Gas Hydrates - The World’s Largest Energy Resource
“But Should I Care”*
By
Timothy S. Collett¹

Search and Discovery Article #80026 (2008)
Posted October 1, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, Texas, April 20-23, 2008

¹Energy Resources Program, U.S. Geological Survey, Denver, CO (tcollett@usgs.gov)

Some Presentation Highlights

What is a Gas Hydrate? Crystalline solid consisting of gas molecules, usually methane, each surrounded by a cage of water molecules. One volume hydrate typically equivalent to about 160 volumes methane gas. Occurs abundantly in nature--Arctic regions and in marine sediments.

Methane Hydrate Stability--temperatures above and below 0°C; stable in Arctic, associated with permafrost and marine sediments (> 500m deep); requires gas source—biogenic and/or thermogenic.

Controls on the occurrence of gas hydrate include:
- Formation temperature
- Formation pressure
- Pore water salinity
- Gas chemistry
- Availability of gas and water
- Gas and water migration
- Presence of reservoir rocks and seals

Actions needed include: 1. conduct exploratory drilling and production testing by first identifying viable test sites through an improved seismic and geologic understanding of gas hydrates; 2. work with industry, government, and the international research community to develop the production technology for safe and economic gas hydrate development; 3. development and calibrate gas hydrate production models through field testing projects – Pilot; long term production rate calculations are critical to evaluating field economics.
GAS HYDRATES - THE WORLD'S LARGEST ENERGY RESOURCE

“BUT SHOULD I CARE”

Timothy S. Collett
Energy Resources Program
U.S. Geological Survey
Presentation Outline

1. Geologic Controls on Gas Hydrate
   The Gas Hydrate Petroleum System
2. Gas Hydrate Energy Assessments
3. Gas Hydrate Production
4. Motivations - Economics and Political
5. NEXT STEPS
What is a Gas Hydrate?

• Crystalline solid consisting of gas molecules, usually methane, each surrounded by a cage of water molecules
  - One volume hydrate typically equivalent to about 160 volumes methane gas

• Occur abundantly in nature
  - Arctic regions and in marine sediments
Methane Hydrate Stability

Temperatures and Moderate Pressures
- Temperatures above & below 0°C

Stable
- Arctic associated with permafrost
- Marine sediments (> 500m deep)

Requires Gas Source
- Biogenic
- Thermogenic
Gas Hydrate Occurrences

Open symbol, gas hydrate recovered
Closed symbol, gas hydrate inferred from other data
Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource
Controls on the Occurrence of Gas Hydrate

-Gas Hydrate Petroleum System-

- Formation temperature
- Formation pressure
- Pore water salinity
- Gas chemistry
- Availability of gas and water
- Gas and water migration
- Presence of reservoir rocks and seals
Gas Hydrate Stability

**PERMAFROST**

- Depth of Permafrost
- Geothermal Gradient in Permafrost
- Base of Gas Hydrate
- Phase Boundary
- Methane Hydrate

**MARINE**

- Hydrothermal Gradient
- Phase Boundary
- Methane Hydrate
- Zone of Gas Hydrate
- Geothermal Gradient
- Base of Gas Hydrate
Gas generation
- Microbial
- Thermogenic
The Gas Hydrate Resource Pyramid

- Increasing in-place
- Decreasing reservoir quality
- Decreasing confidence in resource estimates
- Increasing technical challenges and likely decreasing % recoverable
Gas Hydrate Occurrences

Open symbol, gas hydrate recovered
Closed symbol, gas hydrate inferred from other data
Sand dominated gas hydrate reservoirs
NGHP Expedition 01

Scientific Coring-Logging

- Kerala-Konkan Basin
- Krishna-Godavari Basin
- Mahanadi Basin
- Andaman Islands
Site 15 - Sand Reservoir
-Gas Hydrate Distribution-

Time slice (196 ms below seafloor) of instantaneous amplitude showing a channel cutting through the study area of Site NGHP-15.

Seismic X-line 3023, showing the channel with edges enhanced in reflection amplitude at the BSR level.

Michael Riedel, 2008
Time slice (196 ms below seafloor) of instantaneous amplitude showing a channel cutting through the study area of Site NGHP-15.
NGHP Expedition 01
Gas Geochemistry Summary

NGHP EXP 01 Gas Hydrate Composition
– Microbial origin of methane
– 99.9 - 100% methane, Structure-I hydrate
– Up to 0.1 % CO$_2$
– Up to 0.02% ethane

• Sediment Gas Composition
– Microbial origin, mainly methane, traces of thermogenic gas (C$_3$+) in Mahanadi and Andaman.
Gas Hydrate Occurrences

Open symbol, gas hydrate recovered
Closed symbol, gas hydrate inferred from other data
Alaska NS Gas Hydrates

NPRA

ANWR

ARCTIC OCEAN

Point Barrow

Prudhoe Bay

Eileen & Tarn Gas Hydrate Accumulations

Zone of Potential Gas Hydrate Stability
Eileen Gas Hydrate Accumulation

Top methane hydrate stability field

Base methane hydrate stability field

KRU 1D-8

KRU 1C-8

NWE State-2

DEPTH, IN METERS BELOW GROUND SURFACE

0

3.2 km

6.4 km

GR RES

BIBPF
Mt Elbert Prospect
Eileen and Tarn Gas Hydrate Petroleum System

BROOKIAN SEQUENCE

ELLESMERIAN SEQUENCE

Sagavanirktok Fm.

