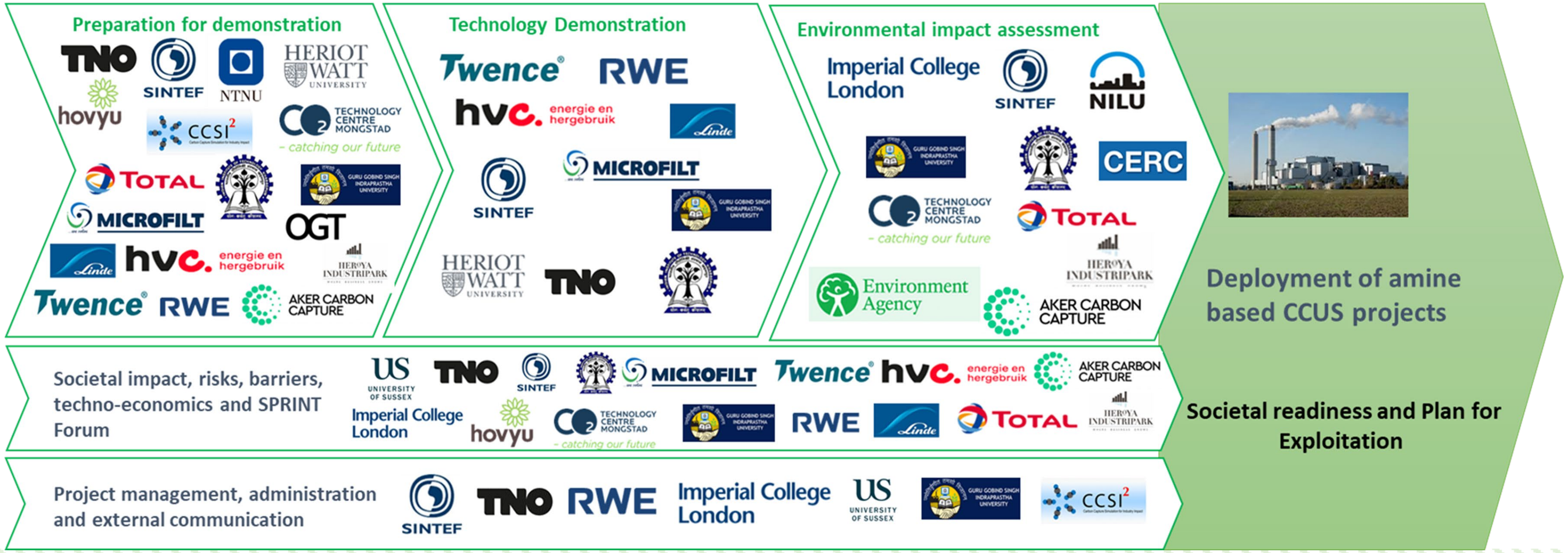
Atmospheric chemistry and dispersion modeling

Biodegradation, Ecotoxicity, Environmental effect concentrations

Content

SCOPE – is accelerating the decarbonisation of industry

- **Objective:** ensure that emission reductions in amine-based CCUS are technically feasible, cost-efficient, and robust enough to mitigate environmental risks and gain public acceptance
- **Collaboration**: Interdisciplinary group of experts from academia, research, technology providers and end-users of the technology



Timeline:
01.10.2021-
30.09.2024

Budget: € 6M
Funding from ACT
€ 3.7M

Partners:
24 (19 from Norway, The Netherlands, UK, and Germany, 2 from USA and 3 from India)

Content

SCOPE test facilities: small pilots to larger demonstration plants

Tiller CO_2 Lab (SINTEF IND), NO

Biomass or propane incineration: 30-40 kg CO_2/h
Solvent: CESAR1 (blend of AMP and PZ)
Flue gas: CO_2 11 vol.-%, O_2 4 vol.-%
Focus in SCOPE: Emission monitoring

Alkmaar (HVC), NL

Waste-to-energy plant 540 kg CO_2/h
Solvent: MDEA/Piperazine blend
Flue gas: CO_2 11.3 vol.-% (dry), O_2 4.1 vol.-% (dry),
Focus in SCOPE: Emission mitigation, effect of particles in the flue gas on emission

Niederaussem (RWE), DE

Lignite-fired power plant: 300 kg CO_2/h
Solvent: CESAR1 (blend of AMP and PZ)
Flue gas: CO_2 15.2 vol.-%, O_2 5.0 vol.-%
Focus in SCOPE: Long-term test campaigns and various emission mitigation tools

Tuticorin site, India

Alkali Chemicals and Fertilizers: 7.5 t CO_2/h
Solvent: CDRmax (Proprietary solvent of Carbon Clean Ltd)
Flue gas: CO_2 ~ 12 vol.-%, O_2 8 vol.-%
Focus in SCOPE: Emission measurement

Hengelo (Twence), NL

Waste-to-energy plant 500 kg CO_2/h
Solvent: 30% MEA,
Flue gas: CO_2 9.5 vol.-%, O_2 8.3 vol.-%,
Focus in SCOPE: Emission mitigation, effect of particles in the flue gas on emission

Mongstad (TCM), NO

Flue gas from CHP and cracker: 10 t CO_2/h
Solvent: CESAR1 (blend of AMP and PZ)
Focus in SCOPE: Results from previous campaigns for comparison and emission limits

Content

Acknowledgements

This project is funded through the ACT programme (Accelerating CCS Technologies), ACT 3 Project No 327341. Financial contributions made by the Research Council of Norway (RCN), Ministerie van Economische Zaken en Klimaat the Netherlands, Department for Business, Energy & Industrial Strategy (BEIS) UK, Forschungszentrum Jülich GmbH, Projektträger Jülich (FZJ/PtJ) Germany, Department of Energy (DOE) USA and Department of Science and Technology (DST) India are gratefully acknowledged. Cash contribution from Norwegian industry partners to the Research partners in Norway is also acknowledged.

www.scope-act.org

@SCOPE_ACT

Zuoan Li

RESEARCH SCIENTIST

Novel molten/solid composite oxygen transport membranes for CO_2 capture

Ph.D in materials chemistry from University of Vienna (2004-2007). Post-doc researcher at UiO (2007-2014). Researcher at SINTEF from 2014. Research area focuses on 1) ceramic and solid/liquid composite materials development for oxygen/hydrogen separation membranes; 2) oxygen carriers' development; 3) chemical looping for hydrogen/chemical production and CO_2 utilization.

Content

CLIMIT SUMMIT

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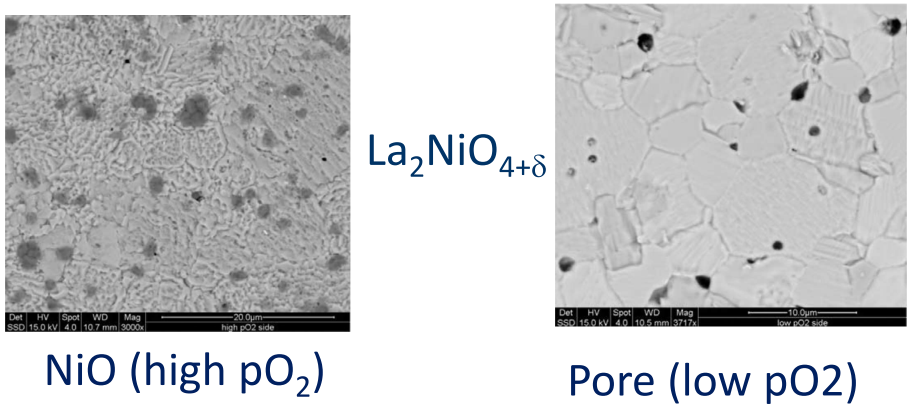
GASSNOVA

