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Insights into research on carbon capture and storage

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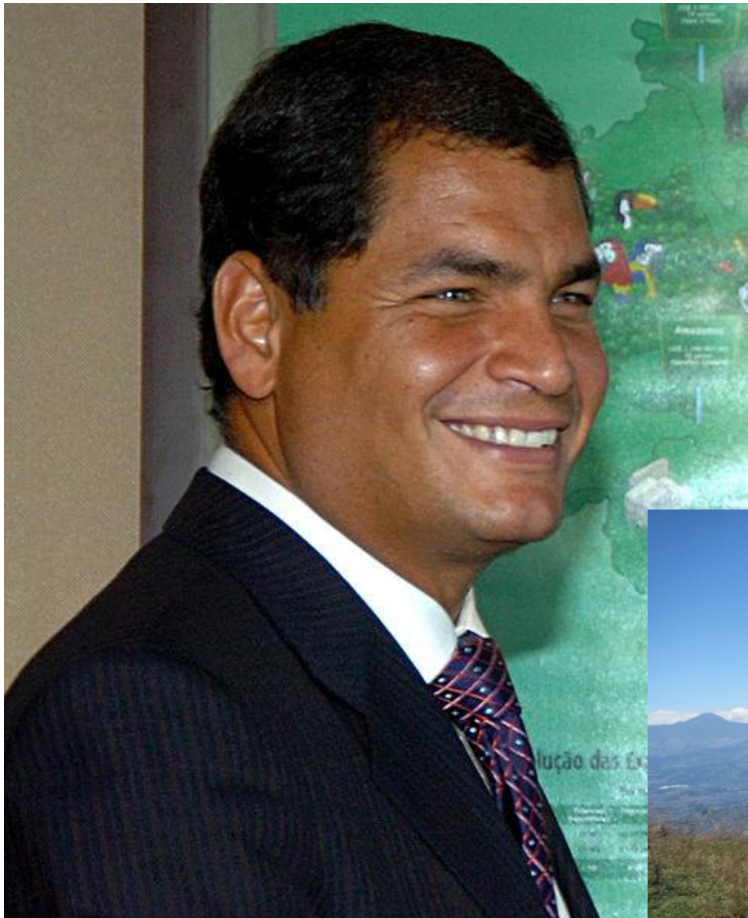

R. Correa

J. Bilbao, H. Fischer

The starting point…

- Climate change
- Greenhouse gas emissions
- Energy demand and supply

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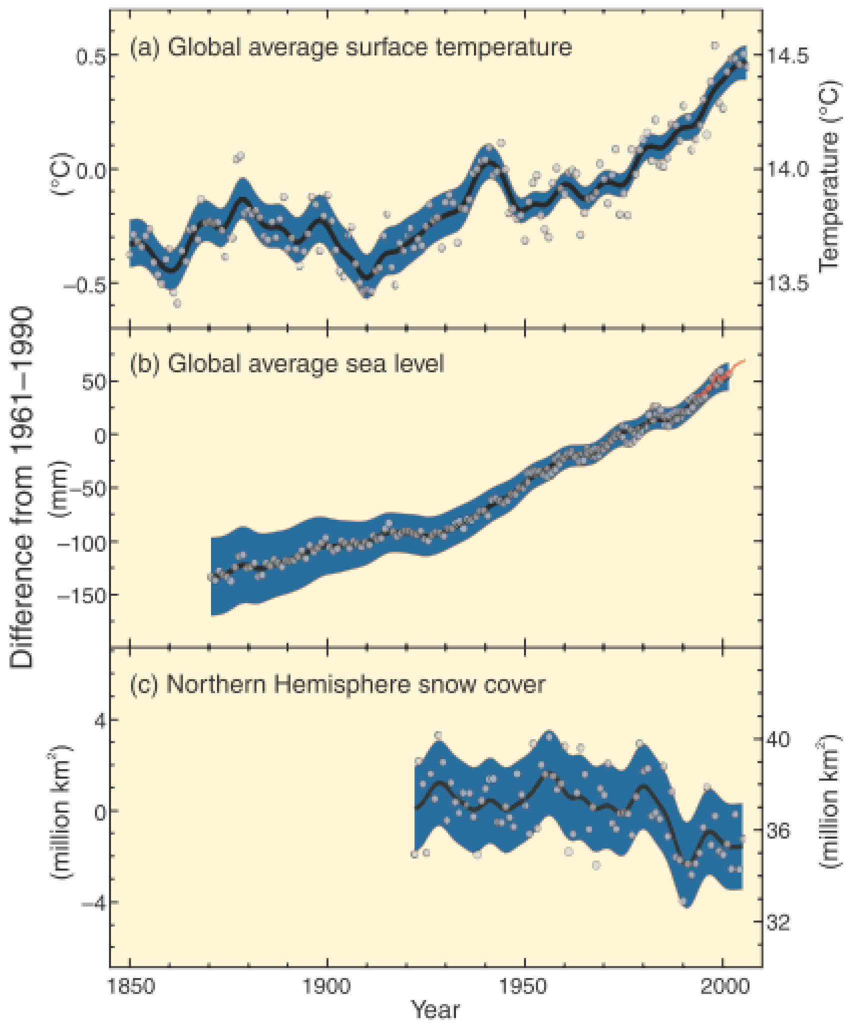
Global Warming



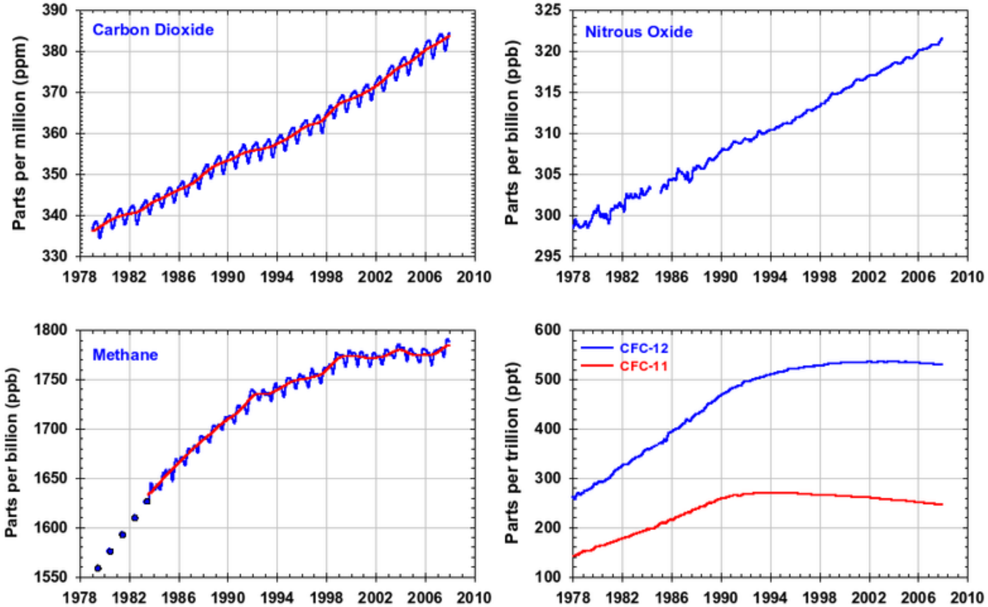
- Of the 12 warmest years ever recorded (~1850) 11 were in the last 2 decades

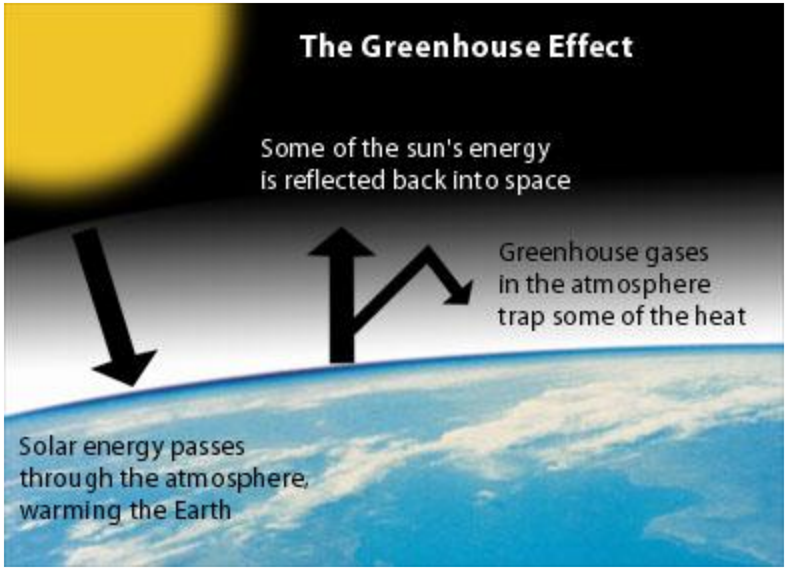
IPCC

Greenhouse effect

"Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas (GHG) concentrations."

