CIrClE 2019

Challenges for the Islands in the era of the Circular Economy

CO_2 Capture and Mineralization: A novel circular economy enabling technology

George Skevis, *Akrivi Asimakopoulou, Dimitris Koutsonikolas, Grigoris Pantoleontos*

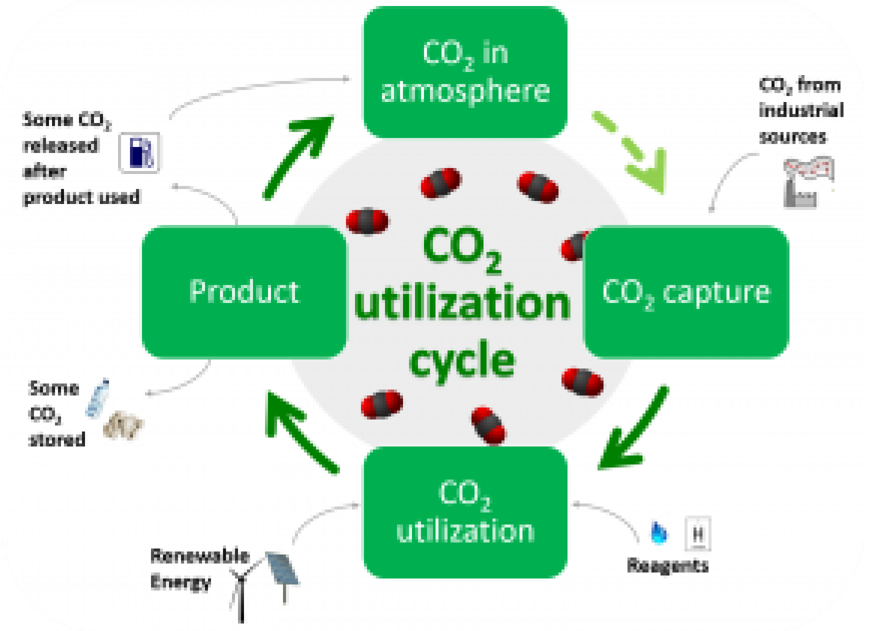
