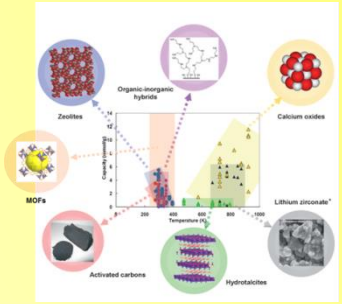
SINTEF strength in performing CLC

MATERIALS – selection and optimization

- Experienced with most types of materials; e.g. oxides, carbonates, sulfides, sulfates, zeolites, MOF etc.



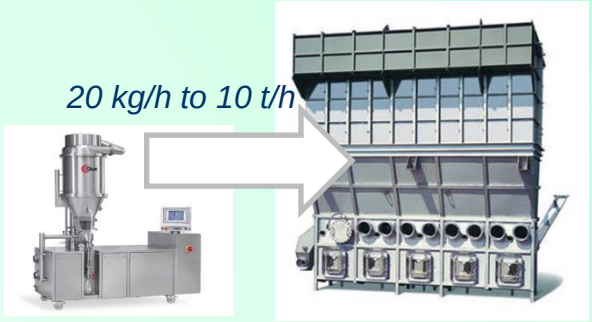
Our expertise

- Prediction based on;
  - Thermodynamics
  - DFT modelling
  - Material properties
  - Stability (chemical – CO_2, H_2S, H2O, CO …, at high pressure)
- Char. of process properties; HPTG, TG-DTA, sorbent isotherms, TPX type measurements etc.
- Char. using SEM/EDS, TEM, XPS, XRD etc.

MANUFACTURING

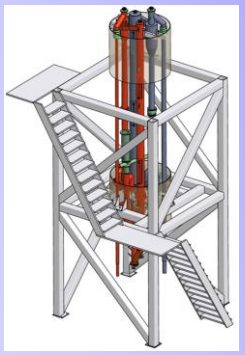
- Different type of powder synthesis
  - Combustion
  - Sol-gel, co-precipitation
  - Hydrothermal
  - Solid state reactions
  - Spray pyrolysis
  - Flame spray pyrolysis
- Different types of granulations
  - Agglomeration
  - Spray granulation
  - Spray coating
  - (Infiltration)
- Pre-industrial production methods

20 kg/h to 10 t/h



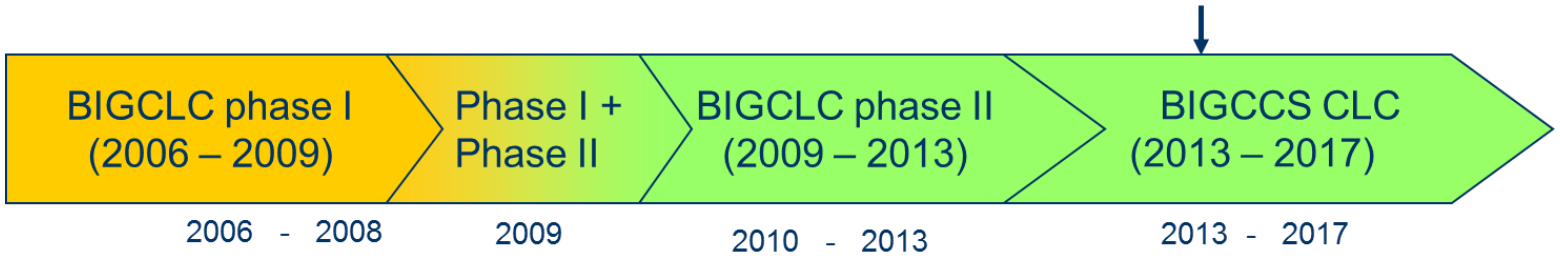
Reactor testing

- Laboratory with 30 bar infrastructures for most gases (including H_2S lab)
- Test several process conditions; TSA, PSA, CSA, VSA , redox, etc.
- Different process layouts; fixed bed, fluidized bed, moving bed etc.
- Small and medium rig for testing materials 3kW and 150kW rig



Several design & fuel

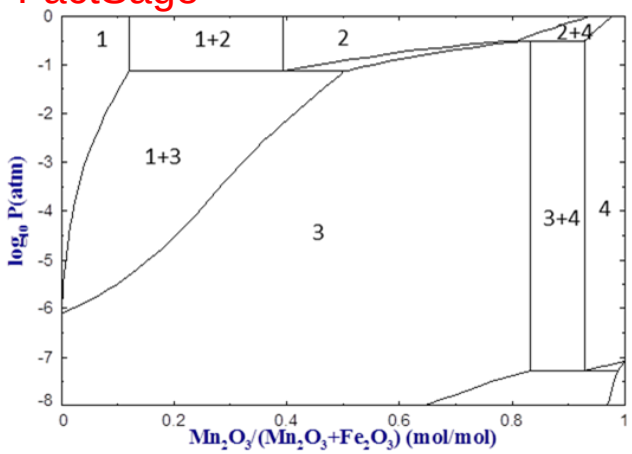
- ENCAP (NG and Coal) 2005 (EU FP6)
  - SINTEF developed $CaMn_{1-x}M_xO_3$ (M=Ti, Fe, Cr), TNO fixed bed, IFP rotating fixed bed, Chalmers fluidized and bubbling bed
- ÉCLAIR / ACCLAIM (Alstom) (RFCS)
  - Demonstration of 1MW demo plant CLC fluidized bed, coal fired
- DemoClock (EU FP7)
  - Demonstration of 500kW demo CLC fixed bed, syngas from gasification of coal
- SUCCESS up-scaling of CMT material production (EU FP7)
- Mineral Scout (FENCO-Net (M-ERA(RCN)))
- Negative CO2 (Bio-CLC) (Nordic Energy Research)
- ITS-CLC (IFP,TNO,SINTEF co-operation)
- COMPOSITE fixed bed (RCN CLIMIT funded)
- BIGCCS / BIGCLC. (RCN CLIMIT funded)
  - SINTEF rotating fixed bed
  - SINTEF double circulating fluidized bed



COAL: Fe-Mn SYSTEM (from ÉCLAIR)