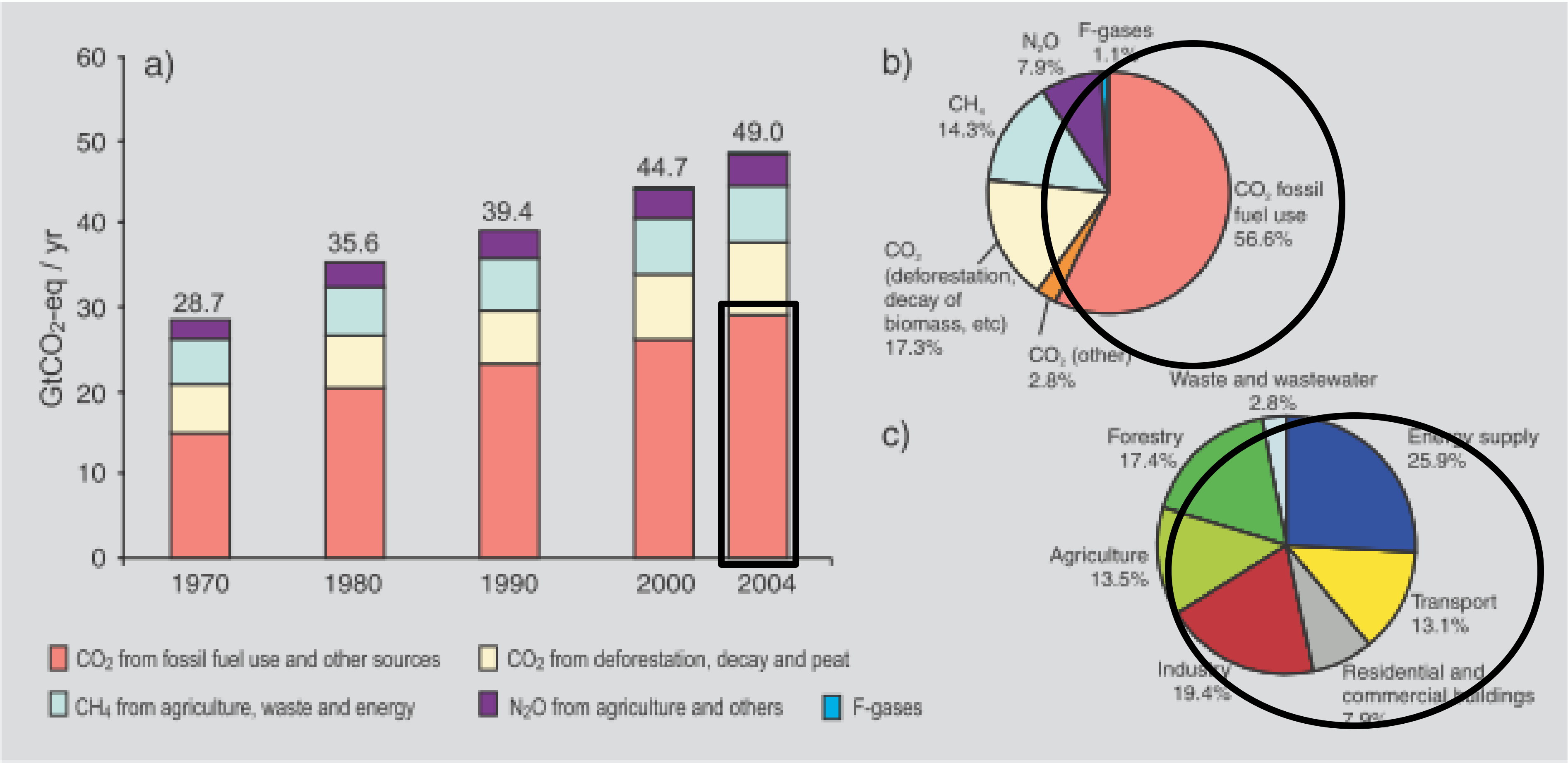
IPCC synthesis report 2007





Source: http://www.esrl.noaa.gov/gmd/aggi/

Global anthropogenic GHG emissions



IPCC

Kyoto political aims

- Restriction of global warming to less than 2 °C
- Drastic reduction in CO_2 emissions
- Energy demand rises (Factor 2 until 2100)
- Largest increase in developing countries

Why CO_2?

- Low global warming potential, but:

  - Long lifetime within the atmosphere
  - High emissions current emissions
  - Increasing emissions due to rising energy demand:

- Highest radiative forcing (about 2/3)
- Emission from point sources

Situation in Germany

- CO_2 from power generation: ~0,35 Gt/a
- Total CO_2 emissions: ~ 0,8 Gt/a

- Reduction aims:
- -40 % by 2020
- -80% by 2050

- Reinvestment in energy production

Energiekonzept 2010, SRU Gutachten CCS

Options to reduce CO_2 emissions

Efficiency

Costs

Nuclear

Acceptance?
Waste storage?

Renewable

Expansion
Power grid?
Buffering?

Fossil with CCS

Costs
Storage savety?

Contents

- Background
- Overview on CCS
- ALCATRAP: Mineral CO2 binding
- Final remarks

The three steps of „classic“ CCS

Flue gas CO_2

→ **Capture**

Purified CO_2

→ **Transport**

Purified CO_2

→ **Storage**

Stored CO_2

The three steps of „classic“ CCS

Flue gas CO_2

→ **Capture**

Purified CO_2

→ **Transport**

Purified CO_2

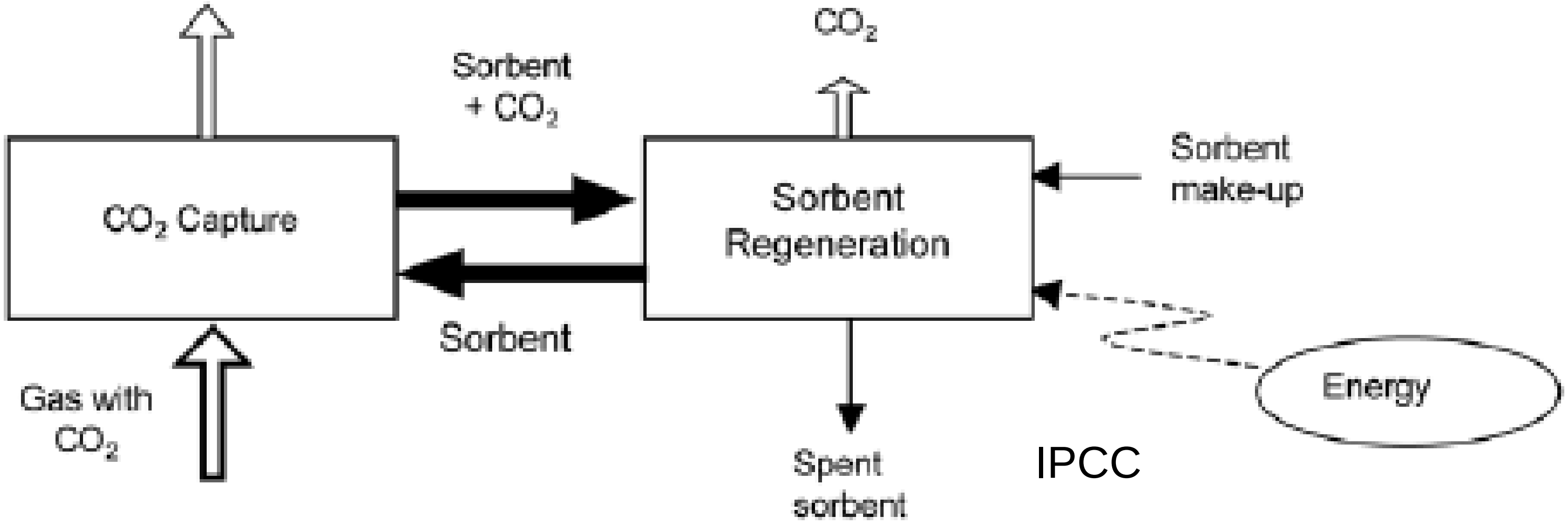
→ **Storage**

Stored CO_2

- Capture options
  - Post combustion
  - Pre combustion
  - Oxyfuel

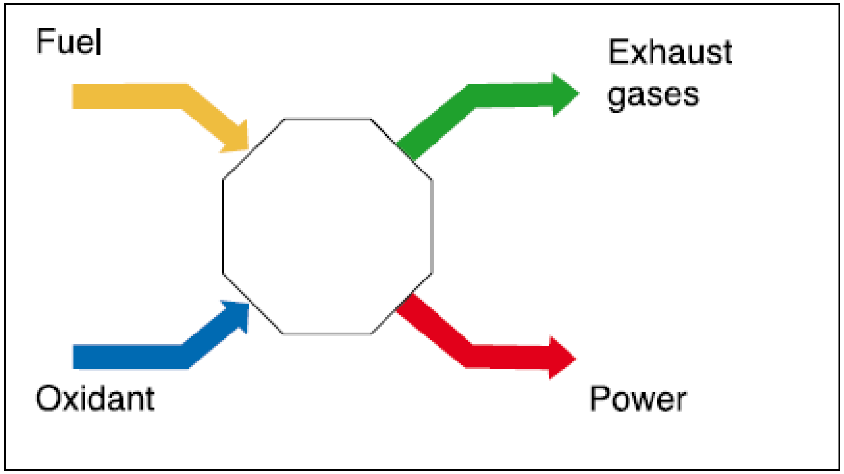
The CO2 capture step

- CO_2: 8-16 % => > 85 %
- Amines etc. as sorbents (recycling!)
- Volume decrease: Purification and compression