CPERI/CERTH

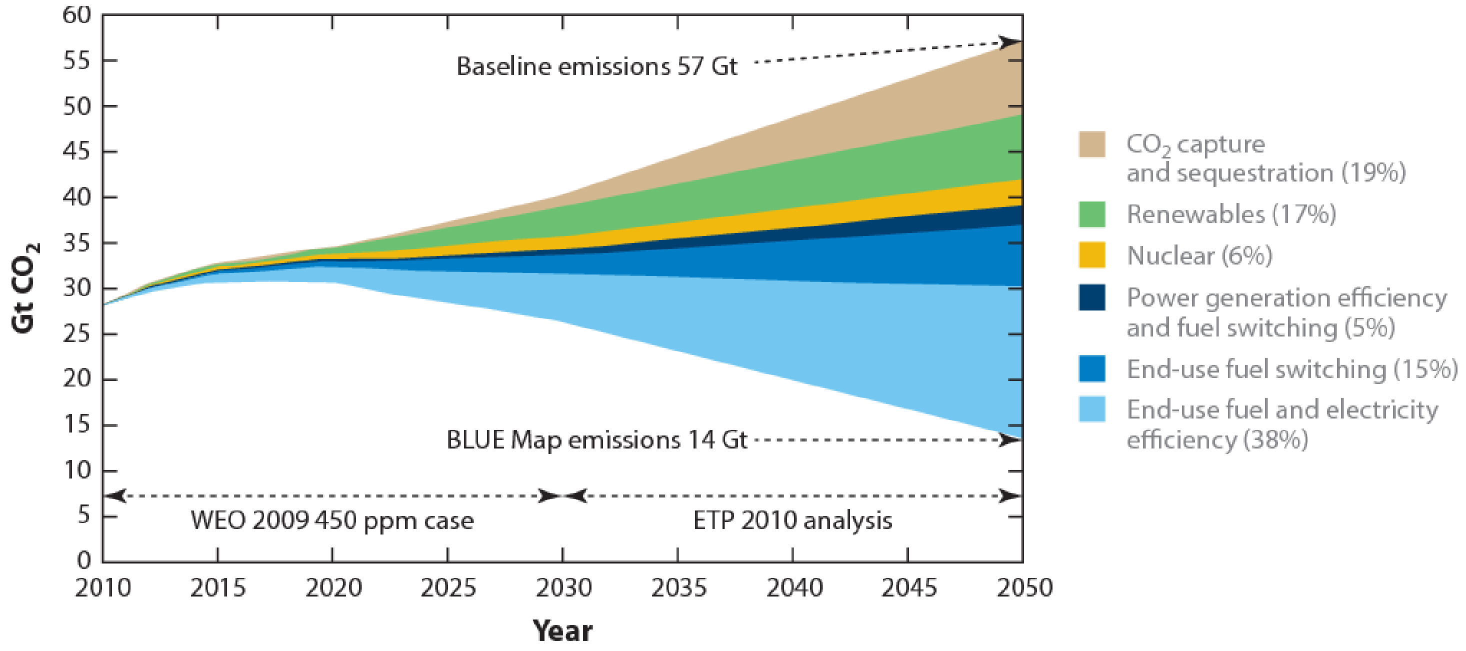
Under the auspices of ENV MOVE

SMile 2019

6th Sustainable Mobility & Intelligent Transport conference

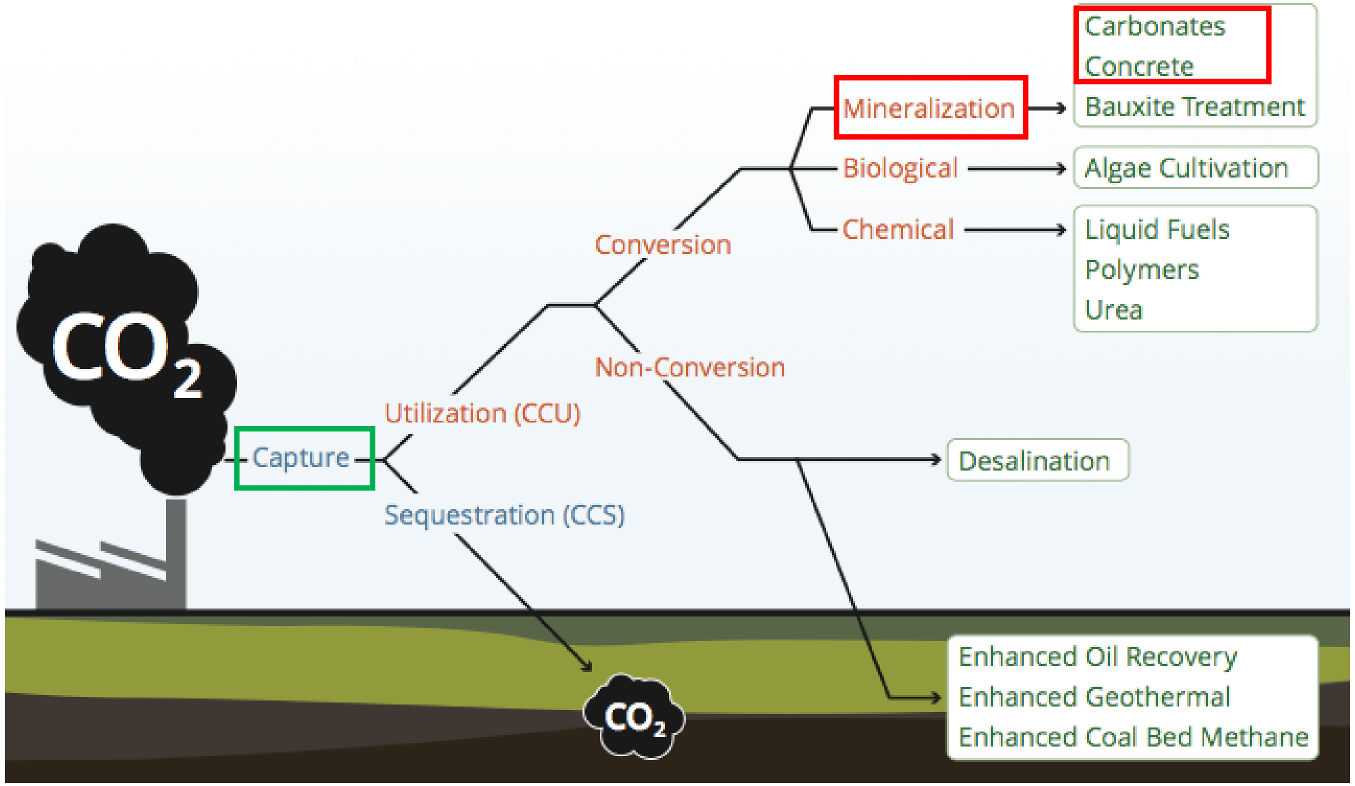
Transition to a CO_2 economy – CO_2 as an asset and not as a waste





