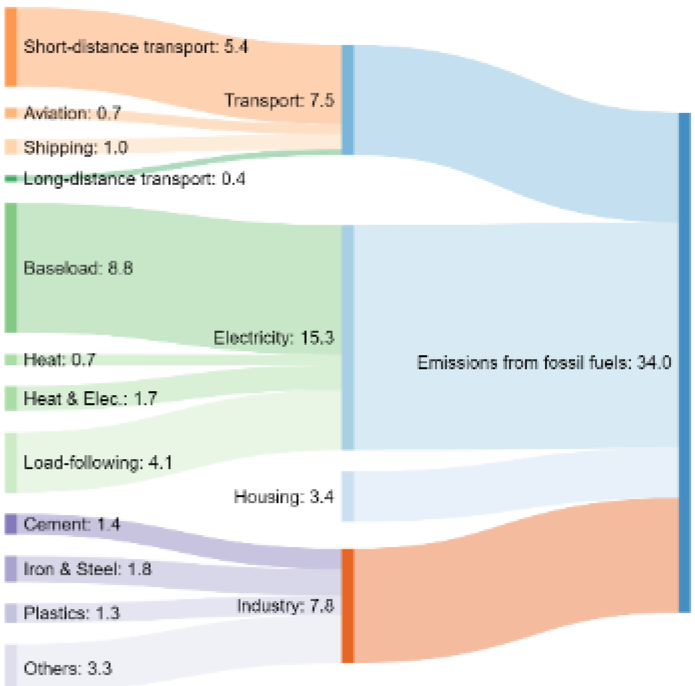
A Very Special CO_2MMODITY for Lime industry

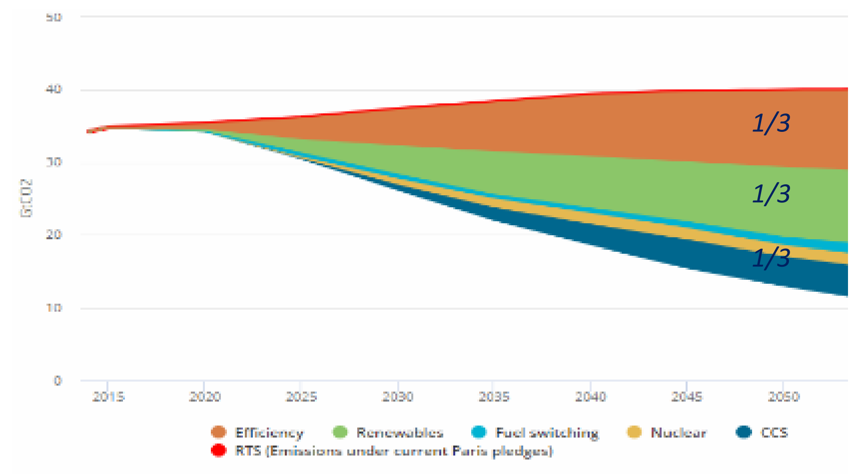
X. Pettiau, T. Chopin
BIRD – Limelette – January 2020

CO_2 : A Global Challenge ?

GLOBAL ANTHROPOGENIC CO2 EMISSIONS IN THE MAGNITUDE OF 34 GTPA



iea 2°C



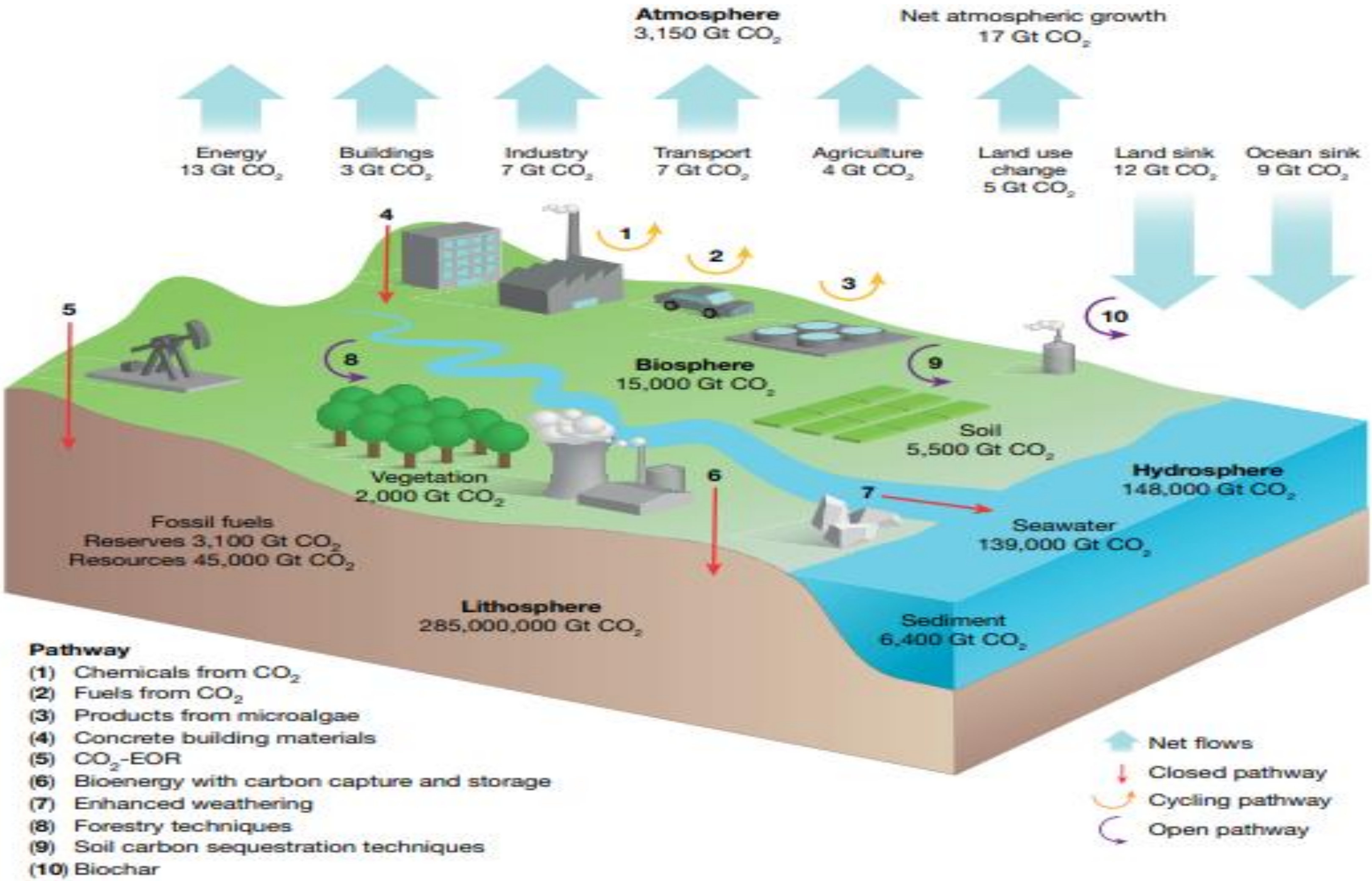
› Global : 6 Gtpa to be removed by 2050

› EU : 300 Mtpa to be removed by 2030

Global lime production related emissions 0.24 Gt_{CO2} per annum

GLOBAL CO2 BALANCE

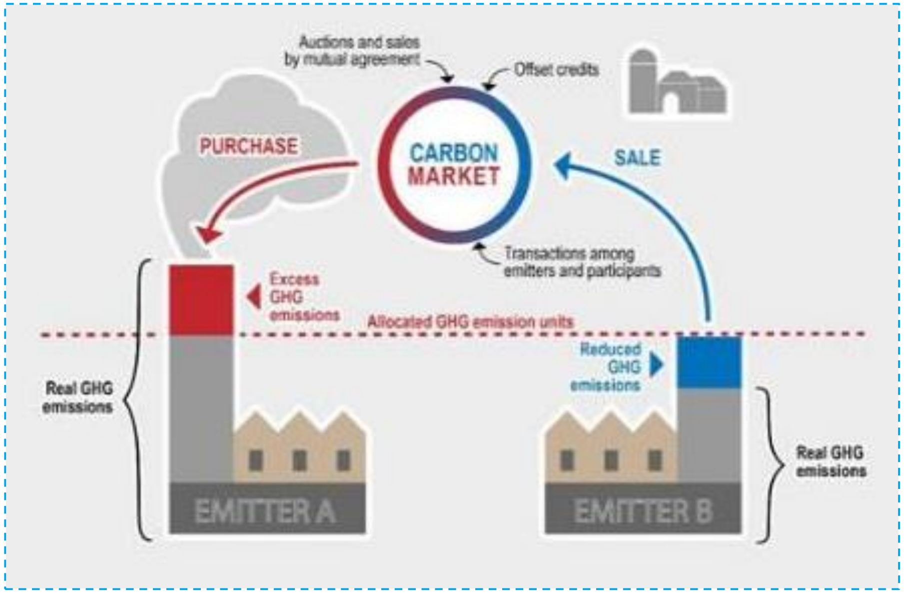
› “*DEFOCILIZATION* RATHER THAN *DECARBONATION* “



Reminder: How does the ETS work?