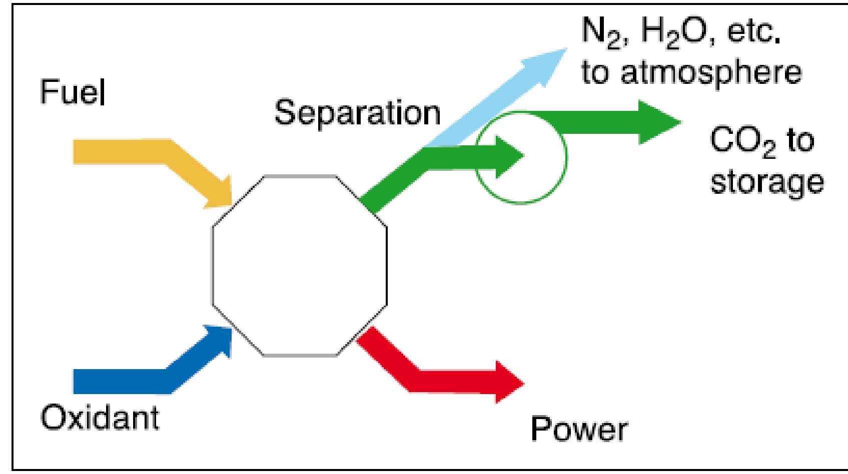


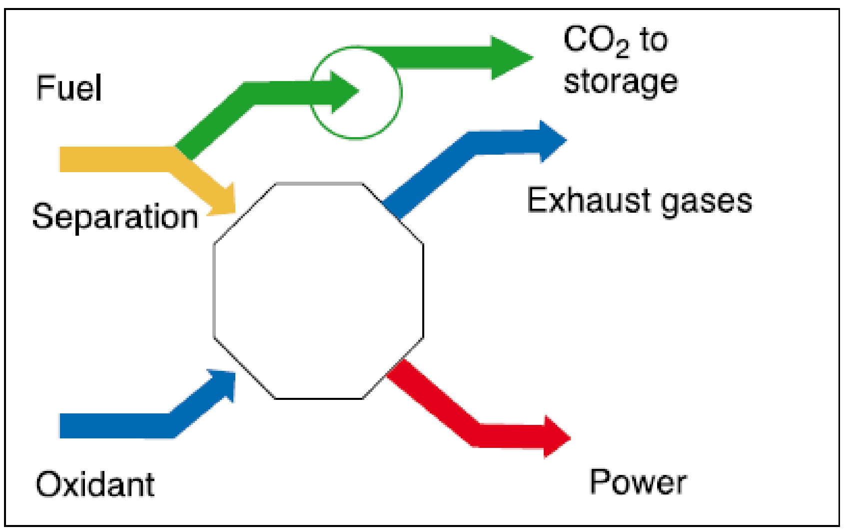
IPCC

Fossile fuel based power generation

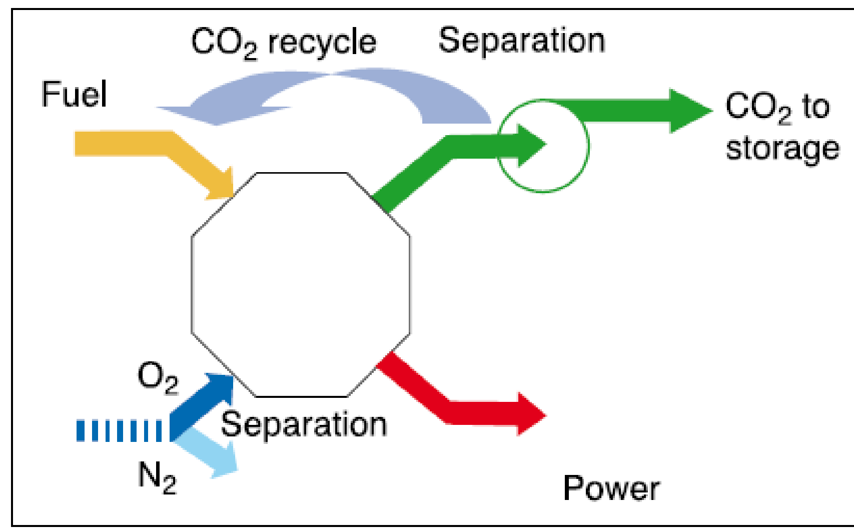


Post-combustion capture





Pre-combustion capture: H2, Fuels



Oxyfuel: Pure O2

IPCC

Summary CO2 capture

- Post combustion is available technology
- (Alternatives in demonstration)
- Up scaling, optimization
- Retrofitting

- Energy required: Efficiency loss of ~10-40 %

  - Power plant efficiency without CCS: 35 – 55%
  - Power plant efficiency loss: 8 to 15 %

The three steps of „classic“ CCS

Flue gas CO_2

→ Capture

Purified CO_2

→ Transport

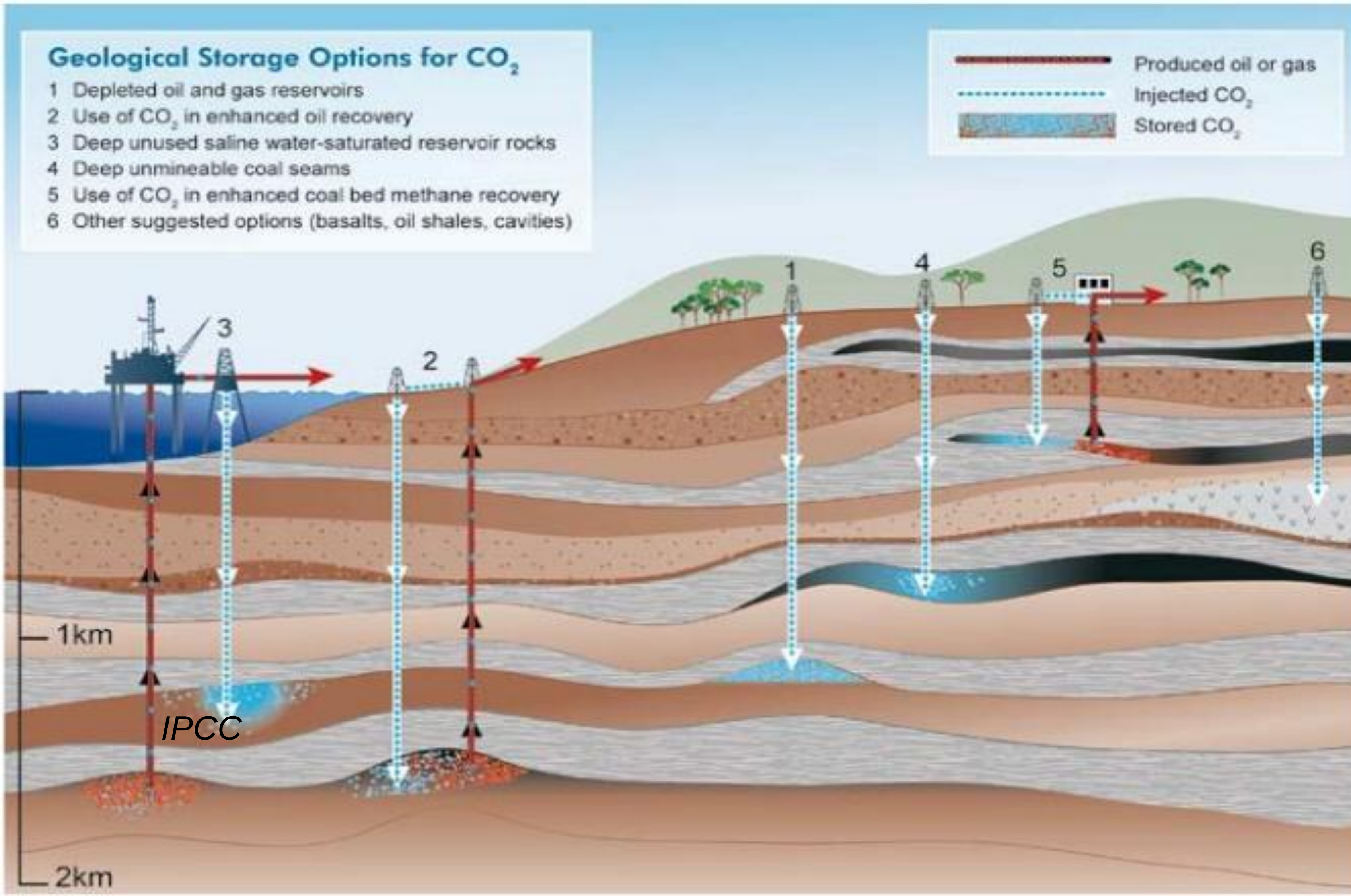
Purified CO_2

→ Storage

Stored CO_2

- Storage options
  - Geological (CCGS)
  - Ocean (CCOS)
  - Minerals (CCMS?)
  - CO2 Utilization

Geological storage



Geological storage capacity

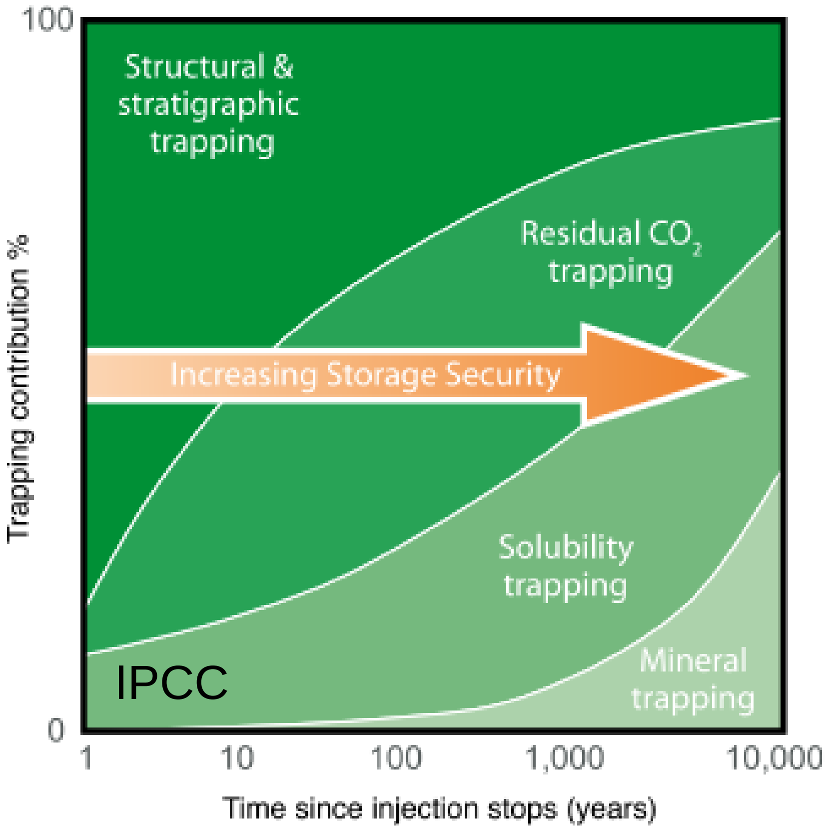
- Theoretical storage capacities

	Lower estimate GtCO2	Upper estimate GtCO2	Germany GtCO2
Oil and gas fields	674	900	~2,7
Coal seams	3-15	200	?
Deep Saline aquifers	1000	Possibly 10^4	~20

- World emissions ~ 8 GtCO2/a from power
- Germany ~0,35 GtCO2/a from power
- Reach: 40 – 100 a