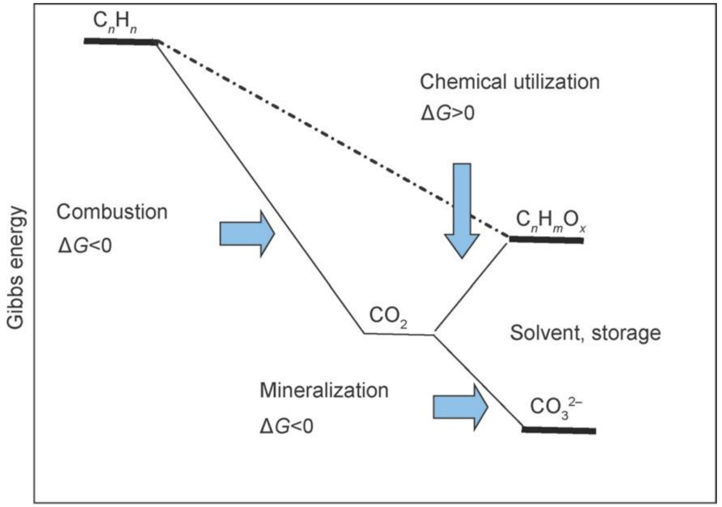
Koutsonikolas et al., International Journal of Energy and Environmental Engineering, (2015) 1-8

Transition to a CO_2 economy – CO_2 as an asset and not as a waste



- Full circle recycling of CO_2 to (carbon-neutral) fuels and (carbon-negative) chemicals **and minerals** using renewable sources

- Technological options to overcome unfavourable thermodynamics



Energy changes in C_nH_n and CO_2 reactions

What is CO_2 Mineralization

- Carbonation technology is based on reacting CO_2 with calcium (Ca) or magnesium (Mg) oxide or silicate to form a solid carbonate mineral structure. These materials can be found either in **natural form** or in **waste streams**
- The mineralization of CO_2 is an alternative to conventional geological storage through the reaction with matrices containing **alkaline-earth** metals to form **carbonates**.
- CO_2 mineralization results in **permanent storage of CO_2 as a solid**, with no need for long term monitoring.
- Carbonation reaction can be accelerated by using high CO_2 concentrations and optimized reaction conditions. **The reaction is exothermic** (releases energy as heat).
- Carbonation processes **do not need any significant input of renewable energy.**

What is CO_2 Mineralization

- Direct ex-situ carbonation involving natural sources (single-step reaction, slow kinetics)

$$\text{Olivine}: Mg_2SiO_4 + 2CO_2 \rightarrow 2MgCO_3 + SiO_2 + 90\ \text{kJ/mol}$$

$$\text{Serpentine}: Mg_3Si_2O_5(OH)_4 + 3CO_2 \rightarrow 3MgCO_3 + 2SiO_2 + 2H_2O + 64\ \text{kJ/mol}$$

$$\text{Wollastonite}: CaSiO_3 + CO_2 \rightarrow CaCO_3 + SiO_2 + 90\ \text{kJ/mol}$$