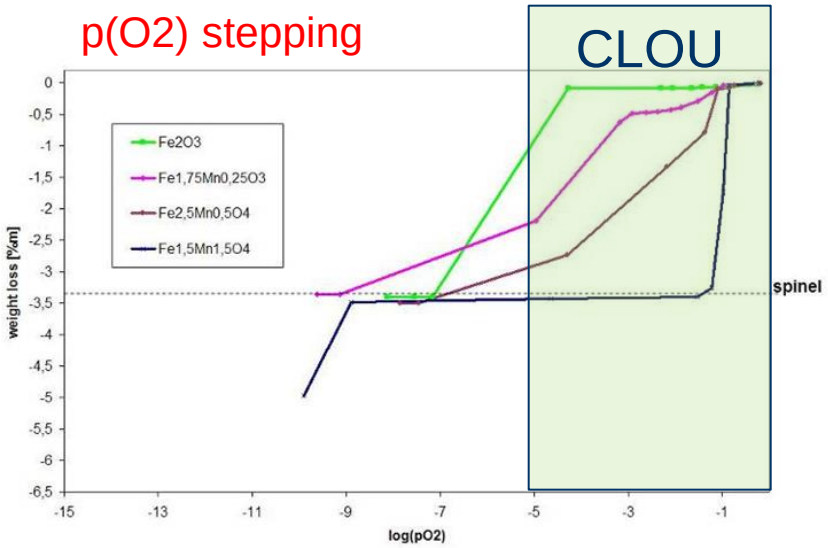
Tools for selecting material:

FactSage

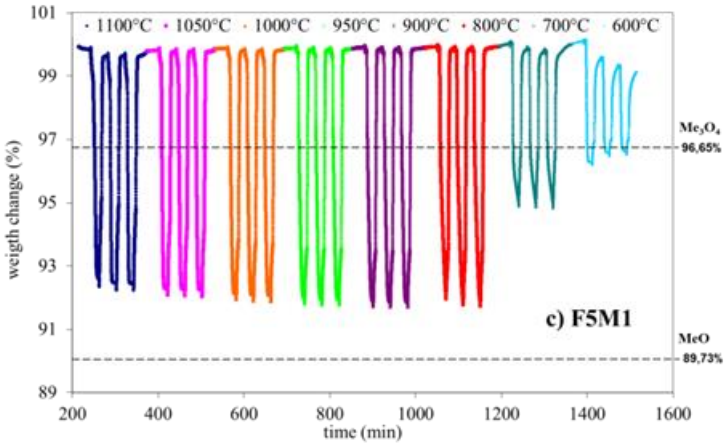


1: Hematite
2: Bixbyite
3: Spinel
4: Hausmannite
5: Manganese
6: Halite

p(O2) stepping

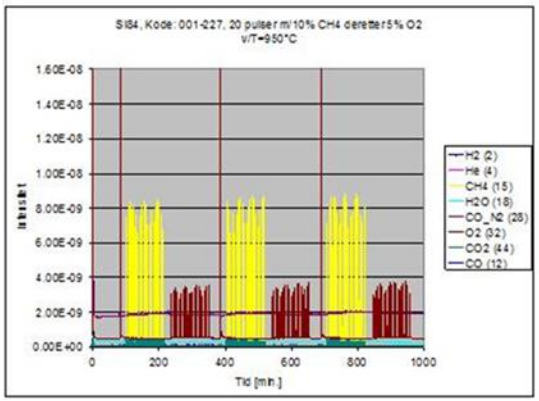


Cyclic experiments

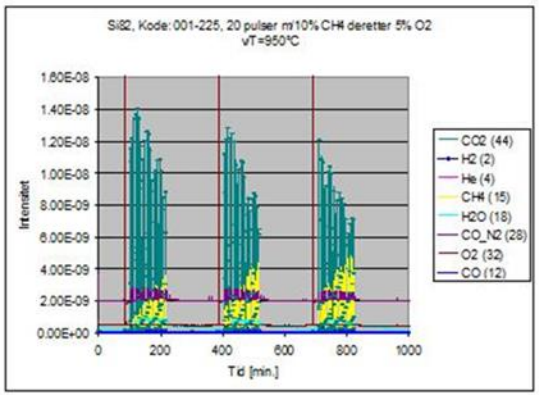


Fixed bed -TPX

$Fe_{1.75}Mn_{0.25}O_3$



$Fe_{1.5}Mn_{1.5}O_4$

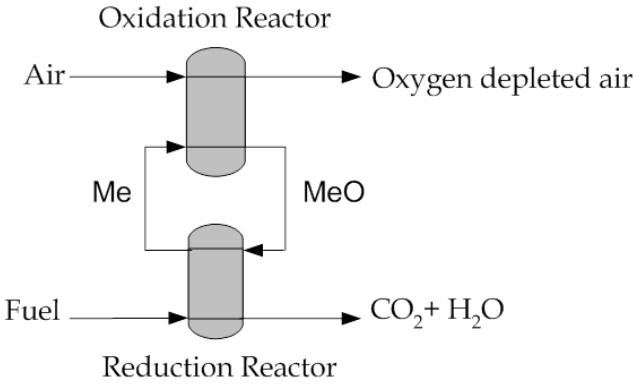


230478 - "Minerals for Sustainable COst and energy efficient chemical looping combUstion Technology"

- Scope
  - Improve the novel Chemical Looping Combustion (CLC) technology for power production with CO2 capture, by finding better oxygen carrier materials with high and fast oxygen release giving full combustion. (Avoiding penalty from extra oxygen elsewise needed from air separation unit (ASU))
  - Find and get hold of 10 new minerals from mining industry, including some from industrial waste.
  - Test and evaluate them against criteria's needed for coal based Chemical Looping Combustion.
  - Down select 2-3 for further testing under rig operation

MINERAL SCOUT

Chemical Looping Combustion



NTUA – National Technical University of Athens

INSTITUTE FOR CHEMICAL PROCESSING OF COAL

SINTEF

UNIVERSITY OF CAMBRIDGE

CERTH CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

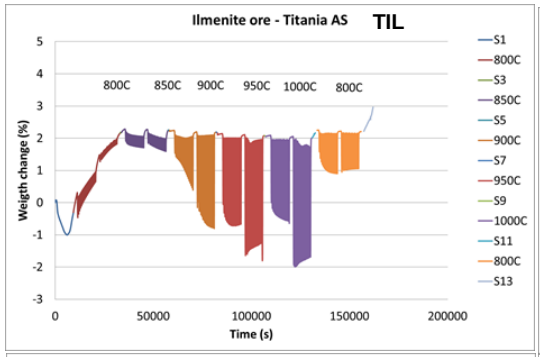
EPSRC Engineering and Physical Sciences Research Council