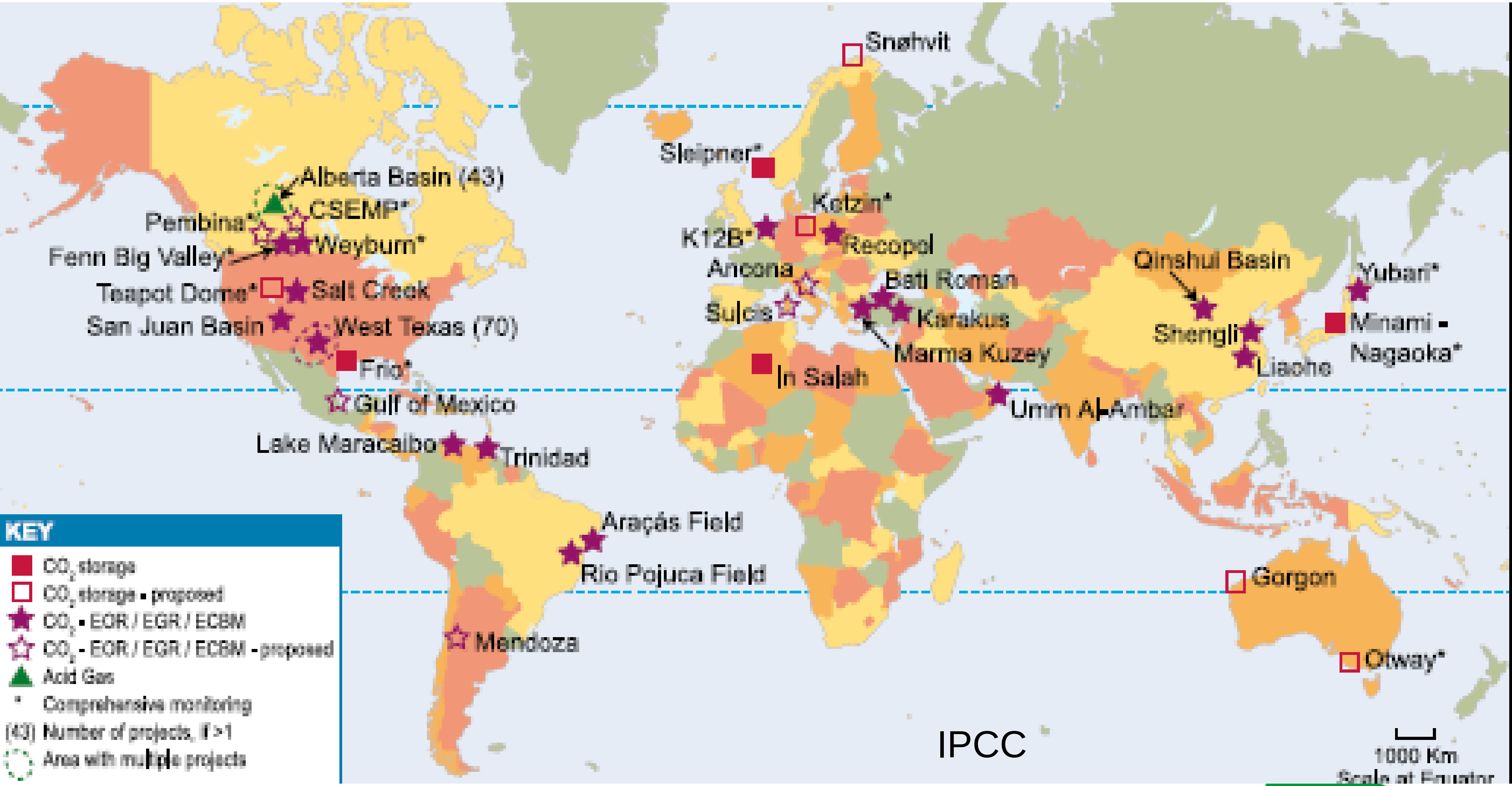
Processes in the formation

- Physical:
  - Trapping below cap rock
  - Hydrodynamic trapping
- Chemical:
  - Dissolution
  - Reaction



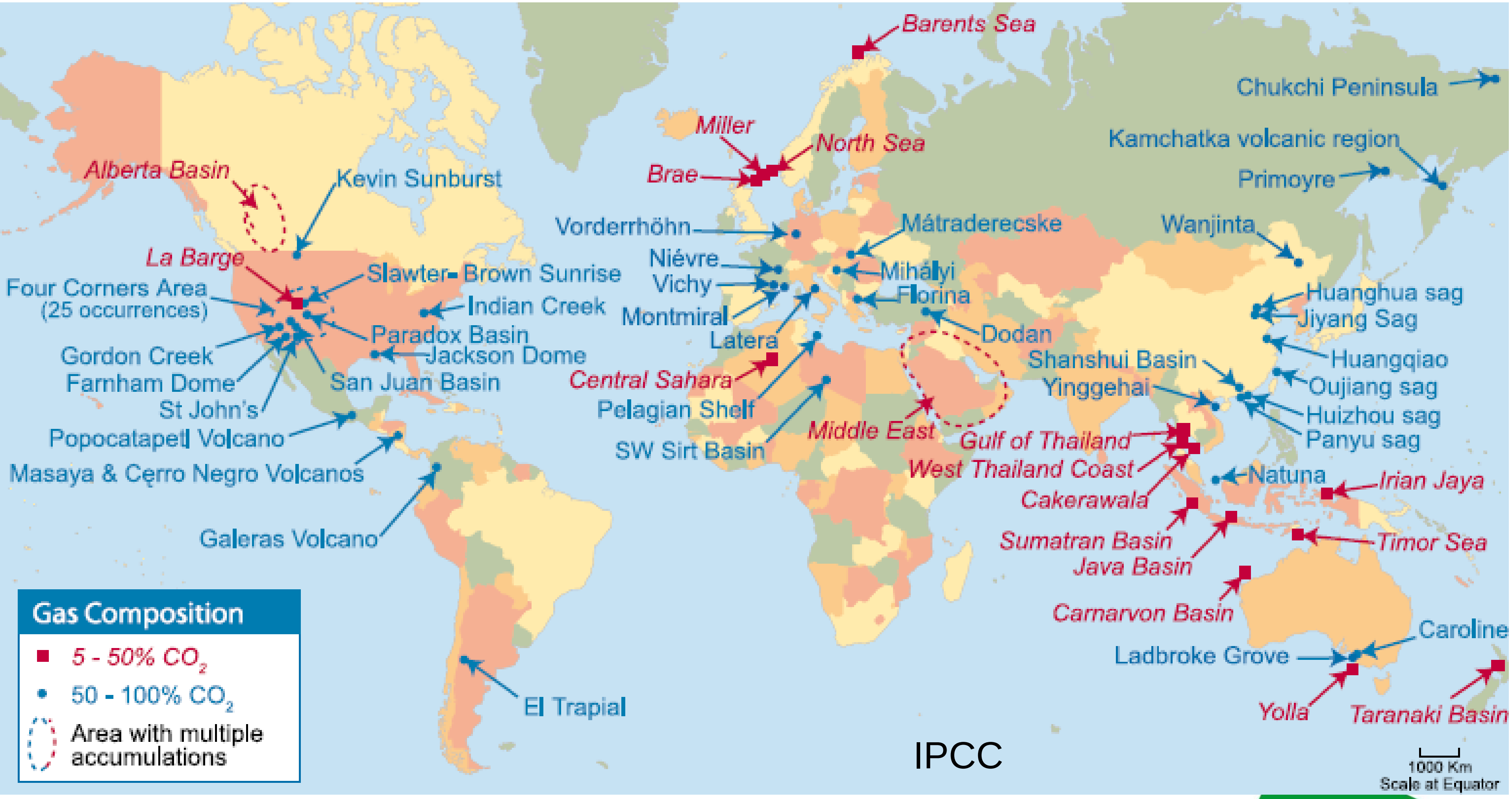
- Safety of storage is expected to increase over time