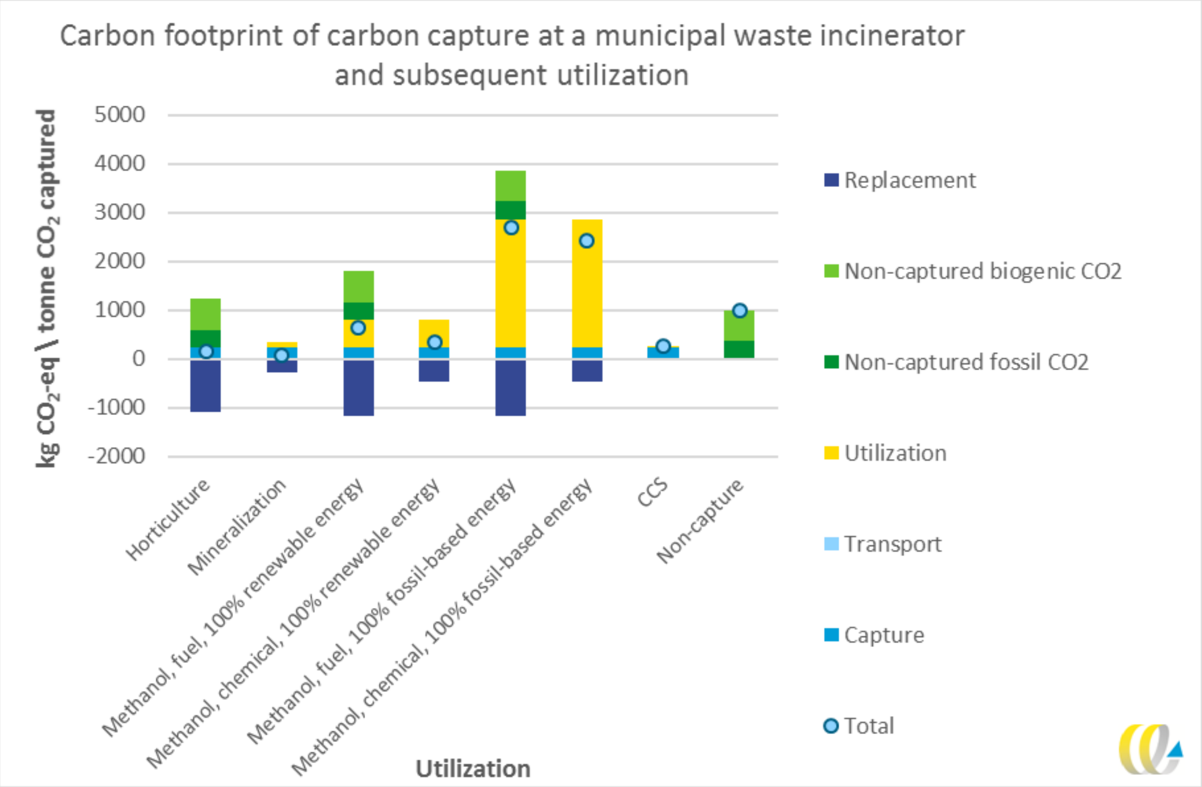
- Direct carbonation is simple but limited (does not require additional chemicals, “small-scale storage”

What is CO_2 Mineralization

- Indirect mineral carbonation route takes place in more than two steps, including (i) extraction of Ca and/or Mg components and (ii) a precipitation reaction step between Ca/Mg and CO_2 in either gaseous or aqueous phases.
- Exploitation of industrial waste streams (e.g. steel slag contains up to 60% CaO with significant amounts of Mg and Si)
- High purity BUT use of additives (effect on efficiency/sustainability)

Slag2PCC: The world's first mineral carbonation pilot plant test facility that converts steel slag and CO_2 into precipitated calcium carbonate (PCC) utilizing ammonia salt solutions.

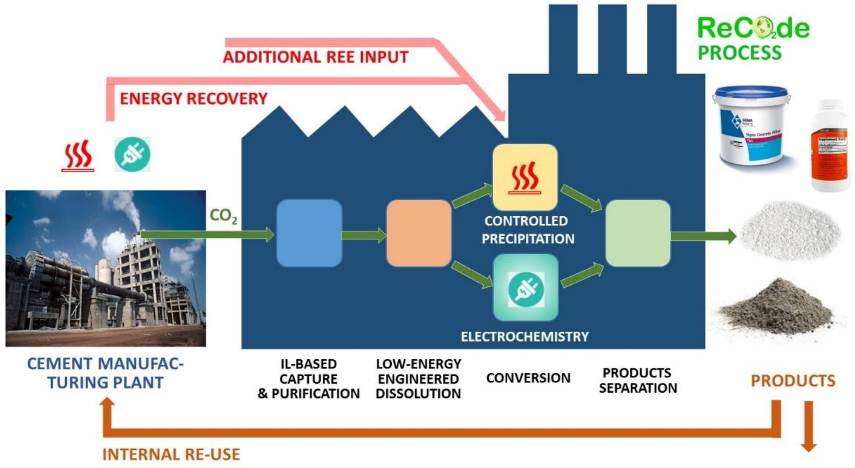
Why CO_2 Mineralization – Life Cycle Analysis