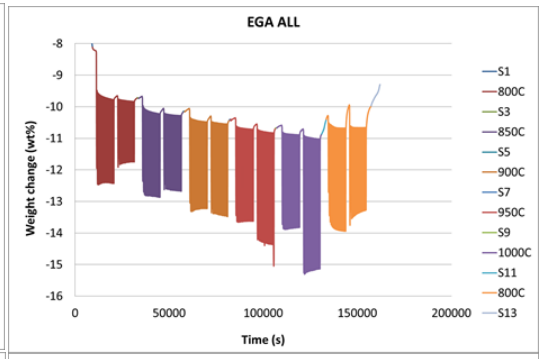
GSRT GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

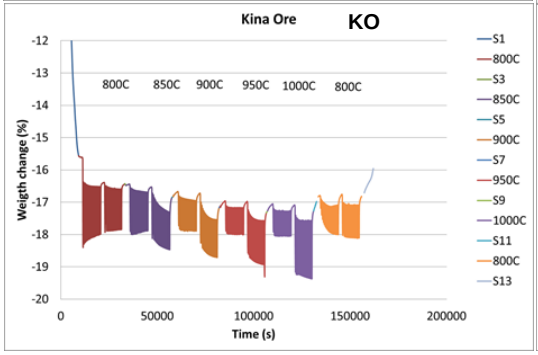
The National Centre for Research and Development

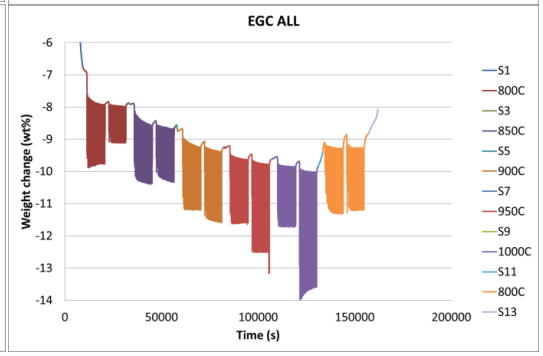
Task conducted at SINTEF the first period

- Pre-testing by TG
  - 800, 850, 900, 950, 1000, 800C
  - At each temperature
    - 20 cycles between air and 5%H2 , 25% CO2, 2%H2O step 2min
    - 20 cycles between air and 10%CH4 , 25% CO2, 2%H2O step 2 min