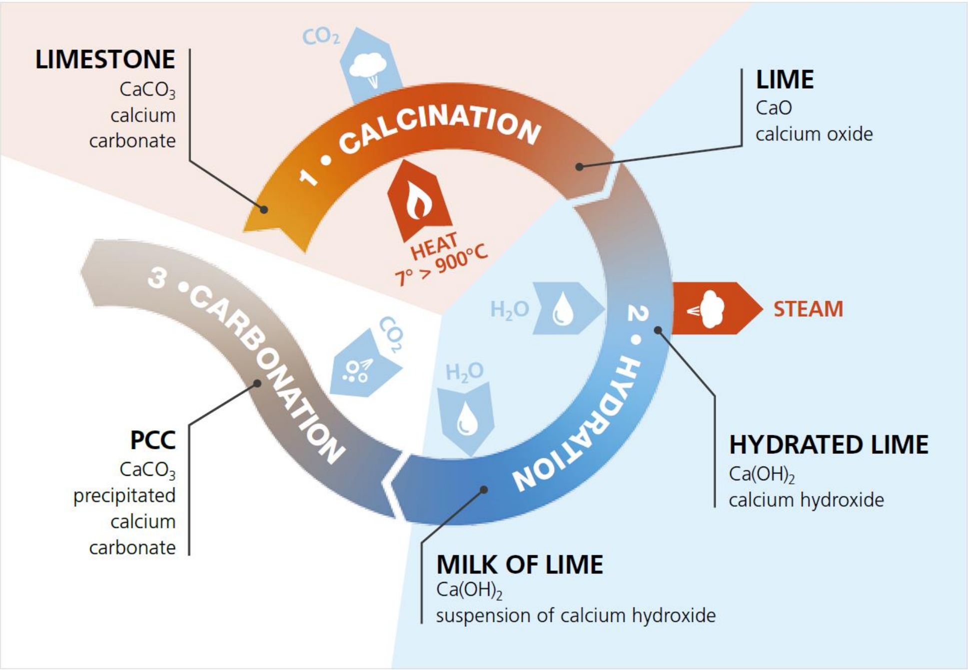
- Since 2005 there is a cap and trade program in the EU regarding Greenhouse Gas emissions (for Lime: CO_2)
- A **cap and trade program** is a system of pollution credits: an emission of 1 tCO_2 has to be covered by 1 credit

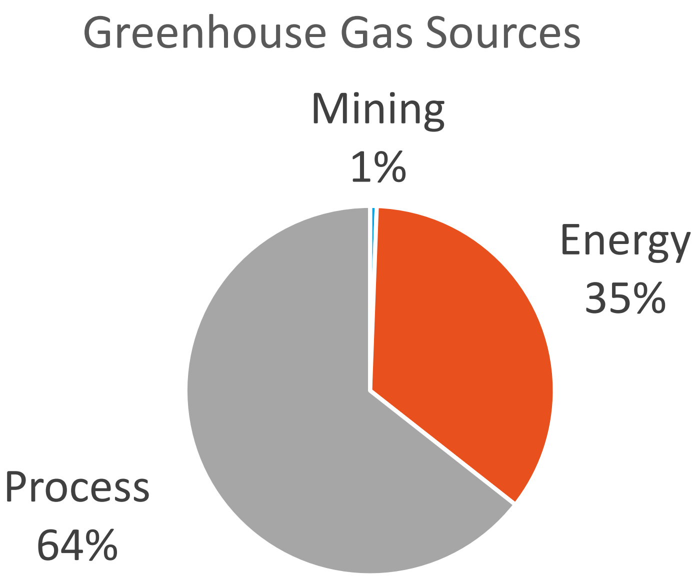
- Credits are freely exchangeable in an open market
- Plants receive **a certain level of free allowances** to avoid competition distortion with non-EU countries (which are not facing similar burden)
  If overall equivalent carbon burden imposed ➔ no more free allowances !
- Several European governments are contemplating a CO_2 tax on top of the ETS scheme.



What is the CO_2 challenge for Lhoist?

CO_2 INTRINSICALLY LINKED TO LIME PRODUCTION AND USAGE





Lhoist produces world wide approx. 18 MT CO_2

to produce ~15 MT of lime & dolime
using ~80 M GJ of energy

CO_2 SOURCES IN LIME PRODUCTION

1 GJ Gas :
56 kg CO_2

1 T lime PFRK :
3,6 GJ

1 T *pure* lime : 785 kg CO_2

1 GJ Lignite :
100 kg CO_2

1 T lime Rotary :
7 GJ

1 T *pure* dolime : 873 kg CO_2

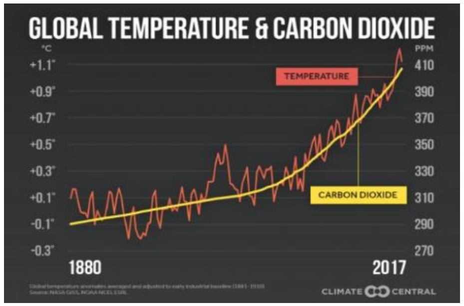
Energy related CO_2 : 200 – 700 kg CO_2

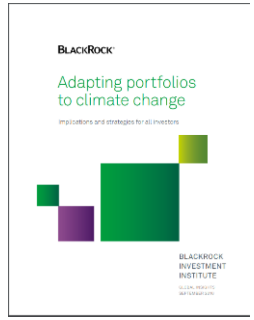
Process CO_2 : 750 – 850 kg CO_2

CO2 LHOIST PRODUCTION IN EUROPE .

CO2 COSTS TODAY

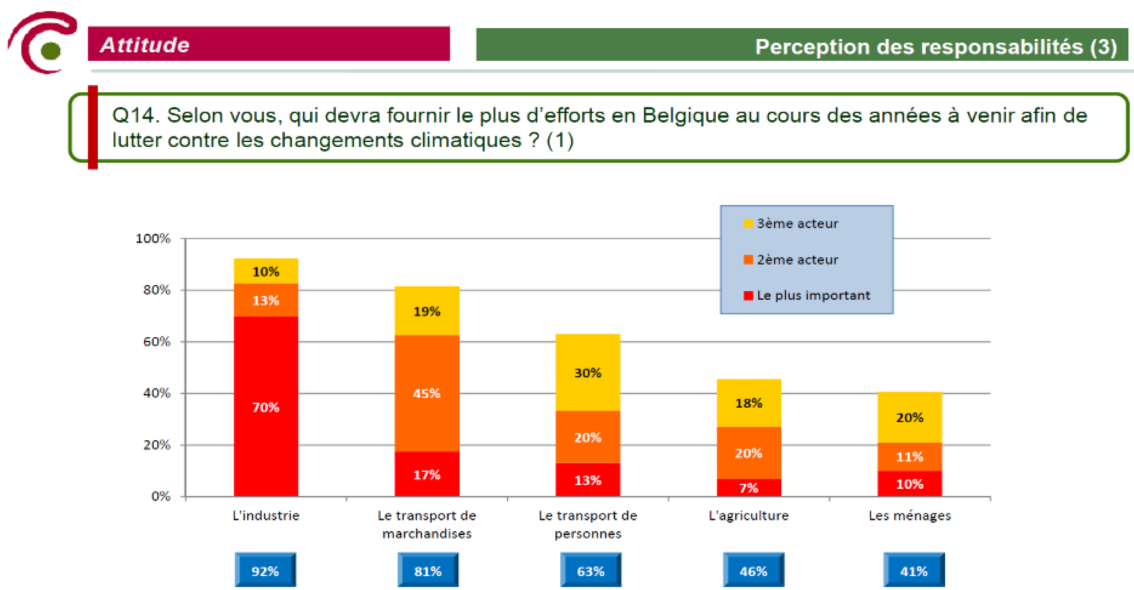
WHY IS CO_2 ON THE AGENDA ? EMOTIONS, SCIENCE, FINANCE





Norway's $1tn wealth fund to divest from oil and gas exploration

World's largest sovereign wealth fund was created to invest North Sea oil profits



SPF Environnement – Enquête Climat

CARBON CHALLENGE FOR LHOIST

GEC + CTO/CIO

Sponsor — C. de Vicq

Project Leader — F. Verhelst

CO_2 and energy
Z. Habib

Reduce energy/ fuel linked CO2 output

- **Efficiency**
- **Energy strategy**
- **Processes**

- *Feed future kiln and production choices*

CO_2 Valorisation
T. Chopin

CCU& CCS - solutions

- **Carbon Capture & Storage**
- **Carbon Capture and Utilization :**

Pilots and next steps

Commercial
M. Liell

Market position and value pricing

- **Cost & behavioral impact**
- **Substitution potential**
- **Pricing impact**
- **Impact on logistics** (outbound)

