CO_2 Capture and Storage in the Baltic Sea Countries
Status and future cooperation opportunities
23 May, Espoo, Finland

CO_2 fixation by serpentinite

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Overview

- Background and scope
  - *CO_2 mineral sequestration*
  - *The ÅA route for stepwise serpentinite carbonation*
- Progress / results since 2006
  - *$Mg(OH)_2$ production from magnesium silicate-based rock*
  - *$Mg(OH)_2$ carbonation*
  - *Process energy requirements*
  - *Avoid CO_2 capture: direct operation on flue gas*
- Conclusions

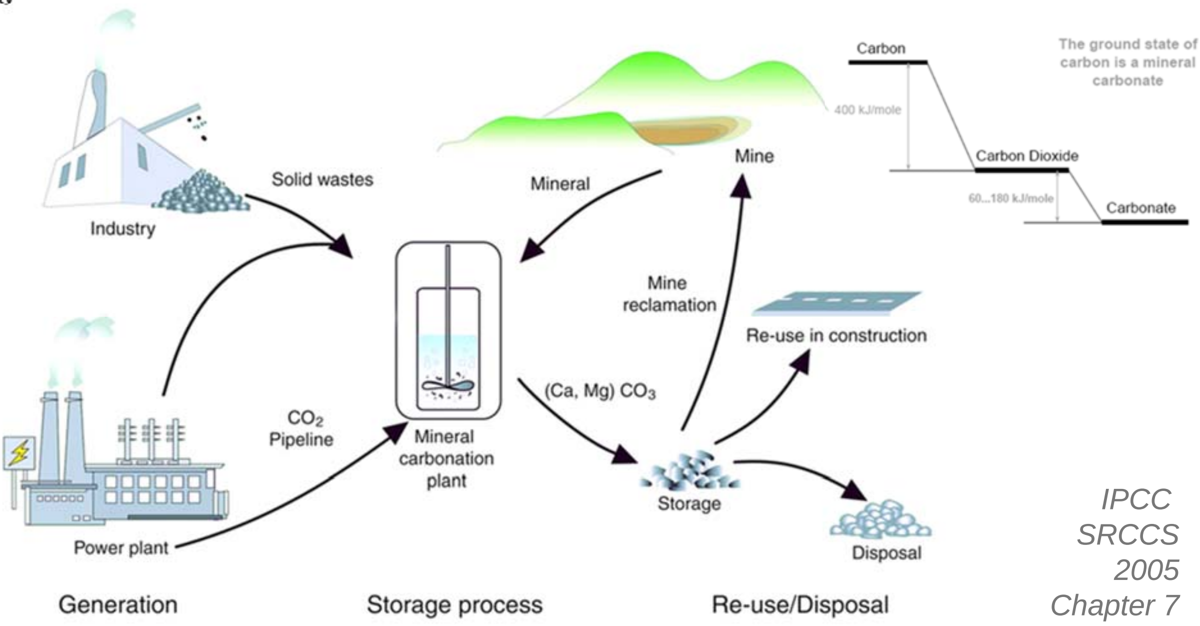
CCUS* in / for Finland

earlier: ”CCS” ↕ ”CCU”

	In Finland	Near Finland / abroad
Geological storage	~~Not possible~~	Baltic sea ?
~~Ocean storage~~	~~Not possible~~	~~Not possible~~
Mineral sequestration	Large potential Projects ongoing	Projects ongoing PT, SG, LT, (CA?, ZA?)
CO_2 utilisation	Several applications (PCC, CO_2 solvent...) Projects ongoing	Projects ongoing US

** Carbon capture, utilisation and storage, or*
Carbon capture, use and sequestration

CO_2 mineralization: what, how



IPCC SRCCS 2005 Chapter 7

Overall carbonation chemistry, with M = Mg or Ca (or Fe, ...)

$$MO.ySiO_2.zH_2O\ (s) + CO_2\ (g) <=> MCO_3\ (s) + ySiO_2\ (s) + zH_2O\ (l) + HEAT$$

