ENERGY for the FUTURE

CO2 as a Commodity for Methane Production from Hydrate Reservoirs

– CCUS Enabler for Efficient, Cost Saving and More Sustainable Oil & Gas Production

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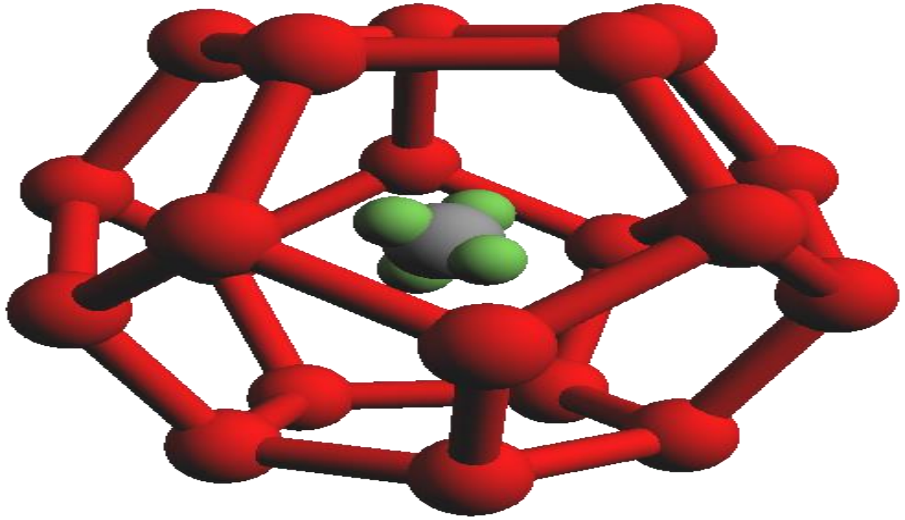
Interdisciplinary CCUS Workshop, U. of Houston, TX, USA, Sept.23-24th, 2019

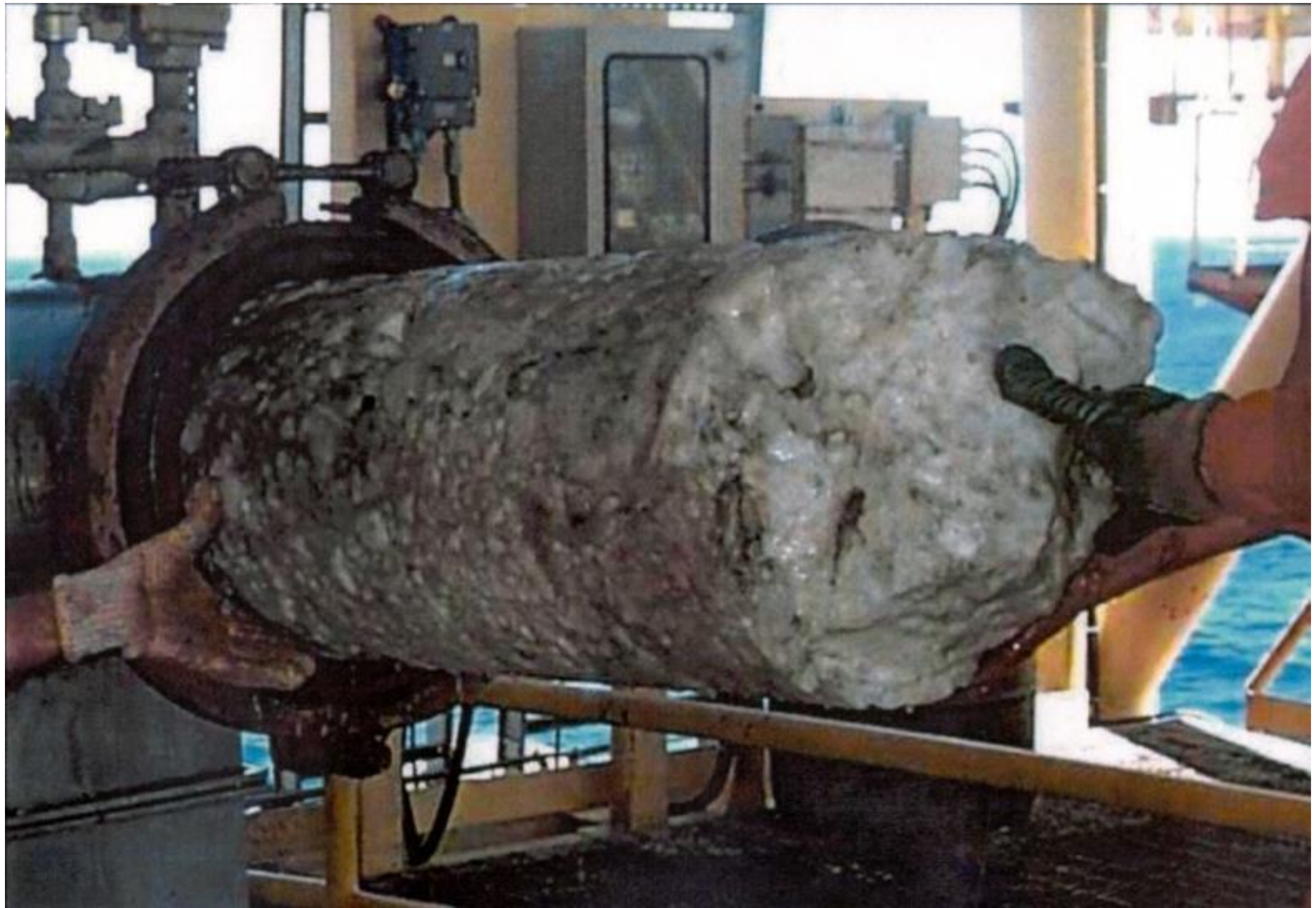
GAS HYDRATES

- Solid state of gas and water where the water molecules form a cavity that encapsulates the guest molecule.



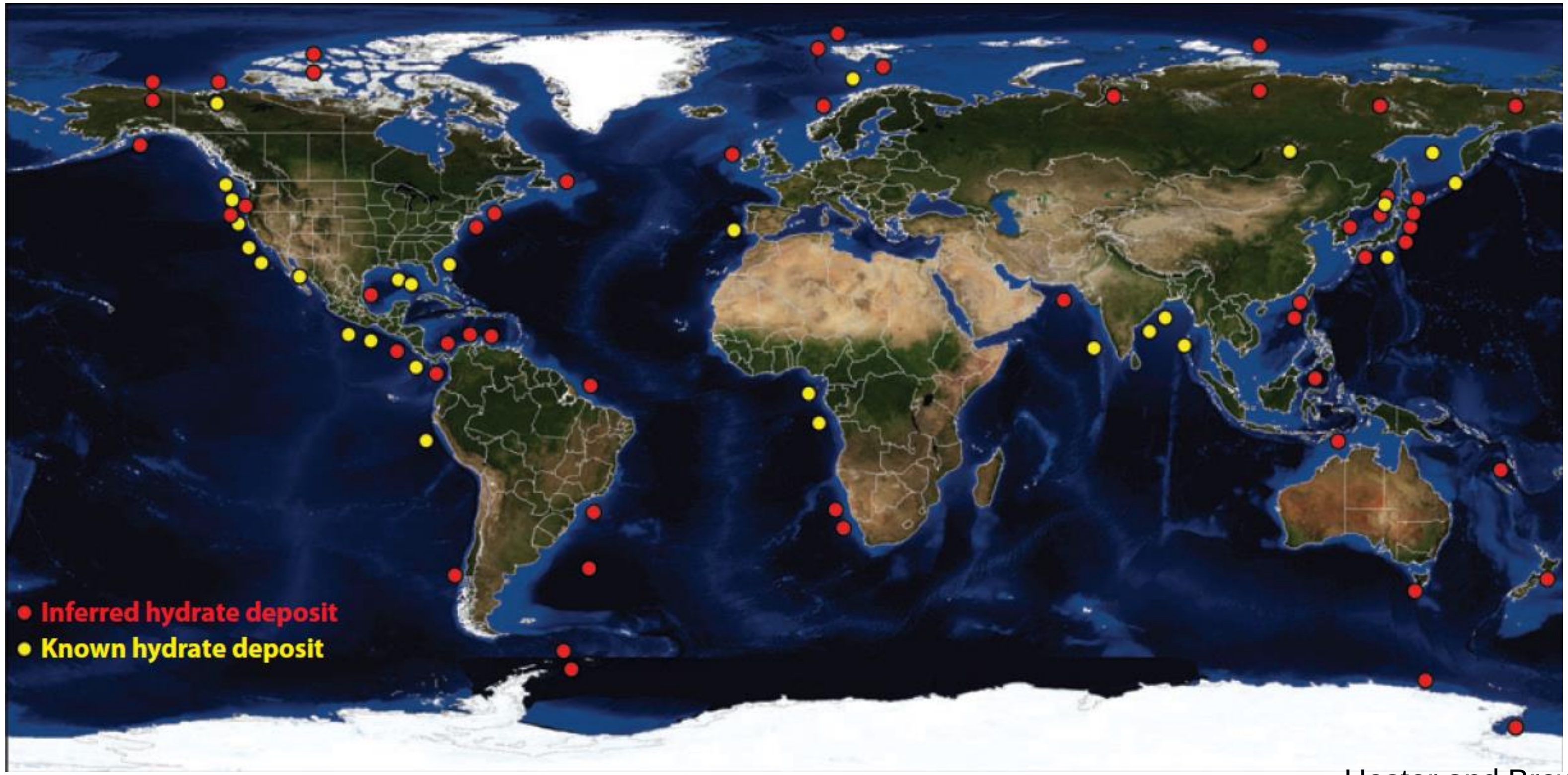
Why are hydrates of interest?