- *Anticipate and act on market dynamics*

Lobbying & Comm.
J. Marhehant

Stakeholders and public support

- **Communication** :
- **Industry sustainability**

- *Improve industry image and assure sustainability*

Financial
T. Tagnit

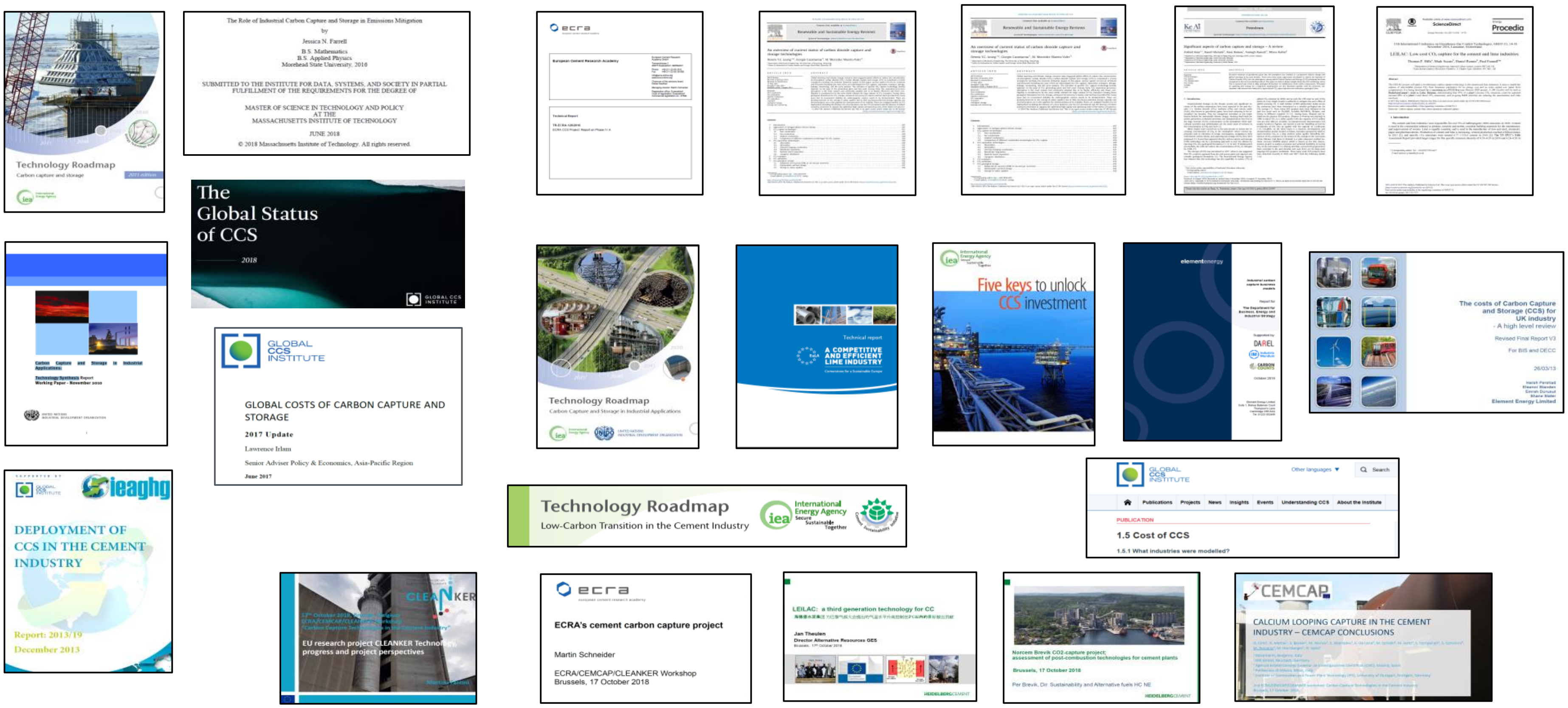
Performance & impact

- **OPEX :**
- **CAPEX** :
- **P&L impact :**

- *CO_2 TCO, fin. impact and management Guidance*

Carbon Capture
Usage & Storage

INFORMATION IS EXTREMELY ABONDANT



CONCENTRATION & PURIFICATION ARE NECESSARY

Table 4.1. Flue gas flow-rate and composition for the three evaluated cases

		Plant A1	Plant A2	Plant B
Flue gas flow rate	Nm^3/h wet	62500	62500	710000
Temperature	°C	120	120	200
Pressure	bar	1.013	1.013	1.013
H_2O	%	5.5	5.5	8.0
CO_2	% dry	18	22	18
O_2	% dry	11	11	11
SO_2	ppm dry	17.5	17.5	17.5
NO_x	ppm dry	170	170	243
NO_2	ppm dry	8.5	8.5	12.2
HCl	ppm dry	6.1	6.1	6.1
HF	ppm dry	1.2	1.2	1.2
Dust	mg/Nm^3	< 10	< 10	< 10
Heavy metals	mg/Nm^3	< 0.5	< 0.5	< 0.5
N_2	% dry	70.98	66.98	70.97

CO2 concentration ranging from 18 to 22%

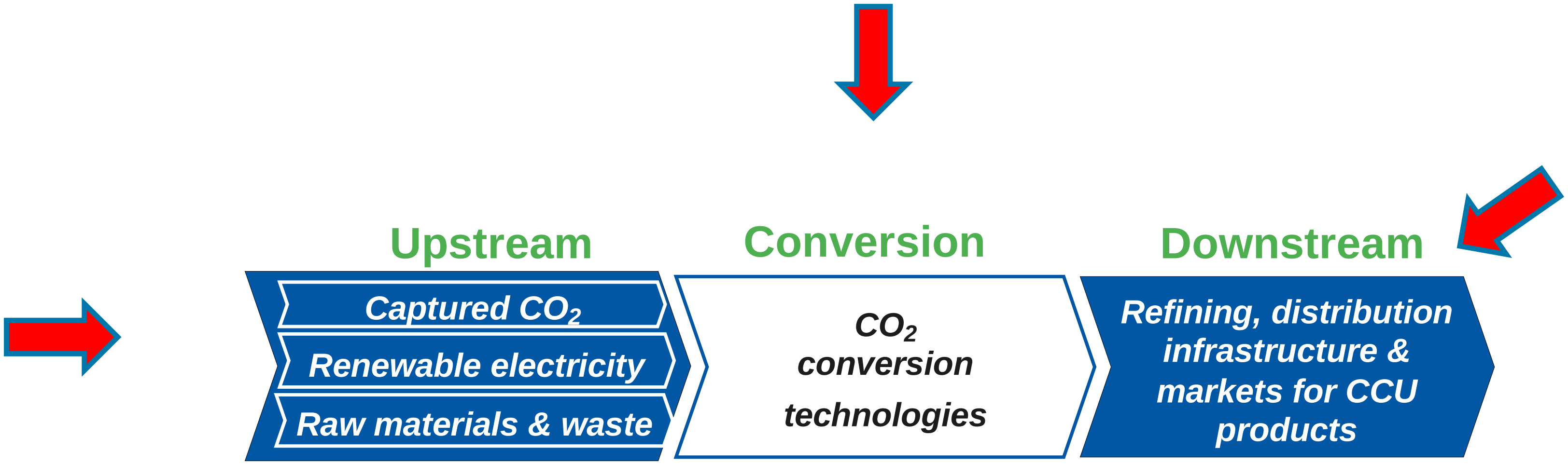
O2 concentration of about 11%

Acid gases and other pollutant residual concentration could be to high for some down stream processes

CONCENTRATION AND PURIFICATION ARE COMPLUSORY FOR DOWN STREAM APPLICATION

LOOKING FORWARD TO OUR FIRST NEUTRAL PLANT…

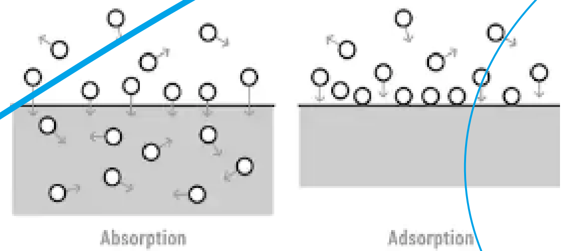
- We are looking for ideas and partnerships in all chains of the cycle :
  - Upstream
  - Conversion
  - Downstream : CO_2 as a feedstock for new materials

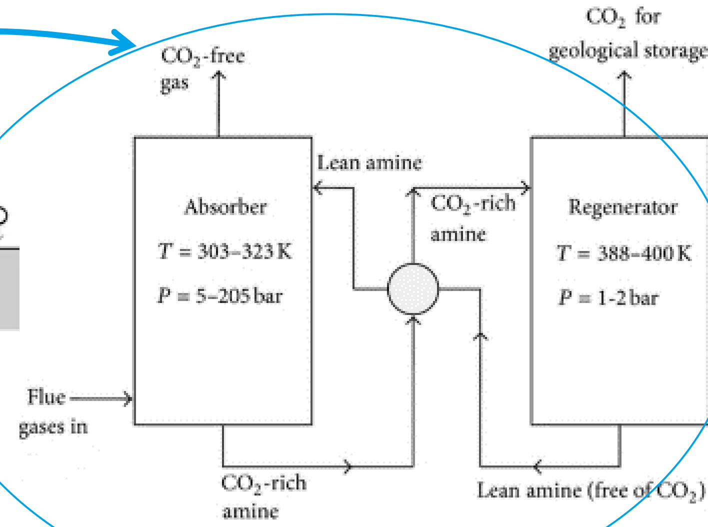


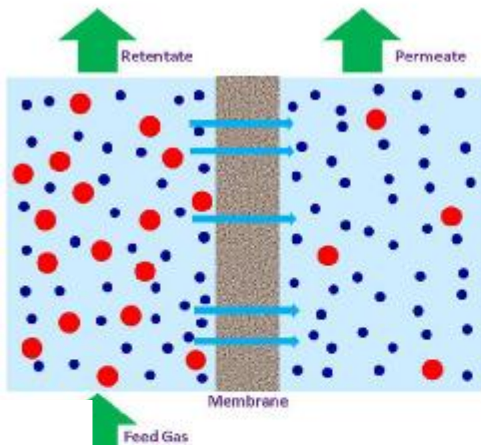
CO2 CAPTURE TECHNOLOGIES ARE LEGION

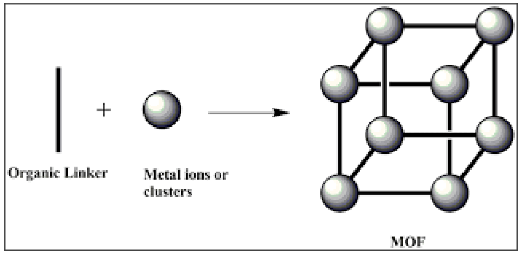
› To be aligned with our objective Lhoist focus on Amine

Technology	TRL*
Absorption	9
Adsorption	7
Membrane separation	6
Cryogenics	6
Metal-organic frameworks	4