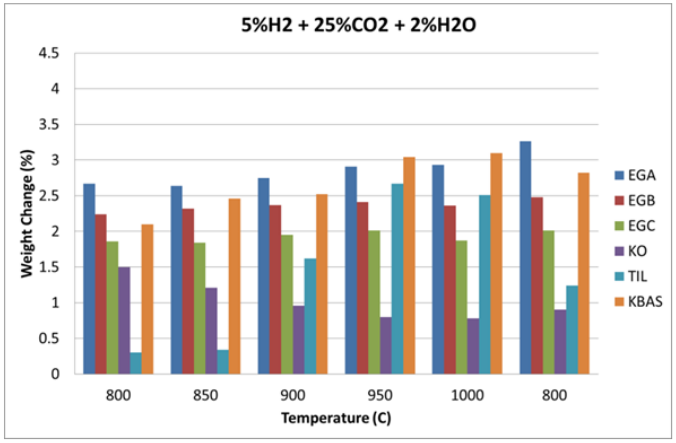


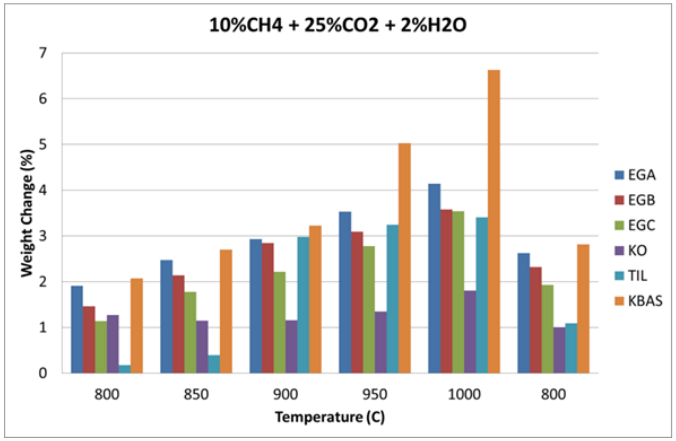






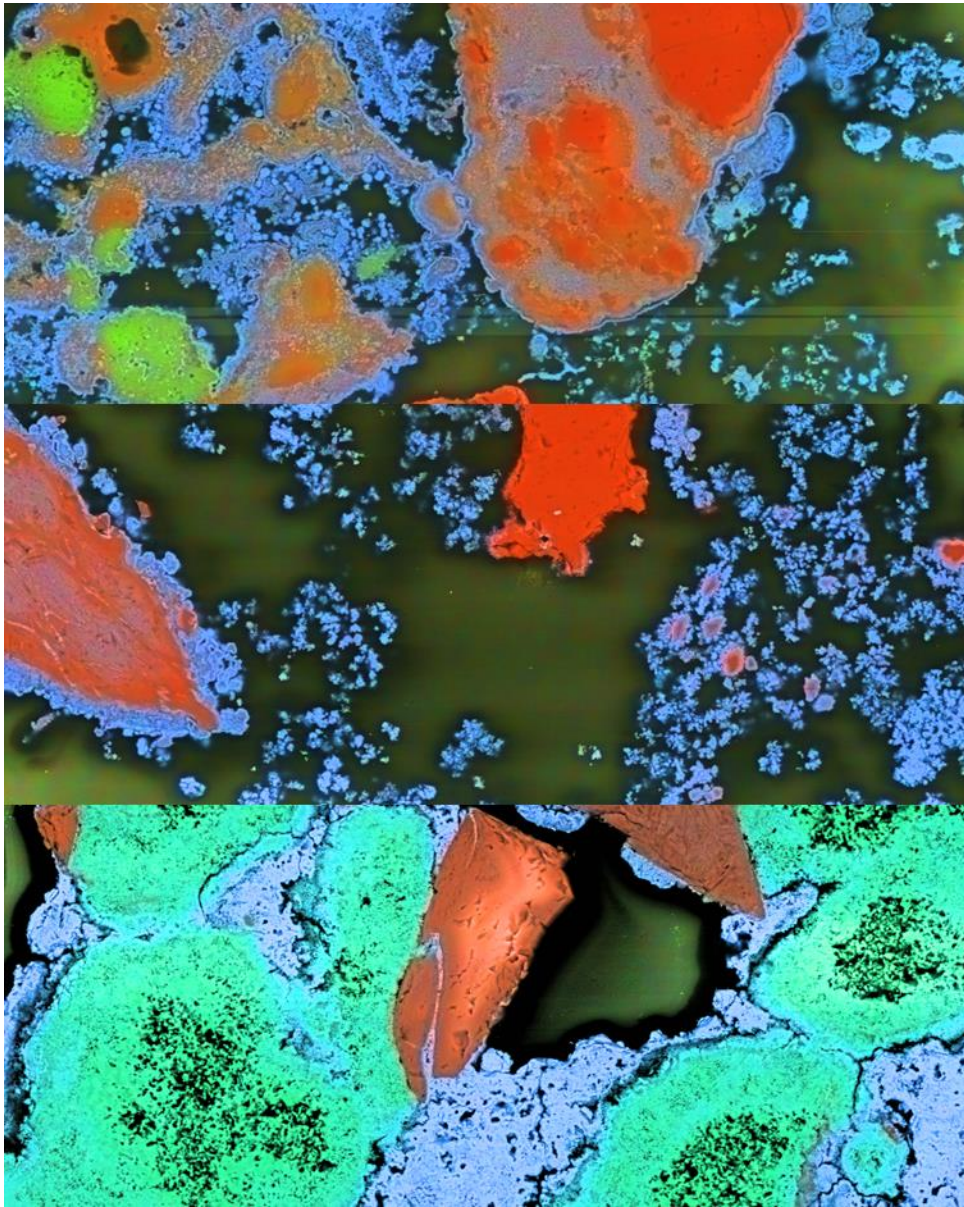
Oxygen carrier capacity and reactivity





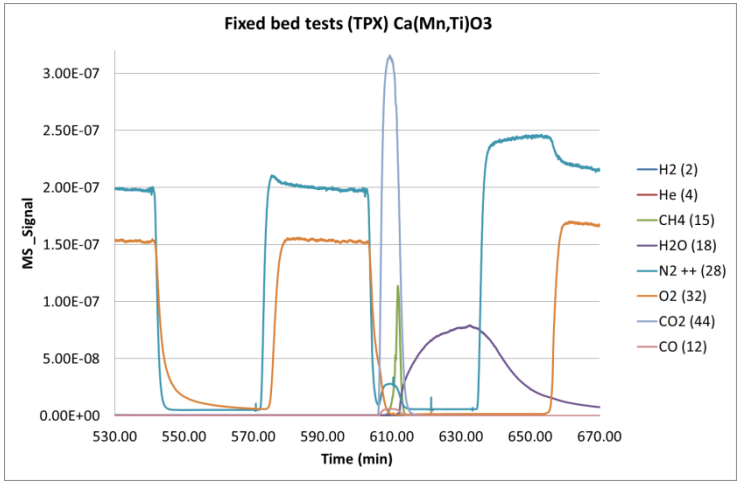
Summary pre-test

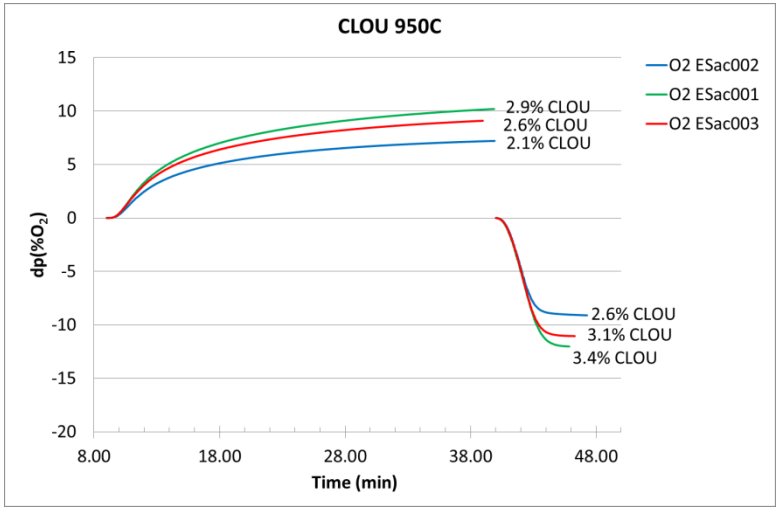
- Elwaleed samples:
  - Inhomogeneous!
  - Fe and Mn not much intermixed, even after testing.
  - Works directly without pre-treatment.
  - High reactivity and oxygen carrier capacity
- Krivbas
  - Nearly pure Fe-oxide .
  - Gets highly porous upon testing.
  - Strength might be an issue.
  - Very high capacity and good reactivity
- Titania ilmenite
  - Nearly pure ilmenite.
  - Fe diffusion to the surface of the grains upon testing.
  - Need activation.
  - Capacity medium