- Initial interest as a curiosity
- Plugging of production and transportation pipelines



Renewed interest

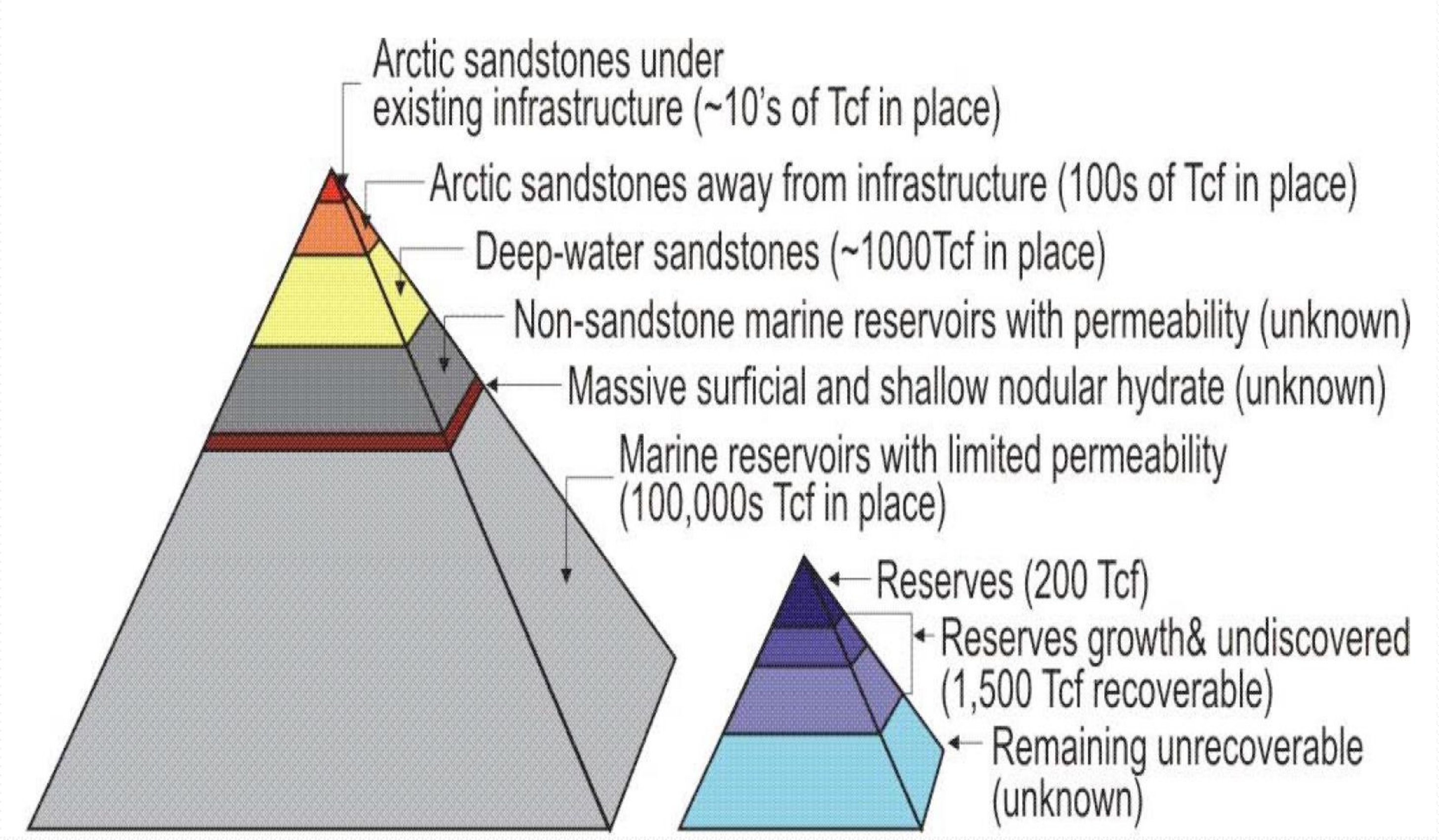
- Significant amount of energy
  - Permafrost regions
  - Marine environments (high water column)



Hester and Brewer, 2009

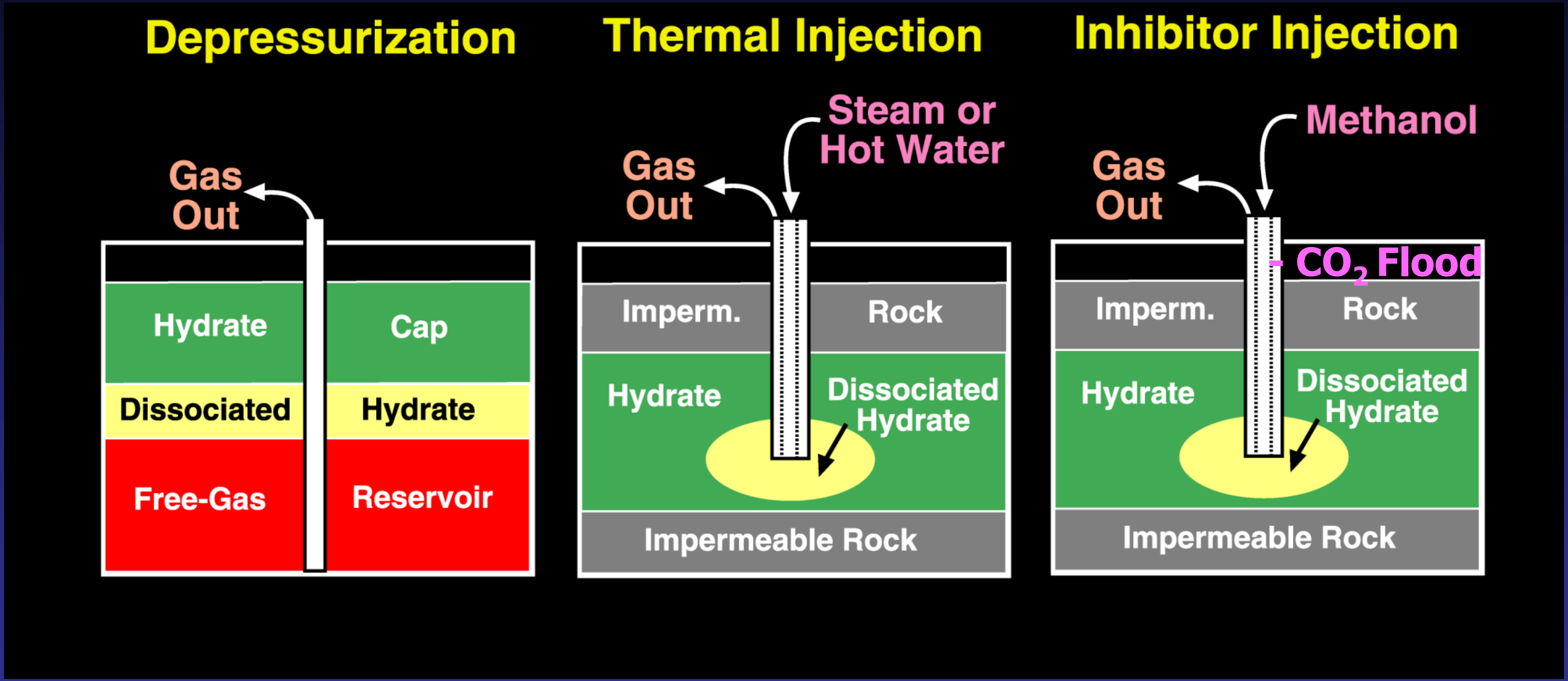
Hydrate as Energy Resource

Ref.: Fire in the Ice, U.S. Department of Energy • Office of Fossil Energy • National Energy Technology Laboratory



Gas Hydrates Resource Pyramid (left). To the right is an example gas resources pyramid for all non-gas-hydrate resources.