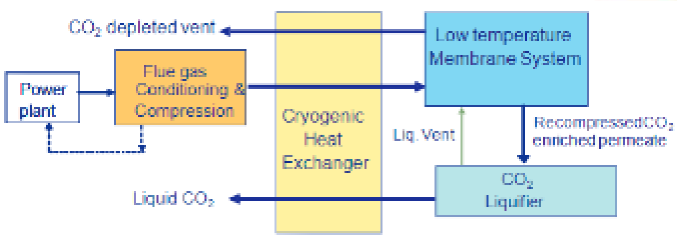


Figure 1. Sub-Ambient Membrane System for CO_2 separation

*: Technology Readiness Level

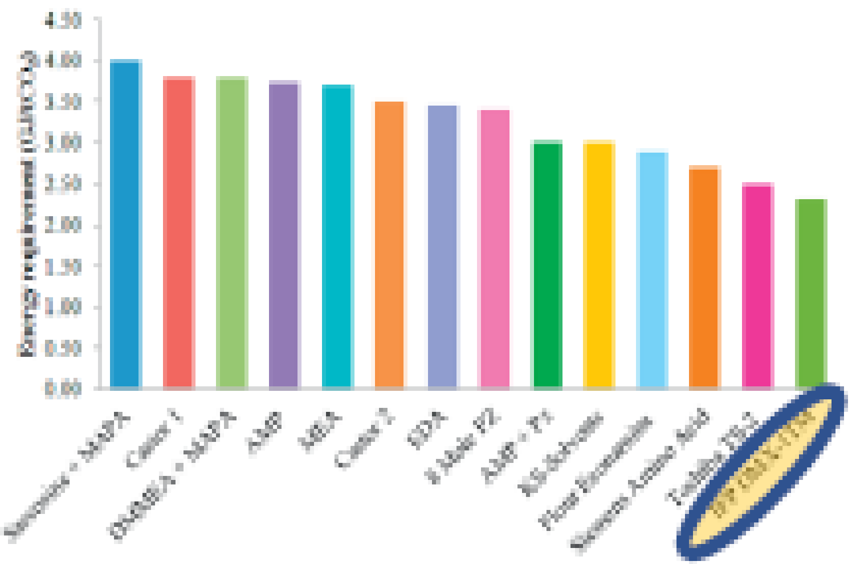
LEARNING CURVE POSITIVELY DRIVES COST DOWN

- Energy consumption of most advanced Amine processes has been reduced from previously about 4 GJ/t CO_2 (level comparable to lime production) to 2,3 GJ/t CO_2.

- Production of waste and necessary makeup of amine is also reduced

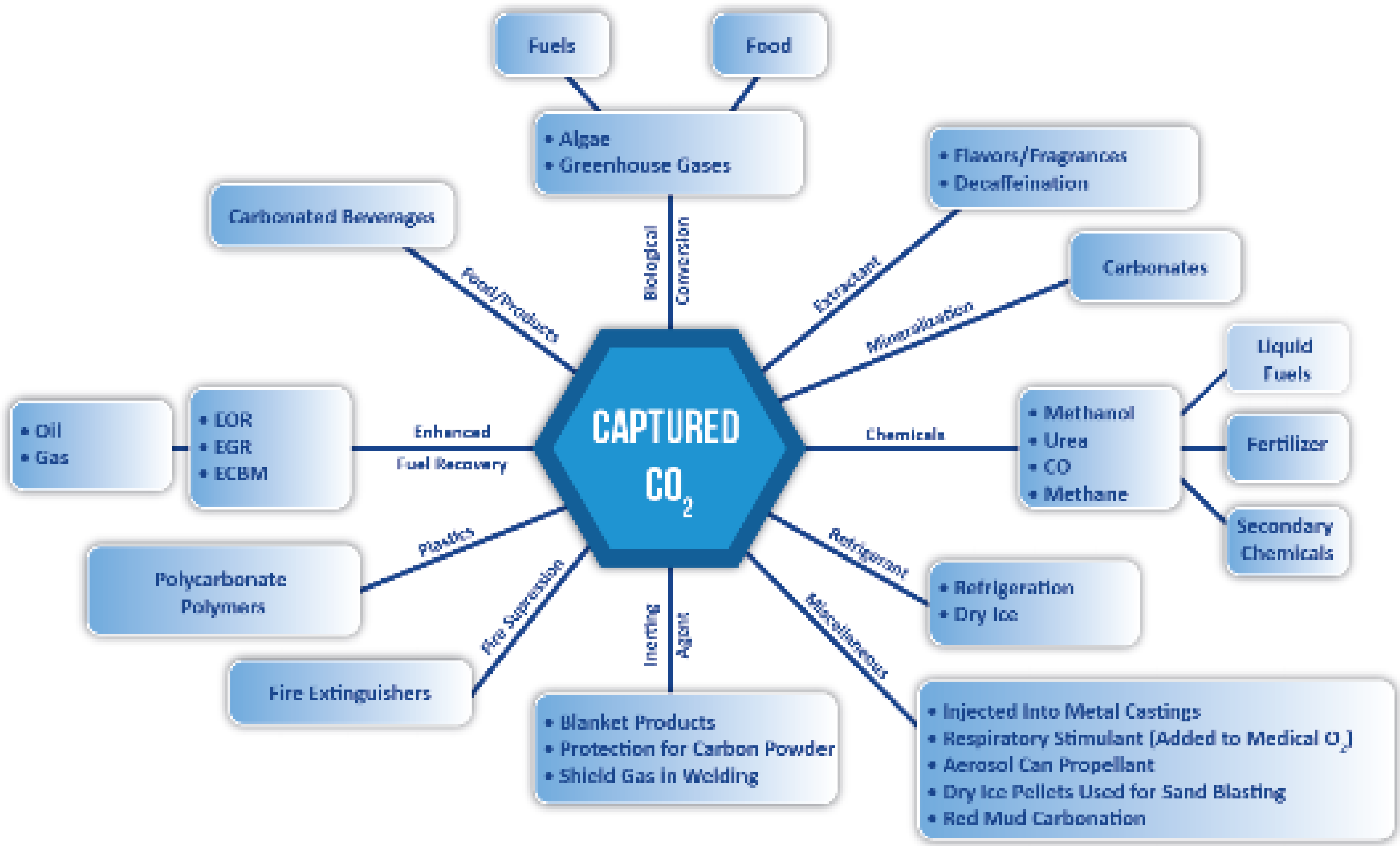
Low Energy for solvent regeneration (< 2.3 GJ/tCO2 @ 90 % capture rate / without any integration)

Singh P. (IEAGHG), Van Swaaij W., Brilman D.,
Energy Efficient Solvents for CO2 Absorption from Flue Ga
and Pilot Plant Study,
Energy Procedia 37 (2013) 2021-2046, Oral présentation ,



Source : IFPEN Kyoto 18-09-2019

CO2 NEW MARKETS FROM CAPTURED CO2



Source : The US Department of Energy's R&D program to reduce greenhouse gas emissions through beneficial uses
Authors : Darin Damiani, John T Litynski, Howard G. McIlvried, Derek M. Vikara, Rameshwar D. Srivastava -2011

NEW CO2 MARKETS : VARIABLE TRL MATURITY AND MARKET VALUE

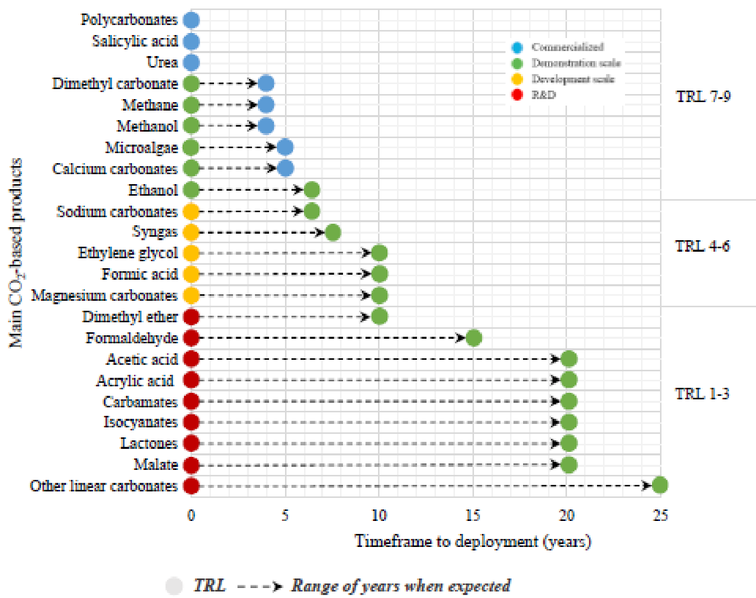


Fig. 3. Technology Readiness Level for main CO_2-based products (non-exhaustive). Based on Ampelli et al. [24], Quadrelli et al. [60].

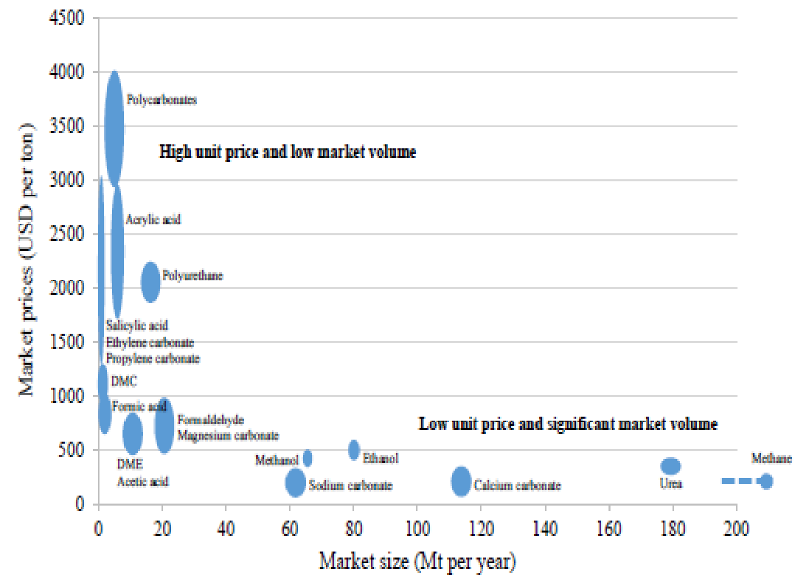


Fig. 1. Market sizes and market prices for the main CO_2-based compounds (non-exhaustive). Based on Forti and Fosse [80].

