



Utilisation du CO<sub>2</sub>, vers un fonds de recherche dédié !



# Ex-situ Mineral Carbonation

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20 juin 2008, Pau, France



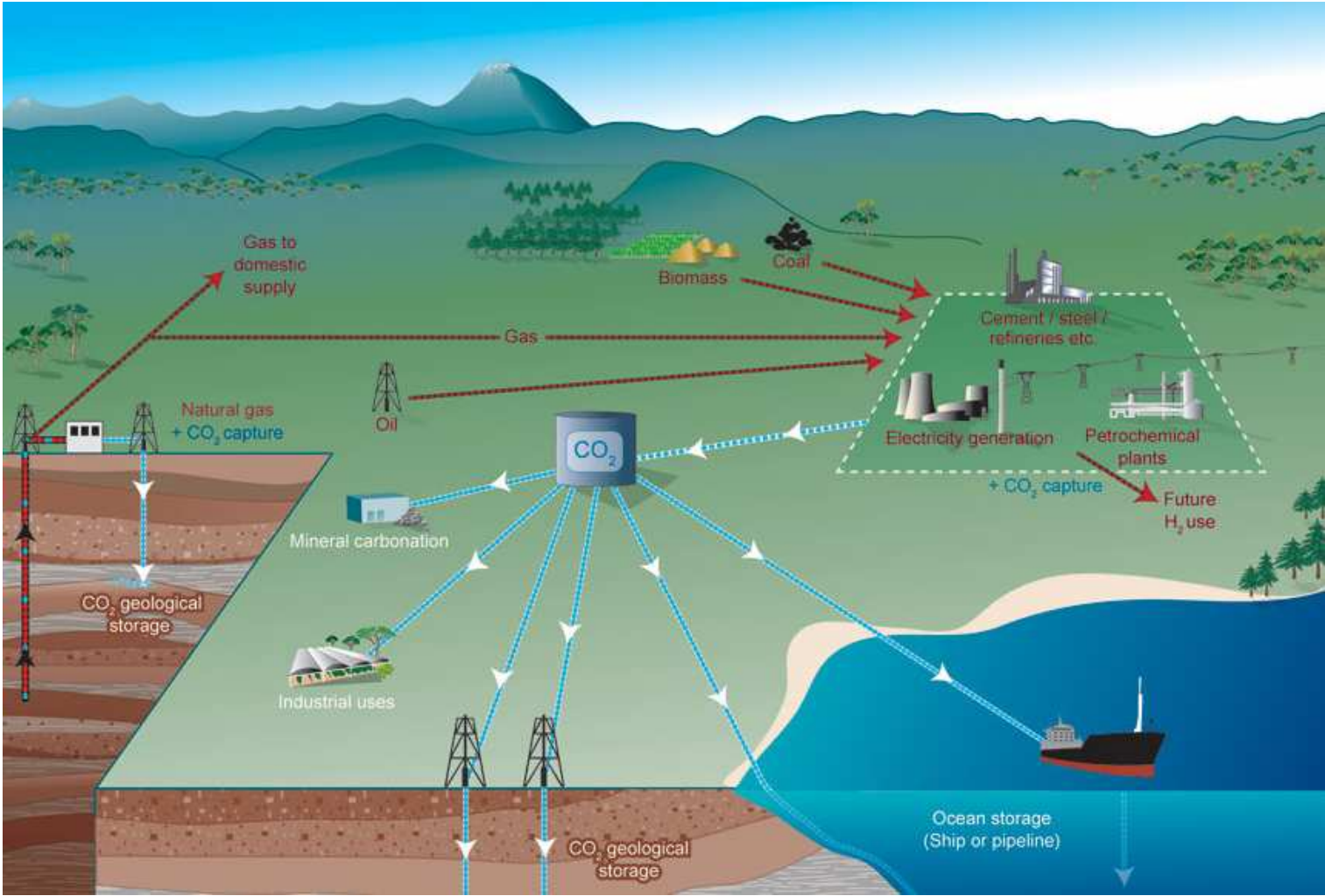
# Outline

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- Fundamentals of mineral carbonation
- Source of alkaline materials
- Process routes
- Gas-solid route
- Aqueous route
- Industrial residues
- Patents
- Conclusions and Challenges



# Carbon Capture and Storage



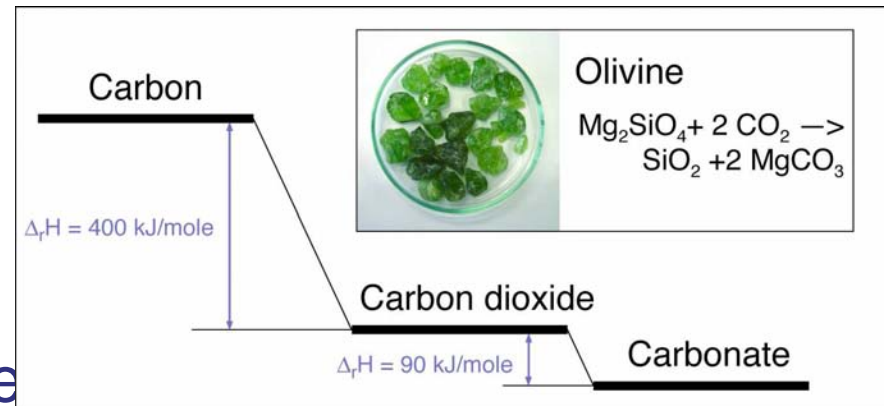
# Mineral carbonation



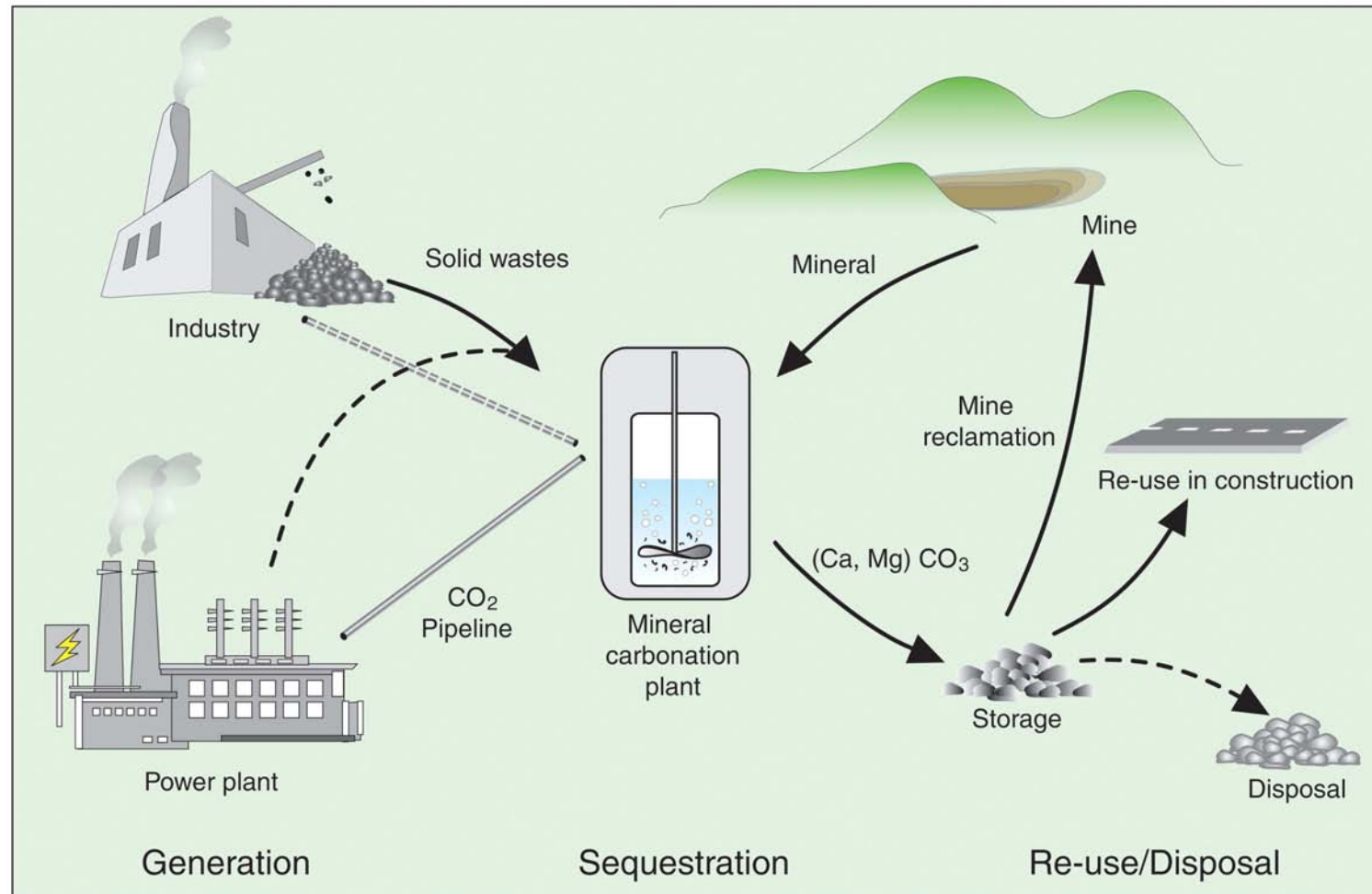
M = Calcium, Magnesium, Iron

## Issues

- stability of carbonates
- availability of alkalinity source
- reactivity of alkaline materials



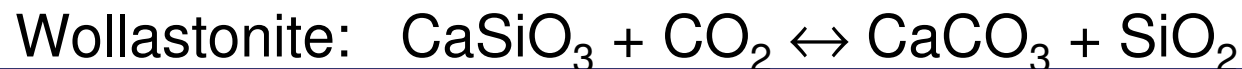
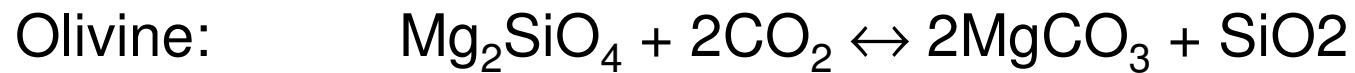
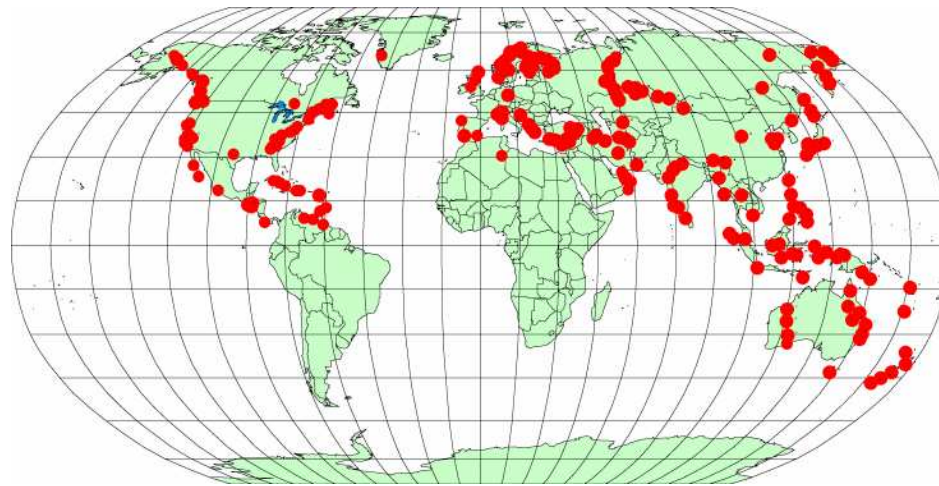
# Mineral carbonation



# Sources of metal oxide - Minerals

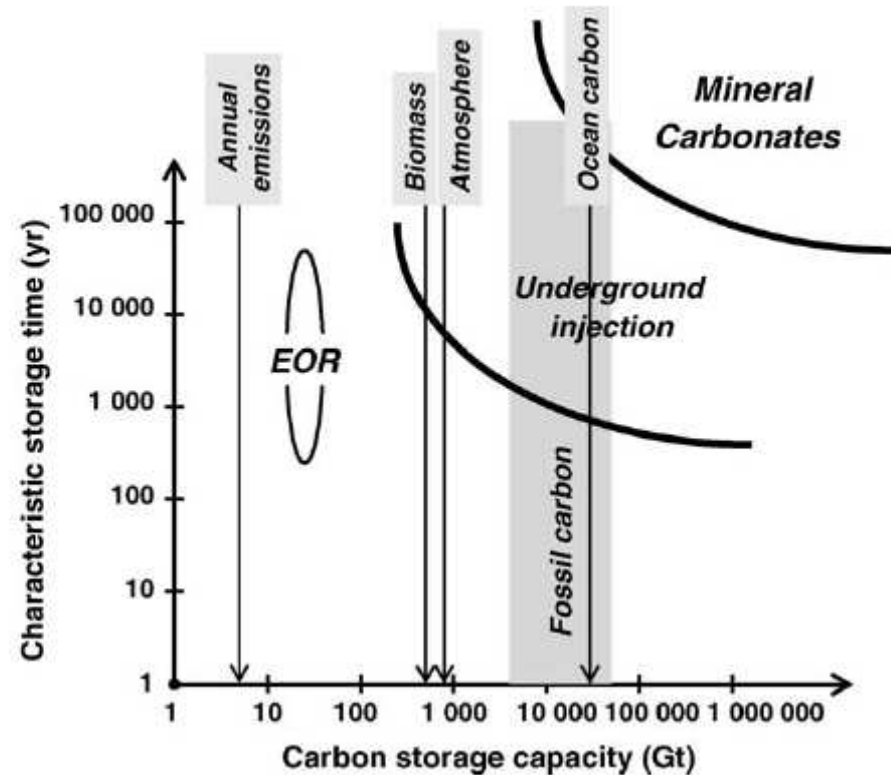
Mg silicates are found in Ophiolite belt complexes