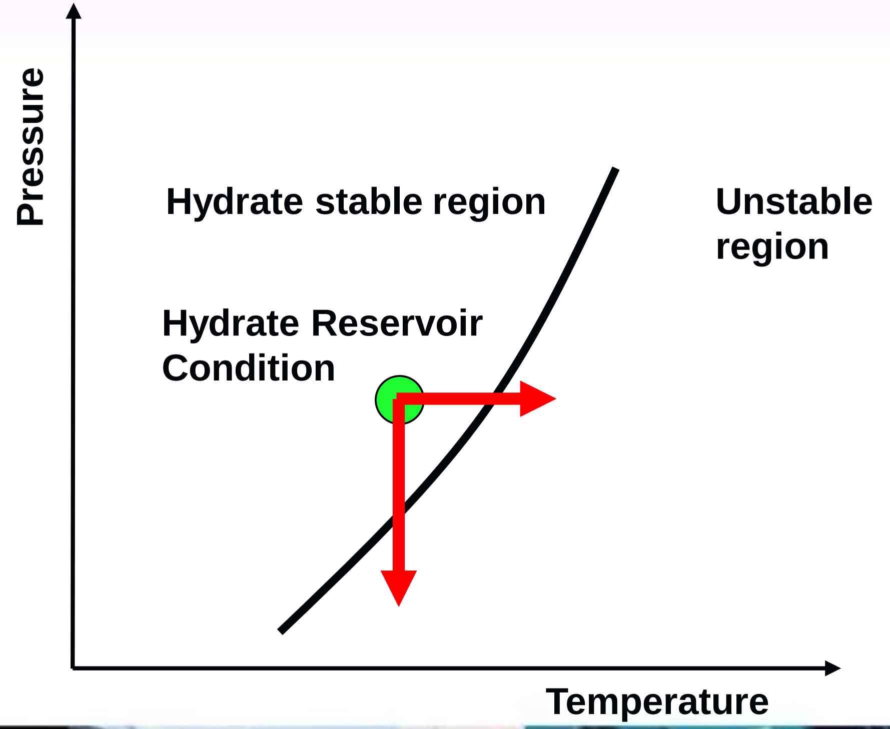
Gas Hydrate Production Methods



Modified from "GAS HYDRATES OF NORTHERN ALASKA", January 2005
Evaluation of Alaska North Slope Gas Hydrate Energy Resources: A Cooperative Energy Resource Assessment Project
US Bureau of Land Management, US Geological Survey, & State of Alaska Division of Geological and Geophysical Surveys
Bob Fisk, USBLM, Anchorage, Alaska, Tim Collett, USGS, Denver, Colorado & Jim Clough, DGGS, Fairbanks, Alaska

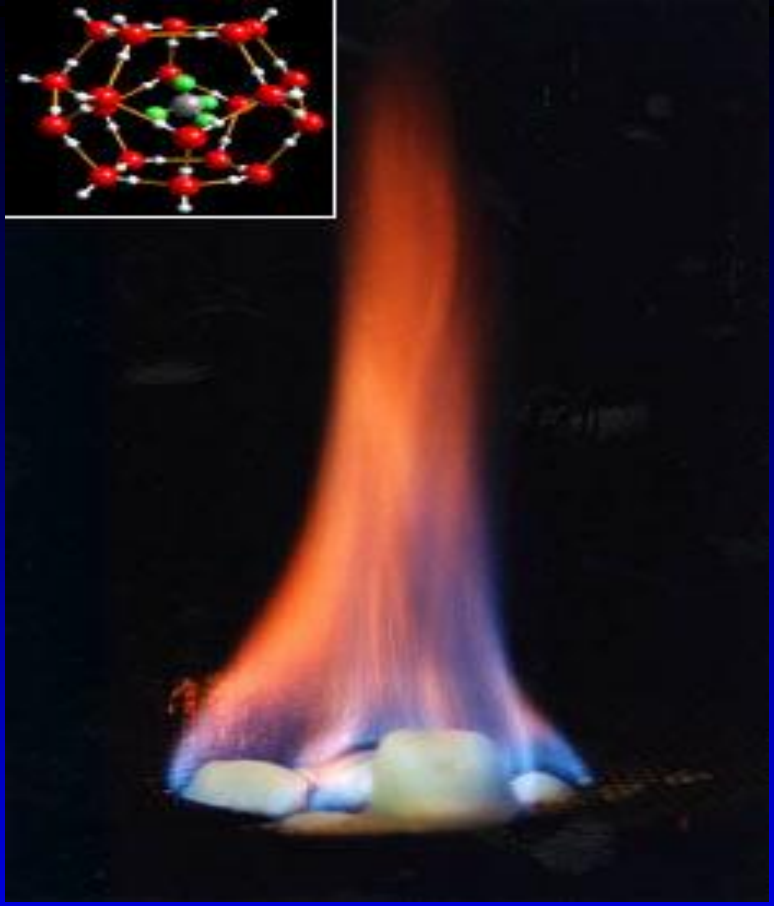
GAS HYDRATE PRODUCTION METHODS

- Move the gas hydrate outside its stability region
  - Depressurization
  - Thermal stimulation
  - Hydrate inhibitors
- CO2 exchange



CO2 Exchange: Project Motivation

- The amount of energy bound in hydrates may be more than twice the world's total energy resources in conventional hydrocarbon reservoirs; i.e. oil-, gas- and coal reserves
- Simultaneous CO_2 Sequestration
- Win-win situation for gas production
- Need no hydrate melting or heat stimulation
- Spontaneous process
- No associated water production
- Formation integrity



CO2 storage in hydrates with associated methane gas production

<u>Challenge:</u>

Determine exchange mechanisms during potential sequestration of CO_2 to produce methane from hydrates

Three component Phase Field Theory

$$F = \int d\underline{r} \left\{ \frac{\varepsilon^2 T}{2} (\nabla\phi)^2 + \sum_{i,j=1}^{3} \frac{\varepsilon_{i,j}{}^2 T}{4} \left(c_i \nabla c_j - c_j \nabla c_i \right)^2 + f_{bulk}(\phi, c_1, c_2, c_3, T) \right\}$$

$$f_{bulk} = wTg(\phi) + [1 - p(\phi)] f_S(c_1, c_2, c_3, T) + p(\phi) f_L(c_1, c_2, c_3, T)$$