- **TRL ranging from 1-3 to 7-9 which means from 20 years to demonstration to 5 years time to commercialization**

- **Large volume – low value potential commodity market and**
- **Low volume – high value specialty chemicals markets.**

Source Selecting emerging CO2 utilization products for short- to mid-term deployment ; Remi Chauvy, Nicolas Meunier, Diane Thomas, Guy De Weireld - *University of Mons*

LOT'S OF POSSIBILITIES … SEVERAL IMPEACHMENTS

Support/impact the CO_2 cost

No market at Lhoist level for diluted CO_2 20%

CO2 Emitted

PURIFICATION and CONCENTRATION IS COMPULSERY

- CCU:
  - Merchant Market — No ETS credit
  - New Utilization: — No ETS credit
    - CO2Fuel
    - CO2Chem
- CCS :
  - Underground storage:
    - EOR / EGR
    - Storage

    ETS credit
  - Mineralization: — No ETS credit except on site
    - By-products
    - Natural deposit
    - PCC
  - Alkalinisation: — No ETS credit ?
    - Ocean liming

CCU - MERCHANT MARKET : FROM WASTE TO HIGH PURITY COMMODITY

CARBOGLACE for new era cooling and last mile delivery

CO2 Bulk Liquified

CYLINDERS for food and drink market
Specialty products for extended food preservation

CCU : CO_2FUEL ,CO_2CHEM CHASING GREEN ELECTRICITY

- Challenges and difficulties : ENERGY

  ✓ Large H_2 needs - large need of green electricity
  - Typically 1 Million tons of CO2 to be converted into SNG require about 1 GW installed based load electricity production.

  ✓ ETS potential issues associated to the source of green energy

  ✓ Lime CO2 off-gas is more challenging than other (CO2/O2/H20…)

- Need to consider :

  ✓ Saturation of the Niche markets

  ✓ Competition of synthetic molecules with traditional technologies :
  - Cost,Certification of quality, Label….

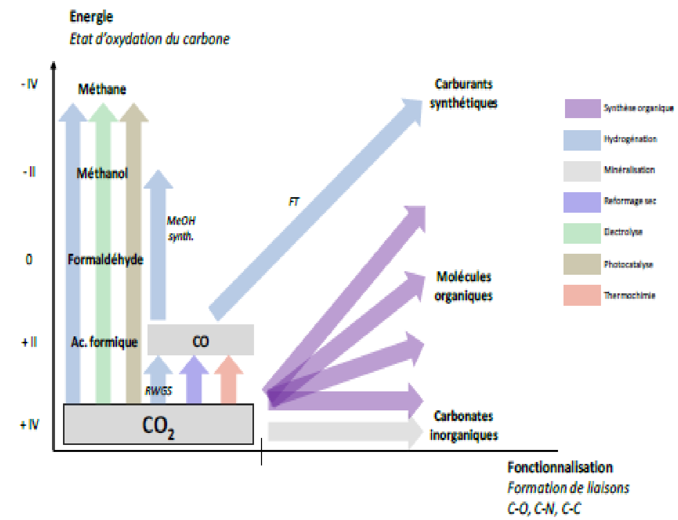
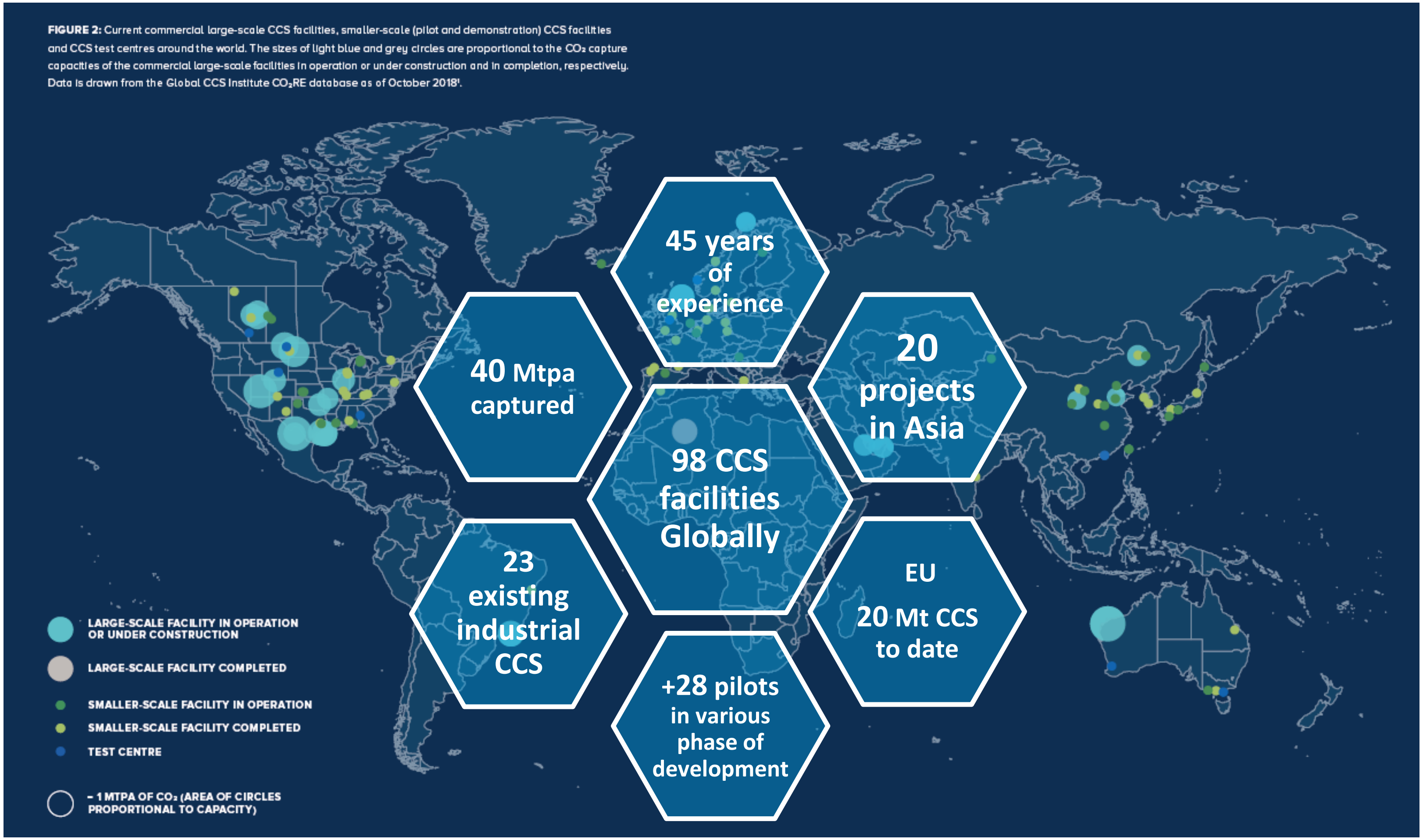


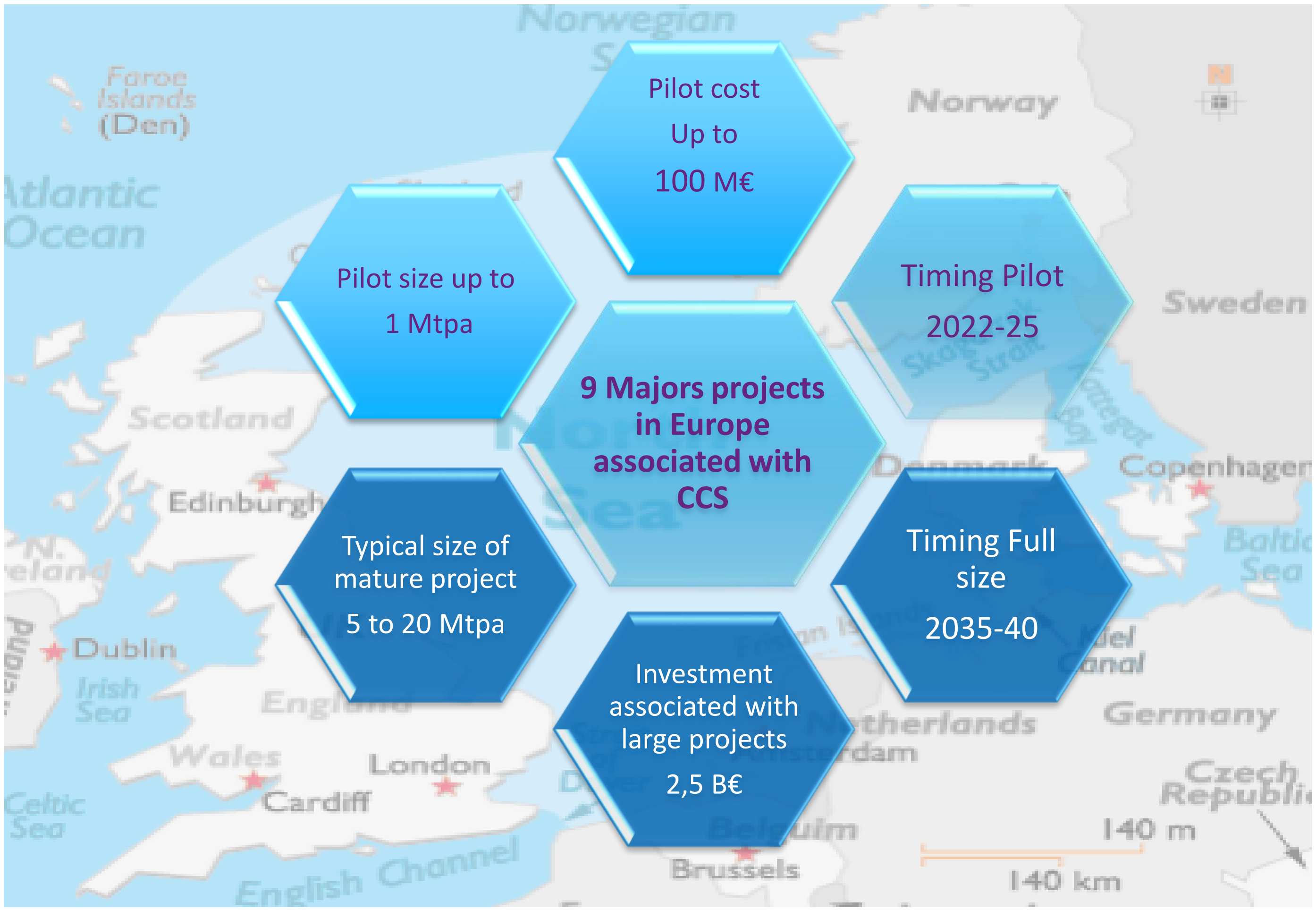
Figure 1 – Principe chimique et énergétique des différentes filières technologiques de valorisation chimique du CO_2

RWGS : Reverse Water Gas Shift ; FT : Fischer-Tropsch ; MeOH synth. : synthèse de méthanol

CCS : A GLOBAL AND EXPERIENCED TECHNIQUE … ADAPTED TO THE LIME INDUSTRY SPECIFICITIES ?