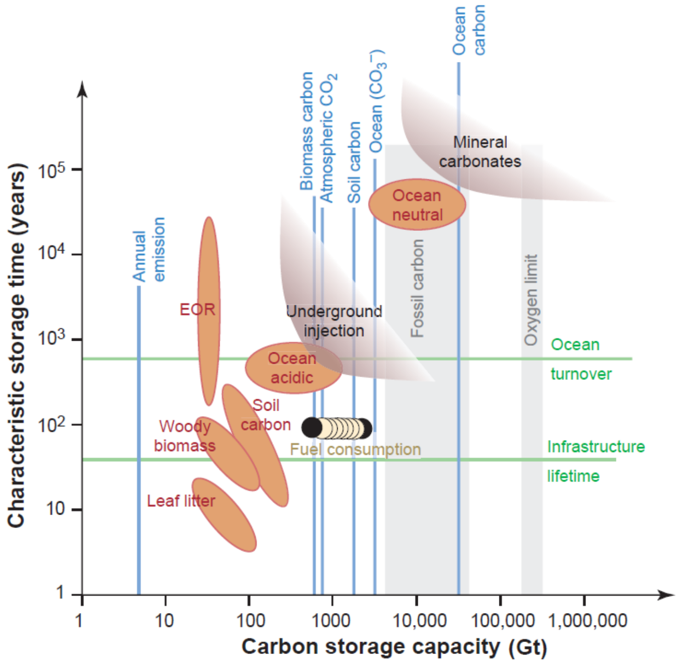
CO_2 mineralization potential

- Much larger potential than other CCUS options, *for example:*

Olivine-containing rock in Oman (350 × 40 x 5 km, ~30% olivine)

- Could bind all fossil carbon
- Available world-wide, hence increasing attention
- No "leakage" problems from carbonates

Lackner, Science vol. 300, 2003, 1677-1678



CO_2 mineralization potential: Oman

Oman: some of the 77 trillion tonnes of ultramafic rocks

Muscat: surrounded by ultramafic rocks

Persian Gulf and the Oman Ophiolite

Olivine-containing rock in Oman (350 × 40 x 5 km, ~30% olivine)

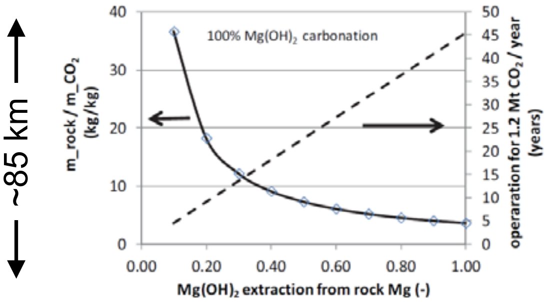
Kelemen & Matter, PNAS 2008)

Pictures: R Hunwick Presented in Sydney, March 12, 2012

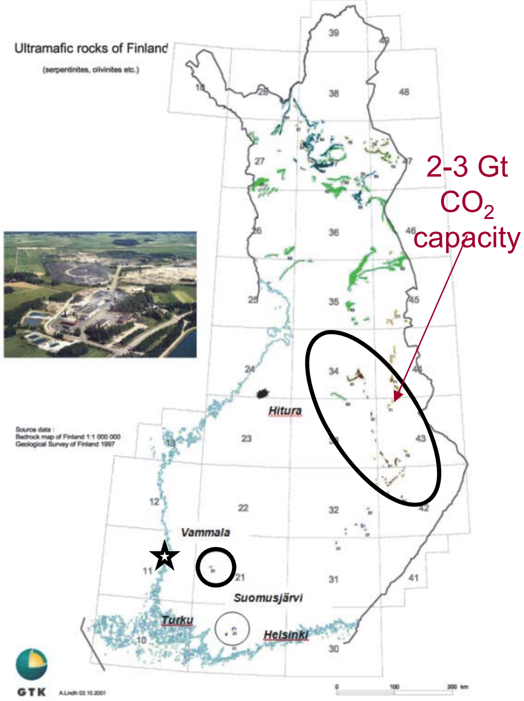
Mineral resources; source-sink links

For example for Finland:

- Vammala Mg-silicate resources (~200 Mt rock)



- Possible application: Meri-Pori power plant (2.5 Mt CO_2/y)