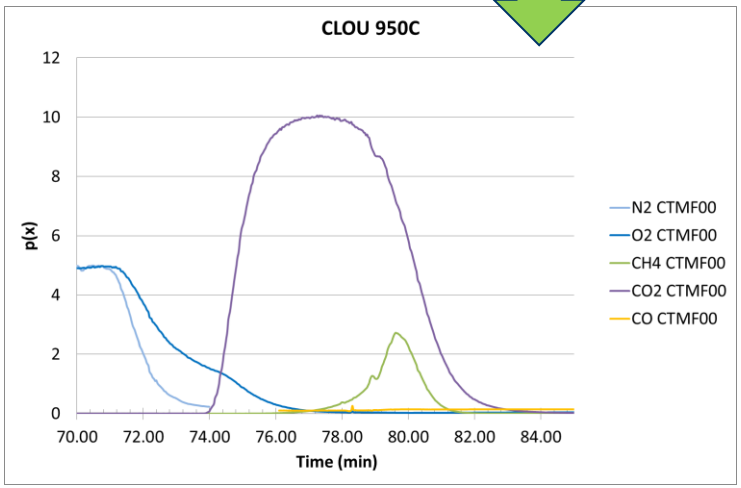


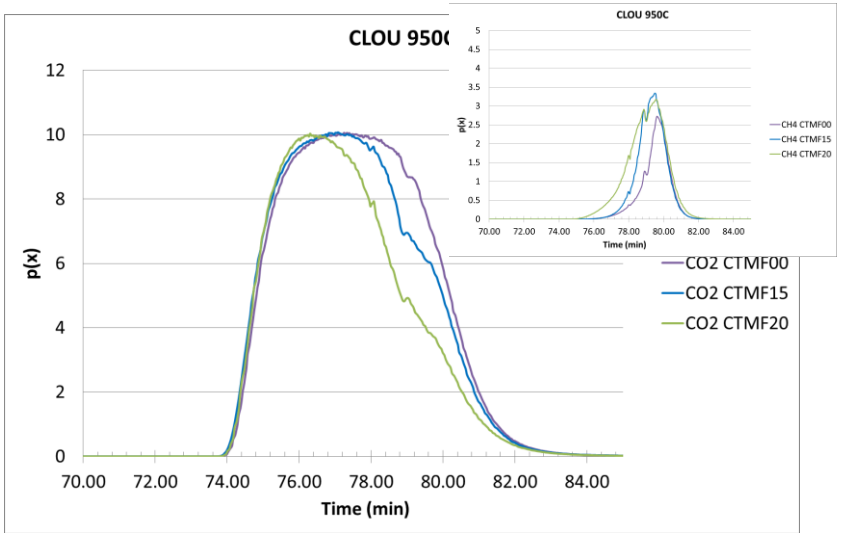
NG: Ca(Mn,Ti,Fe)O3 system (from BIGCCS/SUCCESS)