$$\dot{\phi} = -M_\phi \frac{\delta F}{\delta c} + \zeta_\phi$$

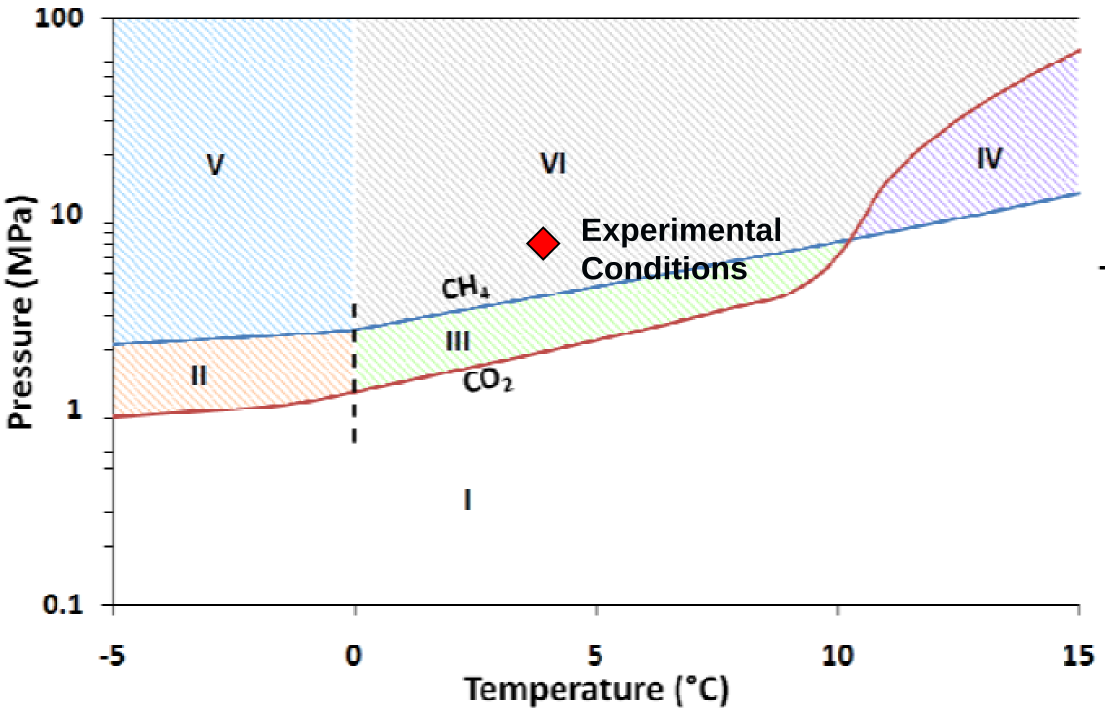
$$\sum_{i=1}^{3} c_i = 1$$

$$\dot{c}_i = \nabla M_{ci}(c_1, c_2, c_3) \nabla \left(\frac{\delta F}{\delta c_i} - \zeta_i \right)$$

Parameters ε and w can be fixed from the interface thickness and interface free energy. ε ij set equal to ε

CH_4 PRODUCTION INDUCED BY CO_2 INJECTION

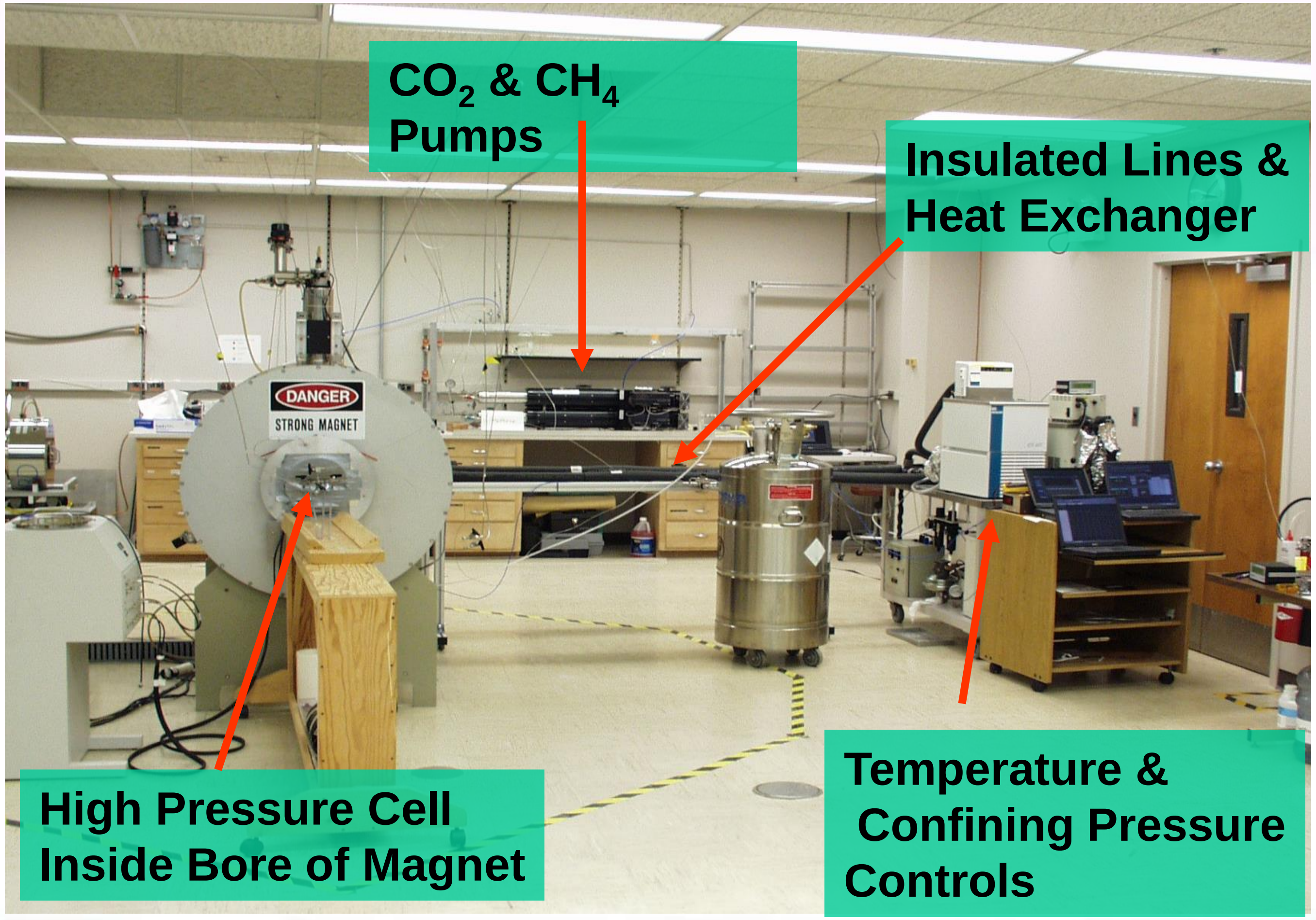
- Provides thermodynamically more stable gas hydrate than CH_4



PT-Area	Water and Hydrate Phases
I	No hydrates
II	$I\text{-}H_{CO2}$
III	$L_W\text{-}H_{CO2}$
IV	$L_W\text{-}H_{CH4}$
V	$I\text{-}H_{CO2}\text{-}H_{CH4}$
VI	$L_W\text{-}H_{CO2}\text{-}H_{CH4}$