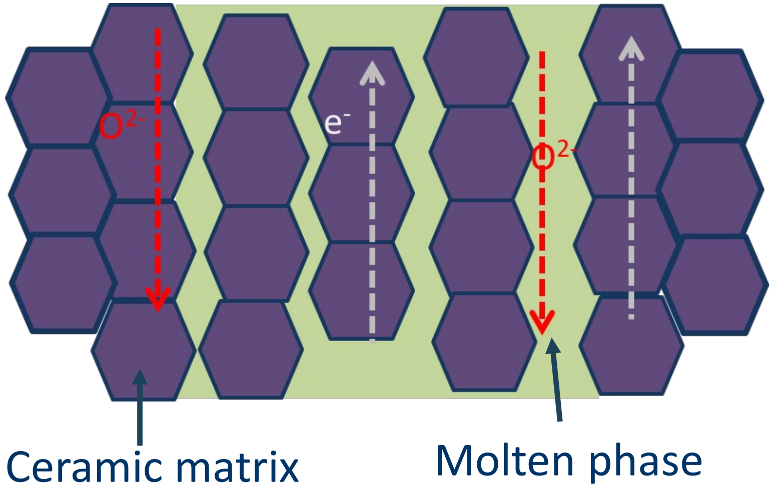
Novel molten/solid composite oxygen transport membranes for CO_2 capture

- Background
  - Requirement for operation at high T (>900°C)
  - Stability issues such as cation diffusion
- Scope
  - Developing cer-cer membranes with high O_2 permeation
  - Developing solid/molten membranes for enhaced oxide ion transport in liquid phase and along the interphase
  - Modelling for fundamental transport and process
- Budget
  - 13 MNOK for 2017-2022
  - Support from CLIMIT 11.3 MNOK
- Consortium
  - SINTEF (coordinator) and UiO (Train one Ph.D)
  - Air Liquide, Cerpotech, CMS, CSM, Imperial College, UTwente as advisory board

Membrane 'Walking-out' issue



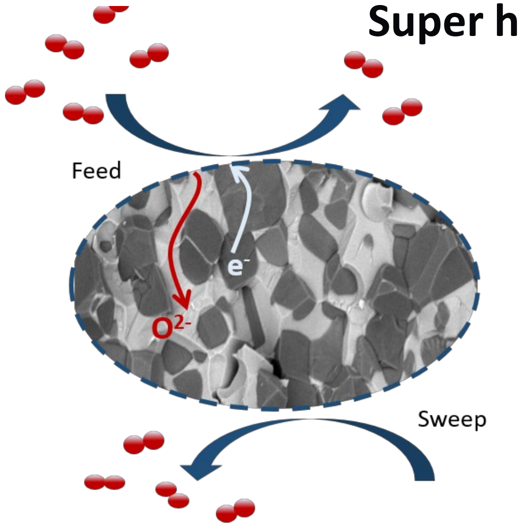
Enhanced oxide ion transport in molten phase

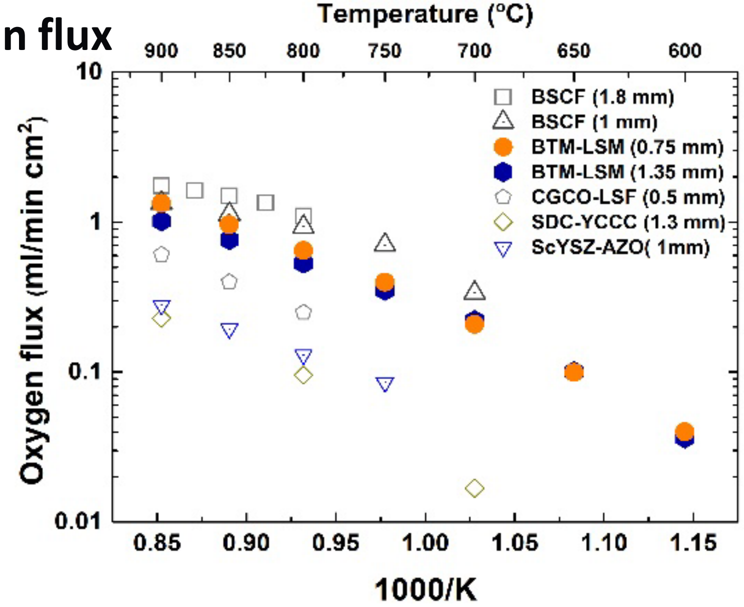


Content

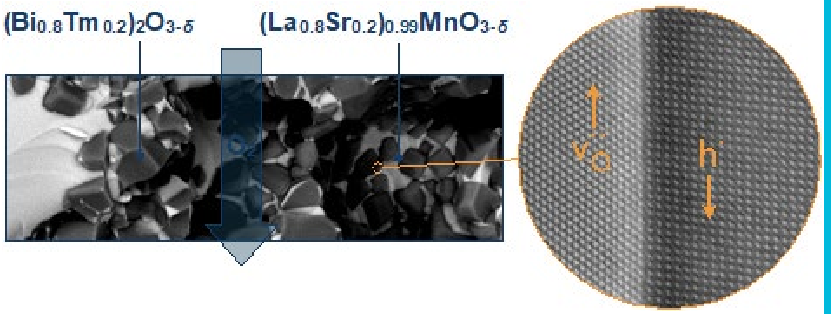
Thermochemically stable composite membranes based on LSM and BTM