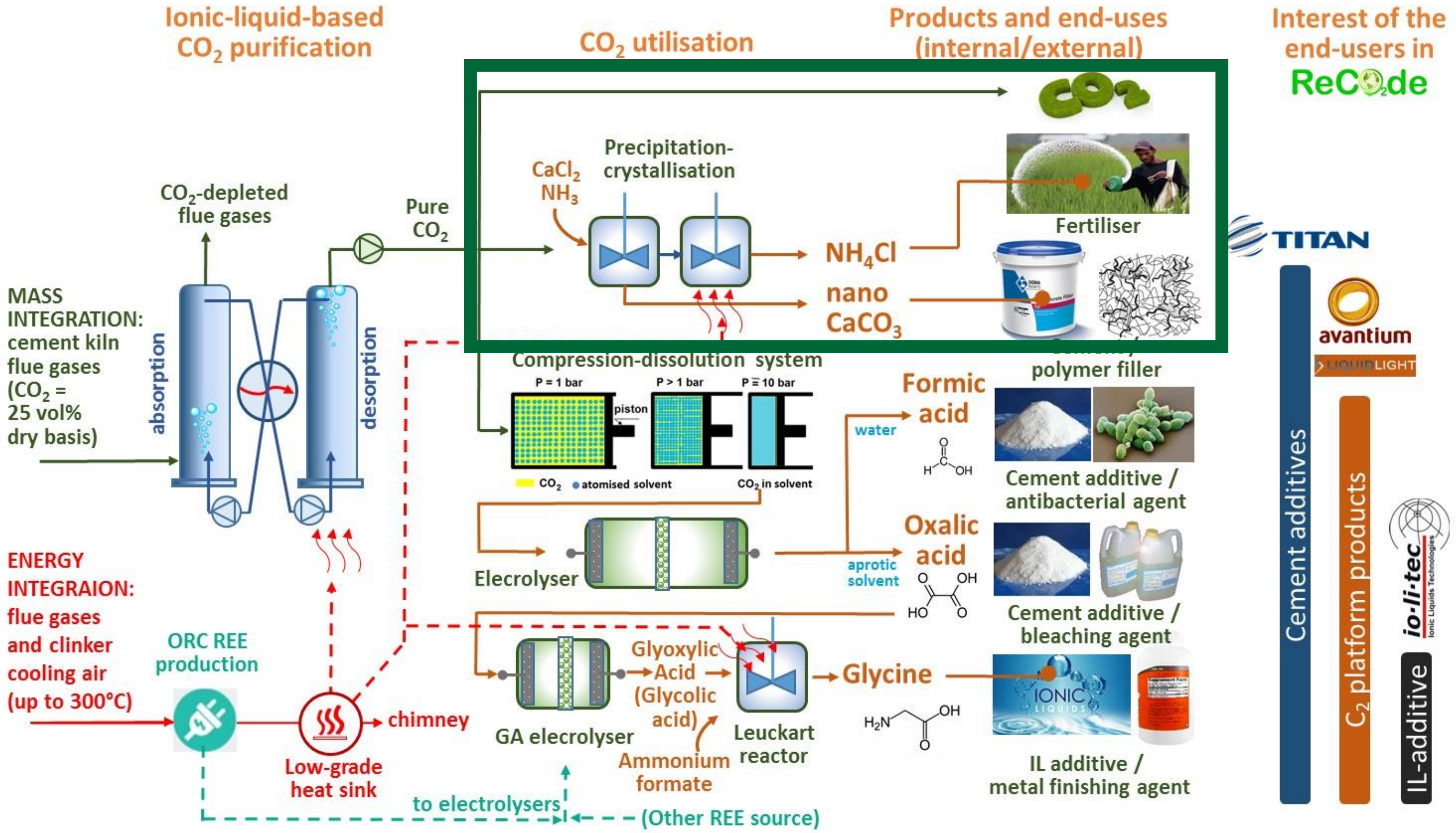


CCU technology	TRL	Current (2017) (kt CO_2)	Near term (5 years) (kt CO_2)	Long term (10 years) (ktCO_2)
Horticulture	9	400-500	850-1,000	1,200
Carbonate mineralization	4-8	0	100-200	100-300
Polymer processing	8	-	12-23	30-45
Concrete curing	7-8	-	-	30
Synthetic methanol (including methane)	8	-	-	220
Methanol yield boosting	9	630	900	1,250
Rounded total		**~400**	**~1,000**	**~1,700**