„Storage“ sites



IPCC

Natural analogues



IPCC

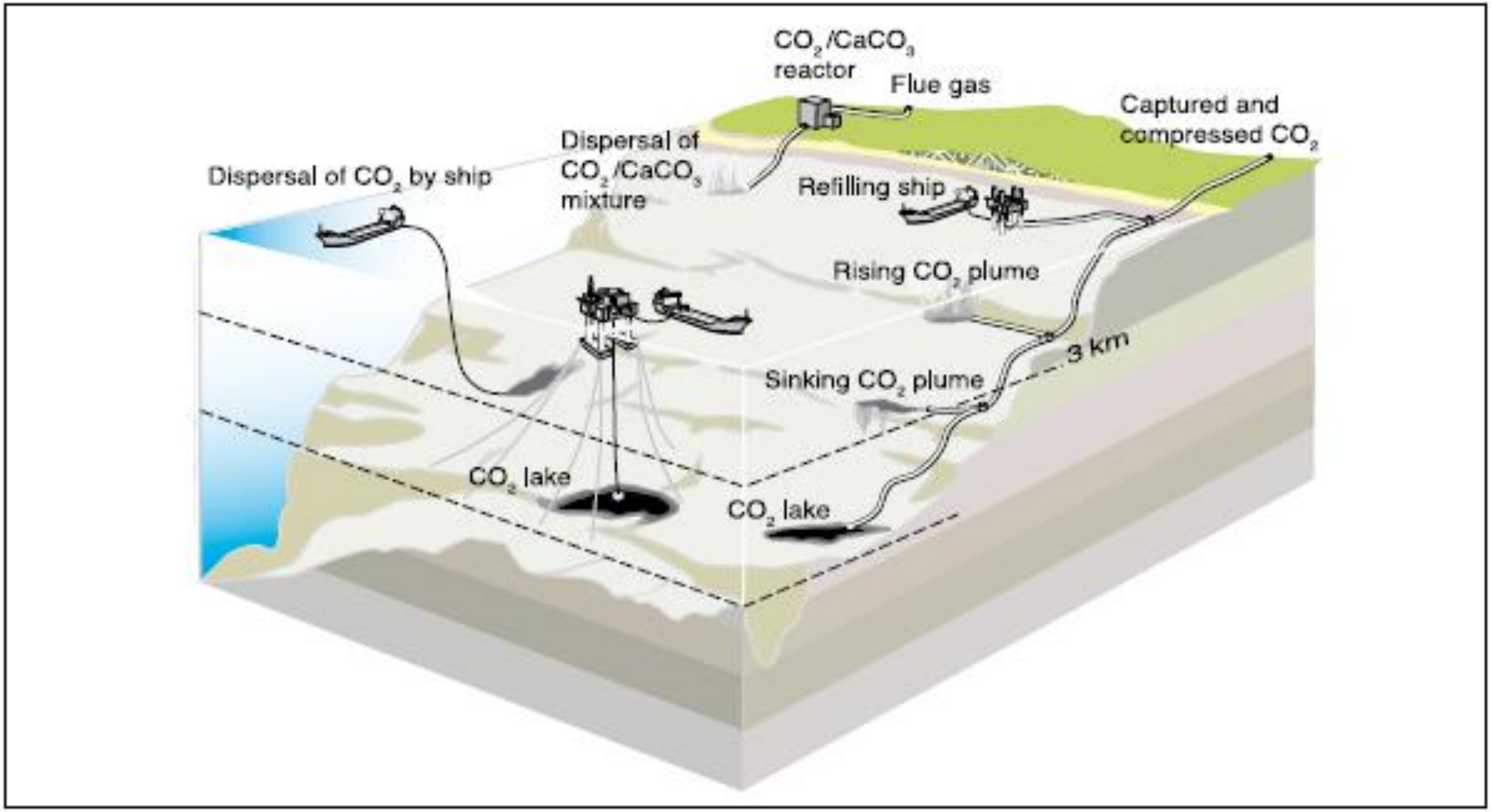
Geological storage risks

- Leakage
  - Gaps or faults in cap rock
  - Bore holes
  - Pressure or reactions weaken cap rock

  - STORAGE FAILED!!!
  - Affected groundwater (pH, metal mobility)
  - Toxicity

- Individual assessment and selection of sites

Ocean storage - +/- given up

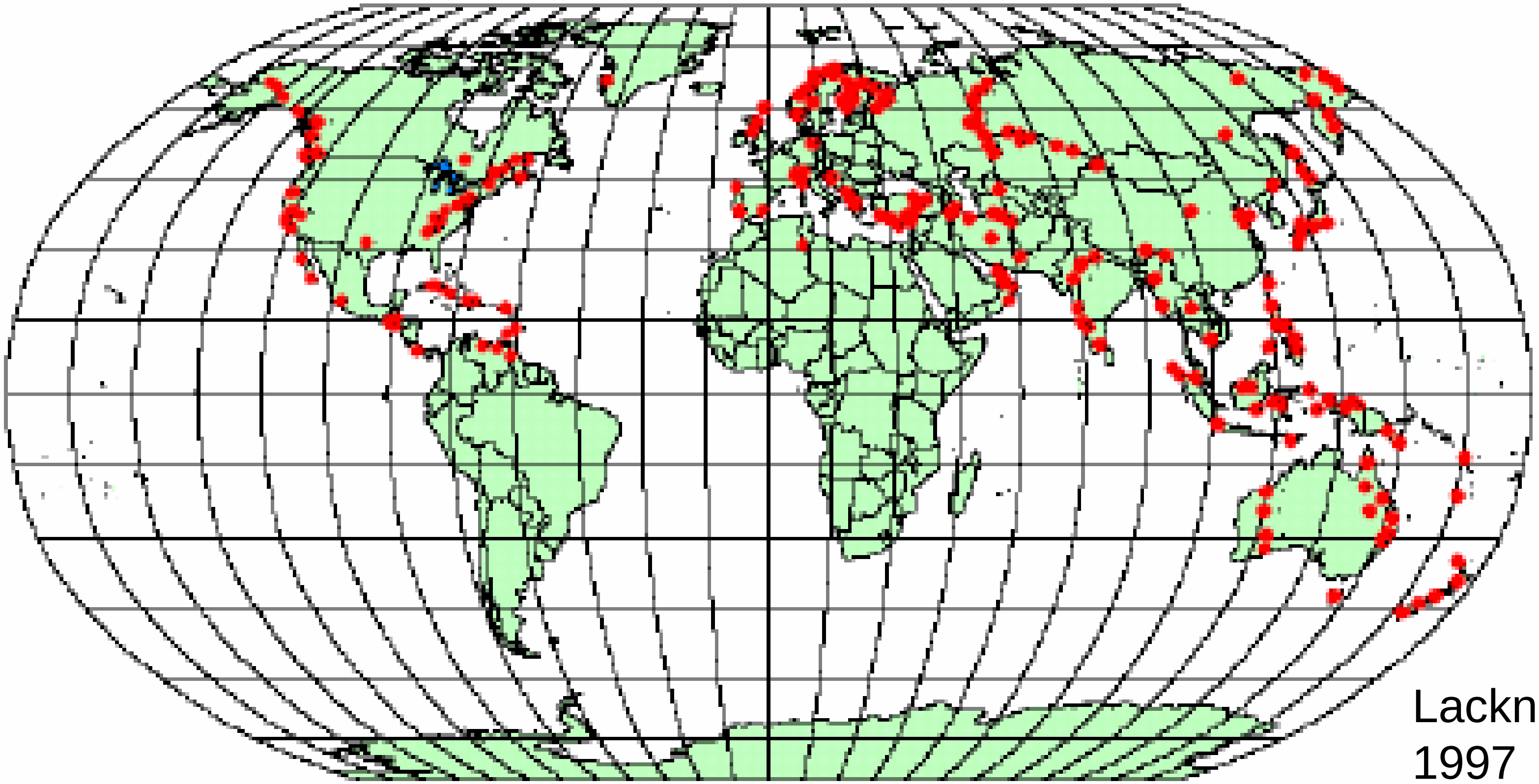


Mineral Trapping of CO_2

- Natural process
  - CO_2 uptake estimate: up to 0,1 Gt C/a
- Longtime stability of the product
- Unlimited pool of reactive materials

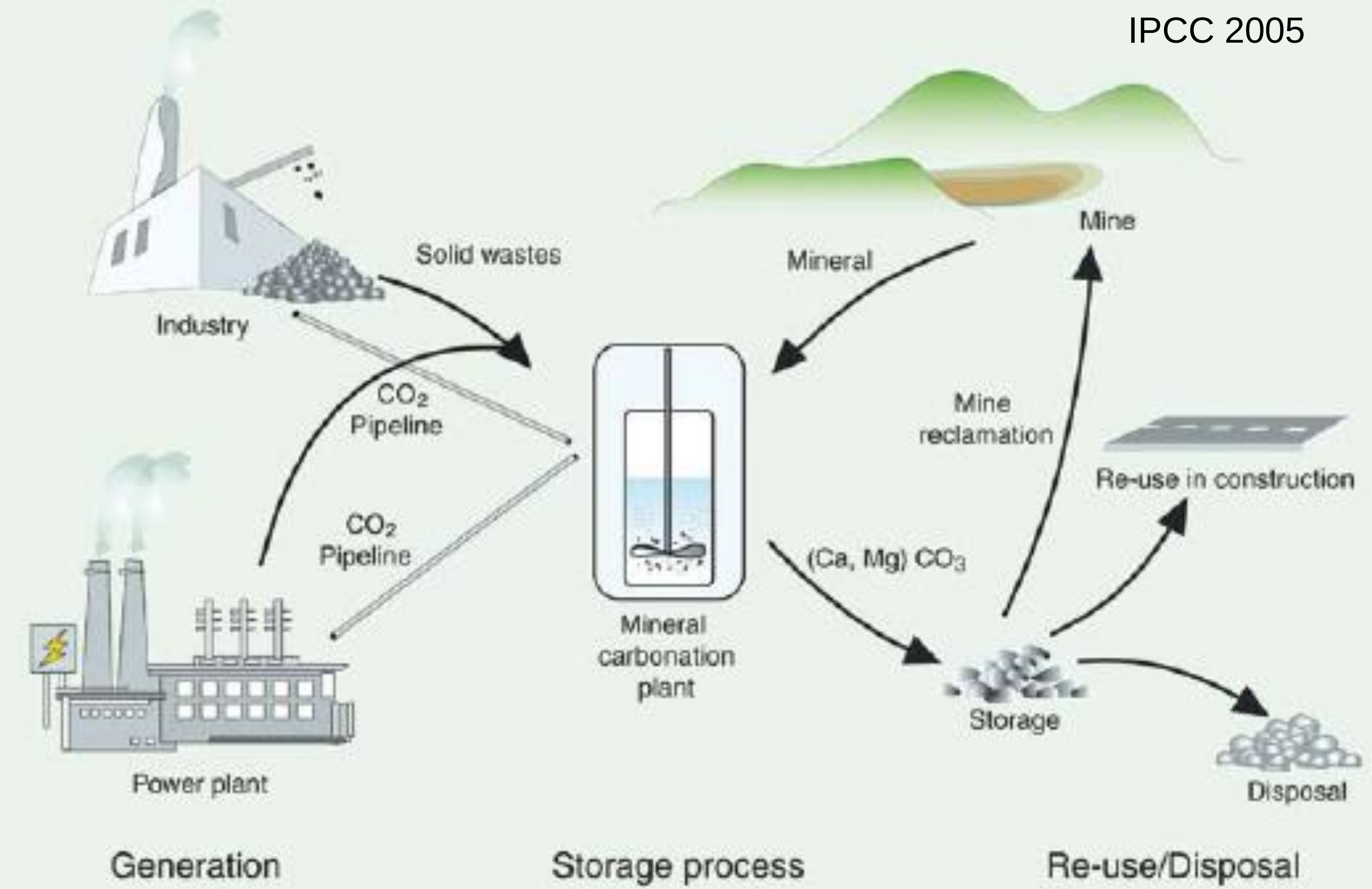
- Flaws:
  - Slow mineral reaction
  - Slow CO2 transport