Fixed bed (TPX) test for CLOU and reactivity evaluation









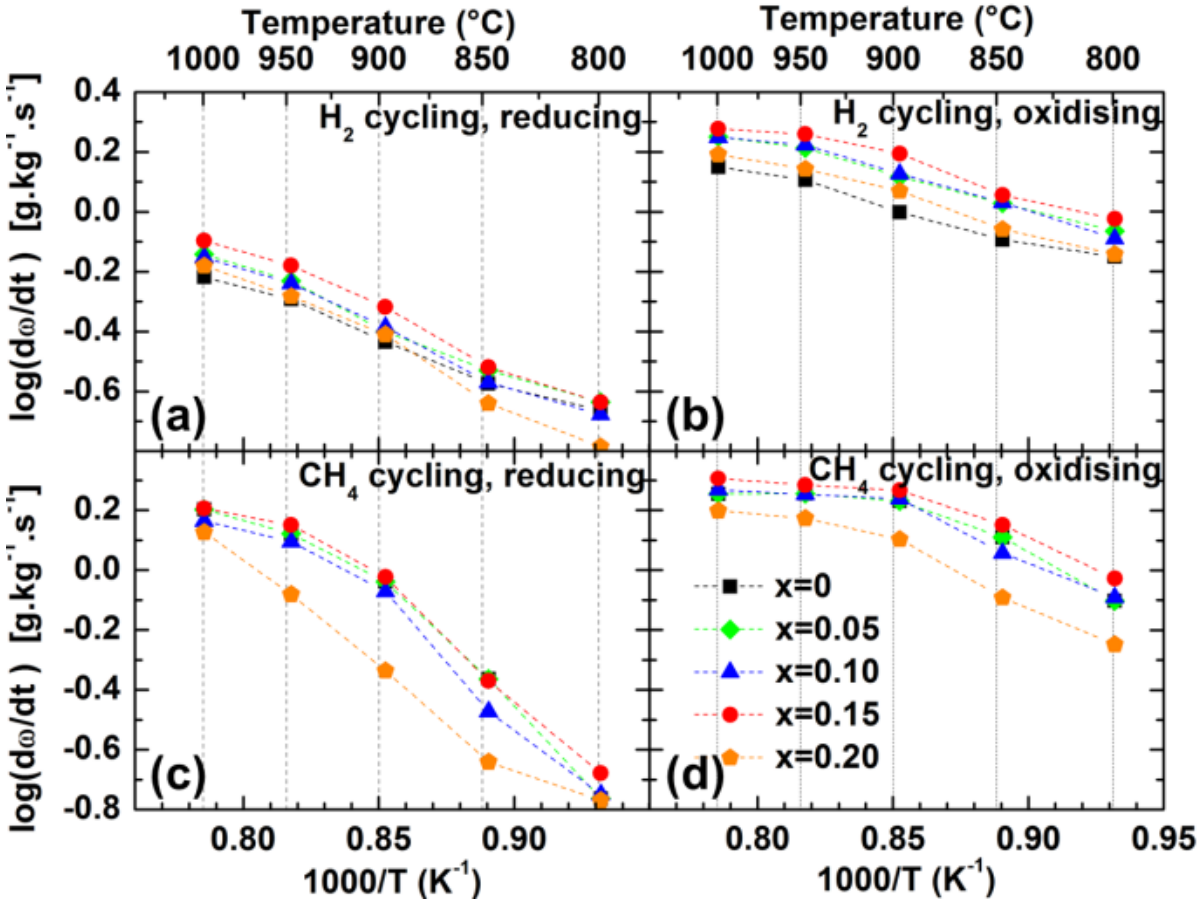
CMT

CMTF05

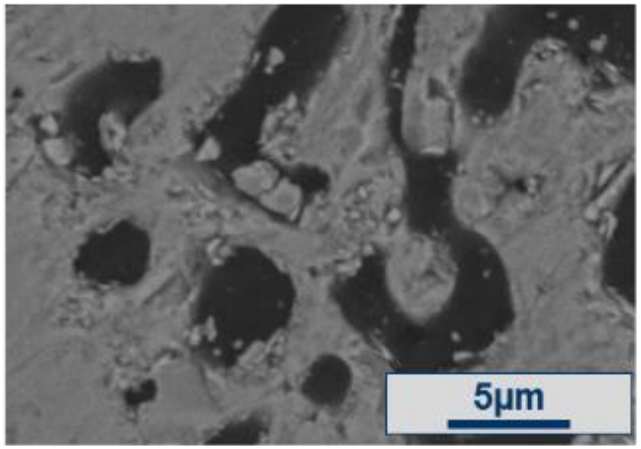
CMTF05

CMTF15

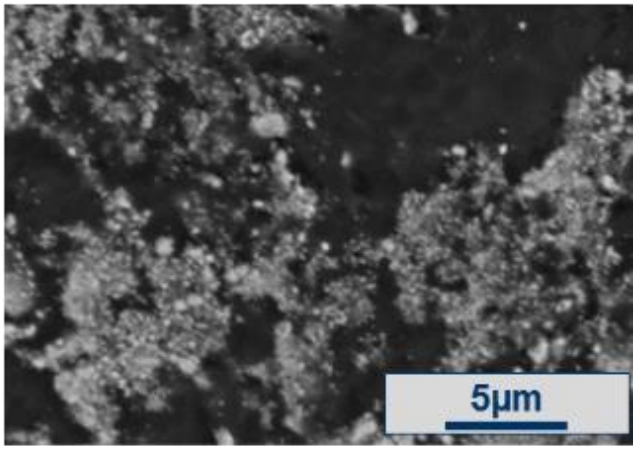
CMTF20



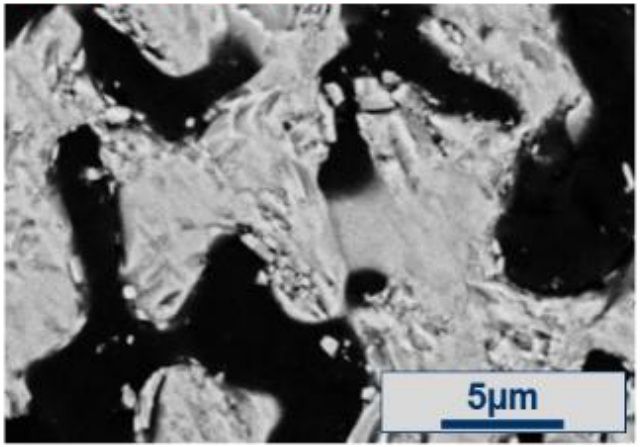
CMT – fresh:



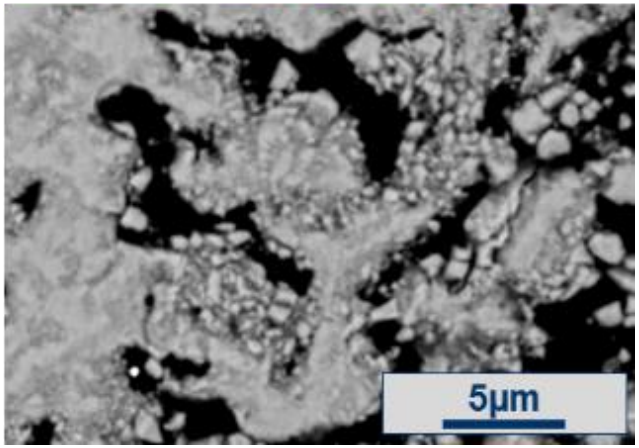
CMT – after 240 cycles:



CMTF15 – fresh:



CMTF15 – after 240 cycles:

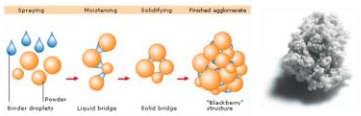


Powder morphology for up-scaling to industrial scale

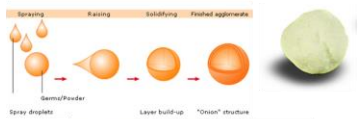
Glatt ProCell unit installed at SINTEF in 2012

- Agglomeration, spray granulation, spray coating

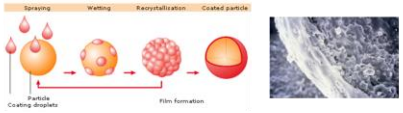
- Agglomeration



- Spray granulation



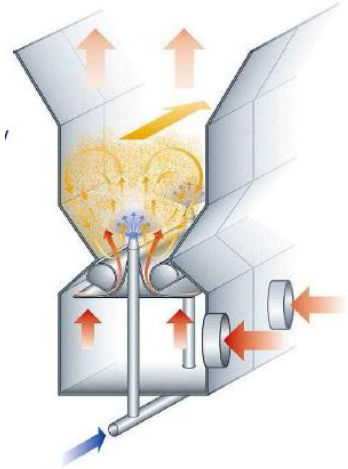
- Spray coating



Ref: Glatt GmbH

9

20 kg/h to 10 t/h

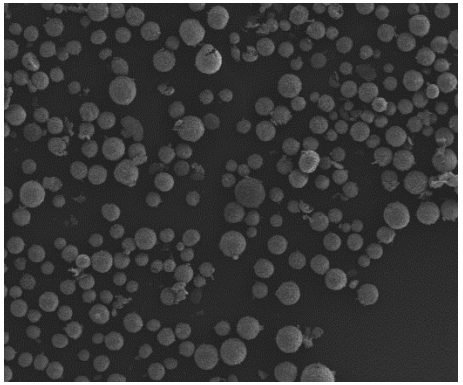


Buchi B-290

Spray Dryer

ProCept

Spray Dryer



GEA Mobile Minor

Spray Dryer

Naberthem furnace

One promising evaluated route

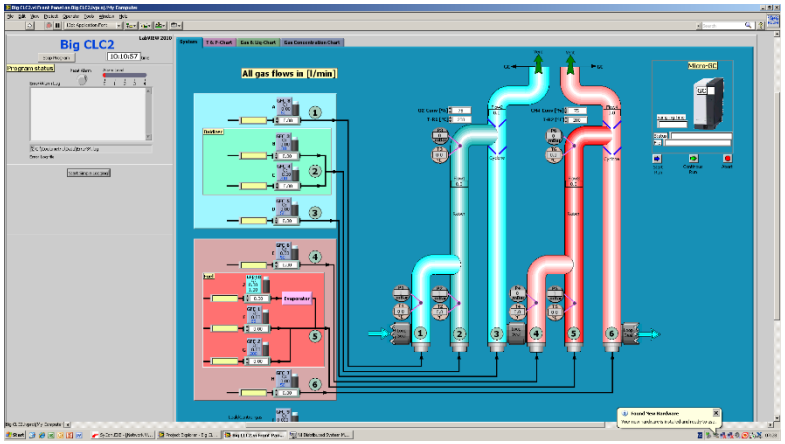
- $CaMn_{1-x-y}Ti_xFe_yO_3$ (CMTF) using cheap, non toxic, raw materials
  - $CaCO_3$, Colormax (Mn_3O_4), TiO_2/$FeTiO_3$
- Production method not selected (Spray drying or spray granulation)
- Must be produced in tons with necessary properties
  - 100-300 µm, spherical, porous, sufficient mechanical strength