- US Klamath mountains: 3000 Gt
- A comprehensive evaluation of available minerals still missing



# Sources of metal oxide - Minerals

MINERAL	FORMULA/COMPOSITION
Basalt	
Eclogite	
Feldspar	$\text{CaAl}_2\text{Si}_2\text{O}_8$
Forsterite	$\text{Mg}_2\text{SiO}_4$
Glauconite <sup>a</sup>	$(\text{K, Na, Ca})_{1.2-2.0} (\text{Fe}^{3+}, \text{Al, Fe}^{2+}, \text{Mg})_{4.0} \times [\text{Si}_{7-7.6}\text{Al}_{1-1.4}\text{O}_{20}](\text{OH})_4 n\text{H}_2\text{O}$
Ilmenite	$\text{FeTiO}_3$
Listwanite	Carbonated serpentinite
Magnetite	$\text{Fe}_3\text{O}_4$
Olivine	$(\text{Mg, Fe})_2\text{SiO}_4$
Opoka <sup>a</sup>	mainly $\text{CaCO}_3$ , $\text{SiO}_2$ , hematite and muscc
Pyroxene	$\text{CaMgSi}_2\text{O}_6 + (\text{Fe, Al})$
Serpentine <sup>f</sup>	$\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$
Serpentinite	
Talc	$\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$
Wollastonite	$\text{CaSiO}_3$



# Sources of metal oxide - Residues

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• **Steel Industry**  
(60-80 MtCO<sub>2</sub>/y)

- Steel slag
- AOD process slag
- Steel converter slag

• **Energy sector**

- Lignite fly ash
- APC fly ash
- MSWI ash
- PF ash

• **Cement industry**

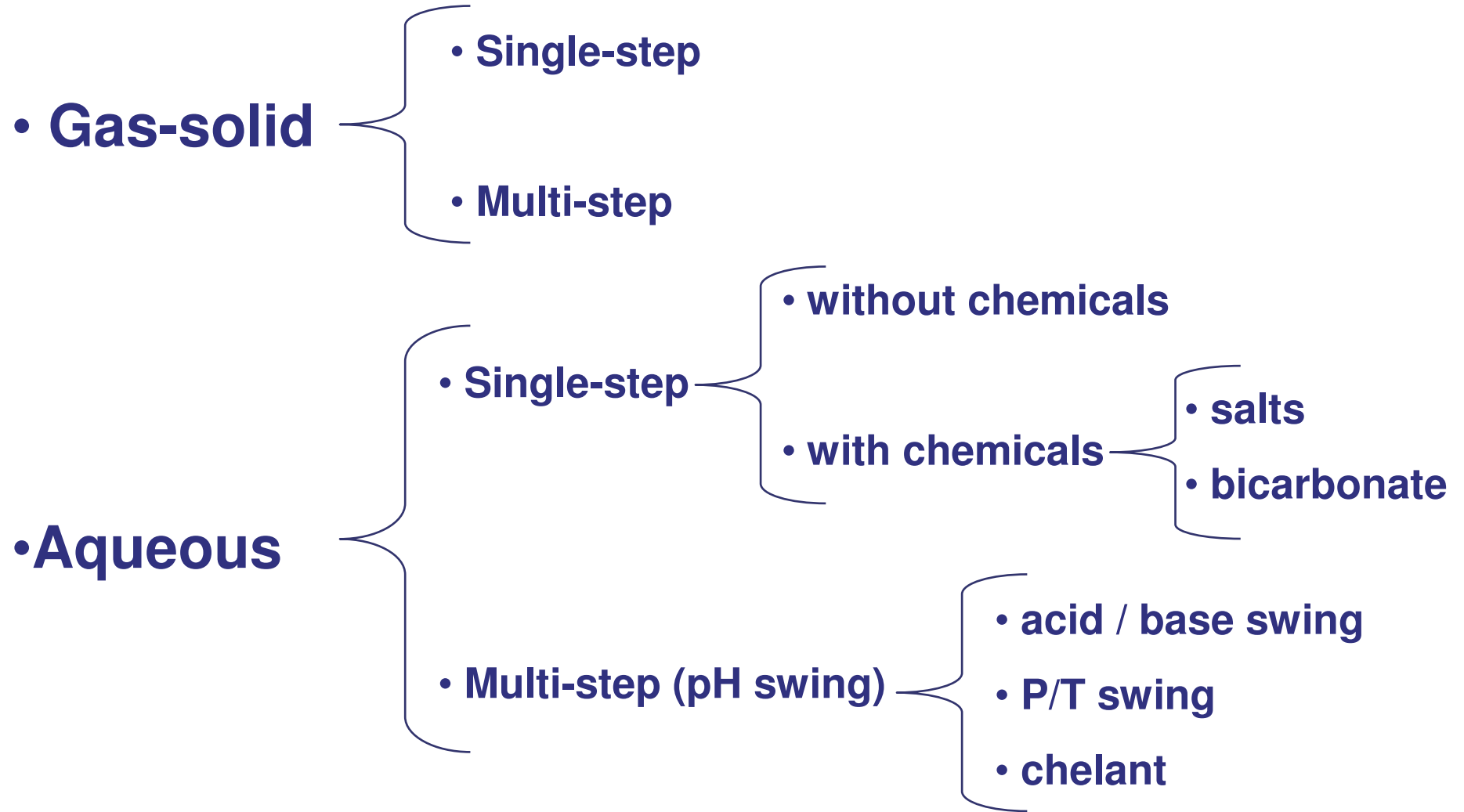
- Waste cement
- Cement Kiln Dust

100s MtCO<sub>2</sub>/y

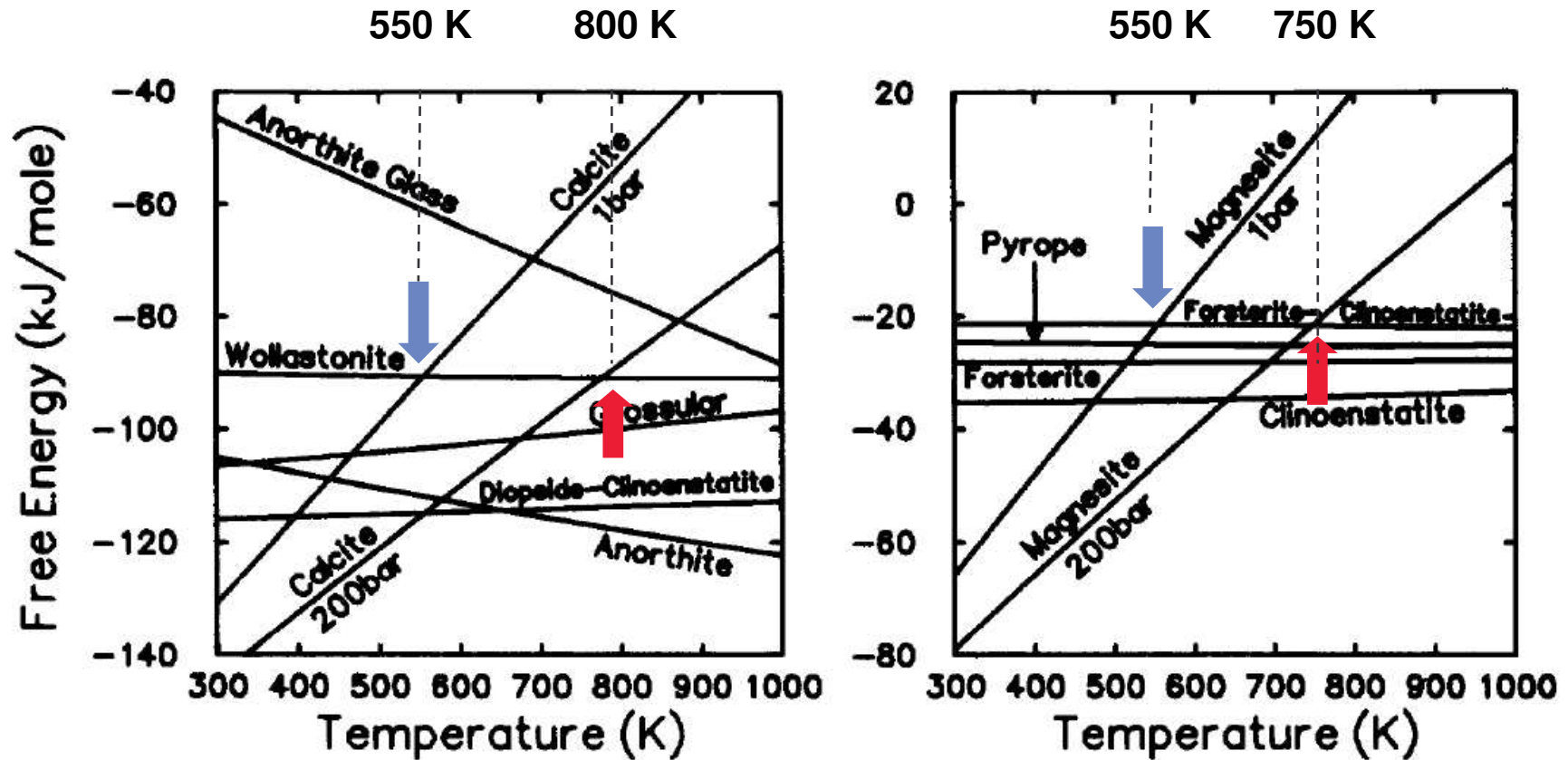


# Mineral carbonation – Process routes

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# Gas-solid route



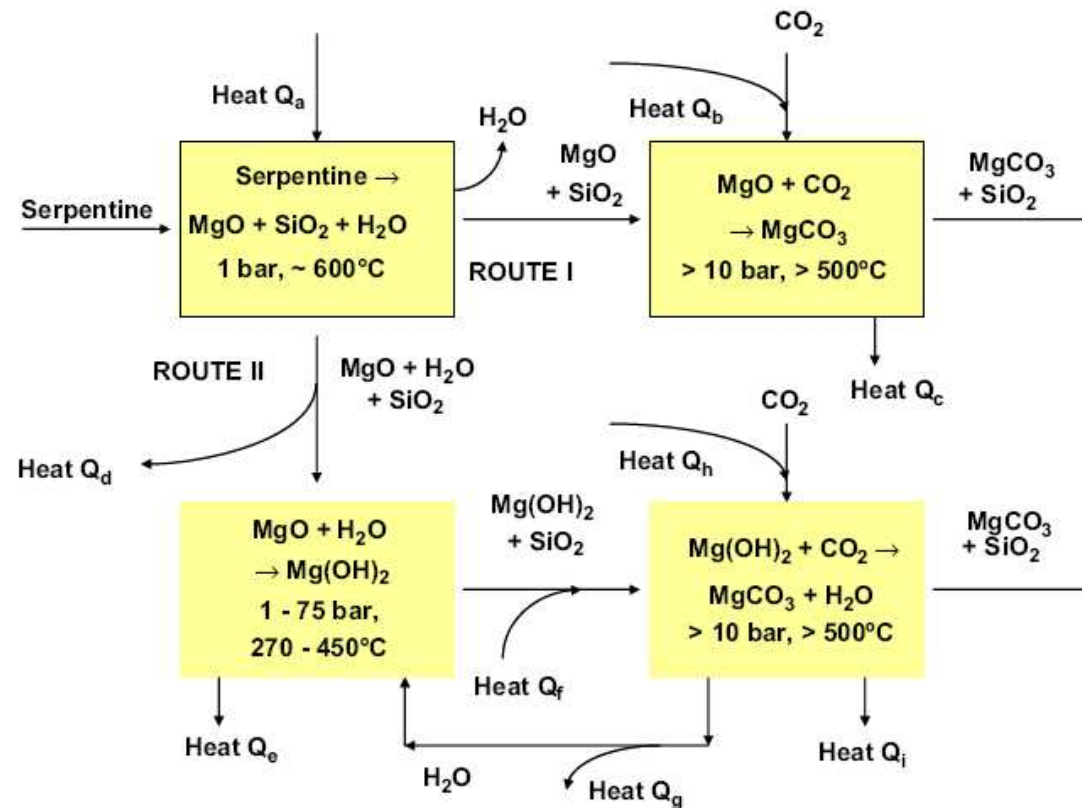
- Thermodynamics favourable up to a maximum temperature
- Kinetics is very slow (geological times) at ambient temperature