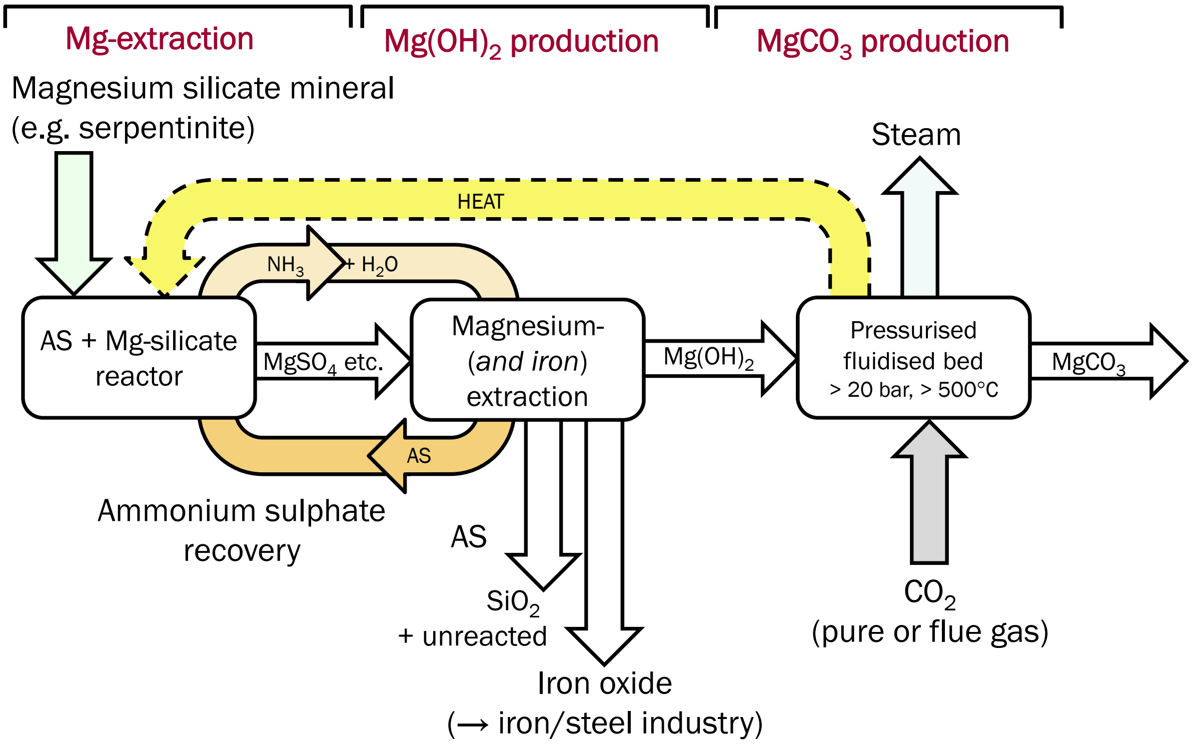
Zevenhoven et al. ECOS2012

Serpentinite materials recently tested, as oxides (%-wt)

	MgO	CaO	Fe_2O_3*	SiO_2	Al_2O_3	Other
Hitura (FI)	36.2	0.5	14.4	24.8	<0.1	24.1
Ni-ore Hitura (FI)	28.5	0.6	15.9	33.9	2.0	19.1 (NiO 1.0)
Vammala (FI)	19.2 – 28.0	1.4 - 90	15.4 – 18.4	39.3 – 46.9	1.3 – 3.5	7.9 – 11.6
Suomusjärvi (FI)	13.5 – 20.9	7.8 – 8.3	10.9 – 11.9	44.3 – 50.2	7.0 – 10.8	6.8 – 7.6
NSW Grt Serp belt (AU)	38.1	0.05	6.9	41.8	1.0	12.1
Bragança 7 fontes (PT)	35.8	0.02	8.2	41.9	1.2	12.8
Bragança Donai (PT)	36.7	0.25	7.29	42.7	1.6	11.5
Varena (LT)	25.5 – 35.4	0.21 – 2.5	14.1 – 33.6	28.8 – 37.2	0.11 – 1.8	9.5 – 15.0

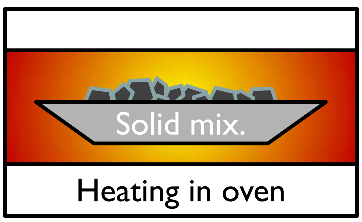
* Calculated, presumably a mixture of FeO and Fe_2O_3, partly (?) Fe_3O_4.