Husebø, 2008

Experimental Setup

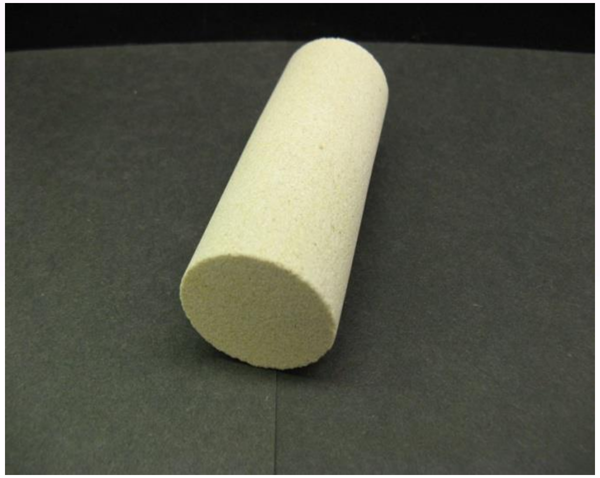


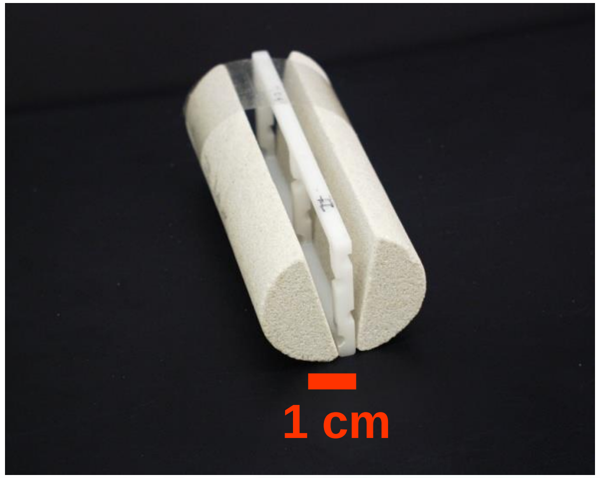
Core Sample Design

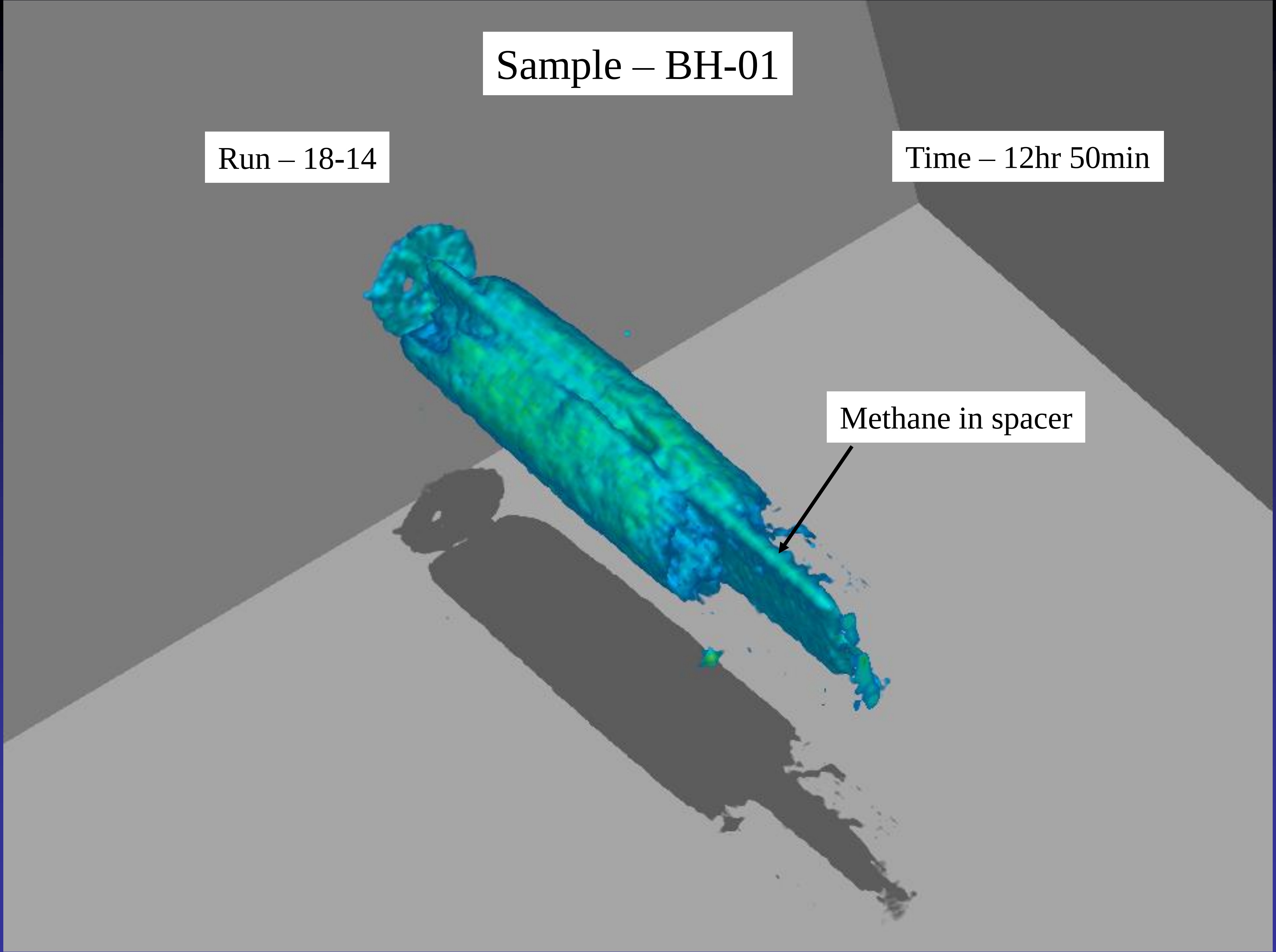
Bentheim Sandstone

20-25% porosity, ~1.1 D Perm

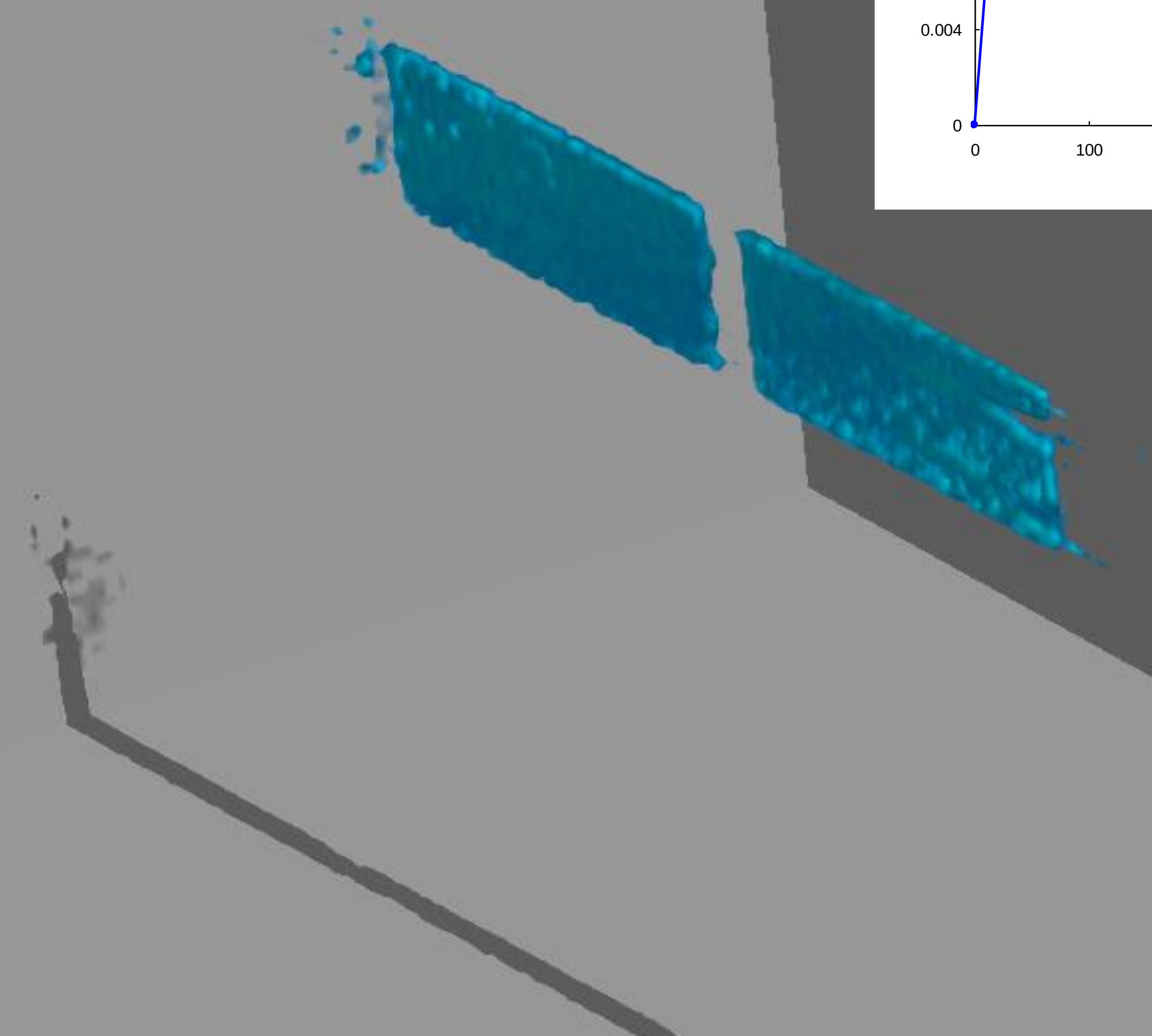
- Whole Core
- Longitudinal Cut With Machined Spacer to Simulate Open Fracture.