Availibility of Mg silicates



Lackner et al 1997

IPCC 2005


Solid wastes
Mineral
Mine
Industry
CO_2 Pipeline
CO_2 Pipeline
Mine reclamation
Re-use in construction
(Ca, Mg) CO_3
Mineral carbonation plant
Storage
Power plant
Disposal
Generation
Storage process
Re-use/Disposal

Mineral Carbonation

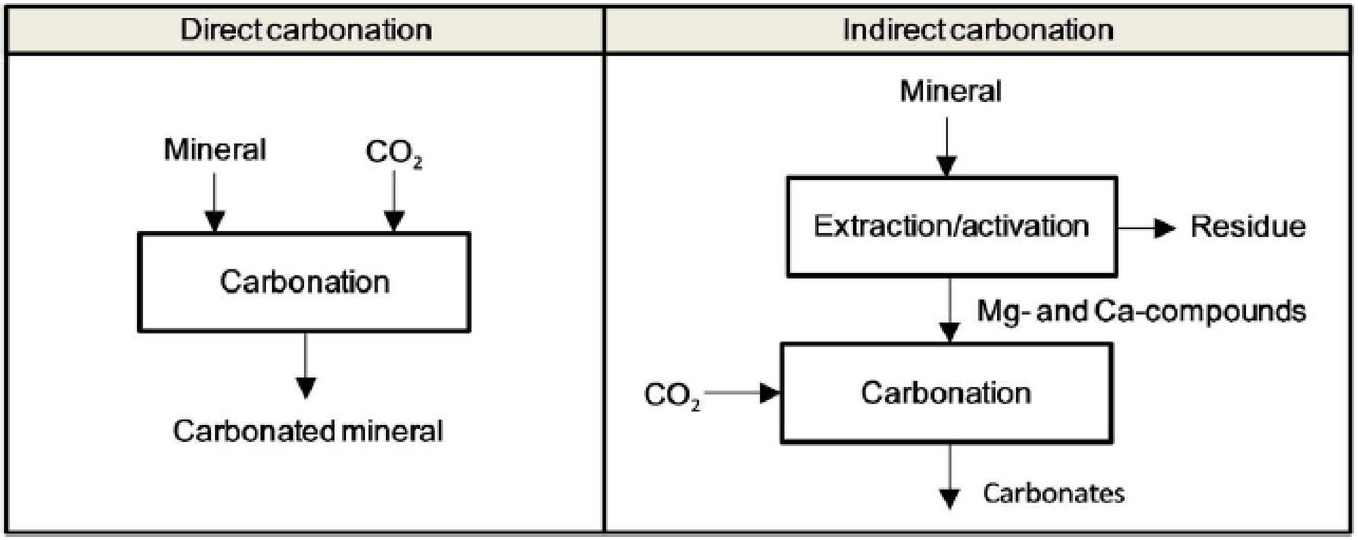
$$Mg_2SiO_4 + 2CO_2 = 2MgCO_3 + SiO_2$$

$$CaO + CO_2 = CaCO_3$$

	Natural minerals	Alkaline wastes
Capacity	+	-
Reactivity	-	+
Pretreatment, Transport	-	+
Waste utilization		(+)

Ex situ mineral carbonation

- Mining, pre-treatment
- Carbonation: Exergonic but slow!
- Dry at high T and p
- Wet system at low T
- Product: 0,35 Gt CO2/a = 0,7 Gt $MgCO_3$/a



Summary Storage

- Still different storage option discusse
- Theoretically > 100 a of storage capacities in geological storage
  - Risk assessment for reservoirs
- „Unlimited“ storage capacity in mineral carbonation
  - Exergonic but slow reaction: Technical issue
  - Product?

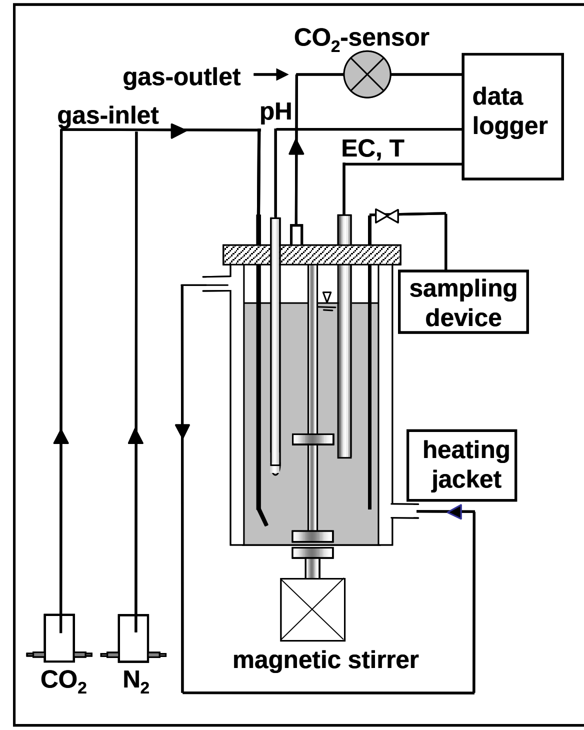
ALCATRAP – Carbonation of alkaline industrial wastes

Source material in Germany

- Alkaline waste production in Germany annually
  - Lignite combustion ~10-15 Mt/a
  - Steel making residues ~10 Mt/a
  - Other sources (Small power plants, …)

- Direct carbonation ex situ at power plant
- Ambient T and p
- Untreated flue gas as source of CO_2