Mg-silicate carbonation: the ÅA route



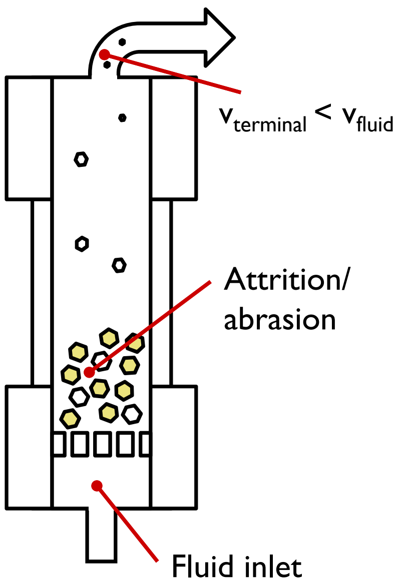
Test methods @ ÅA 2007 →

1. $Mg(OH)_2$ production
   - Mixing serpentinite and AS
   - Heating (<450°C)



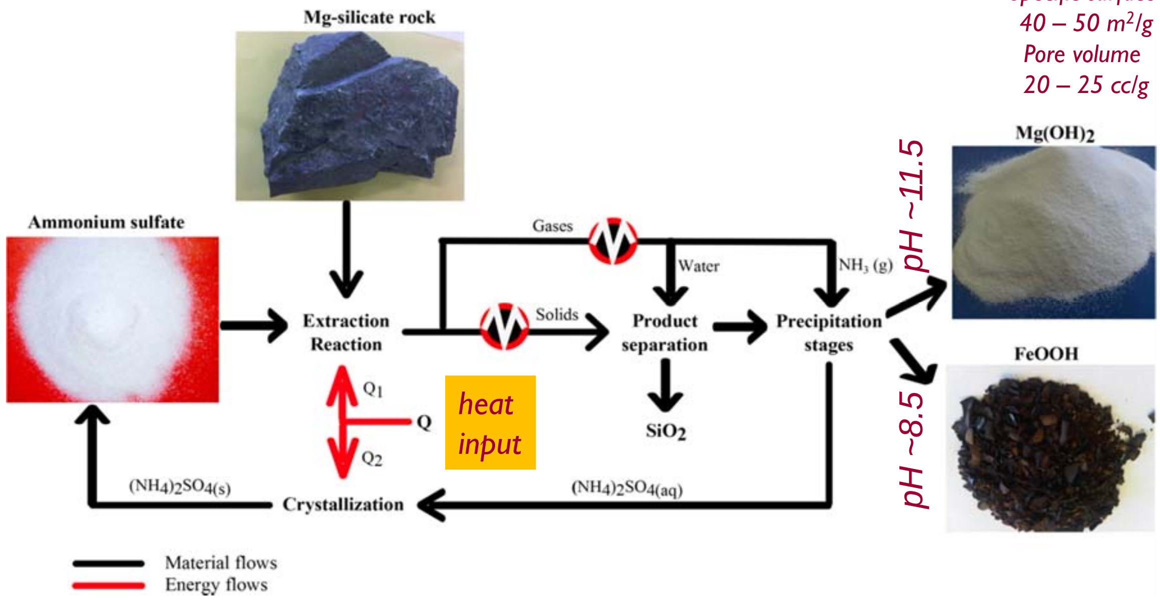
   - Dissolution of $MgSO_4$ and precipitation of $Mg(OH)_2$ from aqueous solution
   - Regeneration of AS salt

2. $MgCO_3$ production



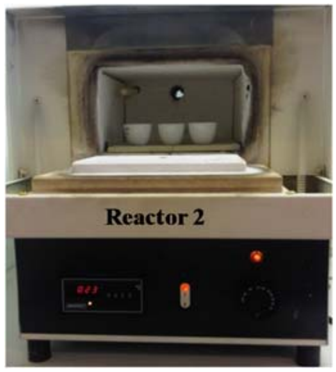
Closed loop process producing $Mg(OH)_2$ from Mg-silicate rock

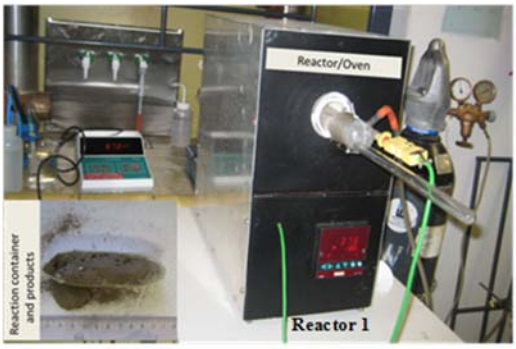
Specific surface
40 – 50 m^2/g
Pore volume
20 – 25 cc/g