Crushing and screening

Granulation / coating

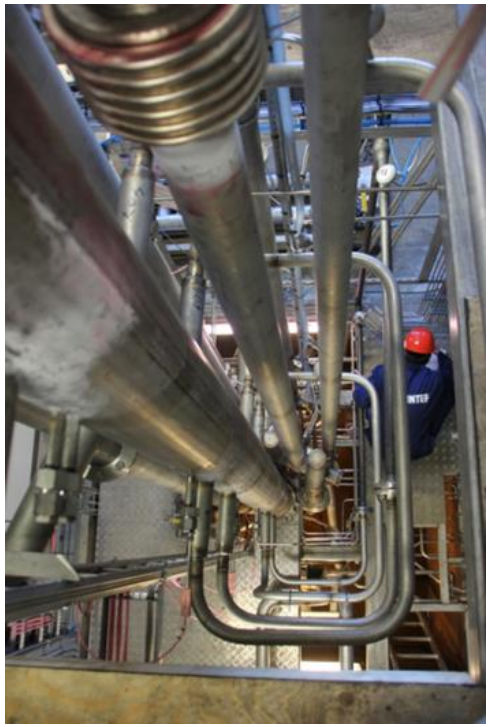
Spray drying

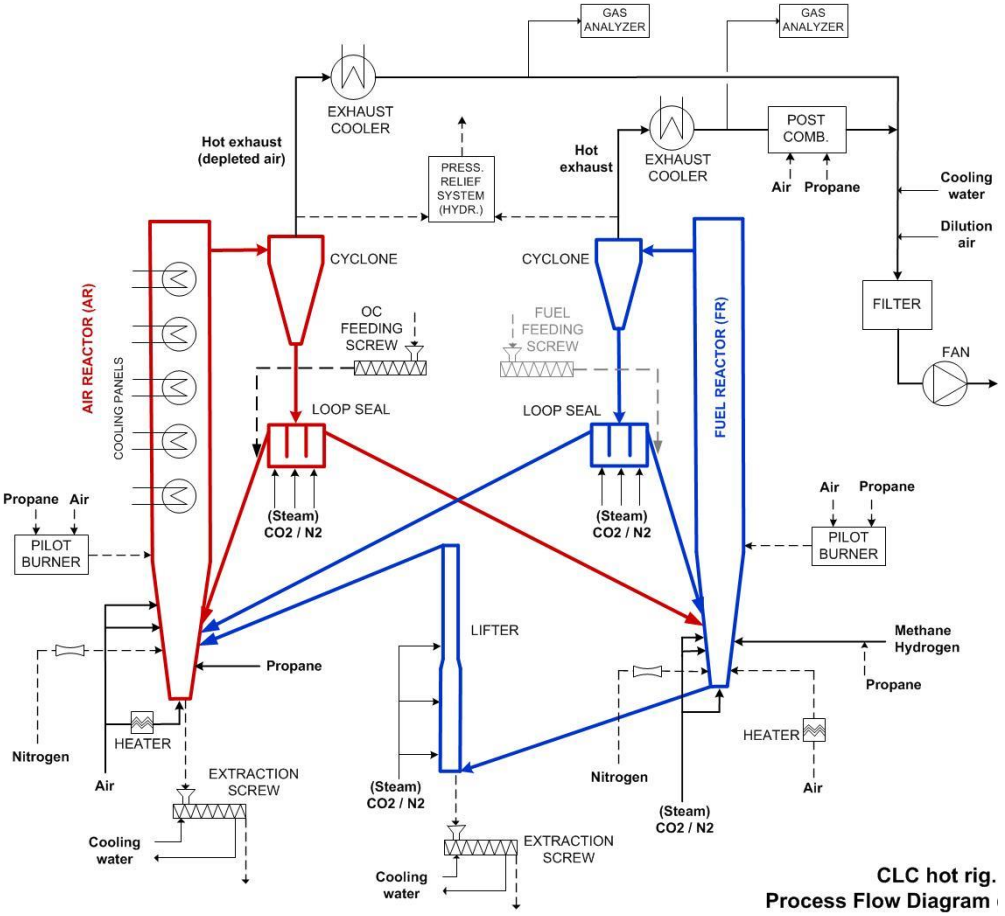
3kW rig developed for hot attrition testing of materials.



150 kW CLC rig at SINTEF

- Double loop CFB reactor system
- Reactor height: 6 m
- Reactor diameters:
  AR 230 mm, FR 154 mm