Lackner et al., Energy, 20 (1995)



# Multi-step Gas-solid route

- Step 1: production of free MgO / Mg(OH)<sub>2</sub>
- Step 2: carbonation of MgO / Mg(OH)<sub>2</sub> to MgCO<sub>3</sub>

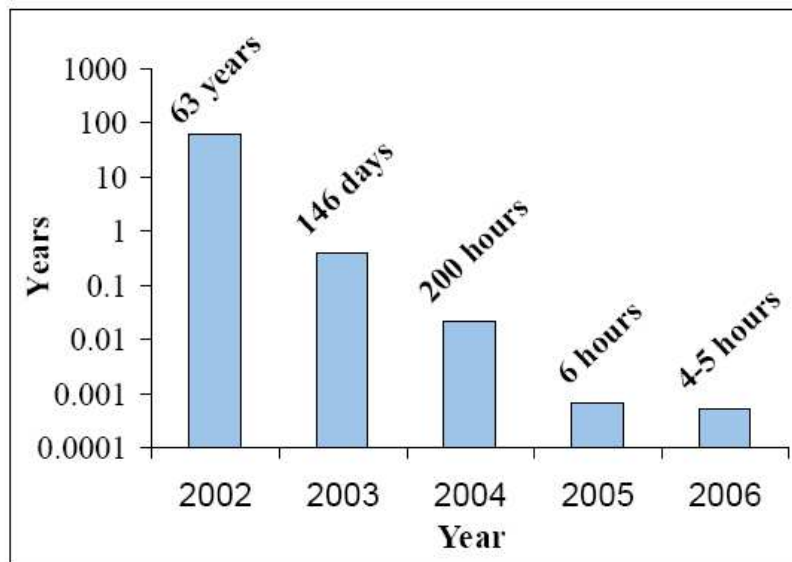


Zevenhoven et al., Energy, 33 (2008)



# Multi-step Gas-solid route

Results of MgO and Mg(OH)<sub>2</sub> carbonation kinetics (74-125 μm)



Year	Carbonation conditions		
	P <sub>CO2</sub> (bar)	T (°C)	Material
2002	1	355	MgO
2003	35	400	MgO
2004	35	510	Mg(OH) <sub>2</sub>
2005	40	510	Mg(OH) <sub>2</sub>
2006	40-45	525-540	Mg(OH) <sub>2</sub>

This process route does not yet look promising.

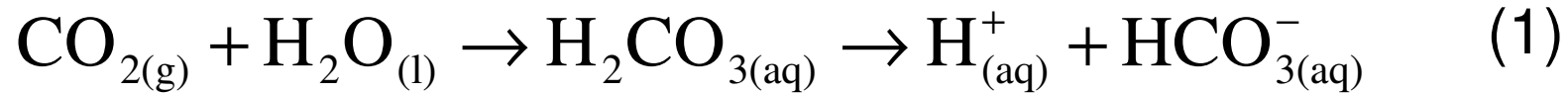
Zevenhoven et al., GHGT-8 (2006)



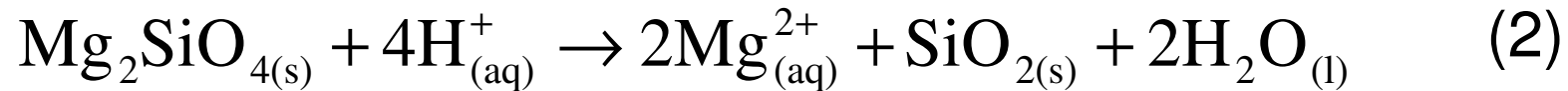
# Aqueous route

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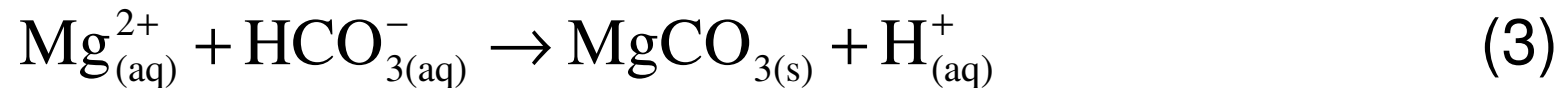
CO<sub>2</sub> dissolution



Mineral dissolution



Carbonate dissolution



# Aqueous route

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**Aqueous carbonation consists of two processes: dissolution and precipitation**

## Single-step

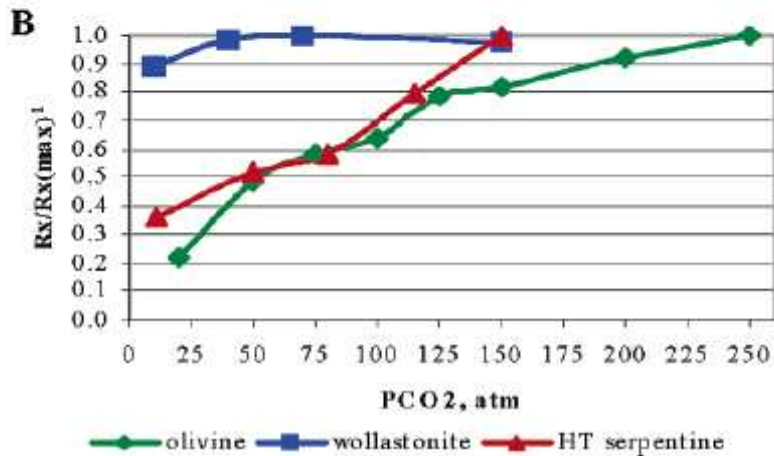
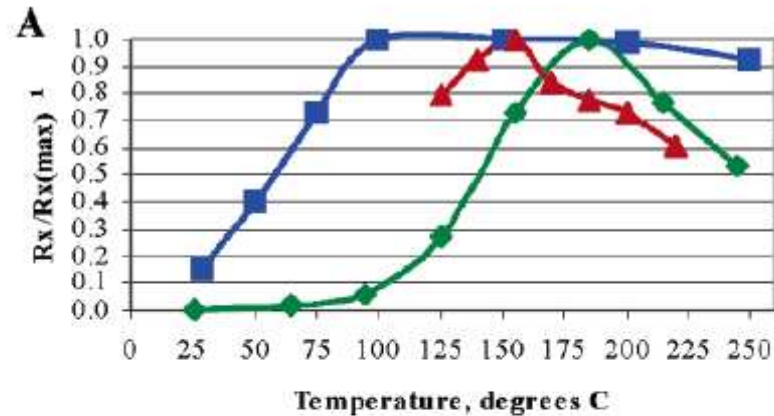
- Mineral dissolution + carbonates precipitation (in a single reactor)

## Multi-step

- mineral dissolution
- carbonates precipitation



# Aqueous route – Single step



## Optimum carbonation conditions

mineral	carbonation conditions		
	$T, ^\circ\text{C}$	$P_{\text{CO}_2}, \text{atm}$	carrier solution
olivine	185	150	0.64 M NaHCO <sub>3</sub> , 1 M NaCl
wollastonite	100	40	distilled water
HT serpentine	155	115	0.64 M NaHCO <sub>3</sub> , 1 M NaCl

Grinding to < 75 um

$R_x$  = extent of reaction in 1h

$R_x(\text{max})$  = maximum extent of reaction in 1h

olivine: 49.5%

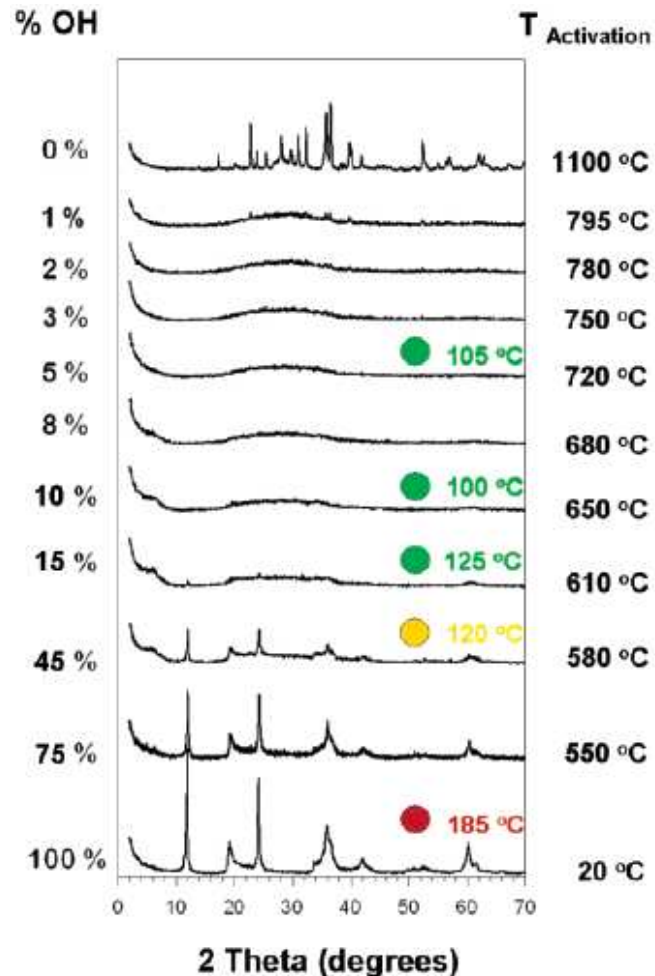
wollastonite: 81.8%

HT serpentine: 73.5%

Gerdemann et al. (2007), ES&T,41 (2007)



# Aqueous route – Heat activation

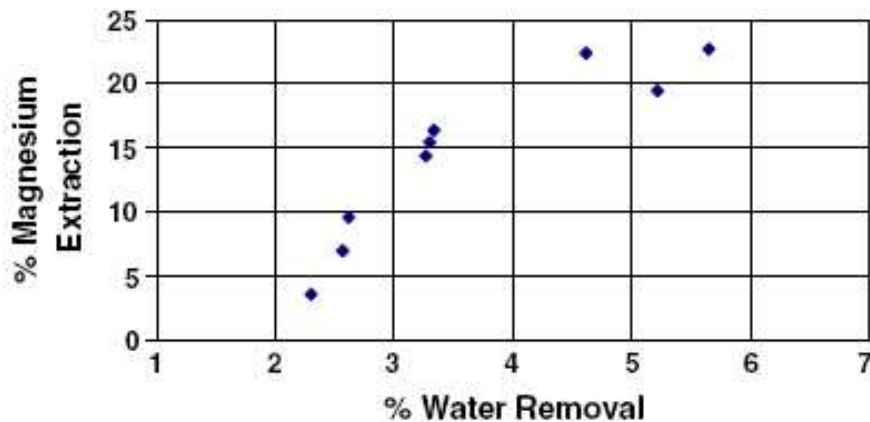
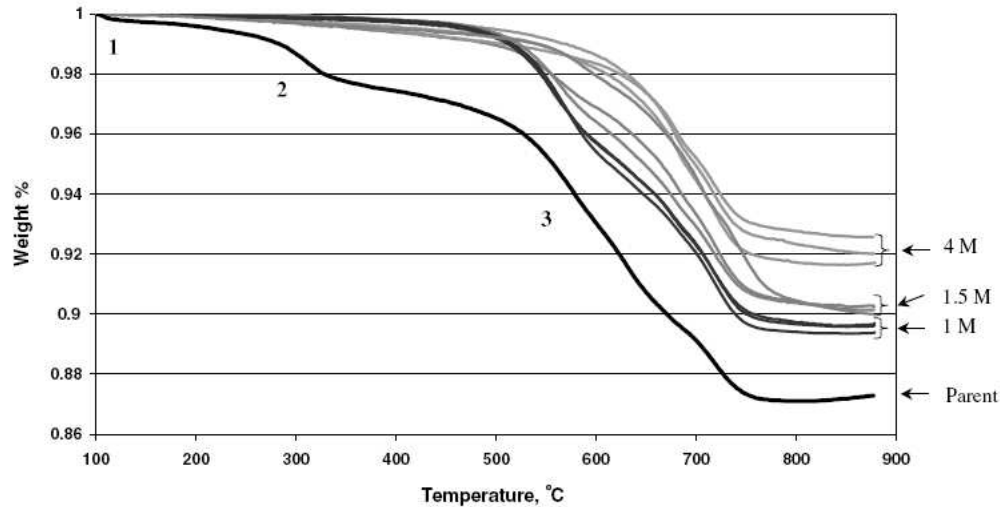


- Thermal treatment of Lizardite (Serpentine);
- Amorphous meta-serpentine is formed.
- No carbonation
- Trace carbonation
- Substantial carbonation
- Lizardite feedstock shows no reaction up to 185 °C
- Material heated at 580 °C showed trace reaction
- Materials heated at 610-720 °C showed carbonation

McKelvy et al. , ES&T,38 (2004)



# Aqueous route – Chemical activation



## Serpentine from Cedar Hills quarry

- Activation with Sulphuric Acid

1. Loss of adsorbed water
2. Loss of crystallized water
3. Loss of OH groups

- Reduction of water content is correlated with Mg extraction.
- This demonstrates the significance of removing hydroxyl groups and the effectiveness of sulfuric acid in this removal.