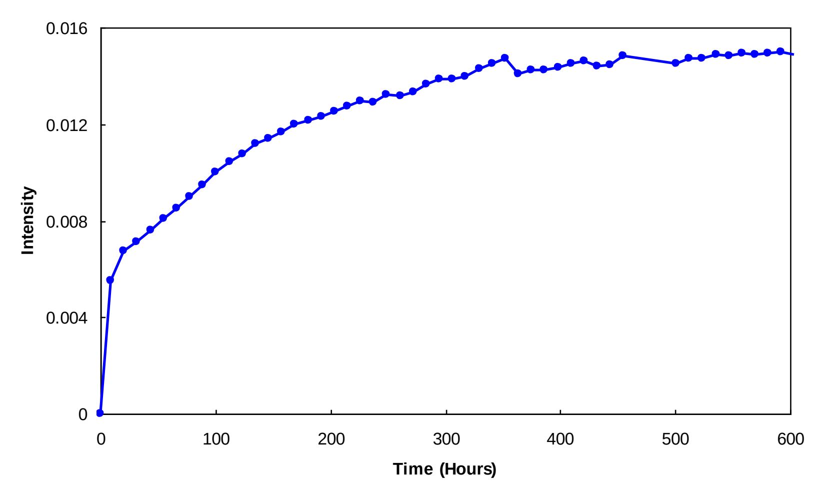





Sample – BH-01
Run – 18-14
Time – 12hr 50min
Methane in spacer

603.9 hrs




0.016
0.012
0.008
0.004
0
Intensity
0
100
200
300
400
500
600
Time (Hours)

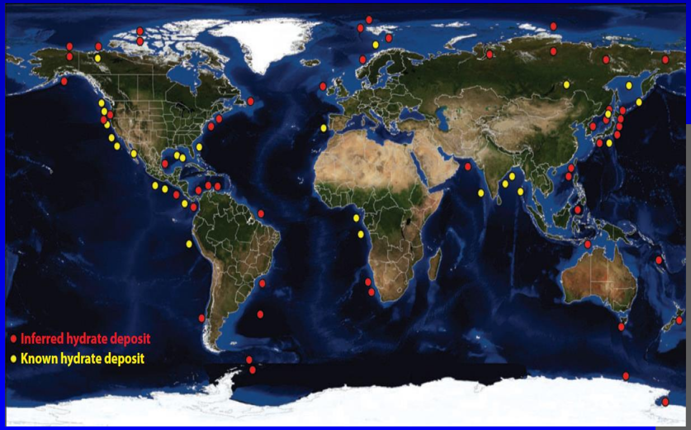
CO_2 Storage in Hydrate Reservoirs with Associated Spontaneous Natural Gas Production

Arne Graue and Bjørn Kvamme, Dept. of Physics, University of Bergen, NORWAY
Funding: ConocoPhillips, Statoil and The Research Council of Norway

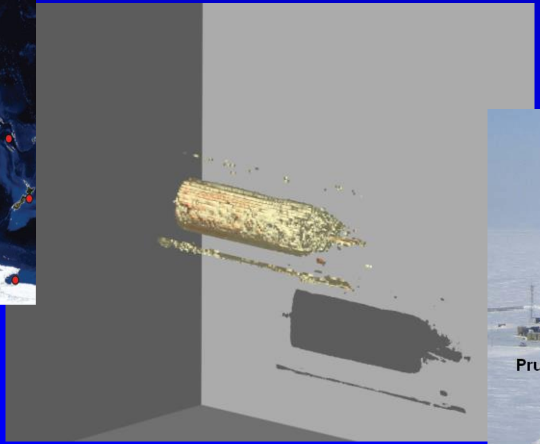
Objectives:

Experimentally and theorethically determine spontaneous methane production when hydrate is exposed to CO2; with the purpose of CO2 sequestration.

Methane hydrate reservoirs



In-Situ imaging (MRI) of hydrate formation



Methane production by CO_2 injection in field test in Alaska 2012

Alaska Field Injection Test 2011-2012

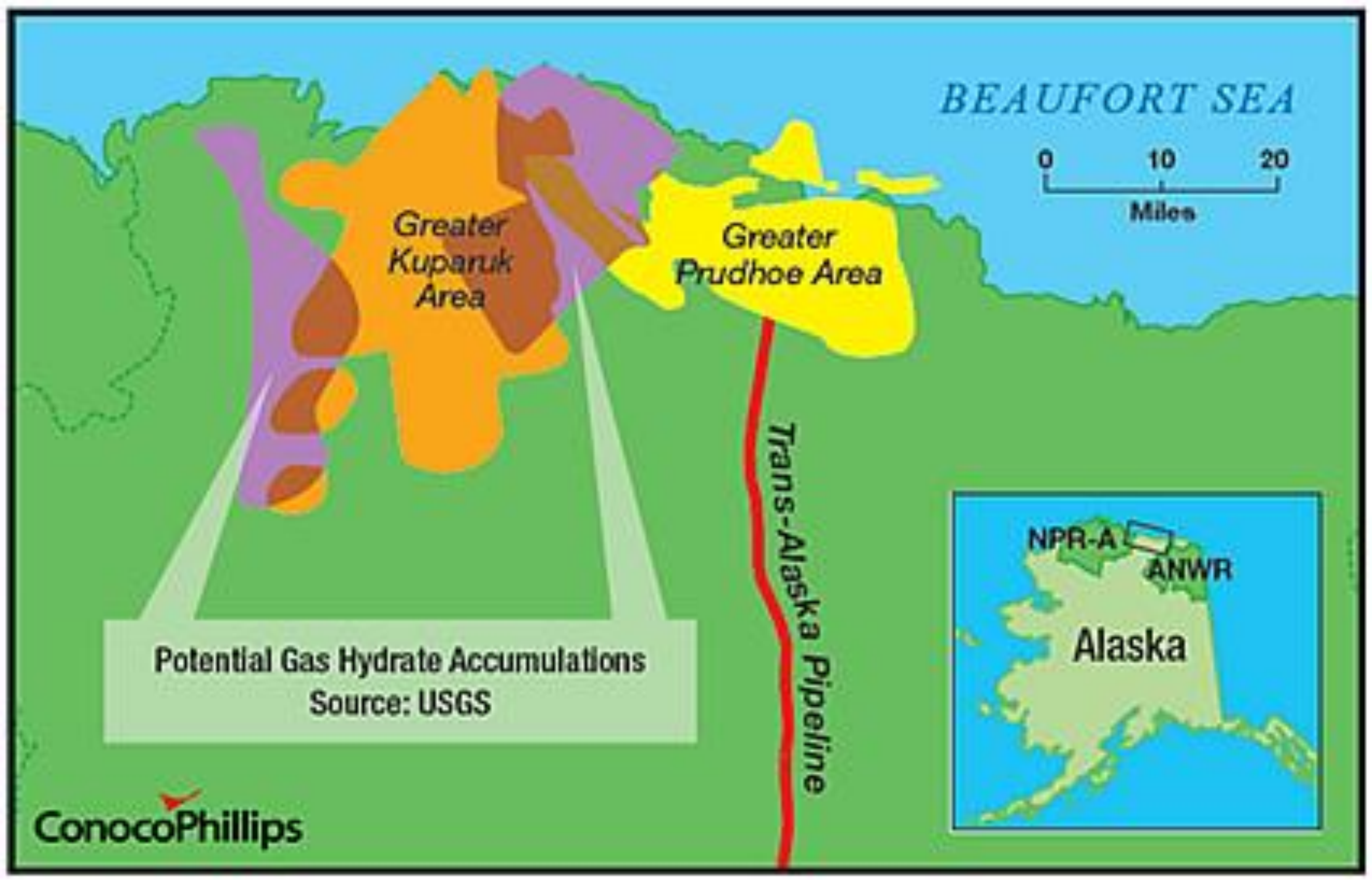
- **ConocoPhillips, USDOE and JOGMEC**
- **US$ 11.6 mill funding from US DOE, total cost ca. US$30mill**
- **CO_2 injection**