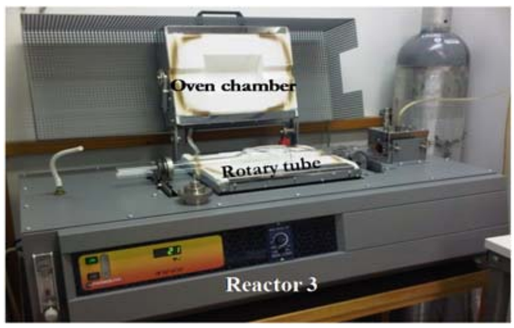


Nduagu, dr. thesis ÅA 2012

Producing $Mg(OH)_2$ from Mg-silicate rock: furnaces used



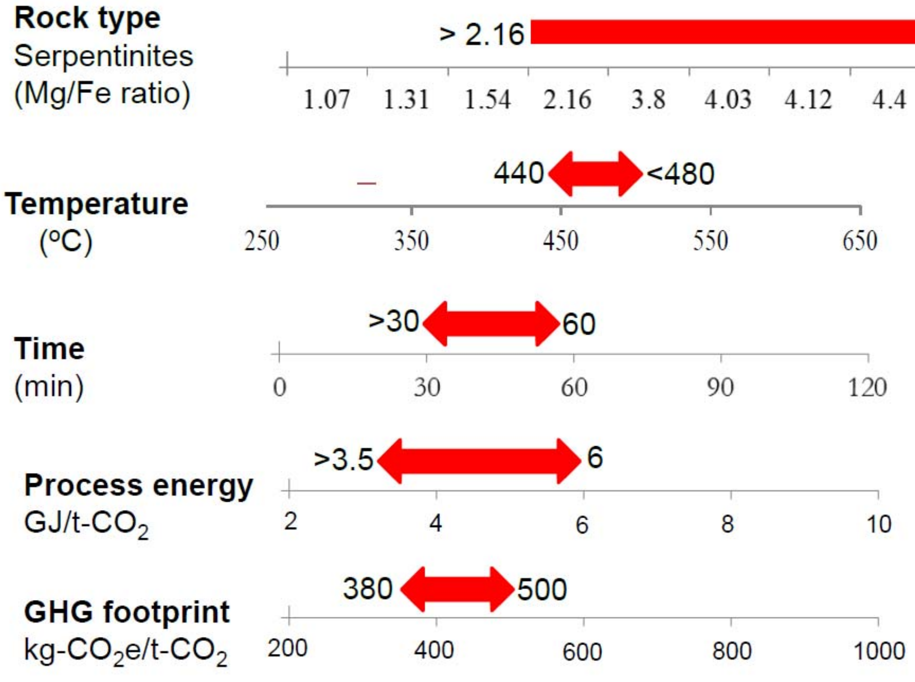




Tested: *1) dry / wet samples*
2) mixing / no mixing
3) layered / pre-mixed
4) Al / ceramic sample holder
5) Ammonium sulphate/ bisulphate