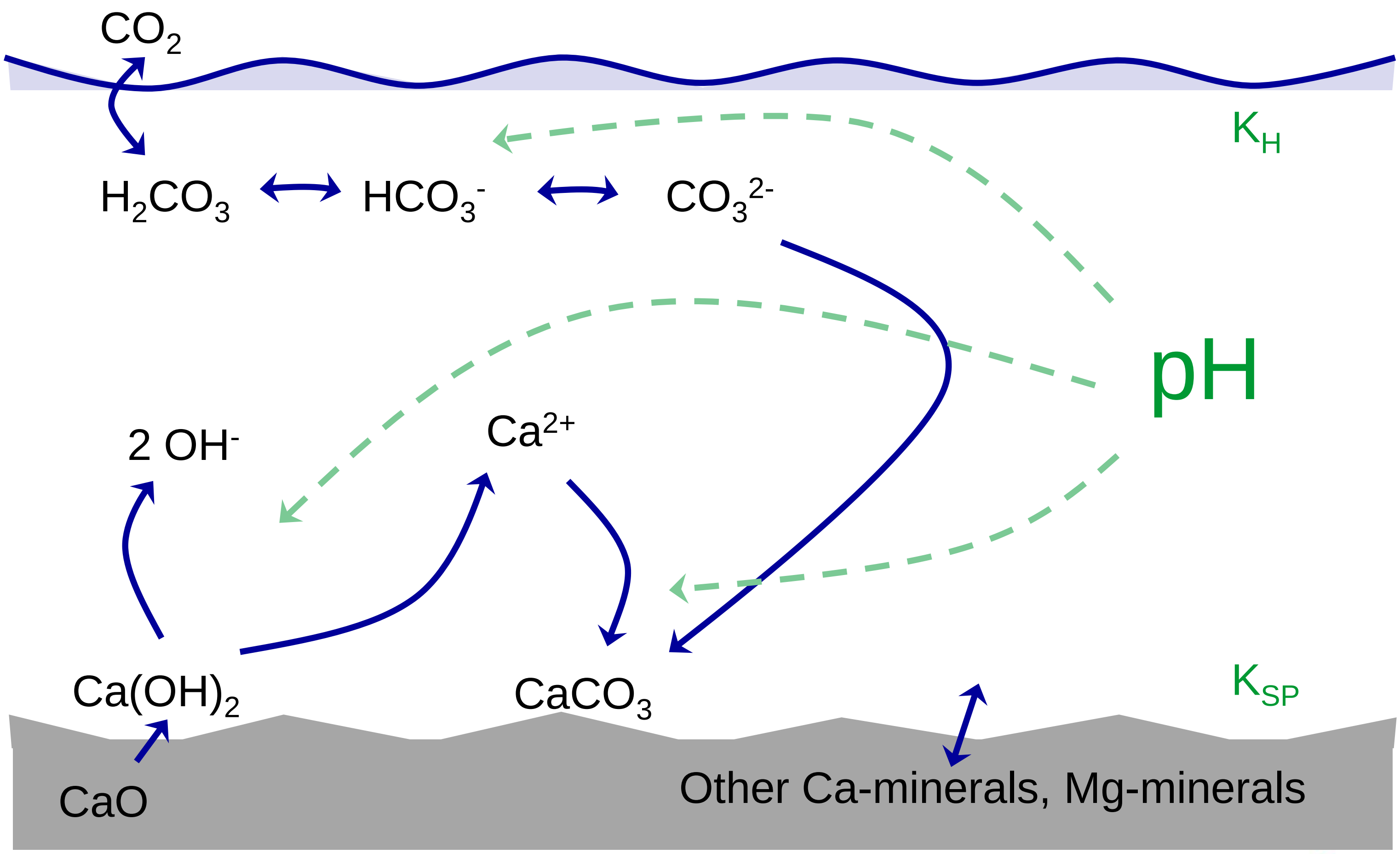
„ALF“ - Aqueous Laboratory Reactor



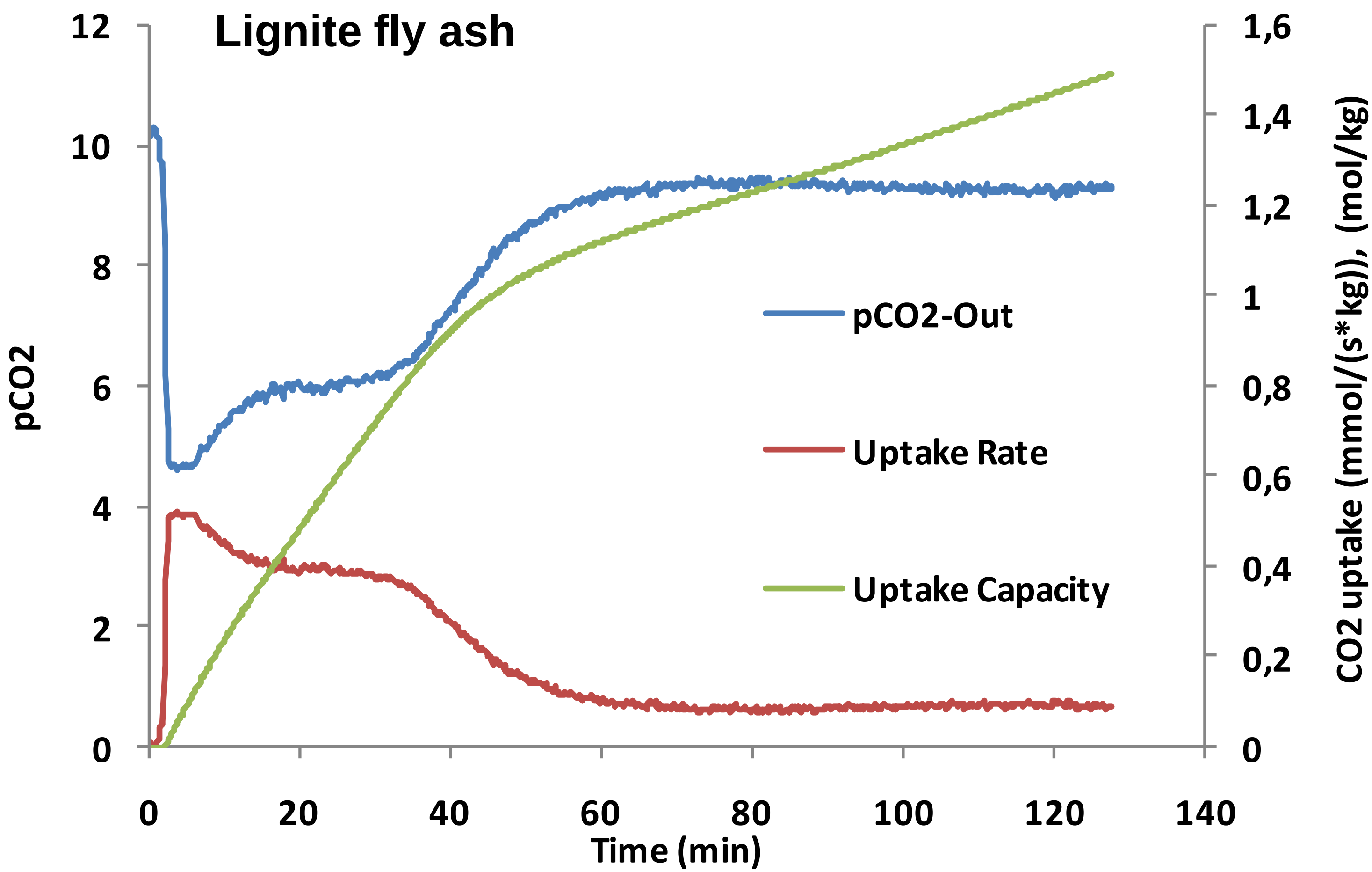
Online data: pH, EC, T, Q(gas), pCO2 (out)

Sampling data: Dissolved species (TDIC, metal, sulfate)
Suspended solid phases (carbonate)

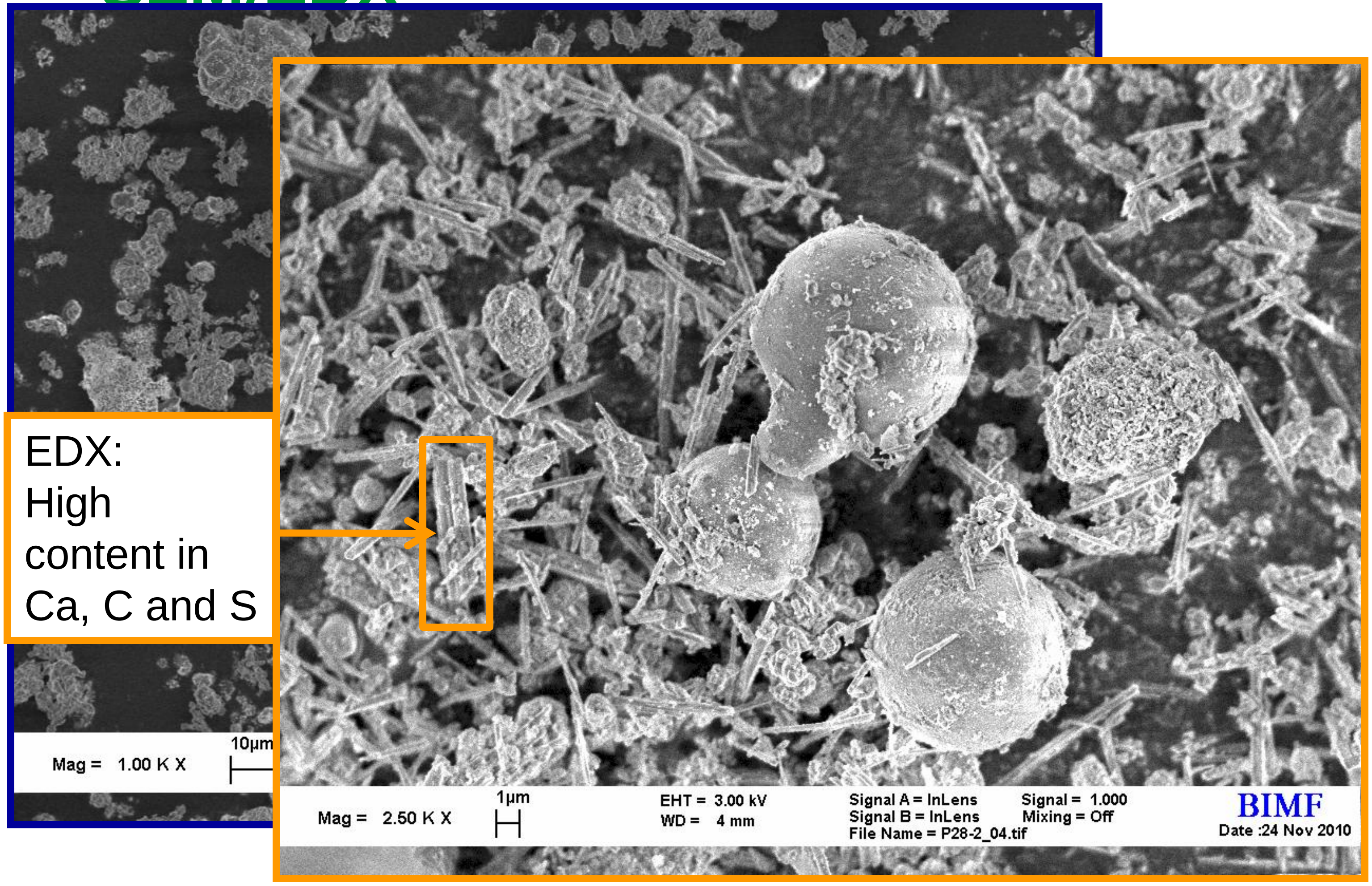
Reactions


CO_2
K_H
H_2CO_3
HCO_3^-
CO_3^{2-}
pH
2 OH^-
Ca^{2+}
$Ca(OH)_2$
$CaCO_3$
K_{SP}
CaO
Other Ca-minerals, Mg-minerals