Super high oxygen flux

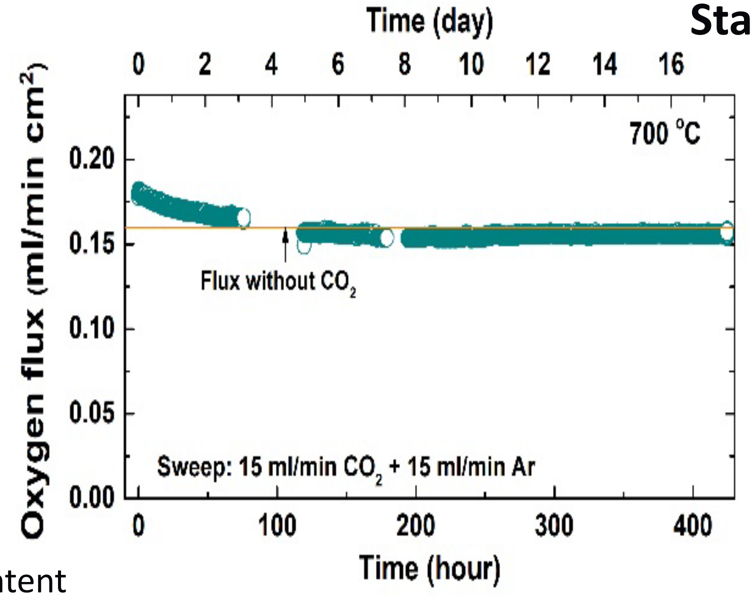


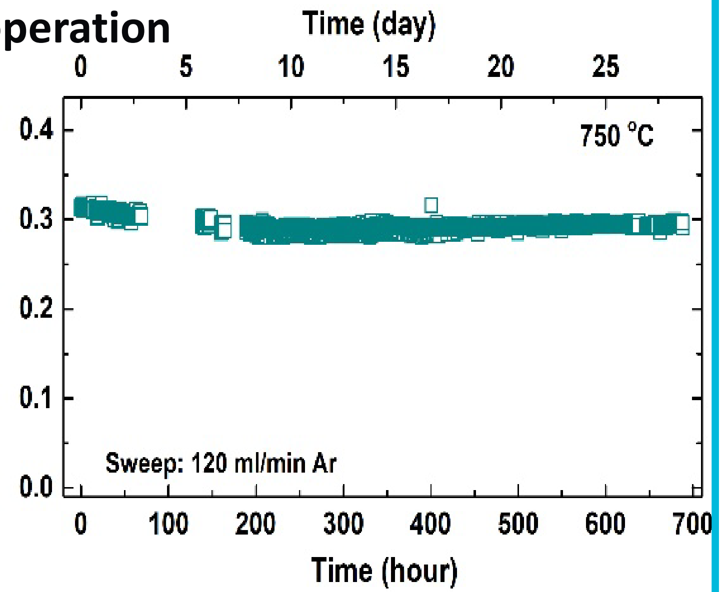


Coherent interface

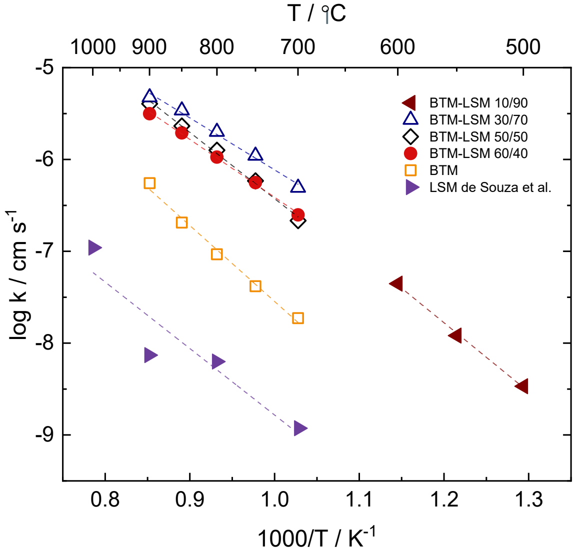


Stable operation





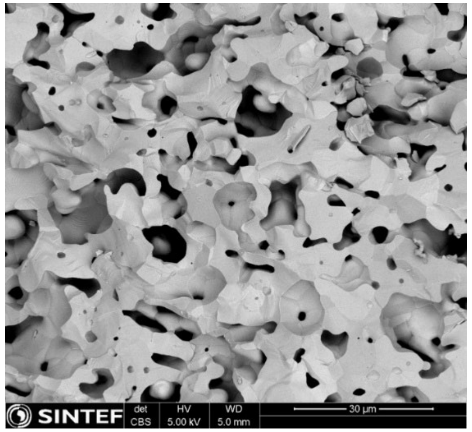
Enhaced surface exchange



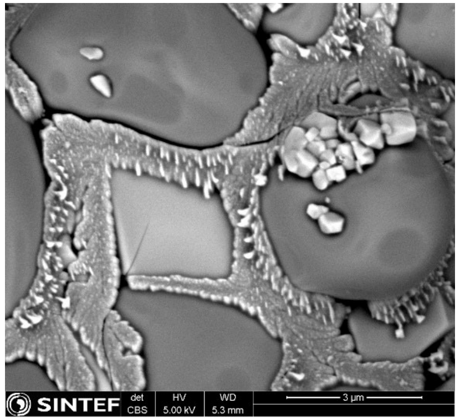
W. Xing et al., Chem. Commun., 2019, 55, 3493

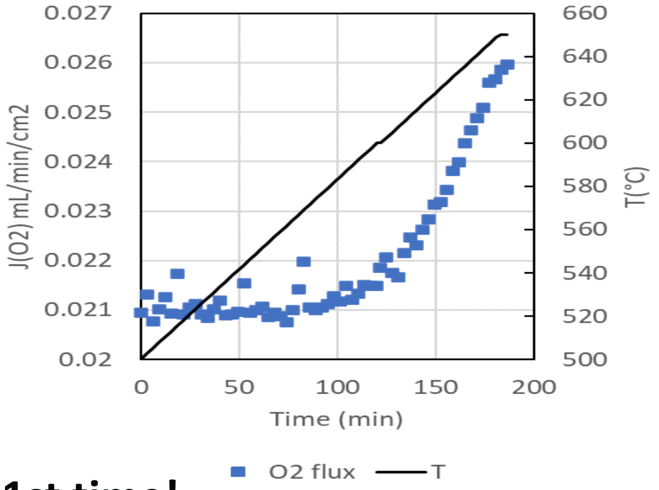
Content

Novel solid/liquid membranes



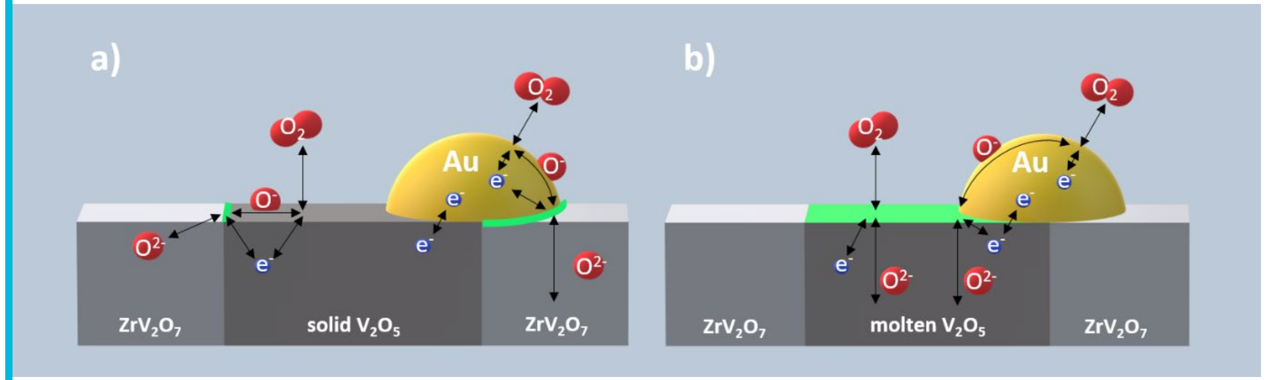
Infiltration of molten pahse



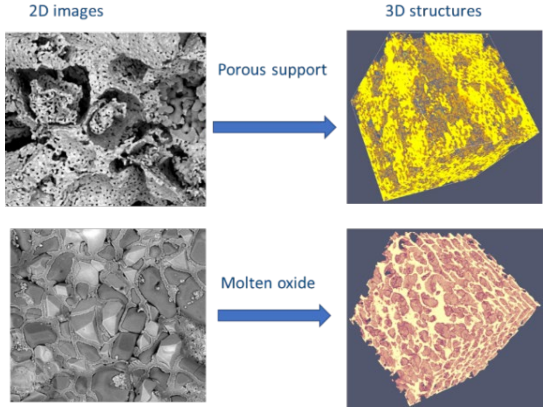


Oxygen permeation at low T for the 1st time!

Faster ionic transport in molten phase



Deep learning for 3D reconstruction



L. Emhjellen et al., J. Mater. Chem. A, 9(2021) 18537

Mario Ditaranto

CHIEF SCIENTIST

Accelerating Carbon Capture using Oxyfuel technology in Cement production (AC2OCem)

Mario Ditaranto is Chief Scientist at SINTEF Energi and has more than 20 years of professional experience in the field of combustion science and technologies covering combustion systems for power and industrial processes. He currently leads research projects in oxy-fuel combustion for the Waste-to-Energy and Cement sectors, and in the use of hydrogen and ammonia for gas turbines and furnaces.

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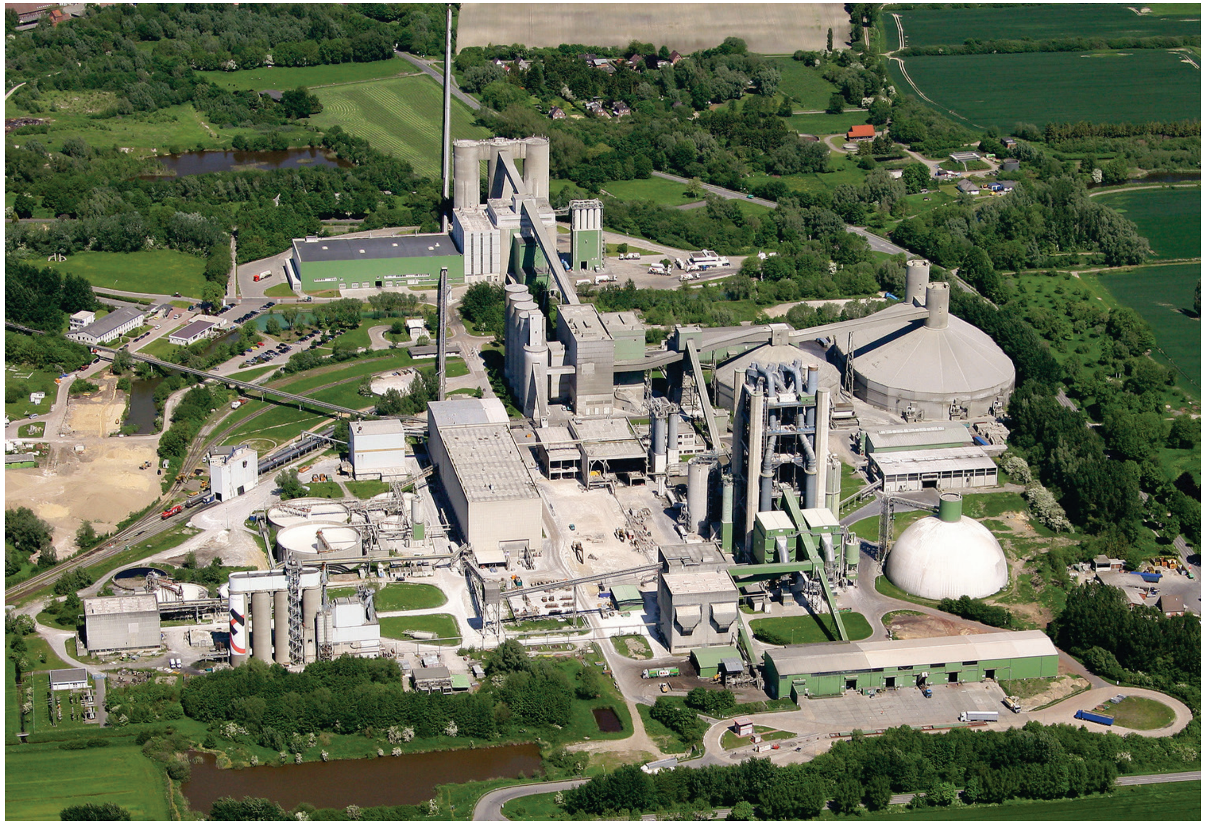
Accelerating Carbon Capture using Oxy-fuel technology in Cement production