Ecofys (2017) Assessing the Potential of CO2 Utilisation in the UK
CE Delft (2018) Screening LCA for CCU routes connected to CO2 Smart Grid

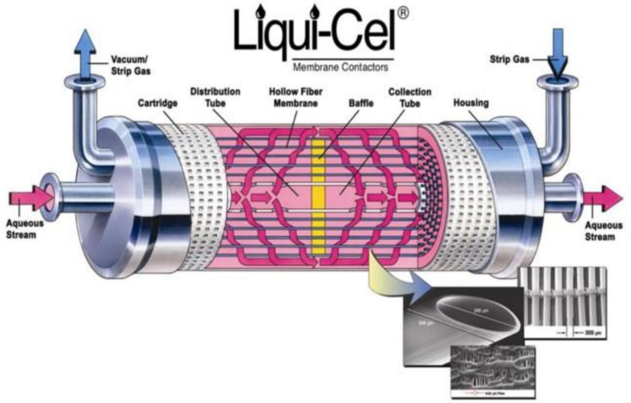
The RECODE Project

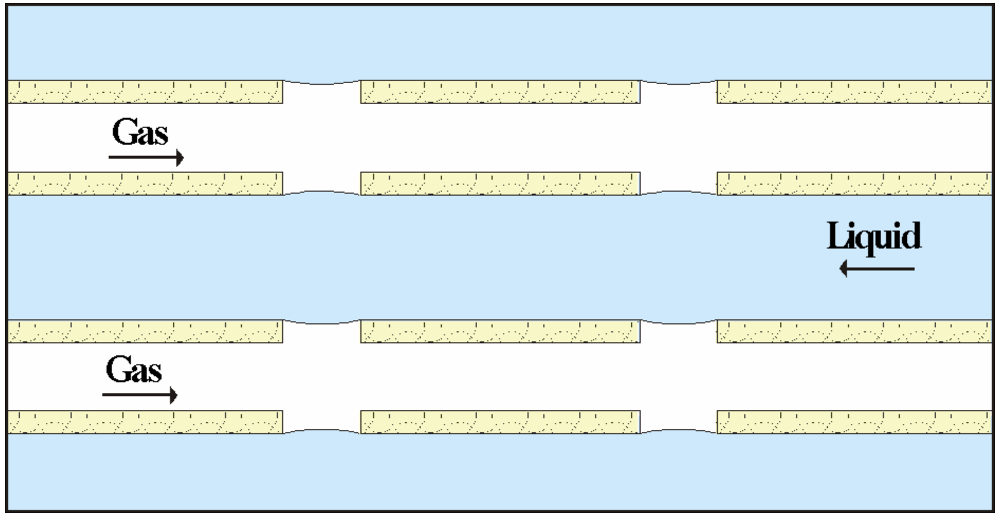




www.recodeh2020.eu

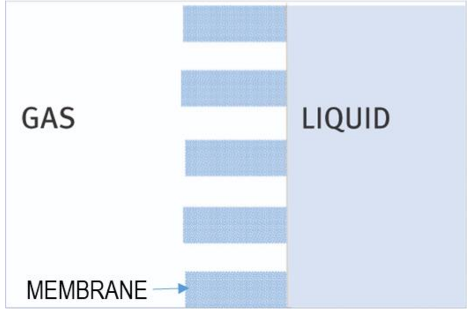
Gas-liquid membrane contactors for post-combustion capture and utilization



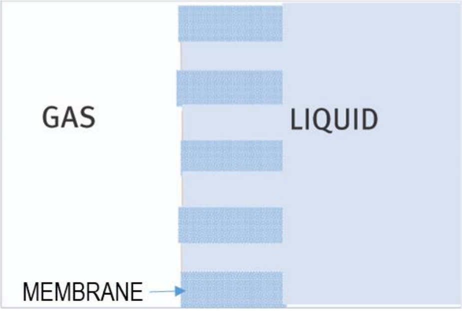


Koutsonikolas, D. et al. (2015), International Journal of Energy and Environmental Engineering, 1-8.