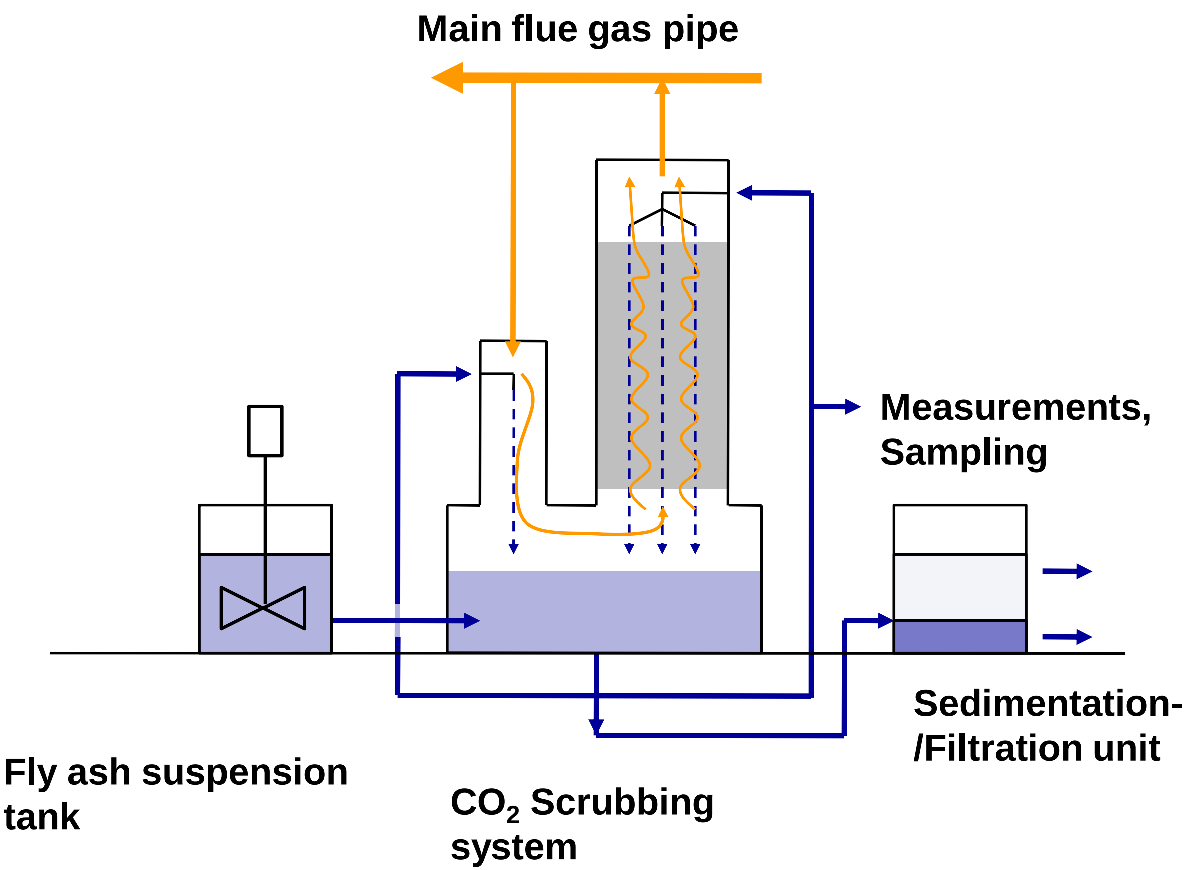
CO_2 uptake in aqueous reaction system

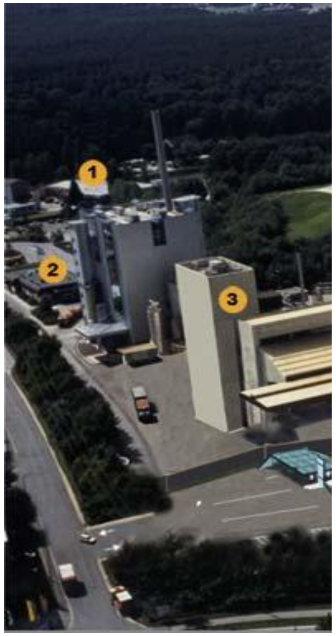


SEM/EDX


EDX:
High content in Ca, C and S
Mag = 1.00 K X
10µm
Mag = 2.50 K X
1µm
EHT = 3.00 kV
WD = 4 mm
Signal A = InLens
Signal B = InLens
File Name = P28-2_04.tif
Signal = 1.000
Mixing = Off
BIMF
Date :24 Nov 2010

The ALCATRAP pilot plant

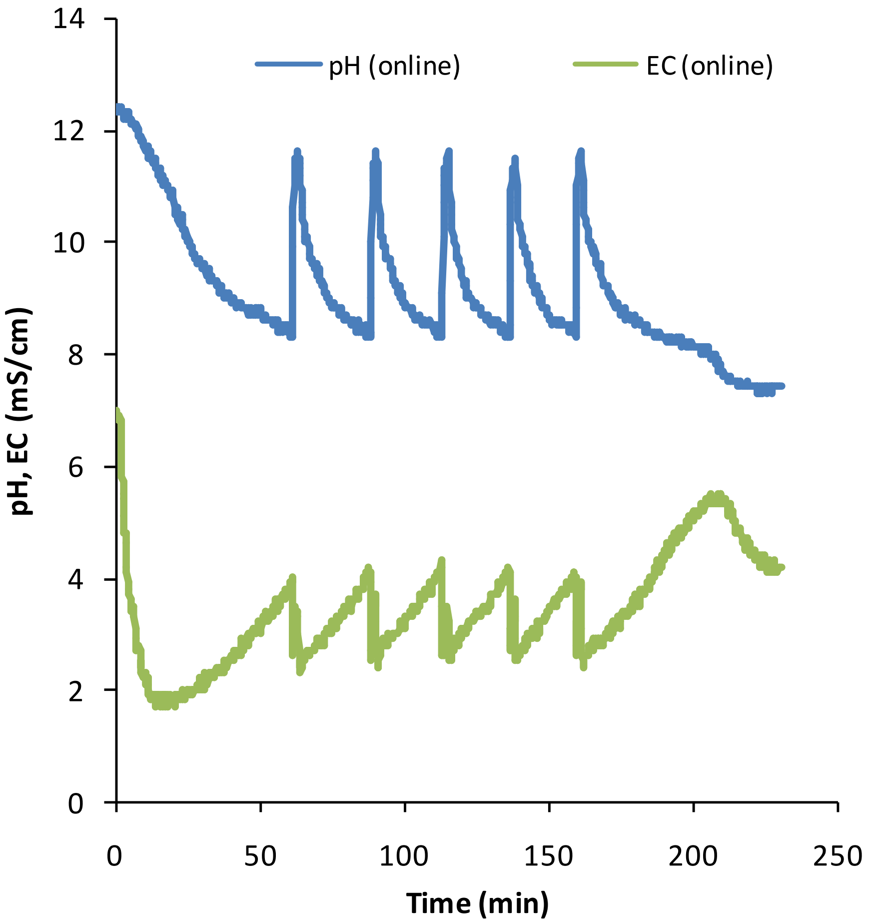


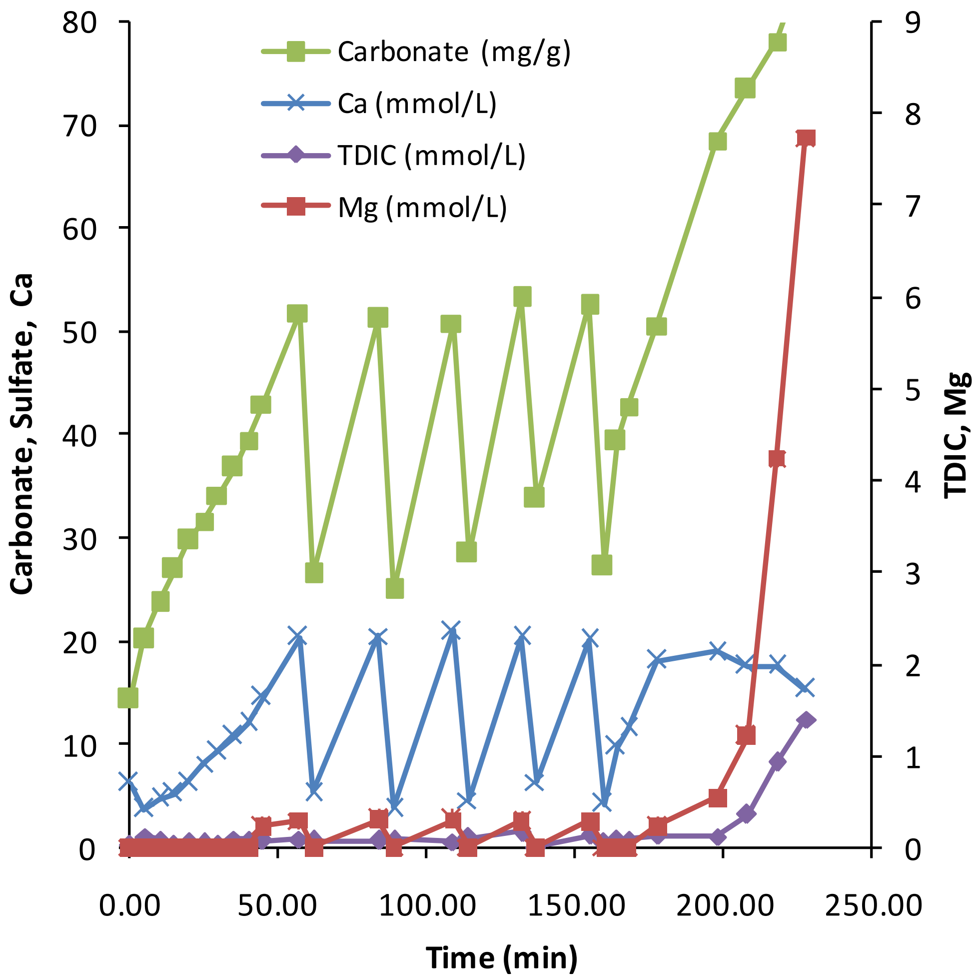


Gewerbepark Natur & Energie (GNE), Rednitzhembach

Biomass power plant

Lignite ash reaction in the pilot plant





- Semi-batch: Regulation by pH: 8,5 to 9,5
- Time between start gas flow to first exchange

CO_2 binding with different materials

	Lignite	Biomass	Wood
Total binding capacity (mol CO_2 / kg material)	**0.7 - 0.9**	**1.2 - 2.1**	**0.5 - 1.1**
CO_2 uptake (% of total flux)	**5-20**	**6-25**	**0.5-9**

Perspective: CO_2 binding potential

- Annually for Germany:
  - Up to 10 - 20 Mt alkaline rersidues
  - Binding potential of up to 2 Mt CO_2

- Within an power plant
  - Internal cycle of a power plant, „on site“
  - Recovery of 0,5 – 1 % of the CO_2

Utilization scenarios

Deposition „as is“ above or below ground

<

Easier deposition above or below ground

<

Application as building material

- „Pacification“ of the waste material

Conclusions on ALCATRAP

- Successful demonstration of CO_2 binding by alkaline waste suspensions in pilot scale
- Estimation of CO_2 storage potential possible
- Optimization potential in engineering, Scale up
- Utilization of products required

Some comments

- Reducing CO_2 emission will cause an increase in energy prices
- Time matters! How fast can the technologies be implemented?
- Society:
  - Public acceptance
  - Global problem
  - Energy imports?

„Air capture“ – The last resort

- If we fail to reduce emissions in time:

- „Artificial trees“: Chemical binding of CO_2 from air

  - 40-70 GJ/t CO_2 energy supplied
  - 30-60 GJ/ CO_2 energy required for air capture,
  - > 50 % loss in efficiency

Source materials

- IPCC 2007: *Synthesis report on climate change*
- IPCC 2005: *Special report on CCS*
- IEA 2004: *World energy outlook*
- Gaia 3/2009: *Schwerpunkt CCS*
- Greenpeace 2010: *Falsche Hoffnungen*
- Nature Geoscience 12/2009: *Locking Carbon in minerals*
- Elements 5/2008: *Carbon Dioxide Sequestration*
- BMBF 2008-2010: *CO2 Utilization, Geotechnologien*
- BMU/BMBWi 2010: *Energiekonzept*
- Etc. …

Thanks to…

- ALCATRAP collegues
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GEOTECHNOLOGIEN

- Financial support: Federal Ministry for Education and Reserach, Germany