mario.ditaranto@sintef.no
SINTEF Energy Research

Project website: https://ac2ocem.eu-projects.de/

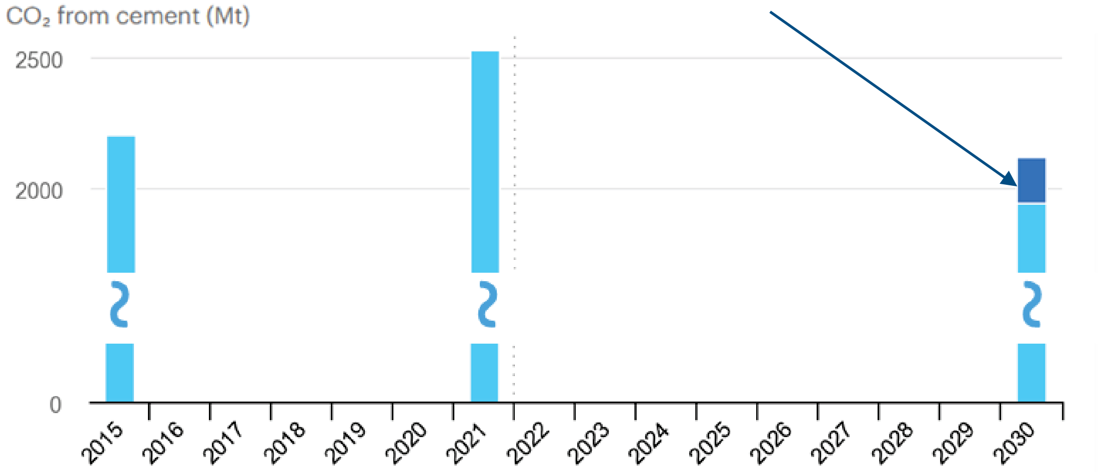
CO_2 emissions scenario for the cement sector