Alexander et al., Fuel, 86 (2007)



# Aqueous route – Single step

## Mass/Energy balance

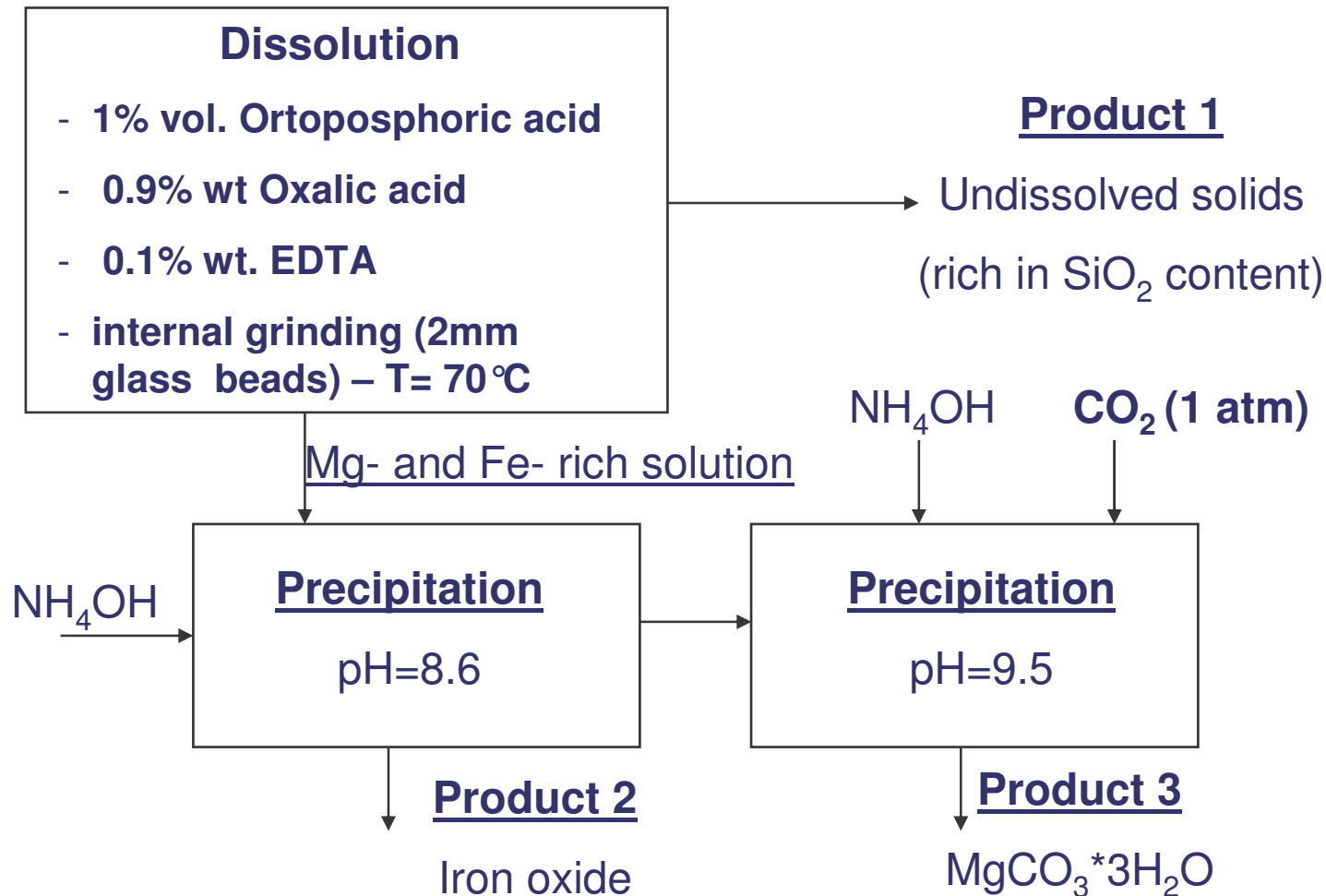
Albany Research  
Center, WA

Coal fired power plant: 10 GJ/t CO<sub>2</sub> (3.6 GJe/t CO<sub>2</sub>)

Ore (pre-treatment)	1h conversion (%)	R <sub>CO<sub>2</sub></sub> (t ore/t CO <sub>2</sub> )	Cost (USD/t ore)	Energy input (GJ/t CO <sub>2</sub> stored)
Olivine (standard)	61	1.8	19	1.1
Olivine (activated)	81	1.8	27	2.3
Lizardite (standard)	9	2.5	15	0.6
Lizardite (activated)	40	2.5	44	0.6+7.6
Antigorite (standard)	62	2.1	15	0.6
Antigorite (activated)	92	2.1	48	0.6+3.0
Wollastonite (standard)	43	1.8	15	0.7
Wollastonite (activated)	82	1.8	19	1.5



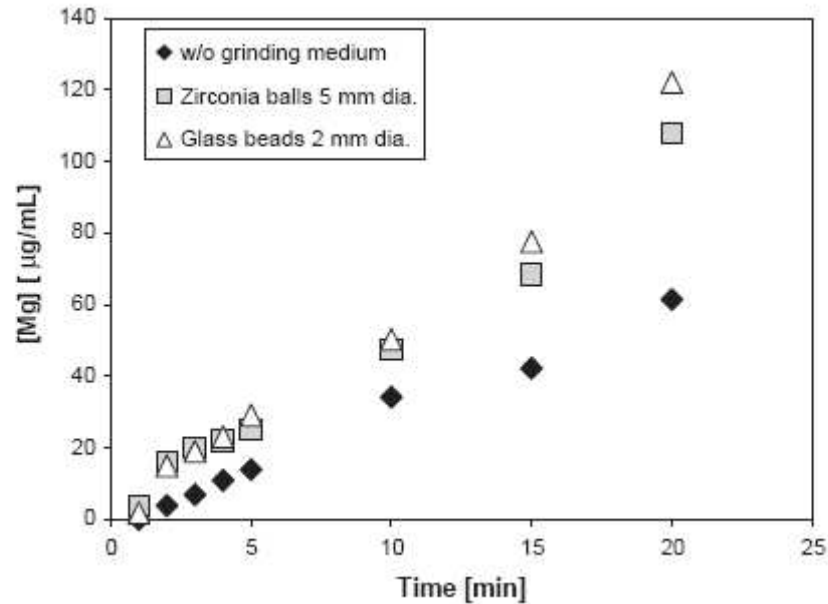
# Multi-step carbonation – pH swing



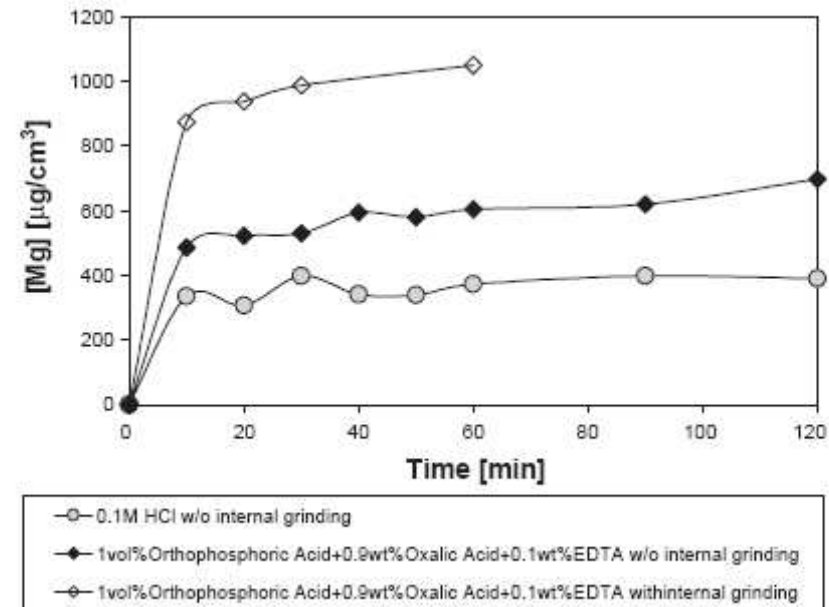
Park and Fan,  
CES 59 (2004)



# Dissolution experiments - Serpentine



No chemical additives (neutral pH)

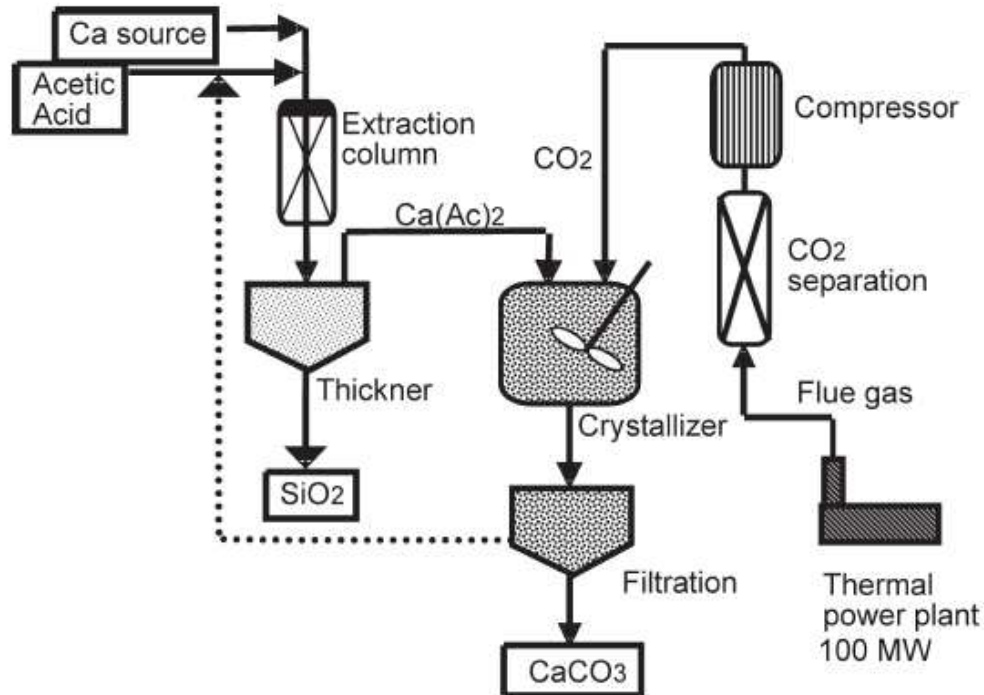


Chemical additives (acidic pH)

- Internal grinding was effective in refreshing the particles' surface (aiding acid leaching)



# Multi-step carbonation – Acetic acid route



- **Dissolution of wollastonite ( $T=60\text{ }^{\circ}\text{C}$ ,  $L/S=5$ )**
- **$\text{CaCO}_3$  precipitation:  $T=40/80\text{ }^{\circ}\text{C}$ ,  $P(\text{CO}_2) = 5\text{-}50\text{ bar}$**
- **Acetic acid pKa (4.76) is between pKa of Carbonic (3.6) and Silicic acid (9.51)**
- **This allows the acid to be replaced by carbonic acid in the crystallization step although low Ca precipitation yield was measured (20%)**

Kakizawa et al., Energy, 26 (2001)



# Multi-step carbonation – Acetic acid route

## Energy requirements

100 MW oil fired thermal power plant (40% efficiency)

Stirred tank reactor for dissolution: 60 °C, 300 rpm, T=60 min, 20 $\mu$ m particles