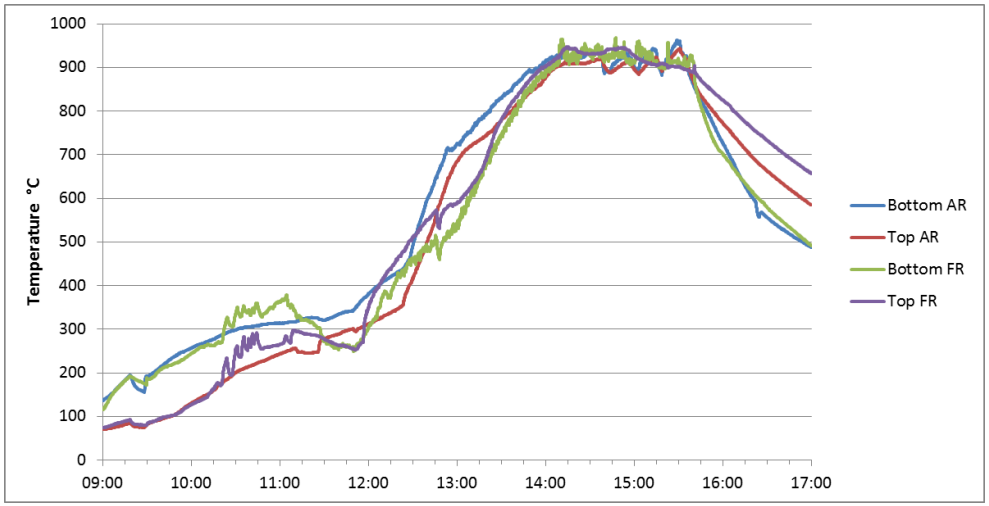




150 kW CLC rig at SINTEF

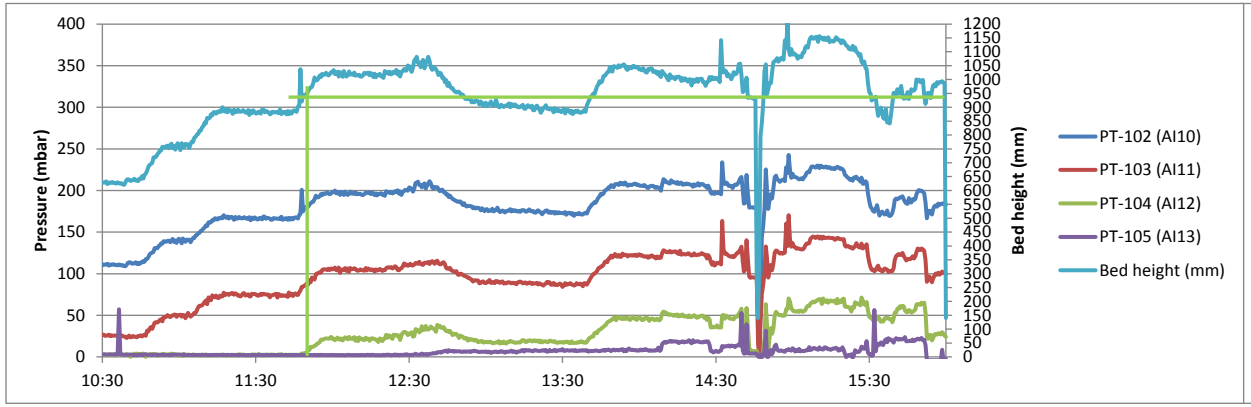
Heat-up of reactor system

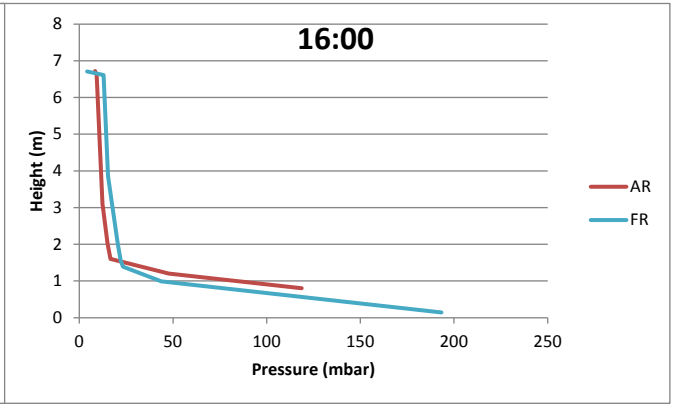
- Required temperatures for CLC is being reached in both reactors (>900°C)



Next step:

- Transfer to CLC mode using
  - **ilmenite and hydrogen**
  - or **CMTF and NG**





Negative CO_2

Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

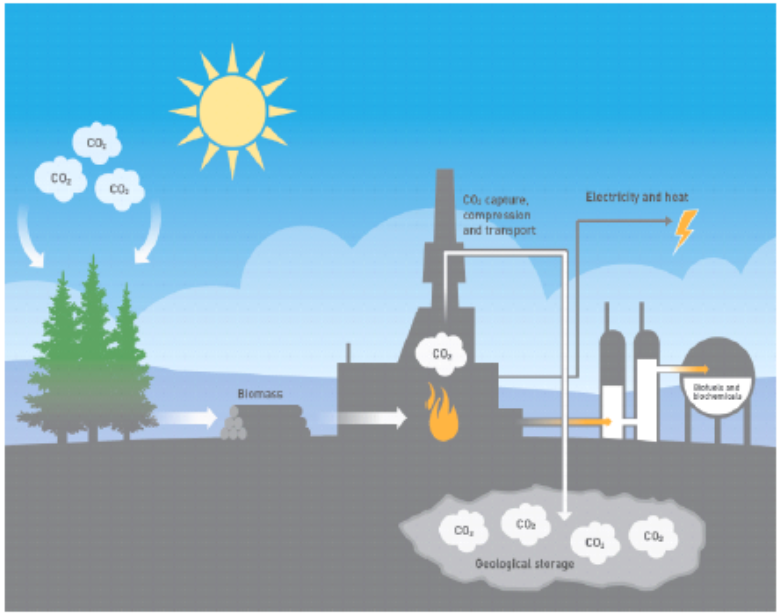
Advisory board associated with the project:

- Alstom Power AB
- Andritz Oy
- AKZO Nobel
- Elkem AS
- E.ON Sverige AB
- Fortum Oyj
- Foster Wheeler Energia
- Göteborgs Energi
- Titania A/S
- Arbaflame

- Negative CO_2 is a multi-partner and cross-disciplinary project funded by Nordic Energy Research that runs from November 2015 to October 2019.
- The research topic is CO2 capture during biomass combustion by CLC.
- Aiming at demo
- Budget 27 Mill NOK

The project partners are:

- Chalmers University of Technology
- The Bellona Foundation
- Sibelco Nordic AB
- SINTEF Energy Research
- SINTEF Materials and Chemistry
- VTT Technical Research Centre of Finland Ltd
- Åbo Akademi University



Schematic description of BECCS (illustration by Doghouse.no/SINTEF).

People working with CLC

Strength introduced by different groups in SINTEF and NTNU(*) working together

- SINTEF MC Oslo (Material selection and characterization)
  - Yngve Larring, Mehdi Pishahang, Bjørnar Arstad, Richard Blom.
- SINTEF MC Trondheim (Material Fabrication)
  - Tommy Mokkelbost, Christian Schøning, Ingeborg Kaus
  - Shariar Amini, Schalk Cloete, John Morud, Abdelghafour Zaabout
- SINTEF ER Trondheim (Rig development and testing - 150kW unit)
  - Nils Haugen, Inge Saanum, Øyvind Langørgen, Jørn Bakken
- NTNU Trondheim (Material optimization)
  - Kjell Wiik, Vincent Thoréton

(*) NTNU: Norwegian University of Science and Technology