Nduagu, dr. thesis ÅA 2012

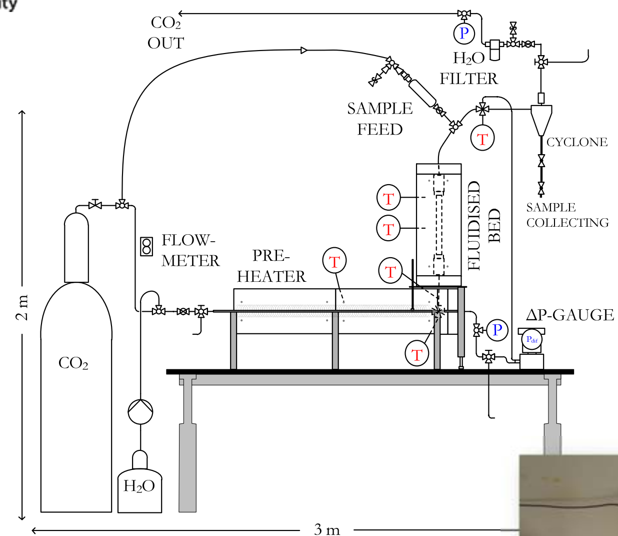
Summary for $Mg(OH)_2$ production



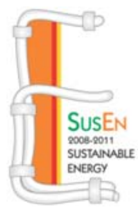
Preferably max 400°C

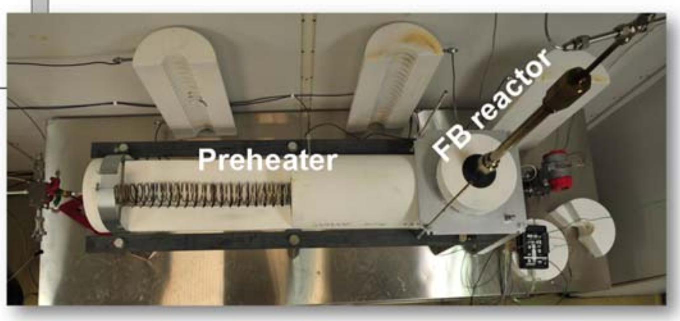
Nduagu PhD thesis defence *lectio* 13.12.12

The pressurised fluidised bed @ ÅA



2008-2011





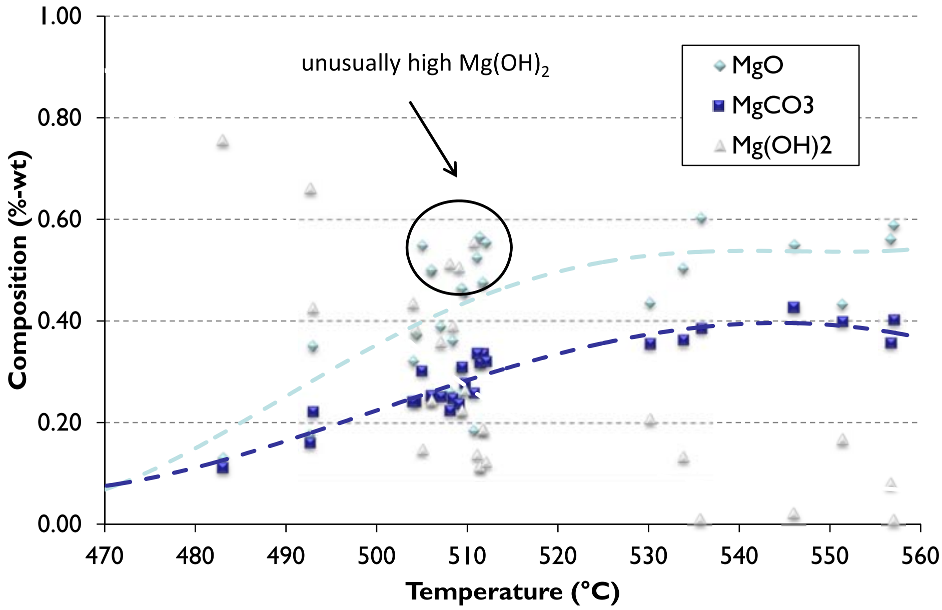
Research questions:

1) *No build-up of $MgCO_3$ on $Mg(OH)_2$ particles?,*
2) *Fast kinetics?*
3) *What about supercritical CO_2?*

$Mg(OH)_2$ carbonation – results

using commercial Dead Sea Periclase material (BET ~ 5 - 8 m^2/g)