Crystallization process: 60 °C, P(CO<sub>2</sub>)=30 bar, 100 rpm, T=10min,

Break-down of the energy consumption for the disposal process

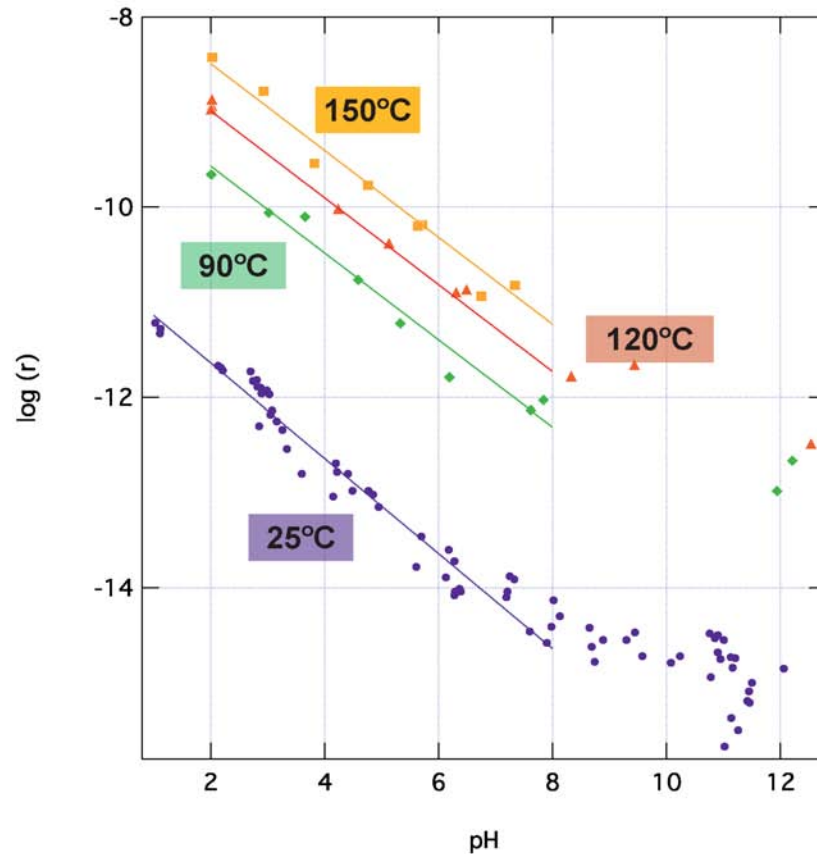
	Energy consumption [MW]	Percentage
CO <sub>2</sub> separation	5.56	27.28
CO <sub>2</sub> compression	4.65	22.82
Pulverization	5.29	25.96
Extraction	1.27	6.23
Crystallization	2.60	12.76
CaCO <sub>3</sub> separation	1.01	4.96
Total	20.38	100

**20% energy penalty**

Kakizawa et al., Energy, 26 (2001)



# Dissolution experiments - Olivine



25°C - Pokrovsky und Schott (2000)

$$\log(r) = -n \text{ pH} - E_A / (RT) + C$$

**T = 150°C:**

$$\log(r) = -0.46 \text{ pH} - 7.58$$

**T = 120°C:**

$$\log(r) = -0.46 \text{ pH} - 8.07$$

**T = 90°C:**

$$\log(r) = -0.46 \text{ pH} - 8.66$$

**T = 25°C:**

$$\log(r) = -0.50 \text{ pH} - 10.64$$

$$r = [\text{mol}/\text{cm}^2/\text{s}]$$

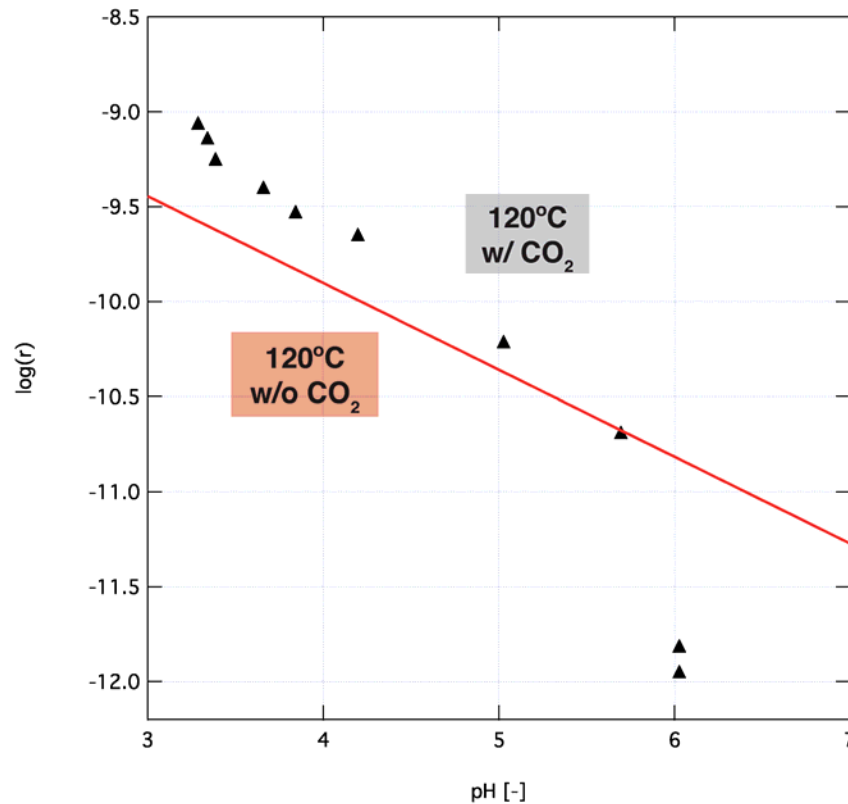
Activation energy:

$$E_A = 52.9 \text{ kJ/mol}$$

Hänchen et al., Geochim. Cosmochim. Acta 70(2006)



# Dissolution experiments - Olivine

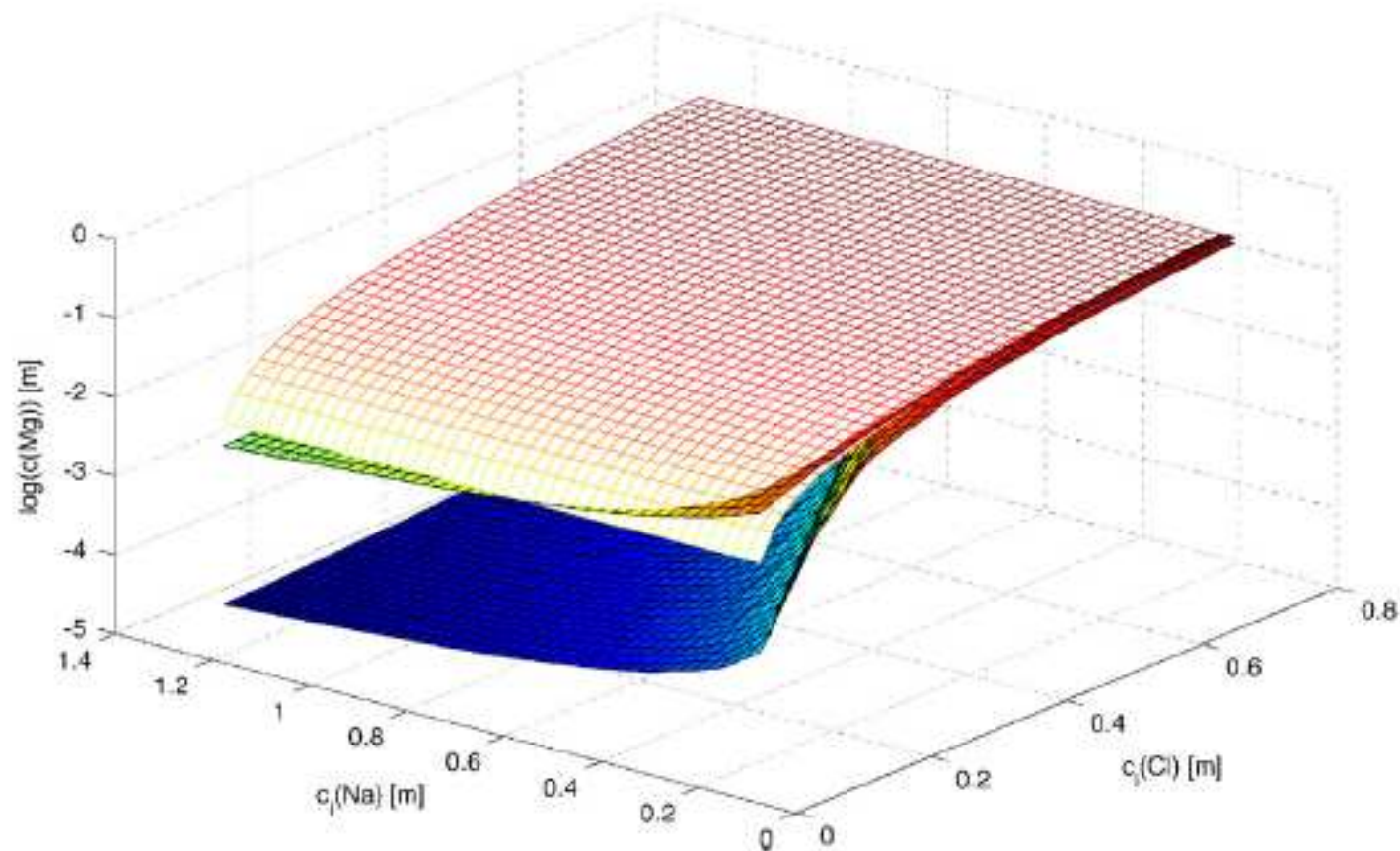


- The pH change due to increasing CO<sub>2</sub> pressure is similar to acid addition
- No evident effect of salt addition on dissolution rate (other than pH shift)

Hänchen et al., Geochim. Cosmochim. Acta 70(2006)



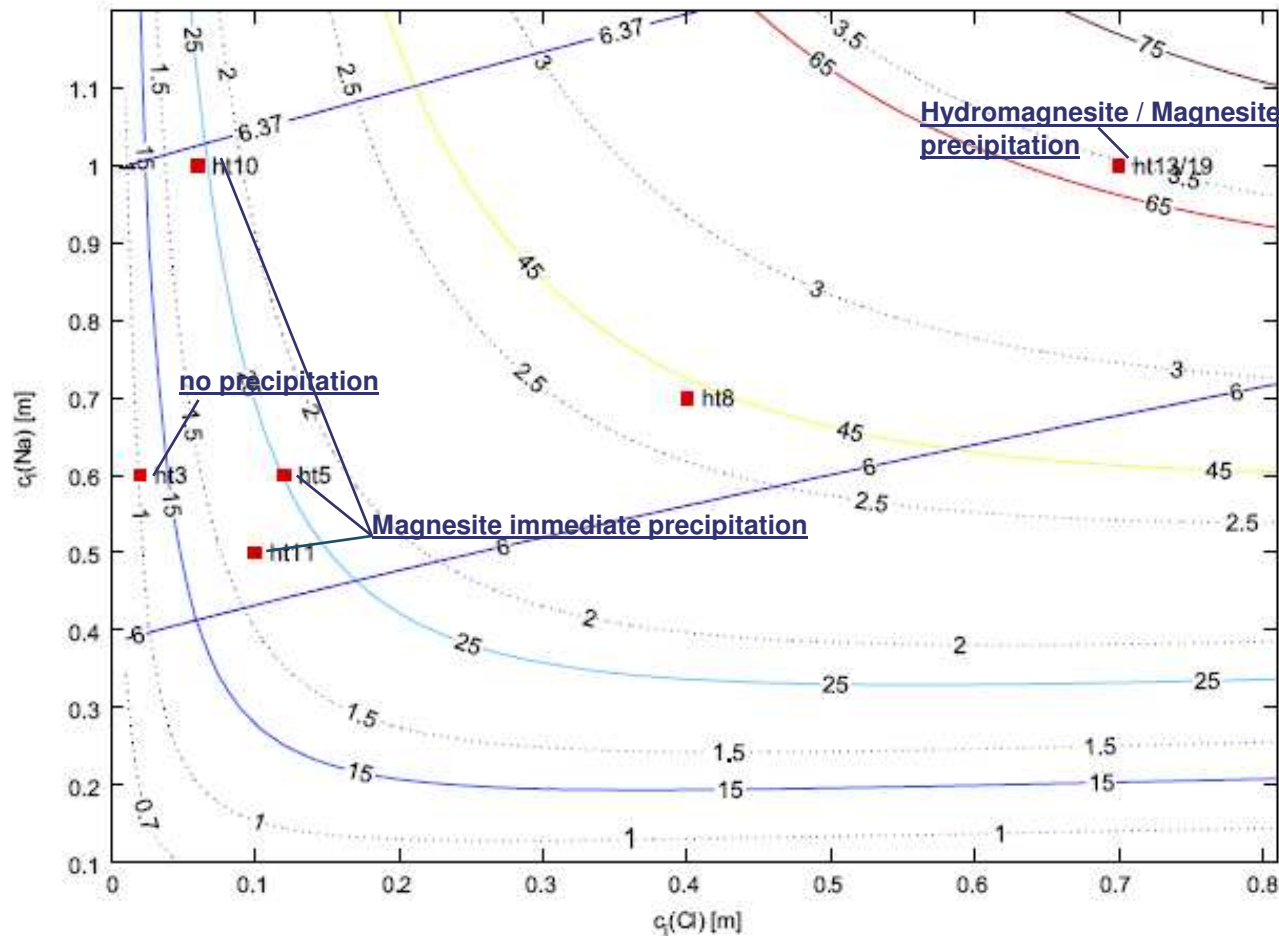
# Precipitation experiments – $\text{MgCO}_3$



- Equilibrium Mg concentration at  $T=120^\circ\text{C}$ ,  $P(\text{CO}_2)=100$  atm
- Blue: magnesite / Green: hydromagnesite / White: initial conditions
- Mg solubility strongly decrease at increasing Na ions concentration



# Precipitation experiments – $\text{MgCO}_3$



Supersaturation ratio

--- Hydromagnesite

\_\_\_ Magnesite

$\text{Na}_2\text{CO}_3/\text{MgCl}_2$

$T=120^\circ\text{C}$

$P(\text{CO}_2)=100\text{ bar}$

Hänchen et al., CES, 62 (2007)