CCS PROJECTS IN EUROPE



CCS - EOR : 45 YEARS OF EXPERIENCE

- CCS with a business case associated with additional oil recovery : acceptable in principle for the future ?

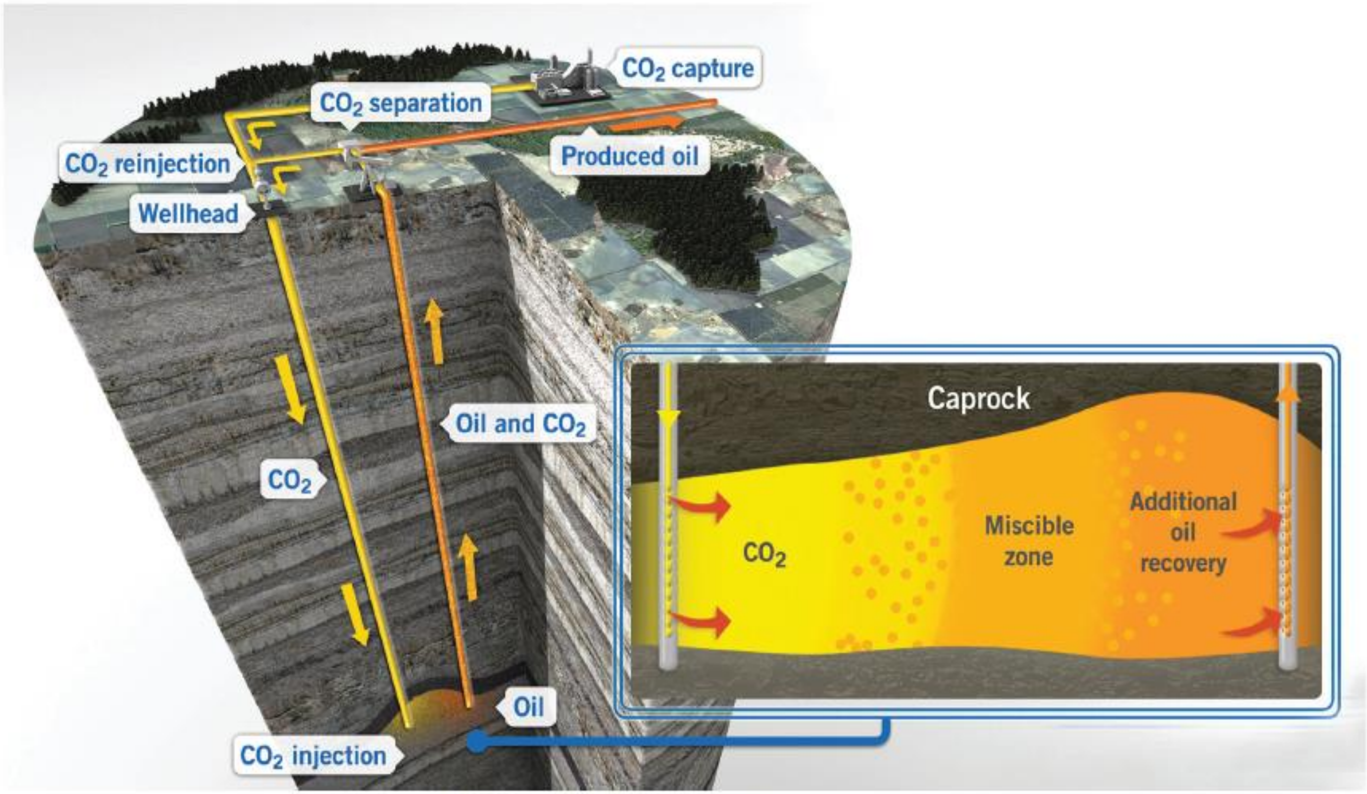


Fig. 19 Schematic diagram of CO_2-EOR process. Source: Global CCS Institute.[964]

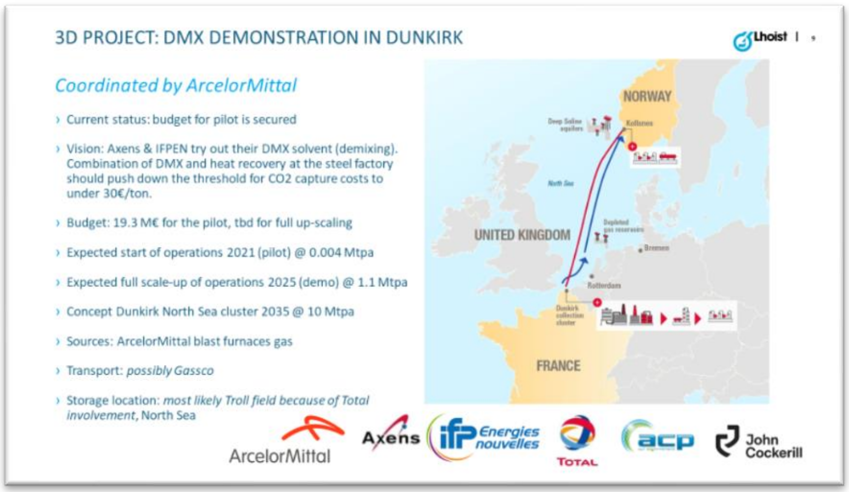
1116 | *Energy Environ. Sci.*, 2018, **11**, 1062–1176

WHERE TO STORE CO2 ?

- Storage location Investigation criteria:
  - Availability
  - Sustainability
  - Capacity
  - Safety
  - Long-term liability of storage site

- Storage option :
  - IN LAND : pushed back in Europe
  - OFF SHORE : socially accepted in coastal areas and in international water
    - Liquid CO2 pool and CO2 dissolution in deep sea is rejected
    - Under seabed saline aquifer and sandstone bed **accepted**

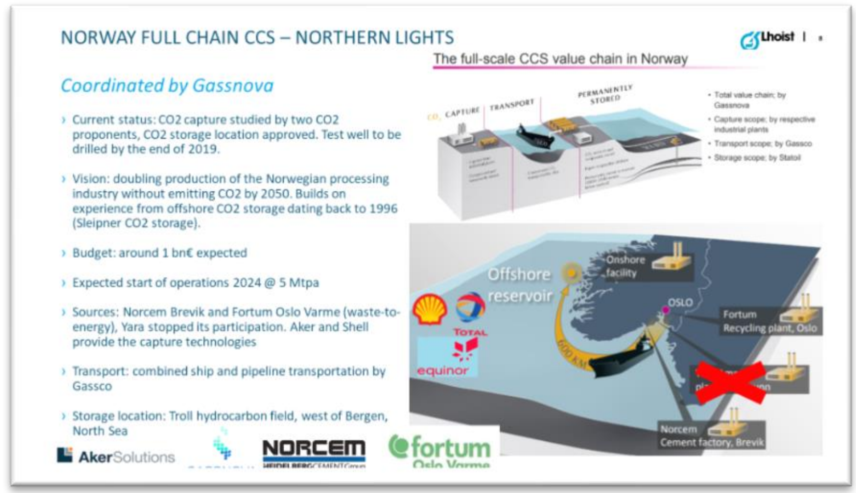
KEY CCS PROJECTS IN EUROPE :



3D PROJECT: DMX DEMONSTRATION IN DUNKIRK

Coordinated by ArcelorMittal

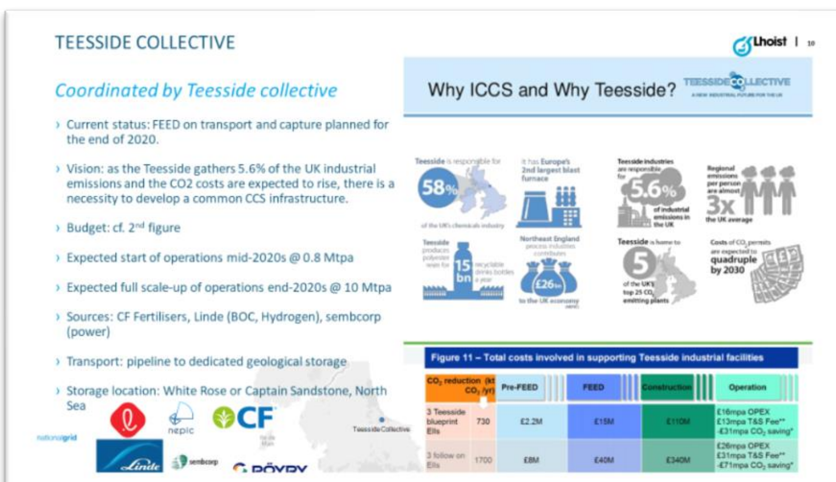
- Current status: budget for pilot is secured
- Vision: Axens & IFPEN try out their DMX solvent (demixing). Combination of DMX and heat recovery at the steel factory should push down the threshold for CO2 capture costs to under 30€/ton.
- Budget: 19.3 M€ for the pilot, tbd for full up-scaling
- Expected start of operations 2021 (pilot) @ 0.004 Mtpa
- Expected full scale-up of operations 2025 (demo) @ 1.1 Mtpa
- Concept Dunkirk North Sea cluster 2035 @ 10 Mtpa
- Sources: ArcelorMittal blast furnaces gas
- Transport: *possibly Gassco*
- Storage location: *most likely Troll field because of Total involvement*, North Sea