Hydrophobic membranes (Polymeric membranes)

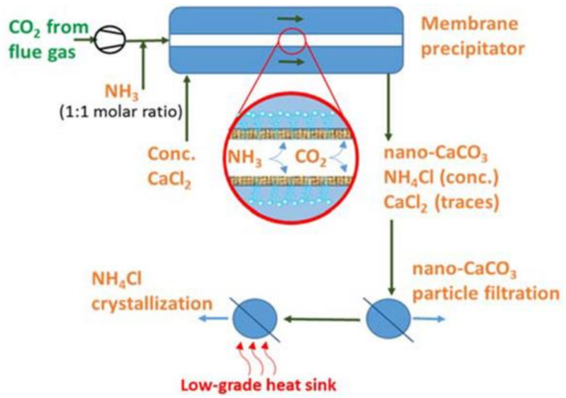


Hydrophilic membranes (Ceramic membranes)

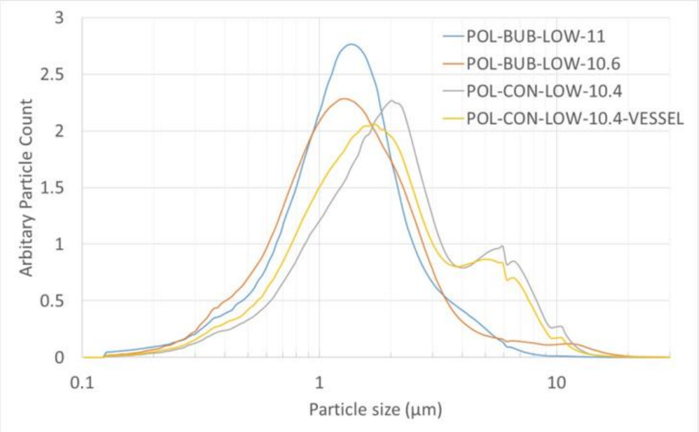


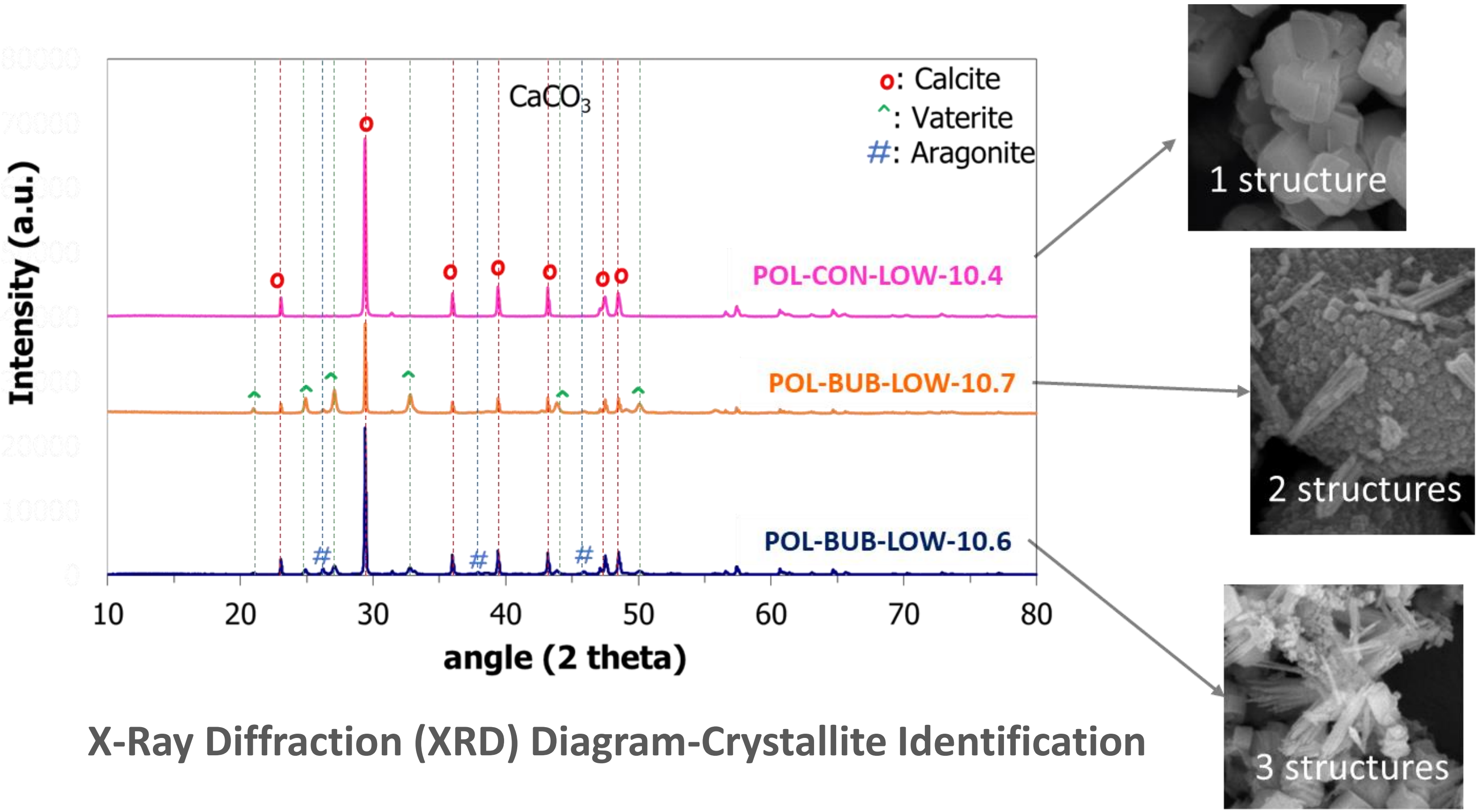
- An immobilized gas-liquid interface is created at the pores mouth where reaction takes place
- No dispersion of one phase in the other
- Very high and well defined surface areas can be obtained
- **This mode of operation can be used for direct CO_2 capture from the flue gases!**
- Easy and modular scale up of the process

Nano-calcium carbonate precipitation



$$CO_2 + 2NH_3 + CaCl_2 + H_2O \leftrightarrow CaCO_3 + 2NH_4Cl$$



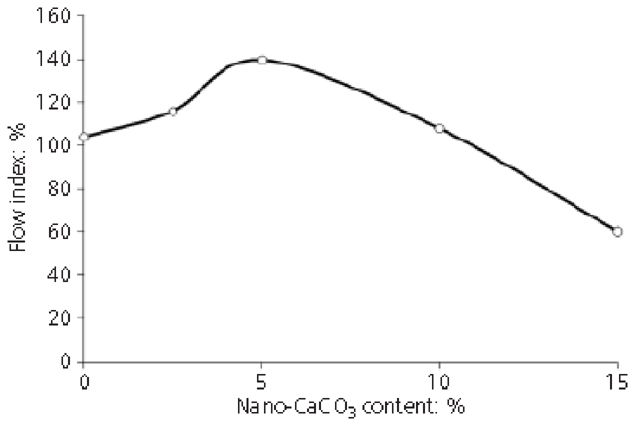


X-Ray Diffraction (XRD) Diagram-Crystallite Identification

Nano-calcium carbonate for the cement industry

• Nano-calcium carbonate partially substitute cement in high-performance concrete.

• Addition of nano-$CaCO_3$ improves flowability and workability of concrete (lubricating effect of nanoparticles)



• Reduction in porosity and enhanced pore structure improves mechanical properties (compressive strength) of concrete

• Optimum mixing proportion of nano-$CaCO_3$ at ca. 3-5% (effect of particle size distribution?)

Camiletti, J. et al., (2013) Magazine of Concrete Research, 65:297-307

Conclusions

- CO_2 mineralization is a promising option for flexible and thermodynamically favourable ex-situ carbon utilization and storage.
- Novel membrane-based technology offers direct capture and mineralization in a compact unit.
- Carbonate production as an enabler of circular economy in energy-intensive industries (e.g. cement).

Thank you for your attention

CERTH
CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

gskevis@cperi.certh.gr