# Carbonation of residues

- Industrial residues are often associated with CO<sub>2</sub> point source emissions
- They also tend to be more unstable than geologically derived materials
- They require a lower degree of pre-treatment and less energy intensive conditions
- Carbonation may also be seen as a stabilisation process
- The leaching behaviour of alkaline residues may be improved by stabilisation

Sample	CaO	SiO <sub>2</sub>	MgO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>
OPC	65.04	20.71	1.03	4.83	2.77
PFA	3.36	46.96	1.76	23.71	11.33
GGBS	41.38	34.59	6.84	14.02	1.51
MSWI-b	22.62	10.32	1.61	5.30	0.95
MSWI-f	35.89	15.29	1.29	6.25	1.11
Deinking Ash	37.69	33.76	3.72	20.12	0.03
Stainless Steel Slag	46.66	27.92	9.75	2.91	1.22

OPC: ordinary Portland Cement

PFA: pulverized fly ash (coal fired power station)

GGBS: Ground granulated Blast Furnace Slags

MSWI-b: Municipal Solid Waste Incineration (Bottom ash)

MSWI-f: Municipal Solid Waste Incineration (Fly ash)

Costa et al., *Env. Monit. Ass.* 135 (2007)



# Aqueous route – steel slags

- Aqueous phase / Single step
- Material: stainless steel slags
- pH=12.6
- Slurry reactor
- No chemicals addition
- Different size fractions tested
- T= 20-225 °C
- P= 1-30 bar (Pure CO<sub>2</sub>)
- Max CO<sub>2</sub> capacity: 0.25 kgCO<sub>2</sub>/kg slag

$$\xi_{Ca} (\%) = \frac{\frac{CO_2 \text{ (wt \%)}}{100 - CO_2 \text{ (wt \%)}} \times \frac{MW_{Ca} \text{ (kg/mol)}}{MW_{CO_2} \text{ (kg/mol)}}}{Ca_{total} \text{ (kg/kg)}} \times 100 \quad (6)$$

TABLE 1. Composition of Fresh Steel Slag Expressed in Terms of Oxides<sup>a</sup>

element	composn (wt %)	element	composn (wt %)
Fe <sub>2</sub> O <sub>3</sub>	35.5	MnO	3.4
CaO	31.7	Al <sub>2</sub> O <sub>3</sub>	1.6
SiO <sub>2</sub>	9.1	TiO <sub>2</sub>	1.3
MgO	6.0		

<sup>a</sup> Only elements present at > 1 wt % are shown.

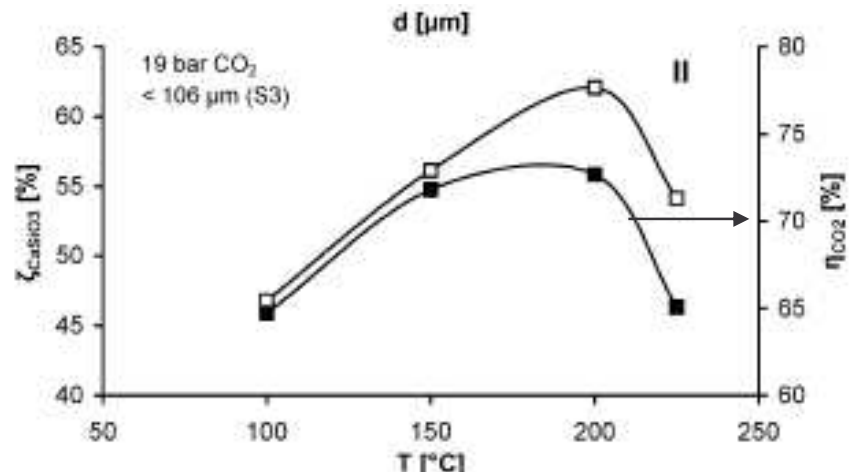
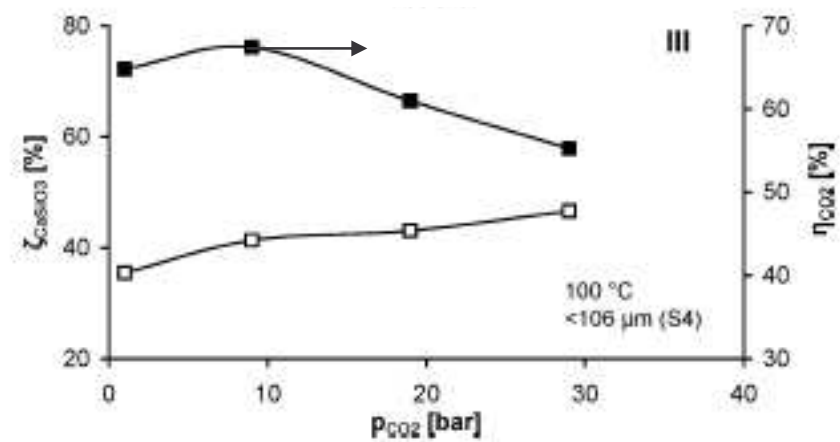
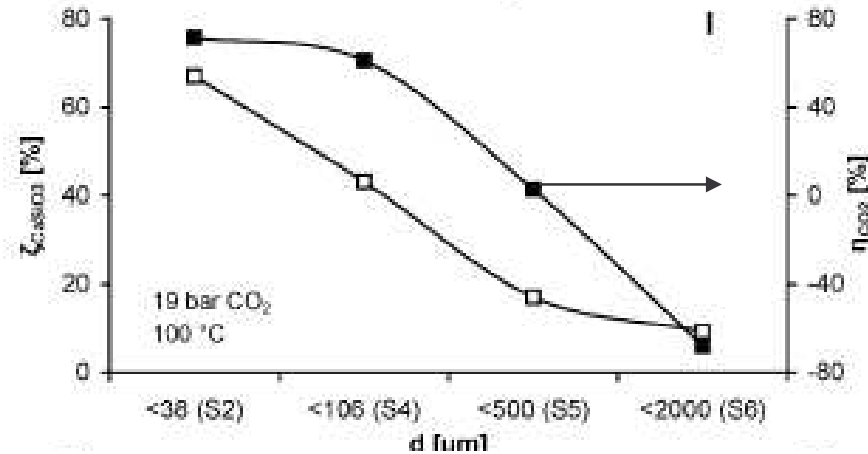
TABLE 2. Identified Minerals in Fresh and Carbonated Steel Slag ( $\xi_{Ca} = 60\%$ ,  $p_{CO_2} = 20$  bar,  $T = 150$  °C,  $t = 30$  min,  $d < 106$   $\mu$ m (batch 3),  $n = 500$  rpm,  $L/S = 10$  kg/kg) with Analysis Method

element	phase	fresh steel slag	carbonated steel slag
Ca	Ca(OH) <sub>2</sub> (portlandite)	XRD	ND <sup>a</sup>
	Ca-(Fe)-silicates	SEM	SEM
	Ca-Fe-O	SEM	SEM
	CaCO <sub>3</sub> (calcite)	TGA-MS (traces)	XRD, TGA-MS, SEM
Mg	Mg-Fe-O	SEM	SEM
	MgCO <sub>3</sub> (magnesite)	ND	XRD (traces)
other	SiO <sub>2</sub>	ND	SEM
	FeO	SEM	SEM

<sup>a</sup> ND = not detected.



# Aqueous route – steel slags



**Optimal operating conditions:**

$P = 20$  bar

$T = 200$  °C ;  $L/S = 5$  (lower is better)

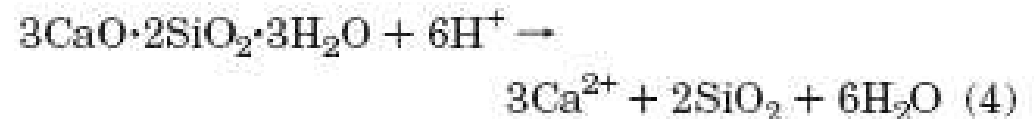
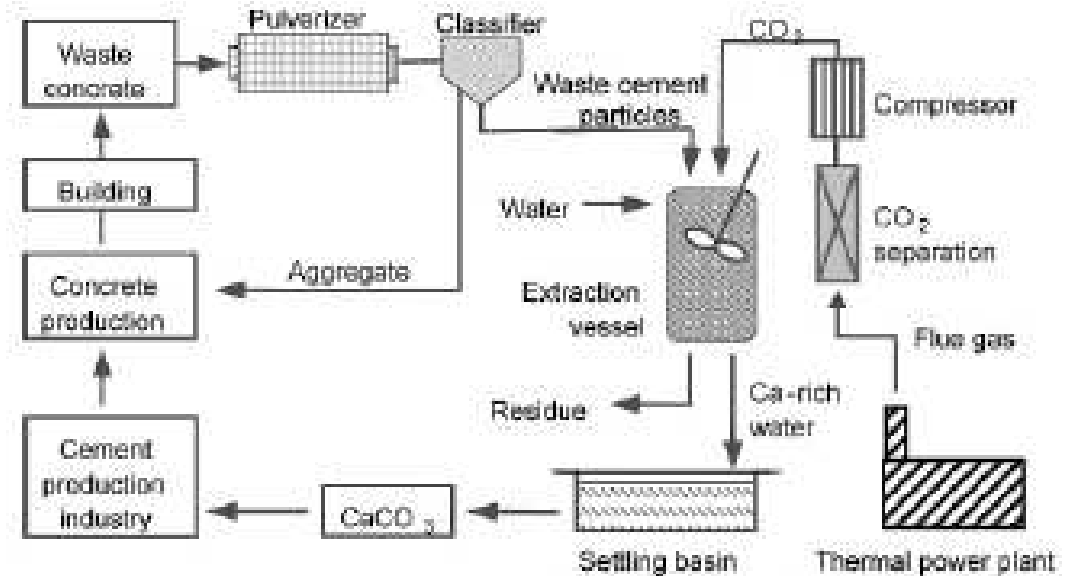
$d < 106$   $\mu\text{m}$  (38  $\mu\text{m}$  preferred)

Huijgen et al., Ind.Eng.Chem. 45 (2006)



# Aqueous route – Waste cement

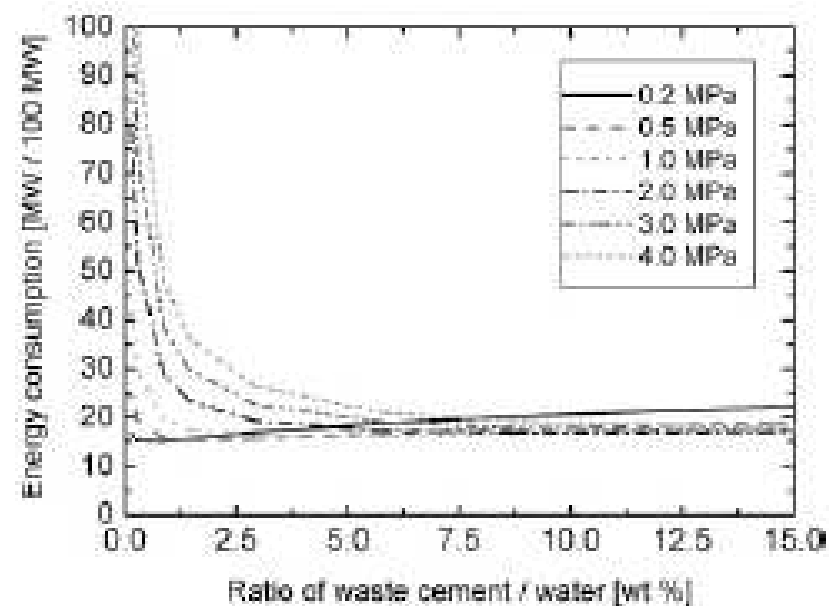
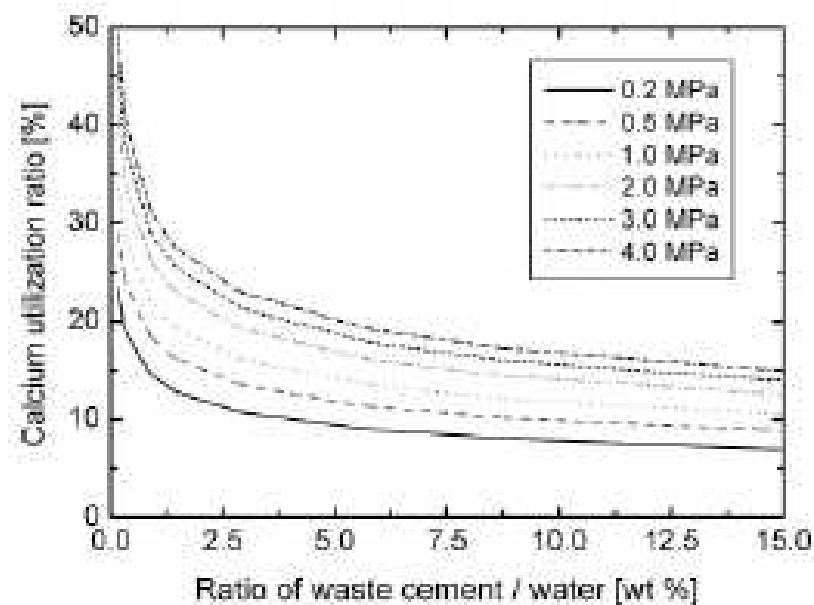
- Waste cement is a Ca rich waste
- Produced in the process for aggregates recovery from concrete
- Reuse of waste cement limited to use as roadbed material
- A long term waste cement supply from building demolition expected
- Carbonation is expected to follow this reaction scheme (dissolution and precipitation):