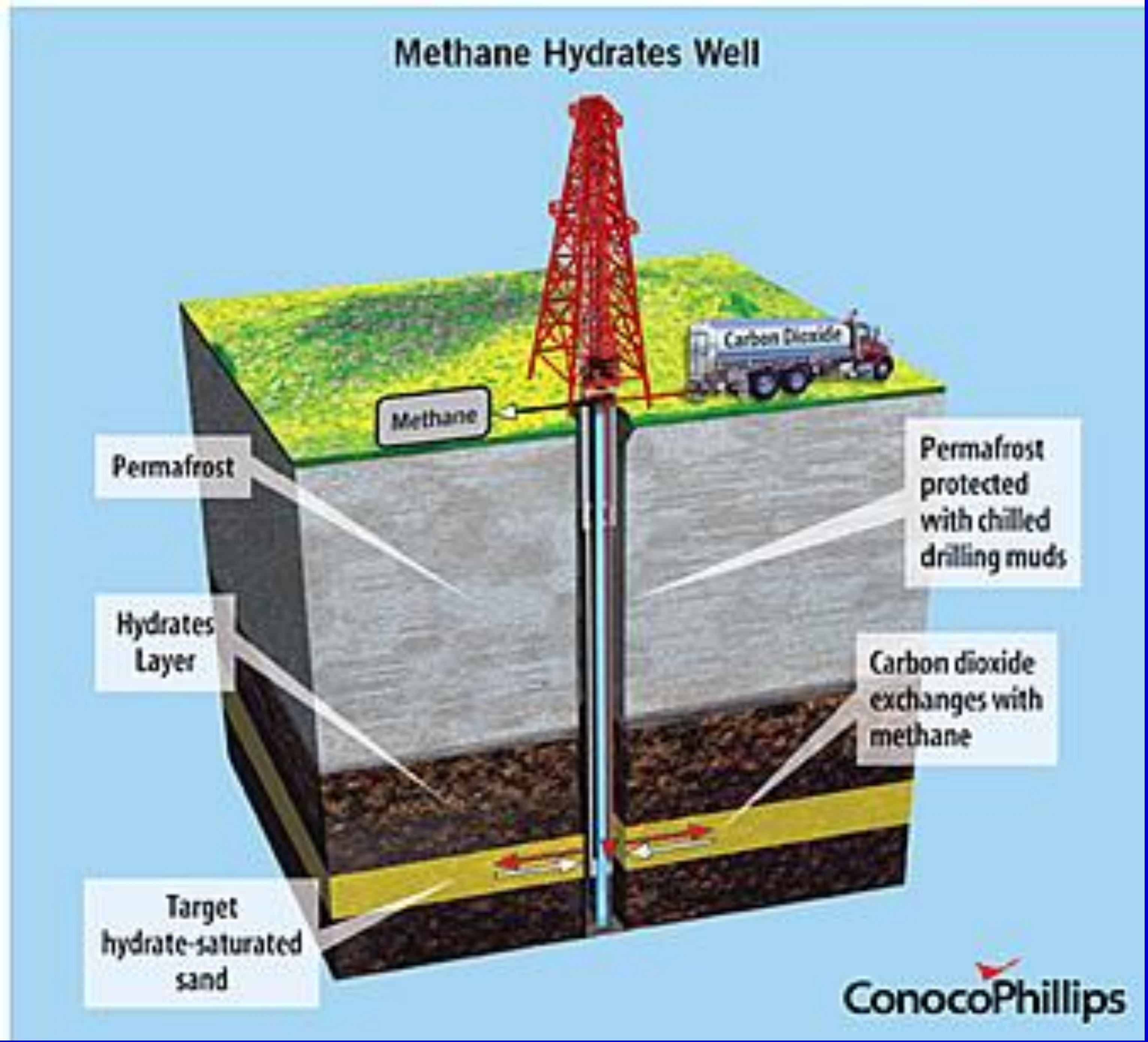
Summary of Field Test (Injection Test)

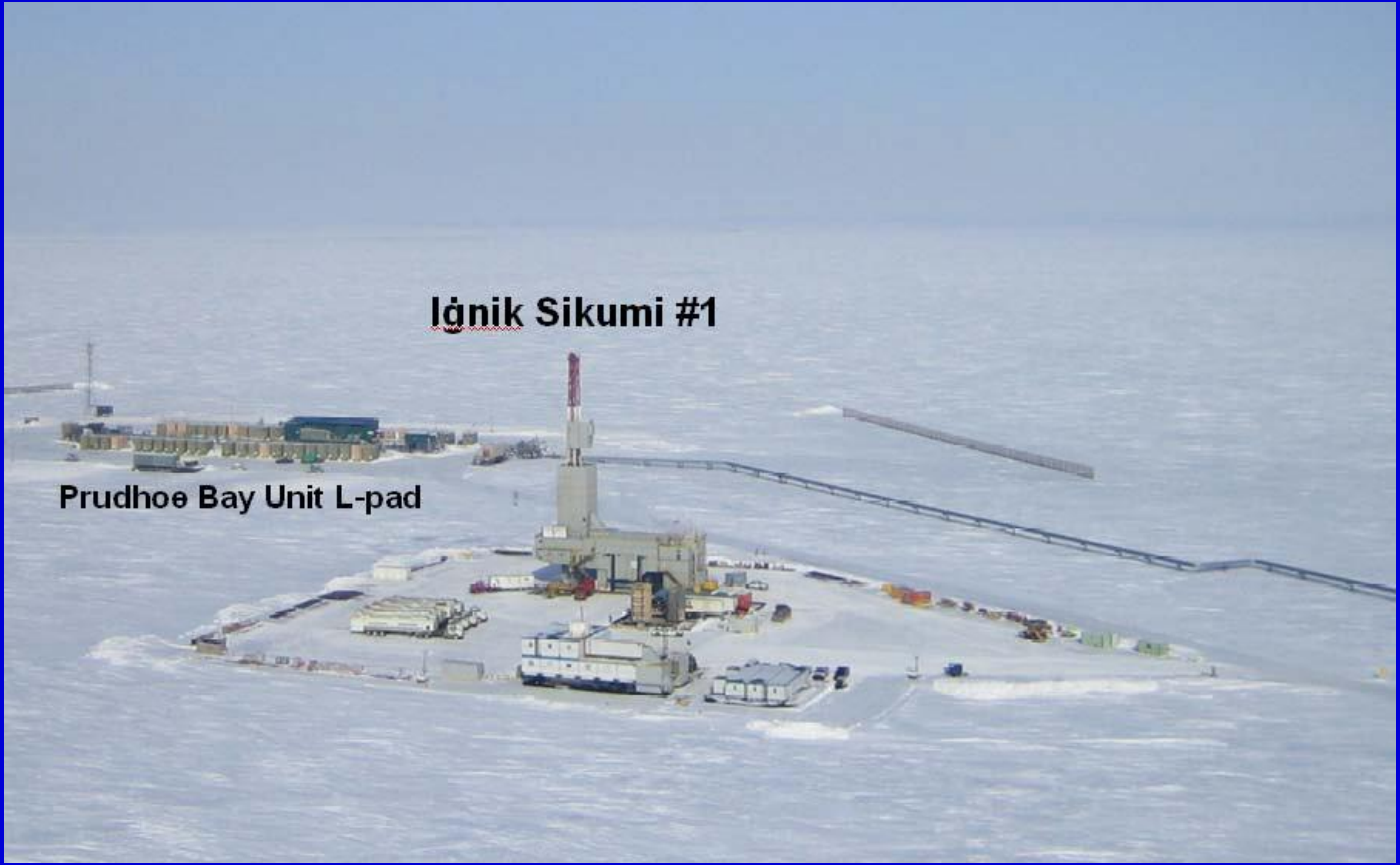
Schedule:

Apr. 2011: Drilling test well (Complete)
Nov. 2011: Finalizing parameters for the field test
Jan.-Apr. 2012: Field test

Location： Prudhoe Bay operating unit in Alaska, USA
Operator： ConocoPhillips Company (COP), through its wholly owned subsidiary, ConocoPhillips Alaska, Inc.
Investors： The United States Department of Energy（DOE）
JOGMEC; Japan Oil, Gas and Metals National Corp.