$CaCO_3$ –> $CaO + CO_2$

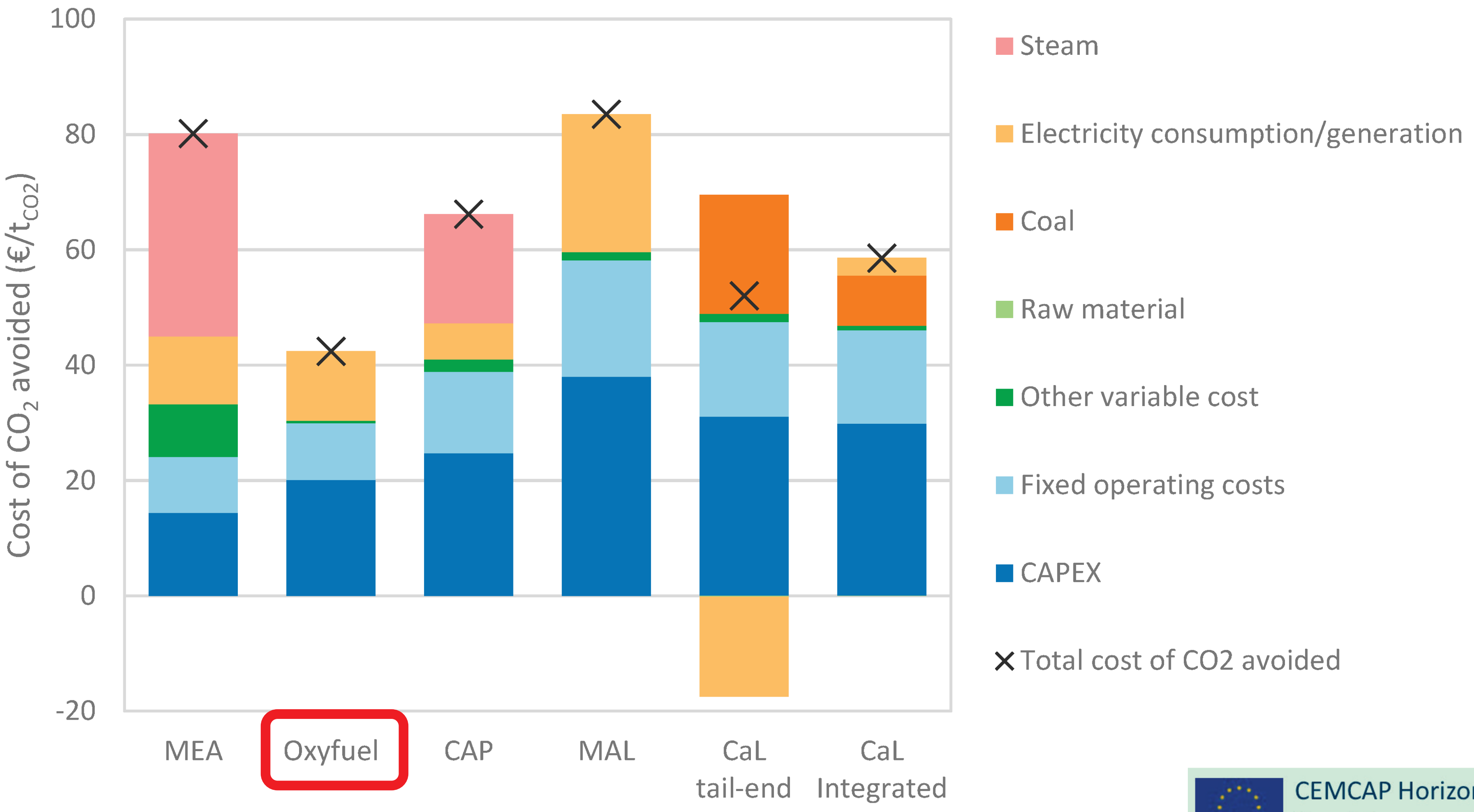
Fuel –> $H_2O + CO_2$

180 Mt to be captured



IEA, CCS deployment in the **Net Zero Scenario**, 2015-2030. Licence: CC BY 4.0

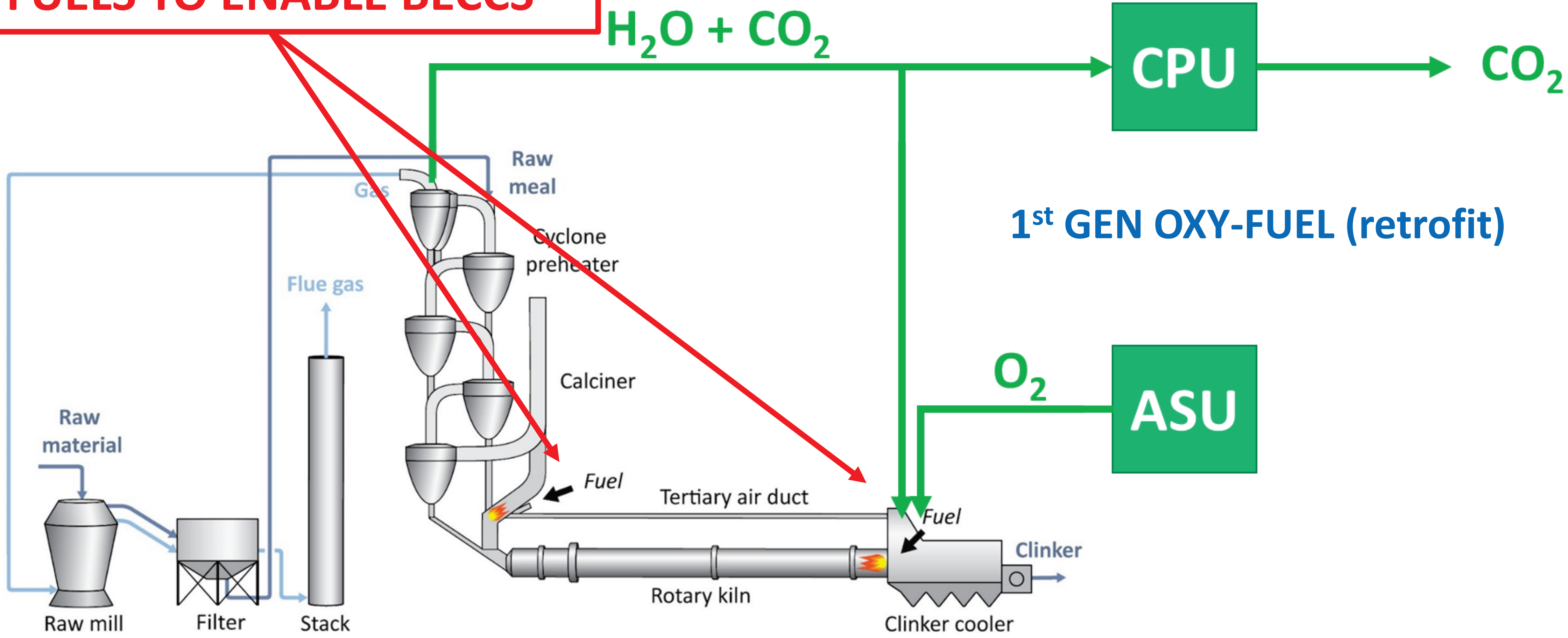
CO_2 capture technologies for cement production



CEMCAP Horizon 2020
Grant Agreement No 641185

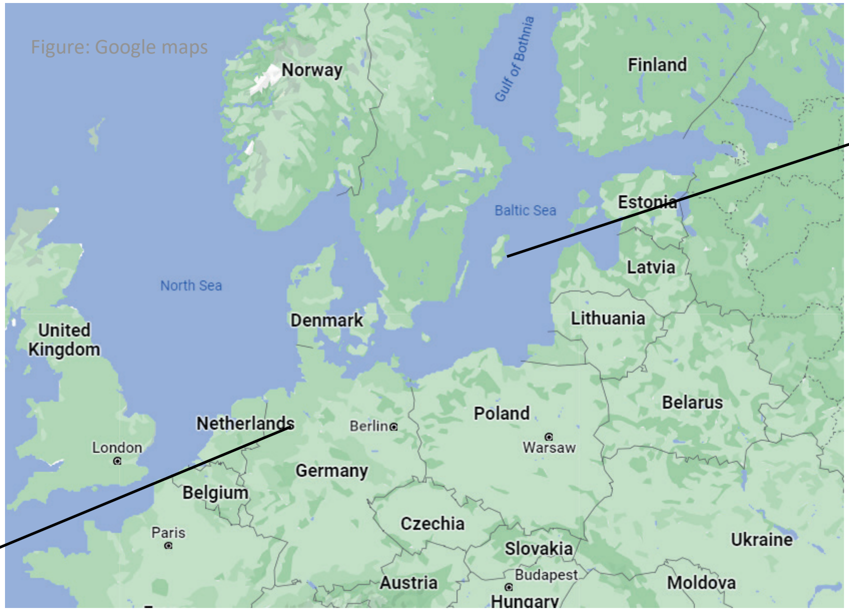
AC²OCem Innovation improvement of 1st Gen

UP TO 100% ALTERNATIVE FUELS TO ENABLE BECCS



1st Gen real case techno-eco analysis

Estimate	Cost year	CAC [€/tonne CO_2]
AC²OCem Plant A	2019	67
AC²OCem Plant B	2019	83
CEMCAP	2014	42



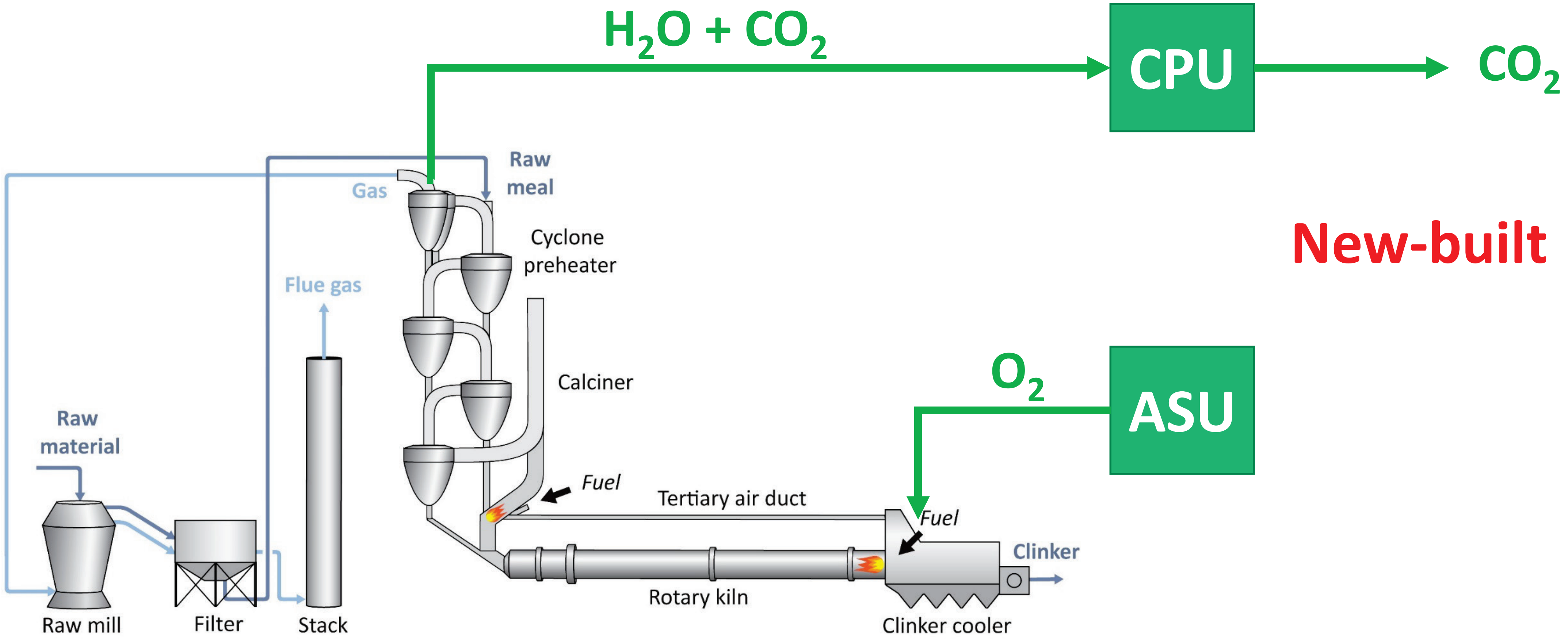
Plant A:
2-3% raw material moisture
Swedish elect. mix 2019:
44 €/MWh (Eurostat)
344 kg CO_2/MWh (Statista)

Plant B:
20% raw material moisture
German elect. mix 2019:
77 €/MWh (Eurostat)
10 kg CO_2/MWh (Statista)