~ 20 bar CO_2 → ~ 58 bar CO_2

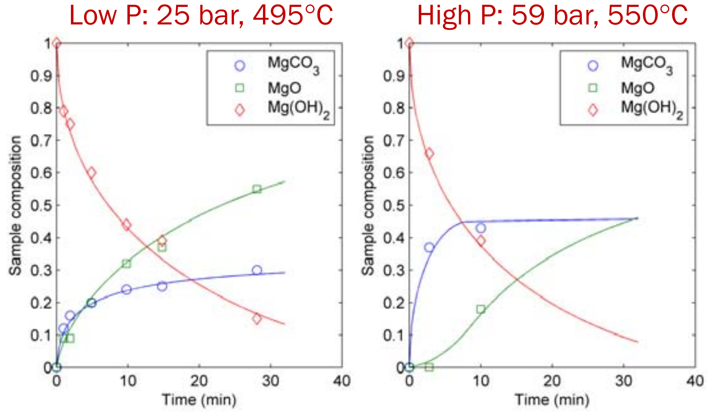


***scCO$_2$*: no advantage** *(tests up to ~80 bar)*

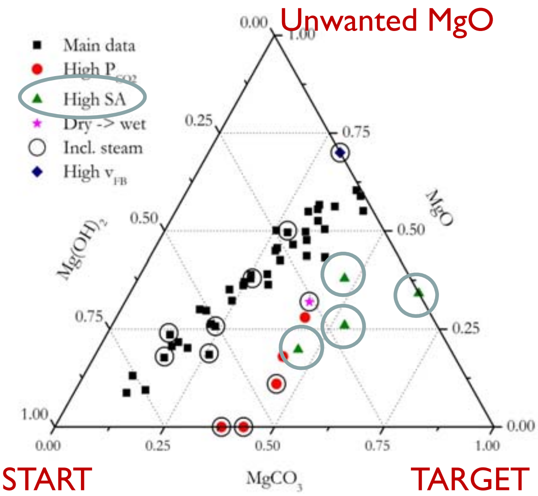
Fagerlund 2009, 2010

PFB carbonation of $Mg(OH)_2$

Low P: 25 bar, 495°C — High P: 59 bar, 550°C



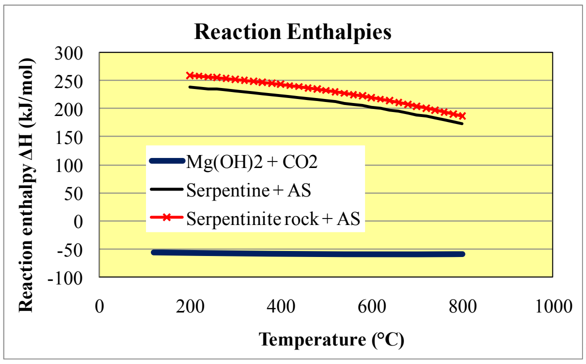
DSP $Mg(OH)_2$



- Competition between dehydroxylation and carbonation
  - Own-produced $Mg(OH)_2$ has good quality (green triangles)
  - Optimise $Mg(OH)_2$ precipitation conditions, control properties

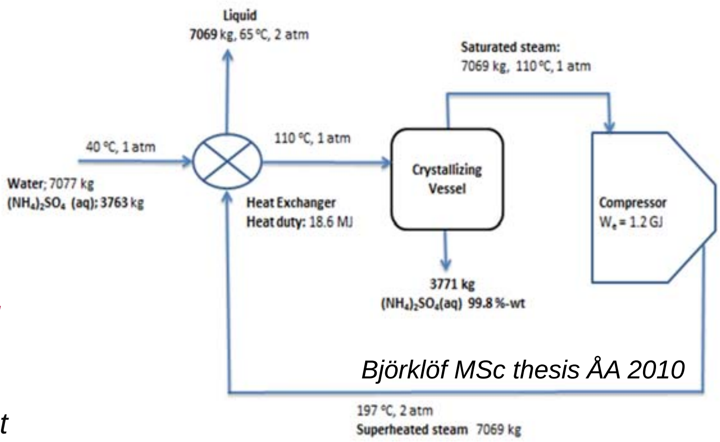
Fagerlund, dr. thesis ÅA 2012

Process energy requirements



Mechanical vapour recompression (MVR) crystallization of AS salt

MVR compression work ~1.2 GJ/t CO_2



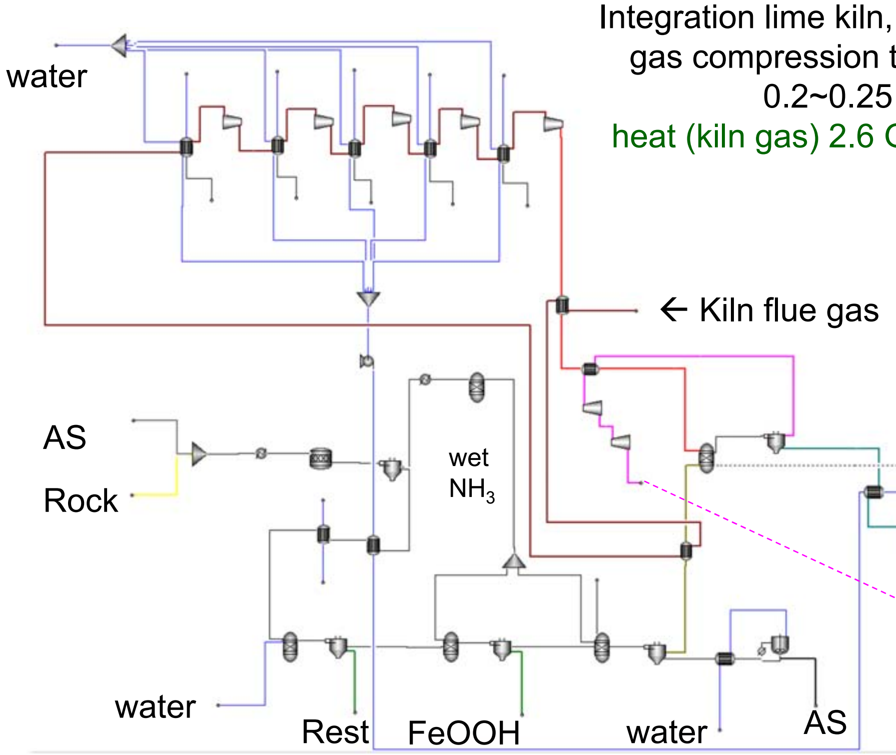
Reaction enthalpies vs. temperature for extraction of 1 mol of Mg from pure serpentine or from Finnish serpentinite, and for the carbonation .