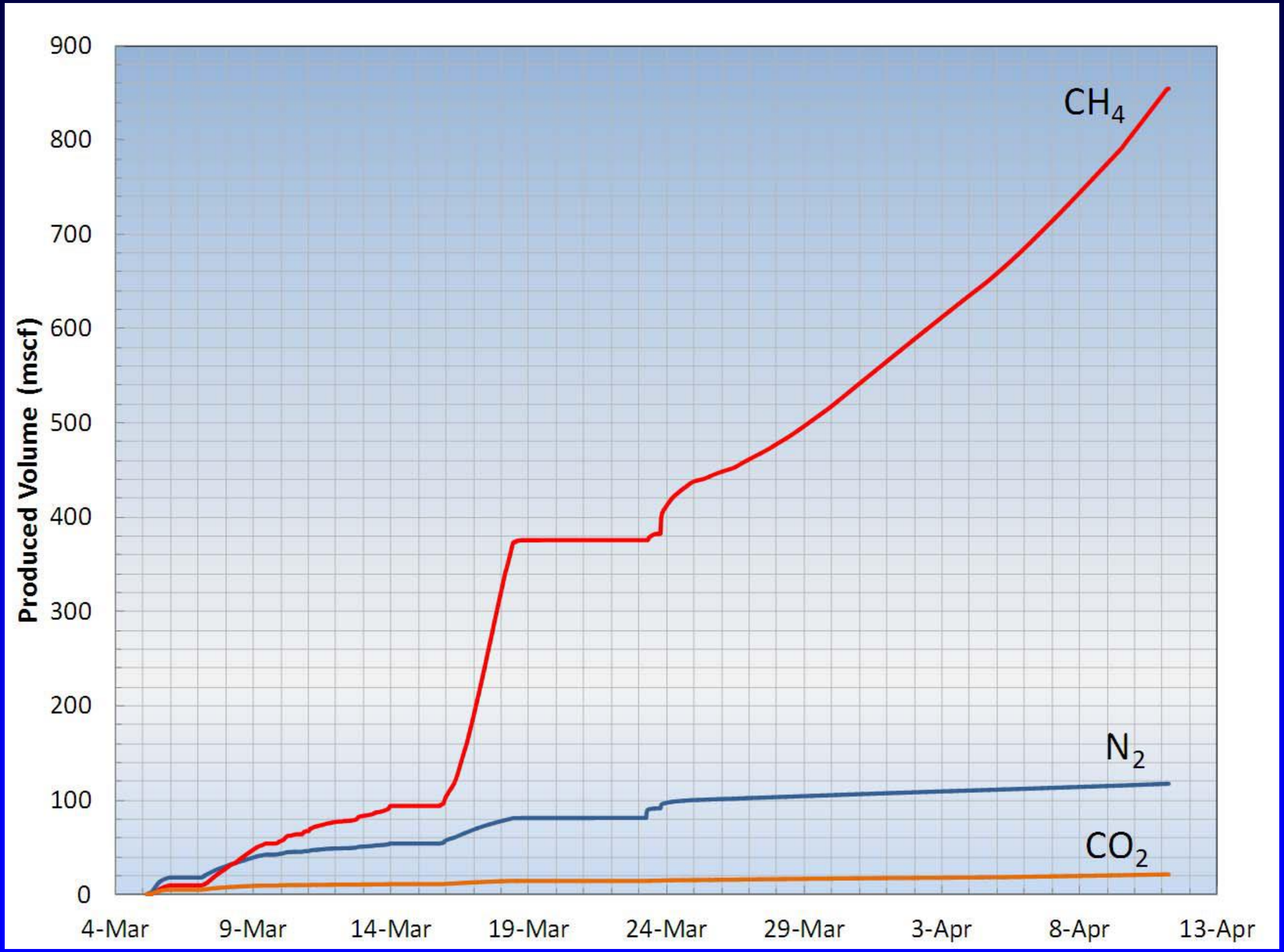

BEAUFORT SEA
0
10
20
Miles
Greater Kuparuk Area
Greater Prudhoe Area
Trans-Alaska Pipeline
Potential Gas Hydrate Accumulations
Source: USGS
NPR-A
ANWR
Alaska
ConocoPhillips


Methane Hydrates Well
Carbon Dioxide
Methane
Permafrost
Permafrost protected with chilled drilling muds
Hydrates Layer
Carbon dioxide exchanges with methane
Target hydrate-saturated sand
ConocoPhillips


Iġnik Sikumi #1
Prudhoe Bay Unit L-pad

Department o

Gas Production from the Field Test

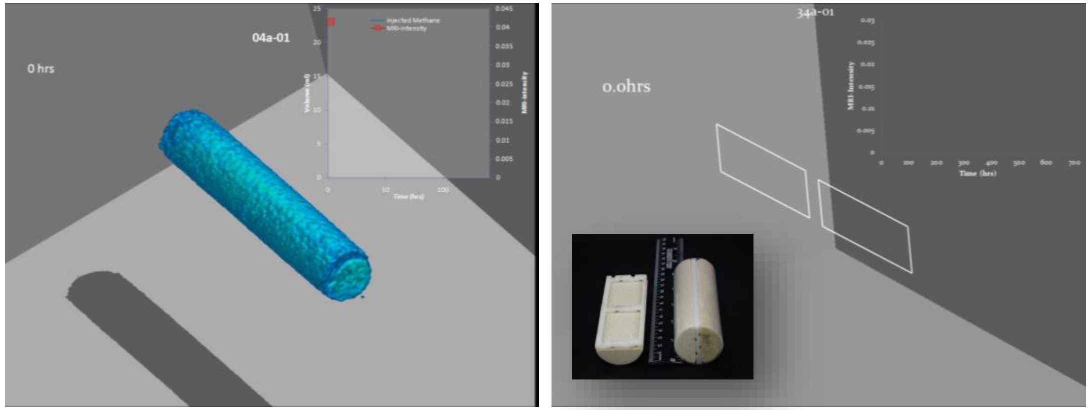


Iġnik Sikumi #1 Flowback/Drawdown: Gas composition

Energy for the Future
Gas Production WITH CO_2 Storage in Hydrates

Energy bound in hydrates **is more than combined energy** in conventional oil, gas and coal reserves

UiB Laboratory Verification of Technology

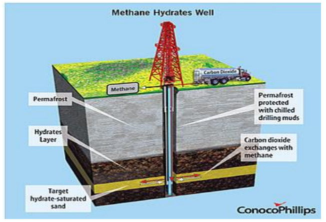


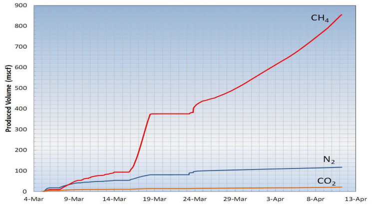
< 10 year

US $30 mill

Field Verification of UiB Technology

"*While this is just the beginning, this research could potentially yield significant new supplies of natural gas.*"
U.S. Energy Secretary Steven Chu, May 2nd 2012





DOE, ConocoPhillips and JOGMEC at the Iġnik Sikumi test site, Alaska

What are Methane Hydrates?

Methane hydrates are ice-like structures with natural gas trapped inside, and are found both onshore and offshore along nearly every continental shelf in the world.

Excerpt from U.S. Energy Secretary Steven Chu's statement

…to conduct a test of natural gas extraction from methane hydrate **using a unique production technology, developed through laboratory collaboration between the University of Bergen, Norway**… [D]emonstrated that this mixture could **promote the production of natural gas**. Ongoing analyses of the extensive datasets acquired at the field site will be needed to determine the **efficiency of simultaneous CO_2 storage in the reservoirs**.

Summary

Use of CO_2 as a commodity:

Business Case for CO_2 Storage:

- **CO_2 EOR**
- **Integrated EOR (IEOR) with Foam: *Carbon Negative Oil Production***
- **Exploitation of Hydrate Energy: *Carbon Neutral Gas Production***

Way Forward

New technologies ready for industrial scale implementation:

- **Onshore in Permian Basin, USA (80% CO_2EOR, EOR target 137Bbbl)**
- **Offshore Opportunities: NCS, Middle East, Asia, Africa and Brazil**
- **International Whole Value Chain CCUS Collaboration Offshore**

Thank you!