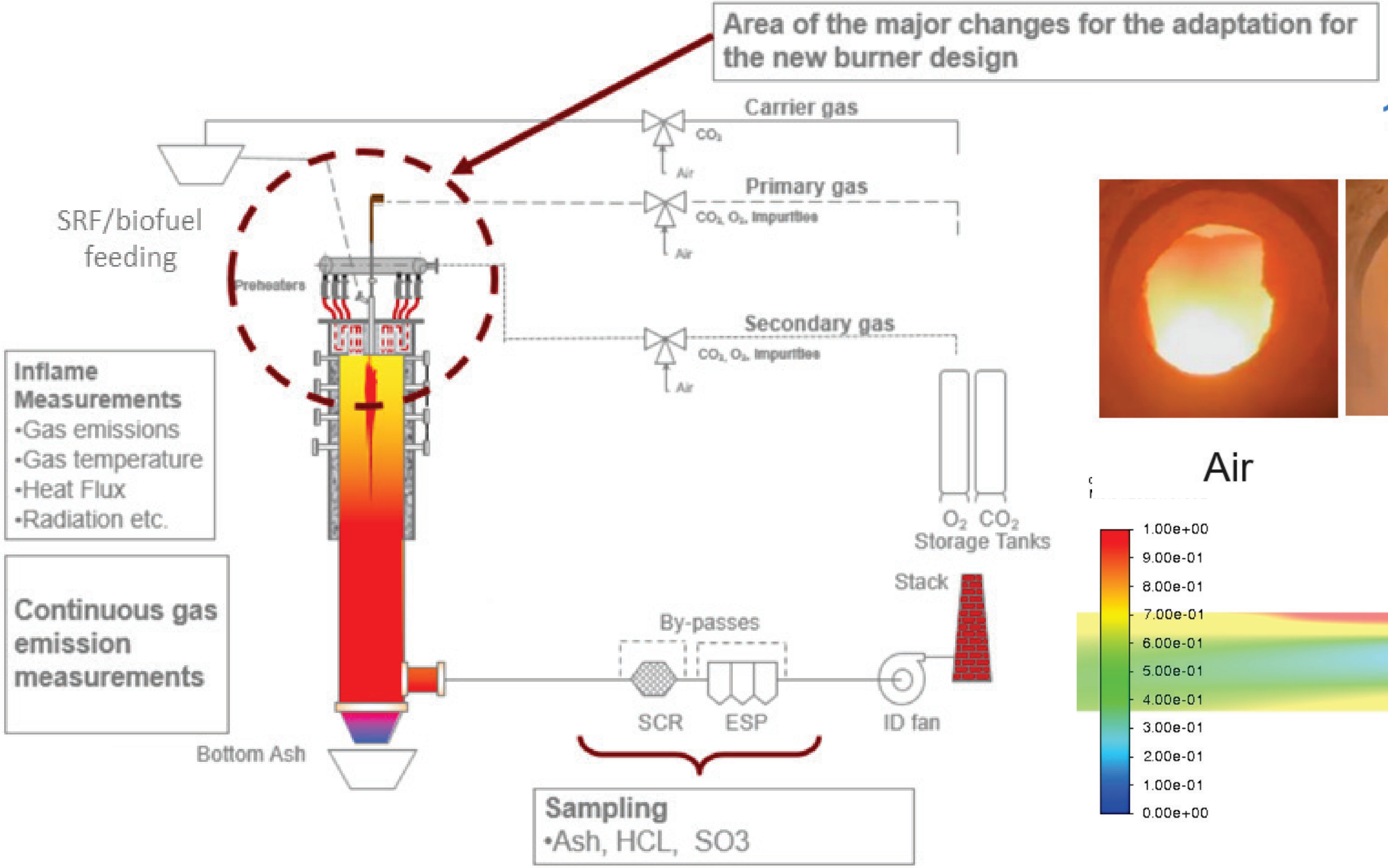
CAPEX and electricity price are the major cost drivers

Innovation improvement 2nd Gen

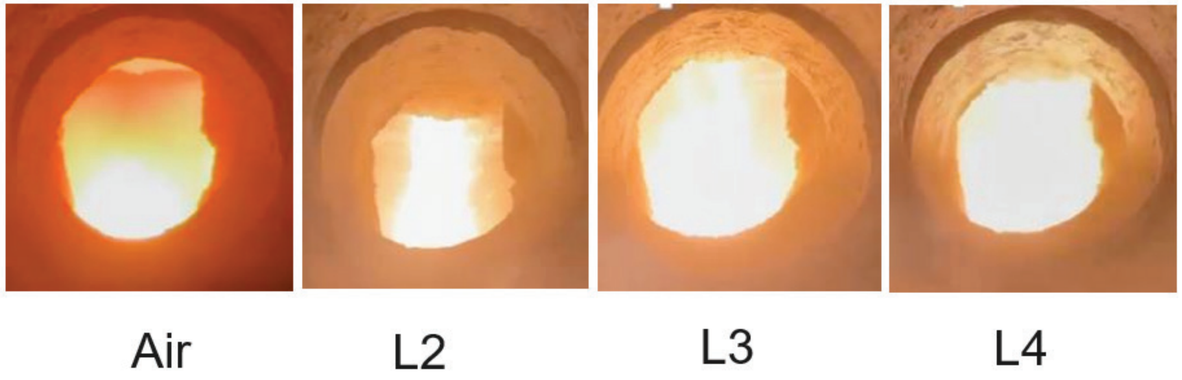
NO FLUE GAS RECIRCULATION

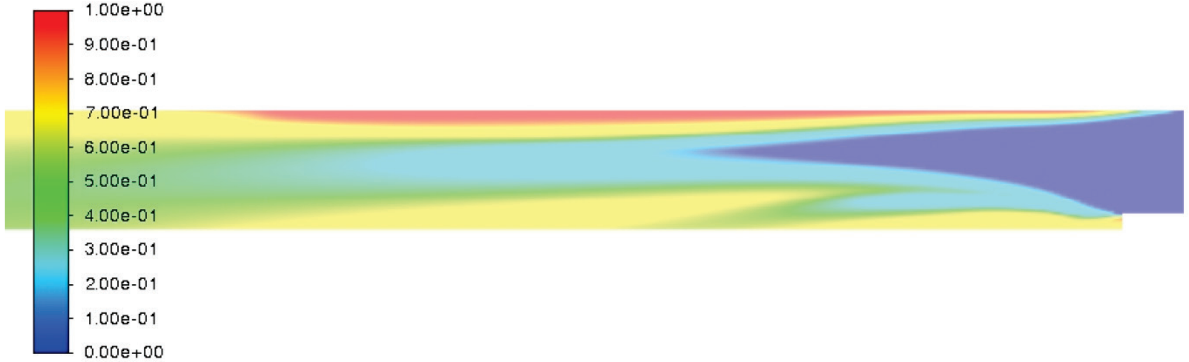


2nd Gen burner development - pilot testing



100 % oxygen tests





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- Swiss Federal Office of Energy (SFOE), Switzerland
- General Secretariat for Research and Development (GSRT), Greece
- French Environment & Energy Management Agency (ADEME), France

ADEME
French Environment & Energy Management Agency

Supported by:
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on the basis of a decision by the German Bundestag

The Research Council of Norway

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

ΕΣΠΑ 2014-2020
ανάπτυξη - εργασία - αλληλεγγύη
Partnership Agreement 2014 - 2020

GSRT
GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

European Union
European Structural and Investment Funds

Ragnhild Skagestad

SENIOR RESEARCHER

EverLoNG

Ragnhild Skagestad is in charge of the Norwegian part of the ACT project EverLoNG which focuses on ship-based carbon capture. Ragnhild holds a Master's degree in mechanical engineering from 2004, and since 2017 she has worked in SINTEF with sustainable development, CO_2 capture and transport and early phase cost estimation. The objective of the EverLoNG project is to accelerate the implementation of ship-based carbon capture, by demonstration the technology on board LNG fueled ships. The project is led by TNO and started up in 2021 and is planned finalized in 2024.

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GASSNOVA

Content

EverLoNG

Ship based carbon capture – SBCC

Funded as part of ERA-ACT 3
4.9 M€ (3.4M€ subsidy)
3 years

Presenter: Ragnhild Skagestad, SINTEF

Project Manager: Marco Linders, TNO

The EverLoNG project is funded through the ACT programme (Accelerating CCS Technologies, Horizon2020 Project No 691712). Financial contributions have been made by the Ministry of Economic Affairs and Climate Policy, the Netherlands; The Federal Ministry for Economic Affairs and Energy, Germany; the Research Council of Norway; the Department for Business, Energy & Industrial Strategy, UK; and the U.S. Department of Energy. All funders are gratefully acknowledged.

CLIMIT SUMMIT Feb 2023

The shipping industry is responsible for around **940 million tonnes of CO_2** annually, which is at least 2.5% of the world's total CO_2 emissions.