Iizuka et al., Ind. Eng. Chem. Res. 43 (2004)



# Aqueous route – Waste cement



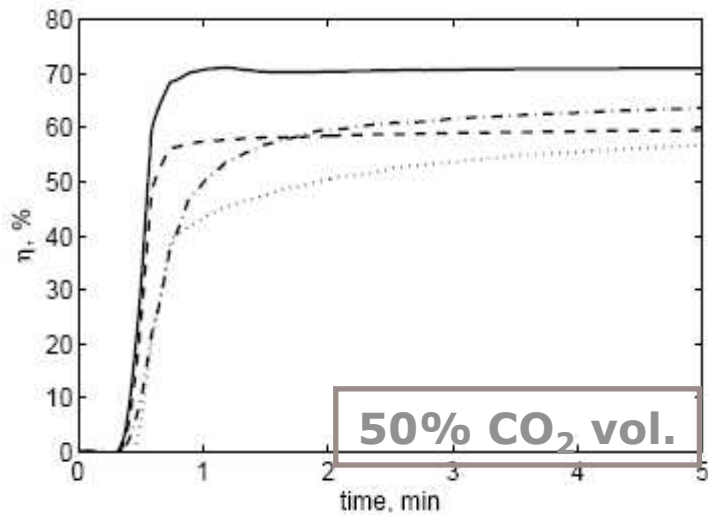
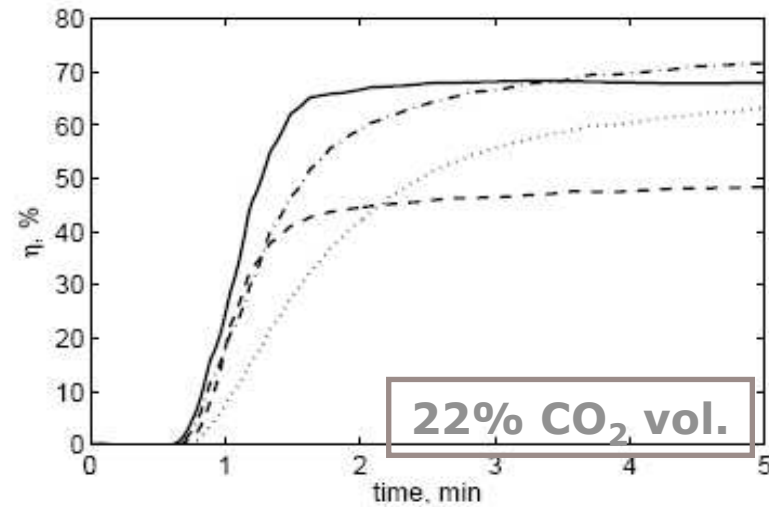
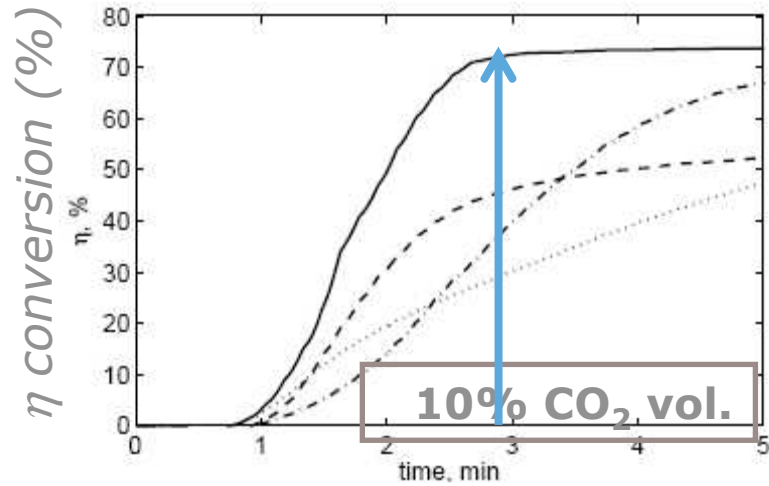
	CO <sub>2</sub> separation	pressurization	stirring	pulverization	revenue by selling CaCO <sub>3</sub>	total
power consumption per 100 MW of power generation (MW/100 MW)	5.5	13.7	0.32	6.4		25.9
power consumption for CO <sub>2</sub> treatment [(kW h)/t of CO <sub>2</sub> ]	89	223	5	104		421
operating cost for CO <sub>2</sub> treatment (ind)/(\$/t of CO <sub>2</sub> )	7.9	19.9	0.55	9.3	15.0	22.6

<sup>a</sup> The ratio of the calcium in the waste cement utilized for the CO<sub>2</sub> treatment is 18.1%.

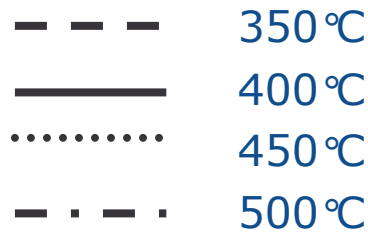
Iizuka et al., Ind. Eng. Chem. Res. 43 (2004)



# Gas-solid route: MSWI-f



Temperatures:



Species	Amount (% w/w)
Ca(OH) <sub>2</sub>	37.8
CaClOH	28.9
CaCO <sub>3</sub>	18.0
CaSO <sub>4</sub>	4.8

Bacocchi et al., Chem. Eng.J. (2008), submitted  
 Energy and Fuels 20, (2006)



# Patents on mineral carbonation

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- Toulhoat et al., (IFP, F) 2005 (EP)
- Geerlings et al., (Shell, NL) 2002 (WO), 2004 (US), 2006 (EP)
- Geerlings et al., (Shell,NL) 2007 (WO, US)
- Gorset et al., (Institut for Energiteknikk,NO) 2007 (WO)
- Park and Fan (Dinsmore & Shohl LLP,US) 2005 (US)
- Maroto-Valer et al., (Penn State Research Foundation,US) 2004 (WO),2005 (US)
- Blencoe et al.. (Battelle, US) 2004 (WO), 2008 (US)



# Patents on mineral carbonation

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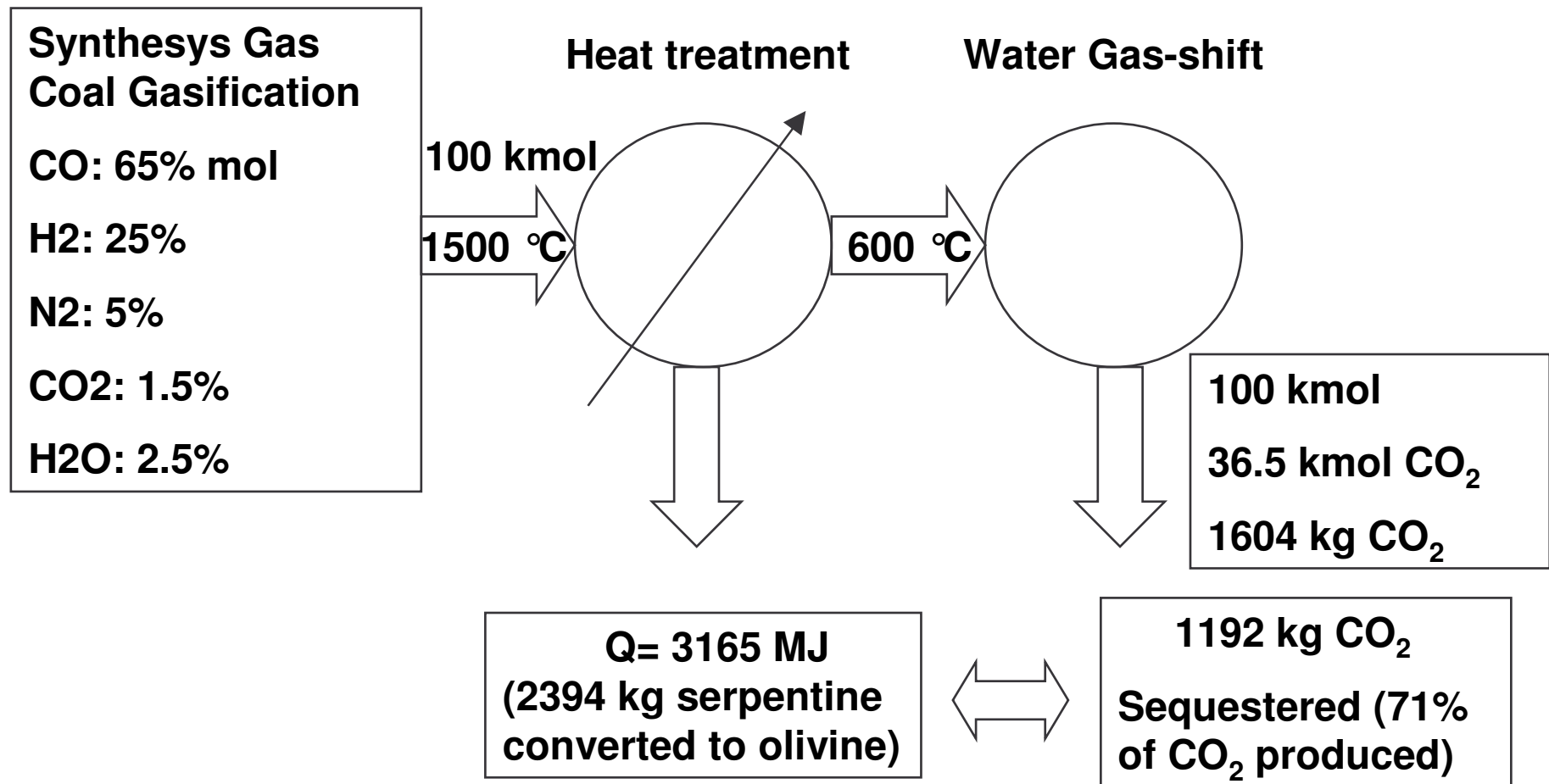
Geerlings et al., (Shell, NL) 2002 (WO), 2004 (US), 2006 (EP)

- **Aqueous mineral carbonation / Single step process with chemicals**
- **Materials:** orthosilicates, disilicates, cyclosilicates (forsterite, olivine, wollastonite, monticellite, diposide, enstatite) – phyllosilicates (sheet) / tectosilicates not suitable
- **Maximum average size:** 200  $\mu\text{m}$  (but  $> 10 \mu\text{m}$ ) / avoid excessive energy for grinding)
- Electrolyte aqueous solution (NaCl, KCl, BaCl<sub>2</sub>, NaNO<sub>3</sub>, KNO<sub>3</sub>, Ba(NO<sub>3</sub>)<sub>2</sub>) 0.1-2.0 M
- **Temperature:** 100-200 °C
- **CO<sub>2</sub> pressure:** 1-50 bar a; Total pressure: 1-150 bar a
- Reactor: Slurry bubble column / Extruder (just mentioned – no design given)
- Product use: construction materials: building blocks, paving stones, roofing tiles



# Patents on mineral carbonation

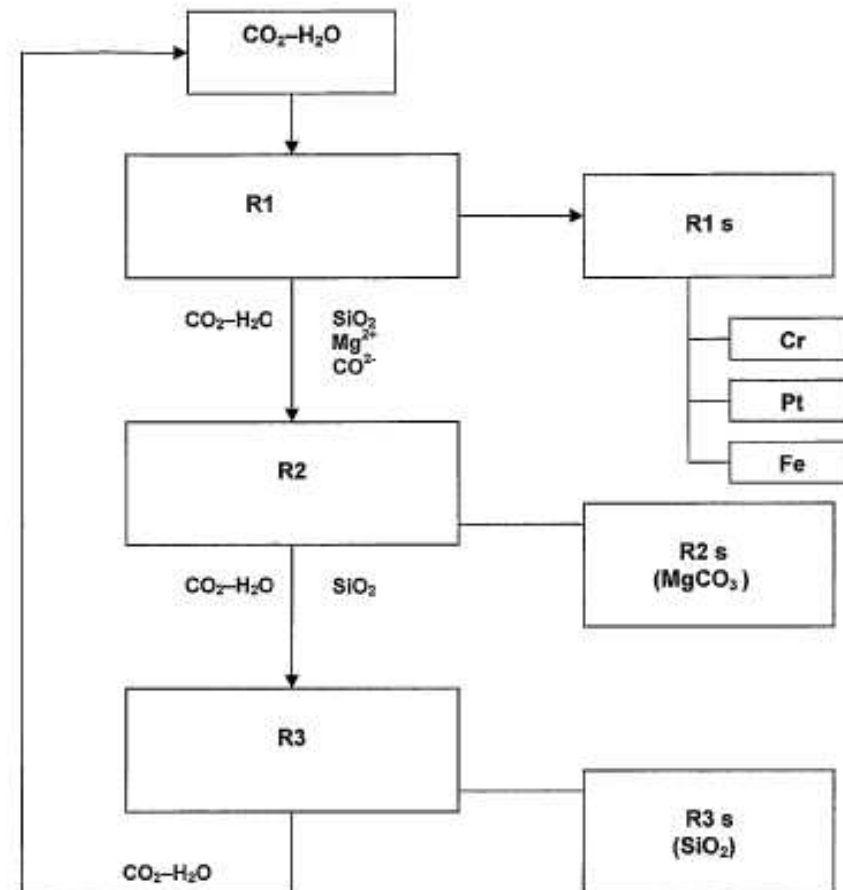
Geerlings et al., (Shell, NL) 2007 (WO,US)



