Methane Hydrates: CO$_2$ storage and natural gas production

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Hydrate technologies may contribute to the reduction of \( \text{CO}_2 \) emissions from fossil fuel power plants.
Molecular structure

Water cage

Methane molecule

Only stable at high pressure and low temperature
Thickness of the methane hydrate stability zone in marine sediments

Source: Wallmann et al. (2012), Energies, 5, 2449-2498, special volume on gas hydrates
Mean Quaternary organic carbon accumulation rates at the seabed (in g m\(^{-2}\) yr\(^{-1}\))

Source: Wallmann et al. (2012)
Global distribution of methane hydrates in marine sediments (in kg C m$^{-2}$)

For Quaternary boundary conditions and full compaction (Wallmann et al. 2012)
Global inventories of fossil fuels

Coal, oil, gas: reserves economically exploitable at current market prices
Gas Hydrates: total marine inventory

3000 ± 2000 Gt C
Hydrate Exploitation

Methane gas may be produced from hydrate deposits via:

- Pressure reduction
- Temperature increase
- Addition of chemicals (incl. \( \text{CO}_2 \))
Hydrate Exploitation

Energy balance for gas production via heat addition at Blake Ridge (Makogon et al. 2007) 2000 m water depth, two ~3 m thick hydrate layers

~40 % of the potential energy can be used for energy production while ~60 % of the potential energy is lost during development, gas production, and transport

Japanese Hydrate Exploitation Program
Hydrate exploitation via pressure reduction has a much better energy balance and may be economically feasible at an oil price of ~54 $/barrel.
CH$_4$(g)-Recovery from Hydrates Exposed to CO$_2$

- CO$_2$(l) Kvalme et al. (2007) after 200 h in sandstone
- CO$_2$(l) Hiromata et al. (1996) after 400 h
- CO$_2$(g)/N$_2$(g) Park et al. (2006) after 15 h
- CO$_2$(g) Lee et al. (2003) after 5 h

Spontaneous exothermic reaction!
The SUGAR Project

- Funded by German Federal Ministries (BMWi, BMBF)
- First funding period: July 2008 – June 2011
- Total funding: ~13 Mio € (incl. support by industries)
The SUGAR Project

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

B: Exploitation and Transport
B1: Reservoir Modeling
B2: Laboratory Experiments
B3: Gas Transport
# SUGAR Partners

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SUGAR Technologies
Major achievements phase I

- Development and successful application of improved exploration techniques for high-resolution imaging of gas hydrates and sediment structures in the top ~0.5 km of the sediment column (hydro-acoustics, 3-D seismic, deep-towed 2-D seismic and CSEM, joint inversion of seismic and CSEM data, autoclave drilling, basin modeling)

- Development of improved production methods at lab scale applying combinations of pressure reduction, super-critical CO$_2$ injection, polymer addition and in-situ methane combustion.
CH$_4$-recovery from hydrates in sand matrix exposed to CO$_2$

- Liquid CO$_2$, 300 h/100 ml
  (Kvamme et al., Univ. Bergen)

- Liquid CO$_2$, 30 h/2000 ml
  (Haeckel et al., IFM-GEOMAR)

- Super-critical CO$_2$, 30 h/2000 ml
  (Haeckel et al., IFM-GEOMAR)

Gas recovery from hydrate in % per day
SUGAR Phase II

July 2011 – June 2014 (funded by BMWi, BMBF and RWE Dea)

A: Exploration

A1: Hydroacoustics & Sensors ELAC Nautik, CONTROS, IFM-GEOMAR
A2: Geophysics & Drilling TEEC, CORSYDE, CONTROS, IFM-GEOMAR, BGR, MARUM
A3: Basin Modeling Schlumberger AaTC, IFM-GEOMAR

B: Exploitation

B1: Reservoir Modeling Wintershall, EON Ruhrgas, Fraunhofer UMSICHT, GFZ, IFM-GEOMAR
B2: Laboratory Experiments RWE Dea, BASF, CONTROS, Fraunhofer UMSICHT, GFZ, Univ. Göttingen, IFM-GEOMAR
B3: Drilling technologies Bauer, Aker-Wirth, TU Clausthal, TUB Freiberg, Univ. Bochum
SUGAR Phase II

Major aims:

- develop gas hydrates as an environmentally sound natural gas resource and medium for CO\textsubscript{2} sequestration
- quantify gas hydrate masses and distributions in the subsurface via enhanced geophysical exploration, data analysis, autoclave drilling, and basin modeling
- enhance methane hydrate dissociation, methane gas release and CO\textsubscript{2} sequestration via a suitable combination of supercritical CO\textsubscript{2} and polymer injection, in-situ combustion, and depressurization
- reduce development and production costs and environmental risks by improved drilling and production technologies
International contacts and cooperations

Bulgaria, Georgia, Romania, Russia, Turkey, Ukraine (Black Sea):
Joint exploration cruises, joint workshop (March 27th – 28th, 2012)

New Zealand: Joint exploration cruises (2011, 2013)


France (Total): Joint exploration cruise off West Africa (2012)

Taiwan: Joint exploration cruises (2013)

India: Joint workshops, RV Sonne proposal, pending


Japan, China, South Korea: Joint workshops and meetings


EU: Coordinated program on environmental risks of sub-seabed CO₂ storage (ECO2: 2011 - 2015)
Field production tests (USA, Japan, South Korea)

On-shore Alaska (Prudhoe Bay, below permafrost)

2012 (DOE, CP, Japan): CO$_2$ injection (short-term)

~ 2014 (Statoil): Pressure reduction (long-term)

Off-shore Japan (~1000 m water depth)

2013 (MH 21): Pressure reduction (short-term)
2014 (MH 21): Pressure reduction (long-term)

Off-shore South Korea (~2000 m water depth)

2014: Pressure reduction with German participation