NORWAY FULL CHAIN CCS – NORTHERN LIGHTS

Coordinated by Gassnova

- Current status: CO2 capture studied by two CO2 proponents, CO2 storage location approved. Test well to be drilled by the end of 2019.
- Vision: doubling production of the Norwegian processing industry without emitting CO2 by 2050. Builds on experience from offshore CO2 storage dating back to 1996 (Sleipner CO2 storage).
- Budget: around 1 bn€ expected
- Expected start of operations 2024 @ 5 Mtpa
- Sources: Norcem Brevik and Fortum Oslo Varme (waste-to-energy), Yara stopped its participation. Aker and Shell provide the capture technologies
- Transport: combined ship and pipeline transportation by Gassco
- Storage location: Troll hydrocarbon field, west of Bergen, North Sea



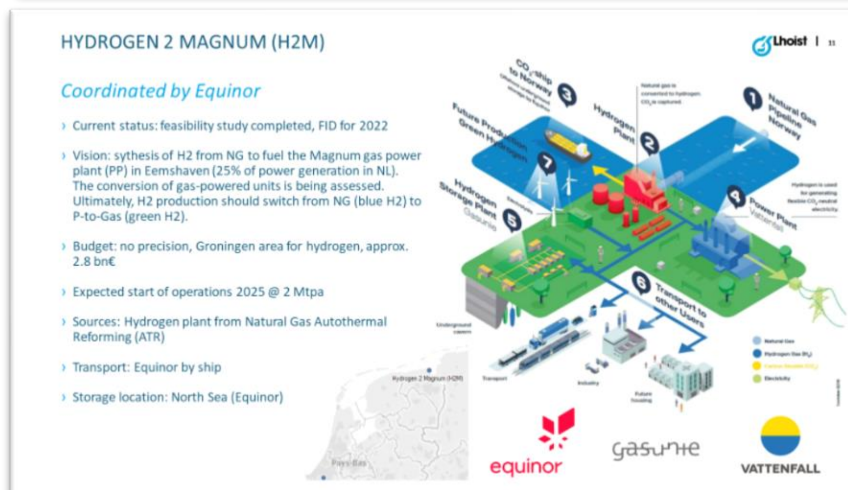
TEESSIDE COLLECTIVE

Coordinated by Teesside collective

- Current status: FEED on transport and capture planned for the end of 2020.
- Vision: as the Teesside gathers 5.6% of the UK industrial emissions and the CO2 costs are expected to rise, there is a necessity to develop a common CCS infrastructure.
- Budget: cf. 2nd figure
- Expected start of operations mid-2020s @ 0.8 Mtpa
- Expected full scale-up of operations end-2020s @ 10 Mtpa
- Sources: CF Fertilisers, Linde (BOC, Hydrogen), sembcorp (power)
- Transport: pipeline to dedicated geological storage
- Storage location: White Rose or Captain Sandstone, North Sea

Figure 11 – Total costs involved in supporting Teesside industrial facilities

CO_2 reduction (kt CO_2 /yr)		Pre-FEED	FEED	Construction	Operation
3 Teesside blueprint EIIs	730	£2.2M	£15M	£110M	£16mpa OPEX £13mpa T&S Fee** -£31mpa CO_2 saving*
3 follow on EIIs	1700	£8M	£40M	£340M	£26mpa OPEX £31mpa T&S Fee** -£71mpa CO_2 saving*



HYDROGEN 2 MAGNUM (H2M)

Coordinated by Equinor

- Current status: feasibility study completed, FID for 2022
- Vision: sythesis of H2 from NG to fuel the Magnum gas power plant (PP) in Eemshaven (25% of power generation in NL). The conversion of gas-powered units is being assessed. Ultimately, H2 production should switch from NG (blue H2) to P-to-Gas (green H2).
- Budget: no precision, Groningen area for hydrogen, approx. 2.8 bn€
- Expected start of operations 2025 @ 2 Mtpa
- Sources: Hydrogen plant from Natural Gas Autothermal Reforming (ATR)
- Transport: Equinor by ship
- Storage location: North Sea (Equinor)

KEY CCS PROJECTS IN EUROPE

PORTHOS: PORT OF ROTTERDAM BACKBONE INITIATIVE

Coordinated by Port of Rotterdam

- Current status: 2018 feasibility study, 2019 look for partners and environmental permits
- Vision: Search for the best opportunities to create a CO_2 capture, transport, and offshore storage infrastructure system, 'backbone' for various industries to connect to.
- Budget: Total Investment Costs expected around 400-500 M€
- Expected start of operations 2021 @ 2 Mtpa
- Expected full scale-up of operations 2030 @ 5-10 Mtpa
- Sources: various industrials
- Transport: pipeline, Gasunie
- Storage location: P18 former gas fields 21km offshore, North Sea

Port of Rotterdam | gasunie | ebn

ERVIA CORK CCS

Coordinated by Ervia

- Current status: feasibility study realized. Continuing.
- Budget status: *undisclosed*
- Expected start of operations in 2028 @ 2.5 Mtpa.
- Sources:
  - Confirmed: Irving Oil Refinery, 2 gas-fired combined-cycle gas turbines in Whitegate (Bord Gais Energy) and Aghada (ESB)
  - Possible other emission-intensive companies located in Cork
- Transport & Storage: Kinsale Energy (owned by Petronas).
- Storage location : Kinsale Gas field to be decommissioned in 2020-21, Celtic Sea.

PETRONAS | Gas Networks Ireland | ervia

NORTHERN GAS NETWORKS - H21 NORTH OF ENGLAND

Coordinated by H21

- Current status: feasibility study for switch from NG to H_2 in the british network conducted in 2016, quantified safety evidence to be delivered in 2020, FEED study in 2023-24
- Vision: heating decarbonization in the North of England by switching from NG to H_2
- Budget status: 10M£ secured (9 from OFGEM, 1 from UK gas networks operators). Expects 250 M£ for FEED.
- Expected start of operations 2026-28 @ 1.5 Mtpa
- Possible full scale operations H21 NoE 2035 @ 20 Mtpa
- Sources: 12.15 GW hydrogen production facility from natural gas (Equinor), other sources
- Transport: Cadent, Equinor
- Storage location: salt caverns, North Sea

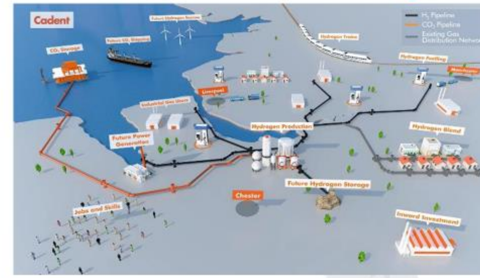
Progression of heat decarbonization from H21 NoE

Cadent Your Gas Network | equinor | Northern Gas Networks

HYNET NORTHWEST

Coordinated by Cadent

- Current status: Phase 1, testing of blends of natural gas and hydrogen
- Vision: switch from NG to H_2
- Budget status: applies for 7M£ grant from UK Governement CCUS Innovation Fund
- Expected start of operations 2023 @ 1.1 Mtpa.
- Sources: Hydrogen production & Carbon Capture plant.
- Transport of H_2 and CO_2: Cadent.
- Storage: in Liverpool bay gas fields, Ireland Sea. Operated by ENI.

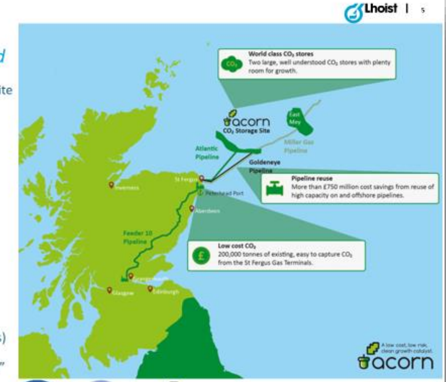


Cadent Your Gas Network | eni | Progressive energy

ACORN SCALABLE

Coordinated by Pale Blue Dot Energy Ltd

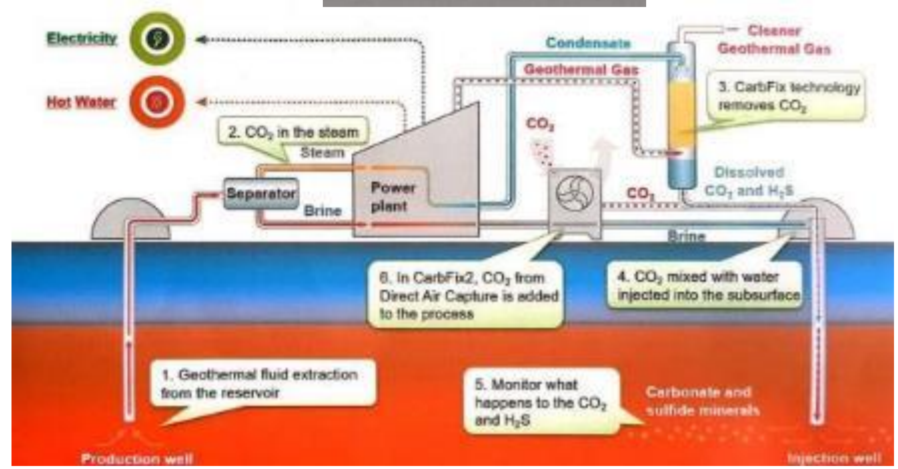
- Current status: Phase II, feasibility study for the storage site development plan completed. Before FEED, additional concept phase activity (ACPA) required.
- Vision: reuse UK's infrastructure to build a project minimizing CO2 capture costs and related risks
- Budget: 1.6 M£ for ACPA, 15.3 M£ for FEED
- Expected start of operations 2022 @ 0.2 Mtpa (from St. Fergus refinery alone)
- Expected full scale-up of operations
  - Conservative: 2022-2060 @ 8.6 Mtpa
  - Optimistic : 2022-2060 @ 16 Mtpa
- Sources: St. Fergus Refinery, emission-intensive Grangemouth area, Peterhead port CO_2 imports (by ships)
- Transport: pipelines now under "Interim Pipeline Regime" (Shell, BP)
- Storage location: Captain and Mey sandstone rock formations, North Sea