The International Maritime Organization has set a target to cut these emissions by 50% by 2050.

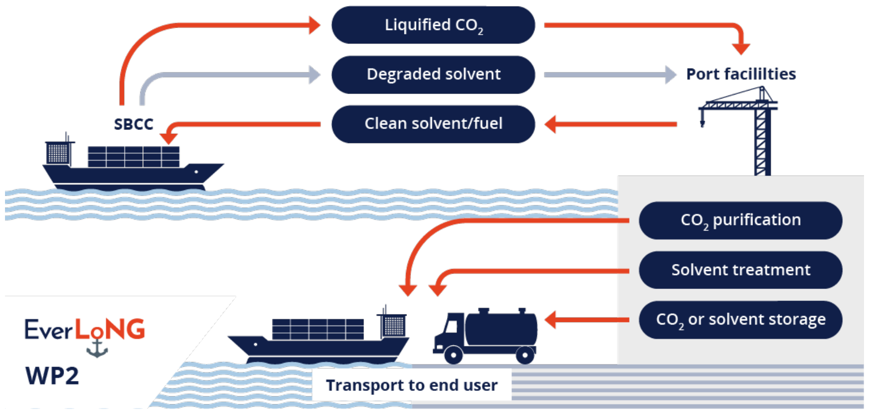
Ship-Based Carbon Capture (SBCC) is proposed as a low-cost alternative to decarbonize the maritime sector, as compared to zero-emission fuels (ammonia, hydrogen)

Photo by Ian Taylor on Unsplash

Objective

The objective of the EverLoNG project is to accelerate the implementation of the SBCC technology by,

- Demonstrating SBCC on-board in LNG-fueled ships.
- Optimizing SBCC integration to the existing shipping infrastructure.
- Facilitating the development of SBCC-based full CCUS chains.
- Facilitating the regulatory framework for the technology.



Content

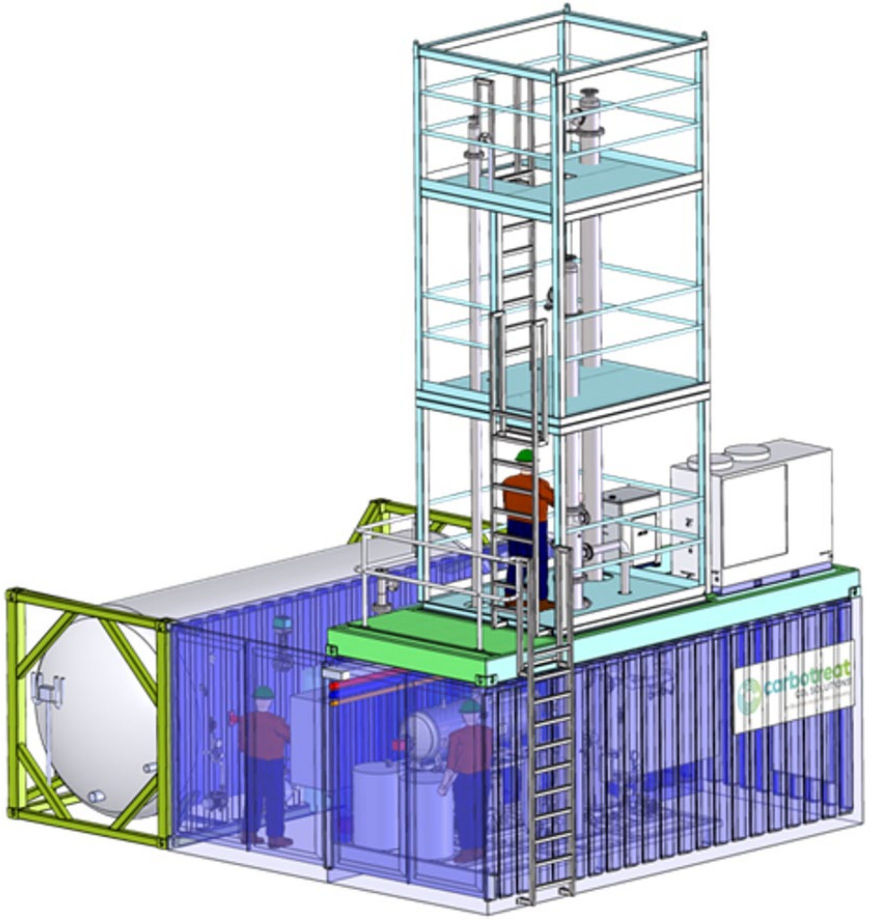
SBCC -So many questions….

- CO_2 capture- volumes, energy supply, space available
- How to handle the CO_2 at the ship? Liquefaction, storage, purification
- Unloading – port facilities, different size of ships, which harbors?
- Time for unloading- possible with container swap?
- Heat integration onboard the ship?
- Environmental footprint
- Cost

Content

Current status

- Piloting of TNO small scale CO_2 capture plant on-board of the Sleipnir ship finalized (0,5 kg/h)
- Prototype ready in March 2023 followed by commission and training of crew (10 kg CO_2/h)
- First campaign will start around August 2023, on one of the TotalEnergies ship, located in Asia.



Acknowledgement

Accelerating CCS Technologies

- ACT funding partners

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

The Research Council of Norway

Department for Business, Energy & Industrial Strategy

Ministerie van Economische Zaken en Klimaat

U.S. DEPARTMENT OF ENERGY

Thank you for listening

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Øyvind Langørgen

RESEARCH SCIENTIST

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LOUISE - Low-Cost CO_2 Capture by Chemical Looping Combustion of Waste-Derived Fuels

He is a research scientist at SINTEF Energy Research, mostly working with CO_2 capture and combustion, such as hydrogen combustion, oxyfuel combustion and Chemical Looping Combustion - CLC. He has been responsible for the CLC activity at SINTEF Energy Research in several projects, including design, building and operation of a CLC pilot unit of 150 kW. He is coordinator for the Norwegian part of the ACT-LOUISE project, which this presentation will be about.

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LOUISE

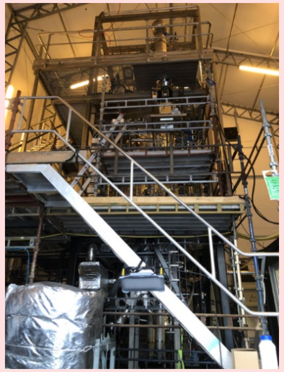
Accelerating CCS Technologies

Low-cost CO_2 capture by chemical looping combustion of waste-derived fuels

Øyvind Langørgen (SINTEF)