→ *$Mg(OH)_2$ production needs 3 - 4x the heat the carbonation gives*

Total penalty ~3 GJ (mainly 400°C heat) and ~3 t rock per ton (1000 kg) CO_2

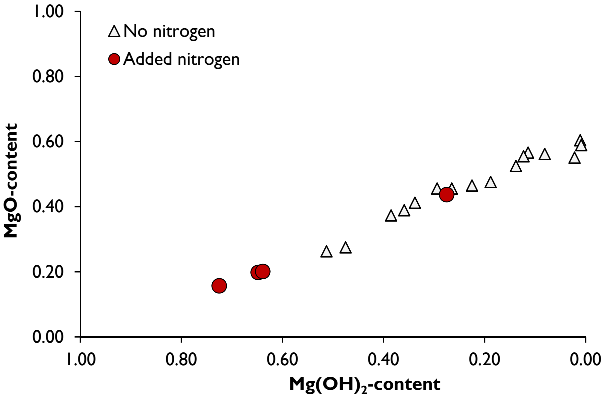
Optional: application at a lime kiln 2013

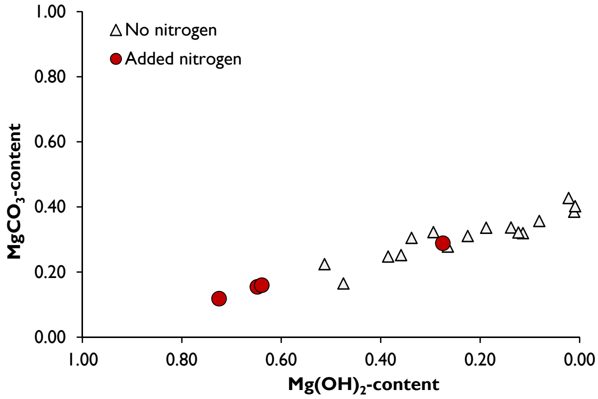
Integration lime kiln, no CO_2 capture, full flue gas compression to 80 bar ~ 20 bar CO_2, 0.2~0.25 t CO_2/h fixed,
heat (kiln gas) 2.6 GJ/t, power 0.9 GJ/t CO_2



Slotte et al. 2012/2013

Conversion of $Mg(OH)_2$ to $MgCO_3$ and MgO in (wet) CO_2 or CO_2 diluted with (26-72%) N_2.





Total pressure 10 – 59 bar, temperature 450 - 550°C, time 15 minutes

Dead Sea Periclase (DSP) $Mg(OH)_2$, 212-425 μm

Conclusions

- CO_2 mineral sequestration offers a leakage-free alternative for CO_2 underground storage worldwide; only option inside Finland
- CO_2 capture from oxygen containing gases isn't "taking off": capture is more expensive than economically viable CCUS! → remove capture step from CCUS chain by operating mineralisation directly on flue gas.
- ÅA staged process route: ~ 80 % Mg extraction from serpentinite + fast (~10 min) $Mg(OH)_2$ carbonation ~65%
- Energy input ÅA route so far ~3 GJ/t, ≈ CO_2 capture from NG
- Challenge: Mg(rock) → $Mg(OH)_2$ > 90% & "good" particles
- Several LCA studies have been reported, uses are found for the solid products. For example heat storage in Mg (hydro)carbonate
- Integrate CCUS with flue gas desulphurisation ?!