Pale Blue Dot. | SCCS | acorn | BELLONA

CCS - MINERALISATION IN SITU : THE CARBFIX PROJECT

- Current status: operational, planned scale-up
- Vision: straight carbon dioxide injection into basaltic formations, turning it into minerals (magnesite/calcite) within 2 years. Co-injection of H2S for mineralization. Price of capture and storage around 25 $/ton.
- Budget: 16 M€ for scale-up received as funding from H2020
- Expected start of operations 2014 @ 0.012 Mtpa
- Expected scale-up of operations « near-future » @ 0.036 Mtpa
- Sources: geothermal plant
- No transport required
- Storage is done on-site



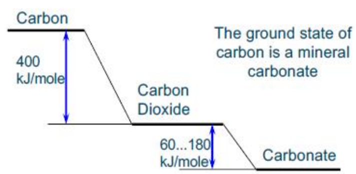
OR Reykjavík Energy

cnrs

CLIMEWORKS
Capturing CO_2 from air

CCS - MINERALISATION AND PRODUCTION IN SITU : THE MCI AUSTRALIA EXPERIENCE

MINERAL CARBONATION



Mineral carbonation is the conversion of silicates to carbonate:

$$Mg_3Si_2O_5(OH)_4 + 3CO_2 \rightarrow 3MgCO_3 + 2SiO_2 + 2H_2O$$

$$\Delta H_{rxn} = -70 \text{ kJ/mol } CO_2$$

….extracting the last useful energy from C !

I PROCESS

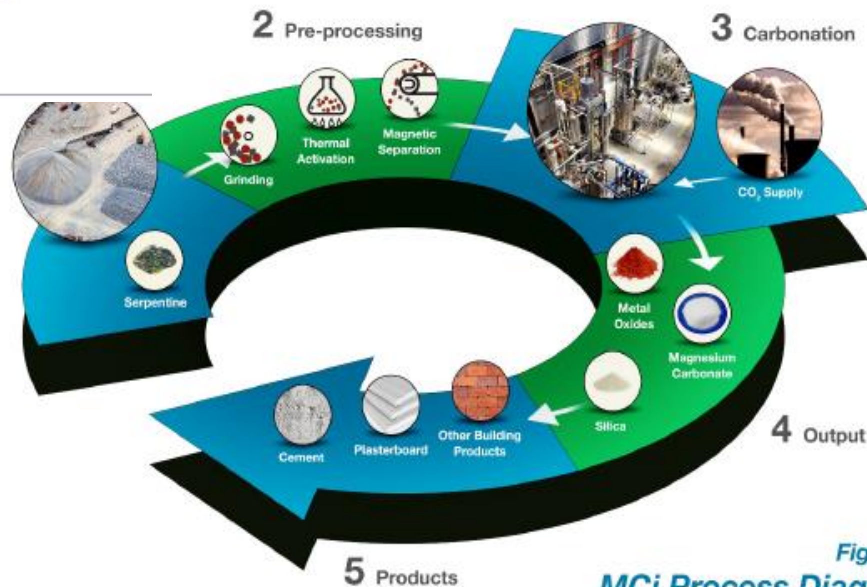


Figure 1
MCi Process Diagram

Reaction of CO_2 with low value minerals converting CO_2 into stable, solid carbonate materials

CCS : MINERALISATION OF BY-PRODUCTS

CARBICRETE

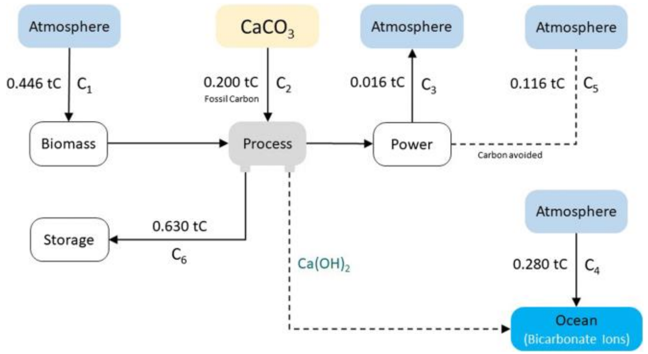
CO_2 Fast Carb
Stockage de CO_2 par carbonatation du béton recyclé

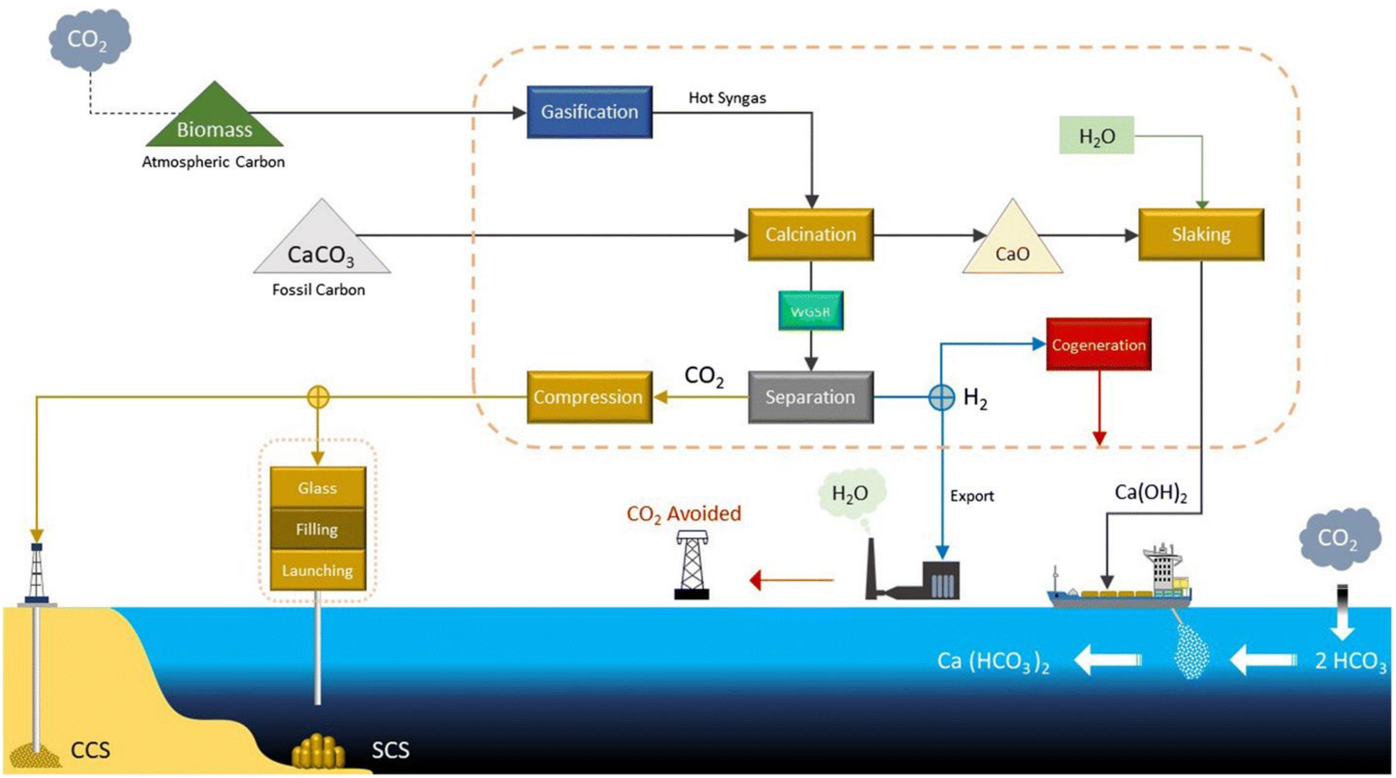
SOLIDIA®

Challenges :

- Source of raw material ? Sustainability ?
- Market reach of the new product ?
- Size of individual plant ? 5 to 25 kTpa CO2 ?

ALKALINISATION OF LARGE WATER BODY





WAY FORWARD

OUR CLIMATE ROADMAP

In order to achieve its Ambition, Lhoist will act on **5 levers of action**:

- **SWITCH / Fuel switching** towards low carbon fossil fuels, waste-derived fuels and biomass,
- **ENHANCE / Enhancing energy efficiency** of production processes and logistics,
- **ENGAGE / Engaging with customers** to enhance efficiency in the use of lime and mineral products as well as to deploy innovative low-carbon solutions,
- **INNOVATE / Leading in Research and Innovation** in production processes and products, as well as in technically and economically feasible CCU and CCS technologies. Lhoist will join forces with other industrial players to develop and scale up the required transformative technologies and solutions,
- **ALIGN / Embedding climate impact in internal management processes,** ensuring alignment and consistency in business decision-making.

›Partnering will be essential to achieve our goals