# Patents on mineral carbonation

Gorset et al., (Institut for Energiteknikk,NO) 2007 (WO)

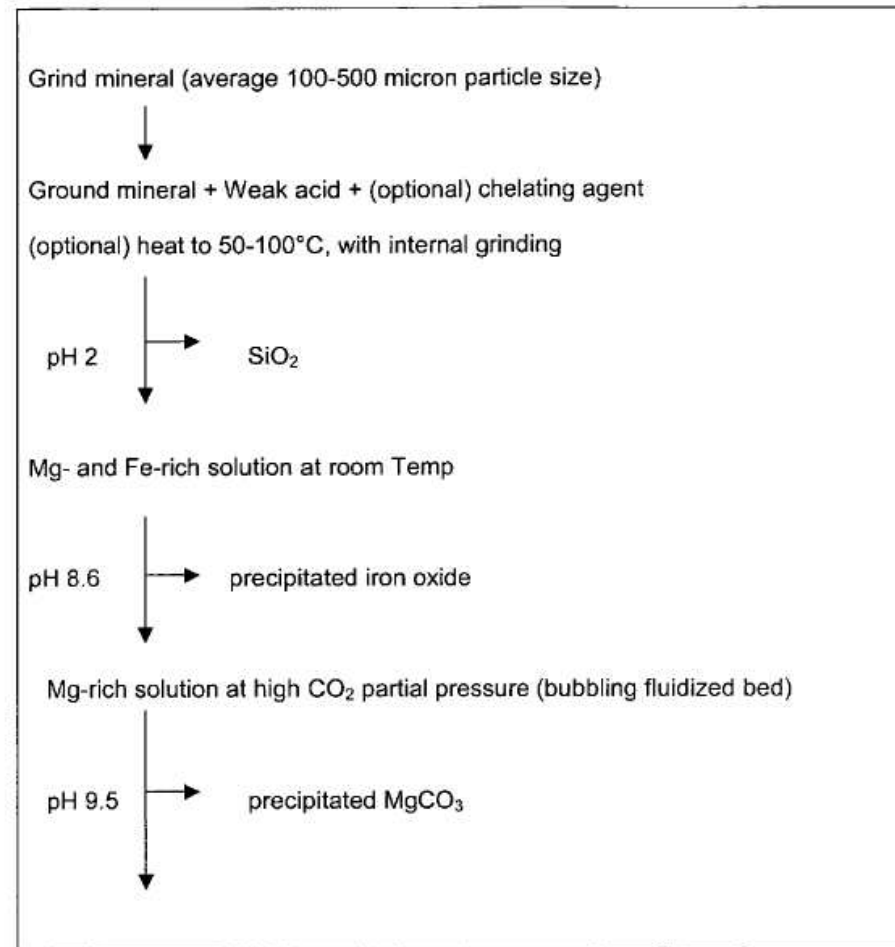
- The patent applies to olivine (forsterite)
- **Aqueous route /multi-step**
- **Pressure/Temperature swing**
- No chemicals addition
- **R1 – Dissolution**  
pH=3-5 P=50-150 bar / T= 100-170 °C
- **R2 – MgCO<sub>3</sub> precipitation**  
pH >> P= 50-80 bar / T= 140-250 °C
- **R3 – SiO<sub>2</sub> precipitation**  
T lower than in step R2



# Patents on mineral carbonation

## Park and Fan (Dinsmore & Shohl LLP,US) 2005 (US)

- **Aqueous route / Multi-step**
- **pH swing**
- Material: **serpentine**
- Slurry fluidized bed reactor
- Particle size: 100-500  $\mu\text{m}$
- Step 1: dissolution with weak acid
- Step 2: precipitation of iron oxide
- Step 3: precipitation of  $\text{MgCO}_3$
  
- **Conditions same as in the literature**





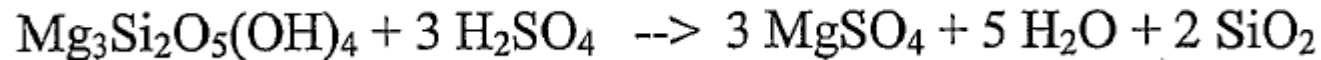
# Patents on mineral carbonation

Maroto-Valer et al., (Penn State Research Fundation,US) 2004 (WO),2005 (US)

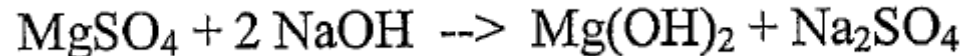
- **Aqueous mineral carbonation / Two step process**

- Materials: olivine, serpentine, waste cement) 70-150  $\mu\text{m}$

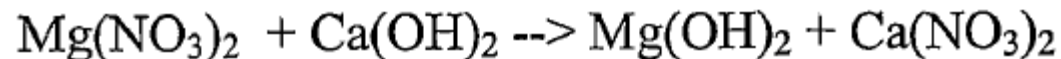
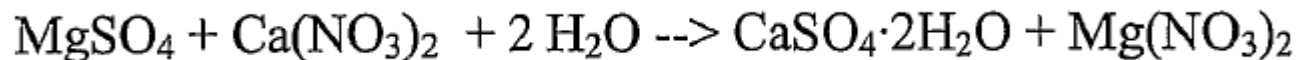
- Step 1: chemical activation with an acid:  $T=15 - 75^\circ\text{C}$ ; 3-12 hours time



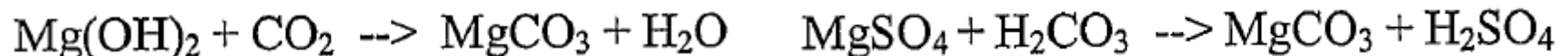
- Step 2a: Use of a base (KOH, NaOH,  $\text{NaHCO}_3$ , Acetates, Formates (pH=7-14)



- Step2b: addition of  $\text{Ca}(\text{NO}_3)_2$



- Step 3: Mg carbonate precipitation and acid recovery (reaction with  $\text{CO}_2$ )



# Patents on mineral carbonation

Toulhoat et al., (IFP, F) 2005 (EP)

- **Aqueous mineral carbonation / Multi step process**

- **Step 1:** CO<sub>2</sub> concentration in liquid phase

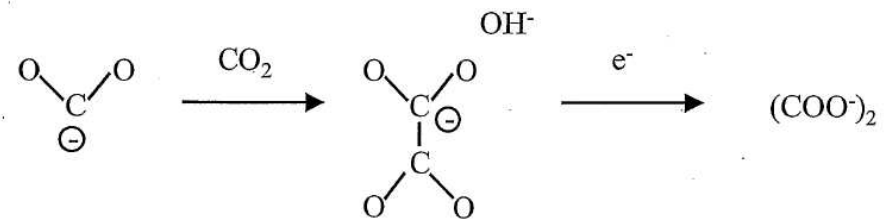
a) CO<sub>2</sub> liquifaction: a liquid CO<sub>2</sub> stream is obtained

b) absorption of CO<sub>2</sub>: polar liquid, ionic liquid, amine, liquid with enzymes: a CO<sub>2</sub> solution in an aprotic polar liquid is obtained

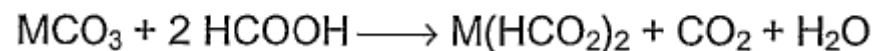
Milieux non-aqueux (électrode Pb, Tl ou Hg) : on forme de l'acide oxalique

- **Step 2:** Electro-reduction in an aprotic liq

pH=3-5, Anode V= 0.5-3.5 V(H<sub>2</sub>)



- **Step 3:** Back extraction of oxalic/formic acid into the aqueous phase (optional, if step 2 was made in a non aqueous phase)
- **Step 4:** Mineralization by reaction of a metal (M=Ca,Mg) carbonate with the acid:



# Mineral carbonation – Costs

Costs mineral carbonation (€/ton CO <sub>2</sub> avoided)	Feedstock	Process route <sup>a</sup>	Extraction agent
93	Wollastonite	Direct	Water
102	Wollastonite	Direct	Water
77	Steel slag	Direct	Water
65	Olivine	Direct	Water <sup>b</sup>
258	Serpentine <sup>c</sup>	Direct	Water <sup>b</sup>
95 <sup>d</sup>	Mg-silicate	Direct	Molten MgCl <sub>2</sub>
25 <sup>e</sup>	Waste cement	Indirect	Water
57 <sup>e</sup>	Wollastonite	Indirect	Acetic acid
>150	Mg-silicate	Indirect	HCl
<i>Other CCS-technologies [€/ton CO<sub>2</sub> injected]</i>			
	<i>Storage type</i>	<i>Costs type</i>	
0.5–7	Geological	Storage	
0.1–0.3/yr		Monitoring costs	
4–25	Oceanic		

- Direct (single-step) route less expensive than indirect (multi-step)
- Use of solid residues make the process more competitive
- Mineral carbonation costs are still much higher than other storage options
- These are 2006 costs, which should be updated in view of commodities price increase.

Huijgen et al., Energy, Conversion and Mgmt (2006)



# Conclusions

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## Pro

- **CO<sub>2</sub> stored in a safe and definitive manner**
- **CO<sub>2</sub> storage potential basically unlimited**
- **It can be done with existing technologies**
- **Ca-silicates/Residues carbonation at relatively mild conditions**
- **Industrial residues are a start-up option**

## Cons

- **Energy penalty and associated costs still too high**
- **Mg-silicates carbonation needs energy intensive pre-treatment**
- **Many process issues still unresolved**
- **Lack of demonstration units (pilot-scale)**



# **Aqueous carbonation – Challenges**

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## **COMBINATION OF DISSOLUTION AND PRECIPITATION**

- a) Dissolution and precipitation steps handling and coupling**
- b) Single-step: methods to match proper dissolution and precipitation conditions**
  - more fundamental study on dissolution and precipitation**
- c) Two-steps: methods for switching conditions and the issue of chemicals recycle**
  - more fundamental study on dissolution and precipitation**
  - investigation on new dissolution / recycle routes**



# **Aqueous carbonation – Challenges**

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## **FUNDAMENTALS OF DISSOLUTION**

- a) Key factors controlling dissolution: pH, ionic strength, etc.**
- b) Routes for mineral activation: chemical, mechanical, thermal**
- c) Routes for dissolution enhancement: strong/weak acid/base, chelating agents, pressurized CO<sub>2</sub>**
- d) Hindering effects on dissolution: silica layer formation, etc.**



# Aqueous carbonation – Challenges

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## FUNDAMENTALS OF PRECIPITATION

- a) Factors affecting nucleation rate: pH, ionic strength, T, P, etc.
- b) Routes for nucleation enhancement: seeding, electrolytes addition, etc.
- c) Conditions to be met to drive precipitation to the desired product when more than one carbonate (i.e. magnesite or hydromagnesite) can be formed
- d) Location of precipitate formation: on the mineral, separated, with silica.



# **Aqueous carbonation – Challenges**

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## **DESIGN OF PILOT / DEMO SCALE INSTALLATIONS**

- 1. Selection of the material (possibly a first generation plant should be based on industrial residues rather than on minerals: steel slags or waste cement could be proposed)**
- 2. Selection of the most suitable carbonation route to be followed**
- 3. Optimization of the operating conditions**
- 4. Design of the reactor with choice of the flow regime:**
- 5. Design of ancillary equipments**
  - a) Pre-treatment of the alkaline material (residue/mineral): grinding, sieving, thermal treatment, chemical treatment;**
  - b) Post-treatment of the carbonation product: solid separation**
  - c) Post-treatment of the mother liquor (if present)**



# **Aqueous carbonation – Challenges**

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## **INTEGRATION OF THE INSTALLATION**

- 1. Life-cycle assessment of the carbonation process, from source materials to end use or storage**
- 2. Environmental aspects in the full chain**
- 3. Integration in a low-carbon economy, synergy between processes (for instance the Shell patent where IGCC and mineral carbonation are integrated gives a good example)**



# Upcoming events

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## **2<sup>nd</sup> International Conference on: Accelerated Carbonation for Environmental and Materials Engineering**

***Rome, 1-3 October 2008***

**<http://w3.uniroma1.it/ACEME>**