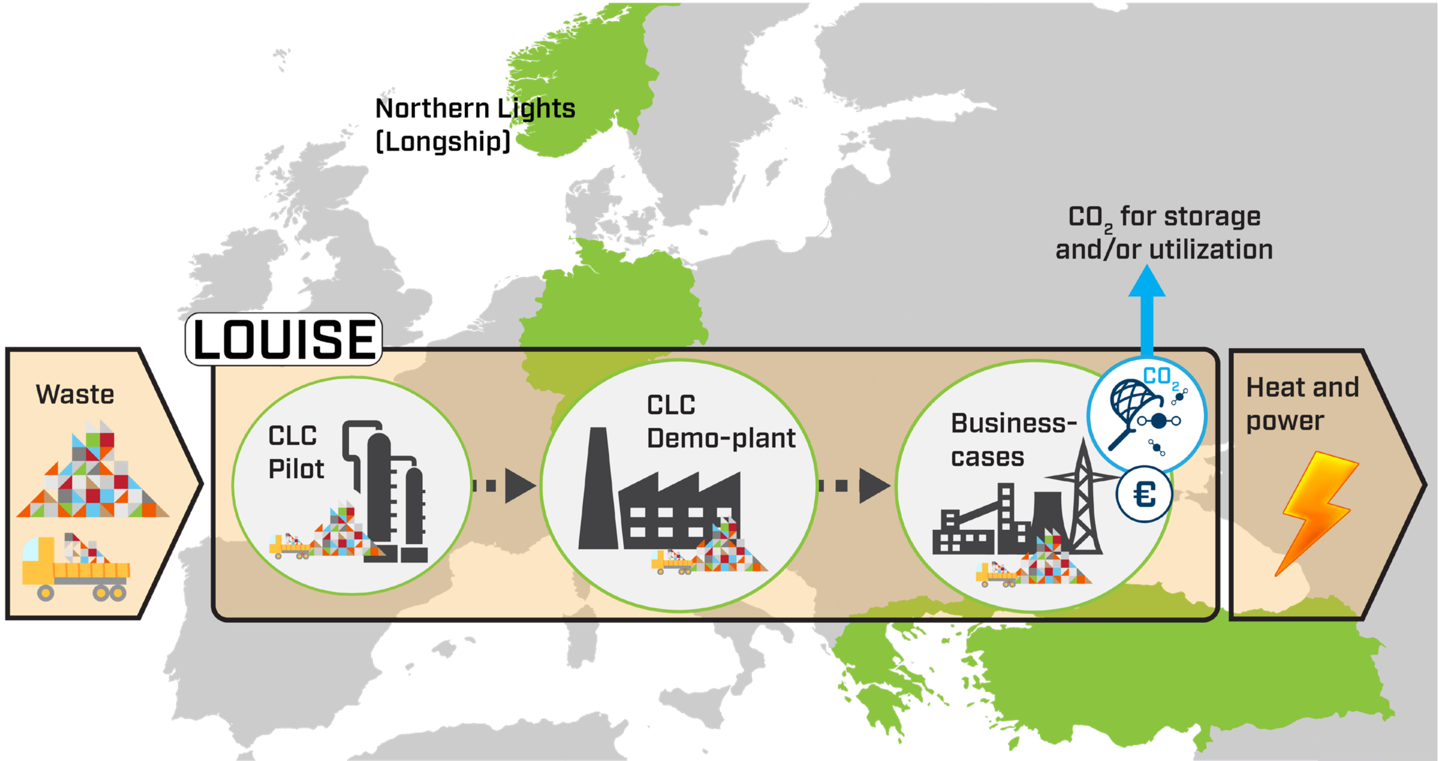
Content

CLC pilot unit testing



150 kW at SINTEF

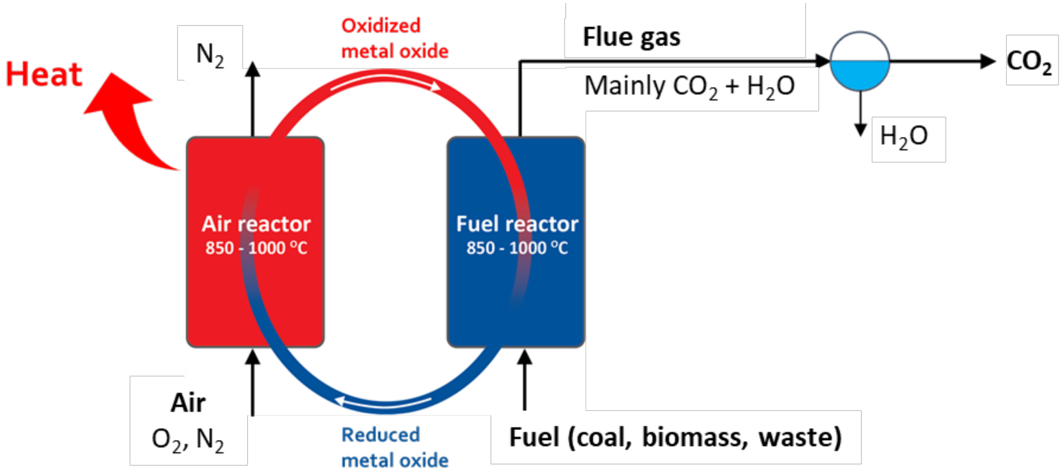
1 MW at TU Darmstadt



Content

What is Chemical Looping Combustion (CLC)?

- Inherent separation of oxygen from the combustion air, using the oxygen for fuel conversion
- Oxygen transported with circulating metal oxide particles
- A type of oxyfuel capture technology, with possible easy CO_2 separation and high CO_2 capture rates
- Based on fluidized bed technology
- Low CO_2 avoidance cost
- Well suited for biomass and some waste-derived fuels
- CLC is highly relevant as a BECCS technology

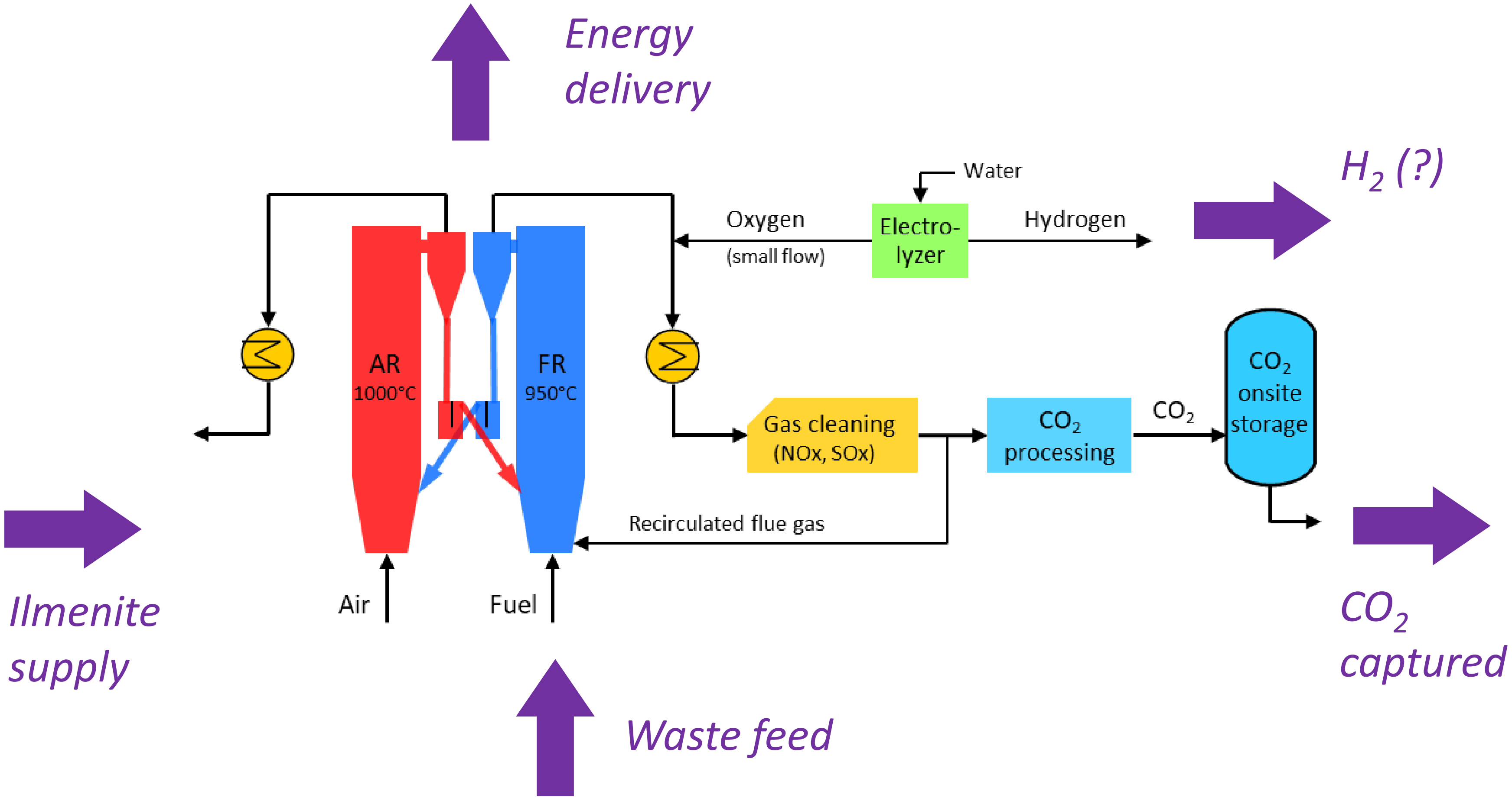


Metal oxide oxygen carrier particles (Ilmenite from Titania)

RDF waste (Ragnsells/Geminor)

Content

Norwegian business case – based at Øra industry site in Fredrikstad



Content

LOUISE

Low-cost CO_2 capture by chemical looping combustion of waste-derived fuels

Content