Gas Hydrates - combining CH₄ production & CO₂ storage

CO₂ → CH₄

Matthias Haeckel
Hydrate Exploitation

Global Methane Hydrate Distribution

Klauda & Sandler (2005) per 1° x 1° grid cell
Global Methane Hydrate Inventory

Coal, oil, gas: reserves economically exploitable at current market prices
Gas Hydrates: total marine inventory
CO$_2$ hydrate is more stable than CH$_4$ hydrate

Duan & Sun (2006)
Hydrate Exploitation

CO₂ Phase Diagram

Critical point (74 bar, 31 °C)

Pressure (dbar = depth in m)

Temperature (°C)

Gas

Shelf

Slope

Hydrate

Liquid

Deep-sea
• injection of liquid CO$_2$ into CH$_4$ hydrate

• water-saturated Bentheim sandstone

• Magnetic Resonance Imaging (MRI) to follow formation and dissociation of gas hydrates in porous media

• Longitudinal cut – spacer simulates open fracture

• Experimental conditions: flow loop at ~4 °C and 83 bar
Methane gas recovery from hydrates exposed to CO$_2$

| CO$_2$(l) | Zhou et al. (2008) | 100 h (sand) / 200 mL |
| CO$_2$(l) | Kvamme et al. (2007) | 200 h (sandstone) / 100 mL |
| CO$_2$(l) | Hirohama et al. (1996) | 800 h / 3 L |
| CO$_2$(g) + N$_2$(g) | Park et al. (2007) | 20 h / 1 mL |
| CO$_2$(g) | Lee et al. (2003) | 5 h / 1 mL |

CH$_4$ recovery
SUGAR project
Submarine Gas Hydrate Reservoirs
Exploration – Exploitation – Transport
SUGAR project

**A: Exploration**
- A1: Hydro-acoustics
- A2: Geophysics
- A3: Autoclave Drilling
- A4: Basin Modelling

**B: Exploitation and Transport**
- B1: Reservoir Modelling
- B2: Laboratory Experiments
- B3: Gas Transport

**Prospection**

**Exploration**

**Quantification**

**Exploitation/CO₂ Storage**

**Pellet Transport**
Marine CO$_2$ storage options

- Cap Rock
- Depleted Oil/Gas Reservoir
- Deep Saline Aquifer
- Gas Hydrates
- Deep-Sea Sediment
- Oceanic Crust

Cost

M. Haackel, IFM-GEOMAR
Marine CO$_2$ storage options

CO$_2$ storage in deep-sea sediments

CO$_2$(l) will slowly dissolve into the porewater and react with the sediment

(Ref: House et al., 2006)
Silicate weathering in anoxic marine sediments

Feldspars + CO$_2$ =>
clays + HCO$_3^-$ + metal cations

Wallmann et al. (2008)
Microbial CO$_2$ produced in anoxic sediments is almost completely neutralized through silicate weathering

Wallmann et al. (2008)

Pore water data from methanogenic sediments deposited at productive continental margins

Wallmann et al. (2008)
CLATHRAT project

Lab experiments

Kinetics of sediment weathering
Hydrate formation in sediments
→ pressure reactors + Raman + NMR-MAS

Numerical Modelling
\[ \frac{\partial C}{\partial t} = \nabla(D\nabla C - uC) + \sum R_i \]
\[ u = - \frac{\kappa}{\eta} \nabla p \]
\[ CO_2 \rightarrow HCO_3^- \rightarrow CaCO_3 \]
\[ CH_4 / CO_2 + 5.75H_2O \rightarrow GH \]

Field work

Analysing lab results
Upscaling from lab into field

In situ process study in natural laboratory
(e.g., Okinawa Trough, Sachalin shelf)