Eileen

Canning Fm.

Eileen Fault Zone

Kuparuk River Oil Field

Prudhoe Bay Oil Field

West

East

GAS HYDRATE
FREE GAS
OIL
Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource
# National-Regional-Local Estimates of the Amount of Gas Within Gas Hydrates

(cubic feet of gas)

<table>
<thead>
<tr>
<th>Location</th>
<th>Estimate (cubic feet of gas)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>United States</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>317,700 $\times 10^{12}$</td>
<td>Collett, 1995</td>
<td></td>
</tr>
<tr>
<td><strong>India</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4,307 $\times 10^{12}$</td>
<td>ONGC, 1997</td>
<td></td>
</tr>
<tr>
<td><strong>Blake Ridge</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>635 $\times 10^{12}$</td>
<td>Dillon et al., 1993</td>
<td></td>
</tr>
<tr>
<td>2,471 $\times 10^{12}$</td>
<td>Dickens et al., 1997*</td>
<td></td>
</tr>
<tr>
<td>2,827 $\times 10^{12}$</td>
<td>Holbrook et al., 1996*</td>
<td></td>
</tr>
<tr>
<td>2,012 $\times 10^{12}$</td>
<td>Collett et al., 2000*</td>
<td></td>
</tr>
<tr>
<td>1,331 $\times 10^{12}$</td>
<td>Collett et al., 2000</td>
<td></td>
</tr>
<tr>
<td>*Includes associated free-gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nankai Trough, Japan</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,765 $\times 10^{12}$</td>
<td>MITI/JNOC, 1998</td>
<td></td>
</tr>
<tr>
<td><strong>North Slope, Alaska, USA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>590 $\times 10^{12}$</td>
<td>Collett, 1997</td>
<td></td>
</tr>
<tr>
<td><strong>Mackenzie Delta, Canada</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35-353 $\times 10^{12}$</td>
<td>Osadetz et al., 2005</td>
<td></td>
</tr>
<tr>
<td><strong>Gulf of Mexico, USA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21,444 $\times 10^{12}$</td>
<td>Frye (MMS), 2008</td>
<td></td>
</tr>
<tr>
<td>(with 6,717 $\times 10^{12}$ in sand reservoirs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Eileen Field, Alaska, USA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42 $\times 10^{12}$</td>
<td>Collett, 1993</td>
<td></td>
</tr>
</tbody>
</table>
Goal: Assess In-Place, Technically Recoverable, and Economically Recoverable Gas Hydrate resources on the U.S. Outer Continental Shelf (OCS)
Gas Hydrate Assessment: Sand Reservoirs

Sand-only Gas Hydrate Resources for the Gulf of Mexico (trillion cubic feet).

<table>
<thead>
<tr>
<th>Region</th>
<th>95%</th>
<th>mean</th>
<th>5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf of Mexico</td>
<td>n/a</td>
<td>6,717 TCF</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Hydrate Resource Assessment
“Economically Recoverable Assessment”
Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource
Gas Hydrate Production Methods

Depressurization

Thermal Injection

Steam or Hot Water

Inhibitor Injection

Methanol
Mallik 2002 Gas Hydrate Production Test Well

- **Japan**
  - JNOC/JOGMEC (METI)
  - JNOC collaborators
- **Canada**
  - GSC
  - BP/Chevron/Burlington
  - (Japex Canada, Imperial Oil)
- **USA**
  - USGS
  - USDOE
- **Germany**
  - GeoForschungsZentrum Potsdam
- **India**
  - National Gas Hydrate Program (NGHP), with DGH, MOP&NG, ONGC, and GAIL
- **International Continental Scientific Drilling Program**
  - Universities and research institutes in Japan, Canada, USA, Germany and China
Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska

INDUSTRY
• BP Exploration Alaska
• Arctic Slope Regional Corporation
• Ryder Scott Company
• RPS - APA Energy
• Interpretation Services, Inc.
• Doyon Drilling, Inc.
• ReedHycalog (Corion)
• Drill Cool Systems, Inc.
• Omni Laboratories
• Schlumberger
• MI Swaco

GOVERNMENT
• US Geological Survey
• Department of Energy

ACADEMIA
• U. Alaska-Fairbanks
• U. Arizona
• Oregon State University
Gas Hydrate Production Modeling

• **TOUGH2/EOSHYDR**
  - Developed by LBNL (DOE)
  - Research Code
  - Multi-component simulator

• **CMG STARS**
  - Industry simulator
  - Commercial quality i/o

• **Methane Hydrate 21**
  - Developed by JOGMEC
  - Research Code
  - Multi-component simulator
General Milne Point Model, Alaska

- 201 x 340 x 2 cells = 136,680 total cells
- 82.5 foot grid spacing
- 3 miles x 5 miles
- Horizontal well; 175 meters long in Small Gas Accumulation
Milne Point, AK - STARS MODEL
Single well down-dip below gas hydrate in free-gas

Pressure Response
Milne Point, AK - STARS MODEL
Single well down-dip below gas hydrate in free-gas

Hydrate Saturation
Reservoir Model - Depressurization

Production Profile Comparison

Typical Production Profiles

INCREMENTAL GAS

Gas Rate (mscfd)

Cumulative Gas (scf)

Gas Rate : Base Description
Gas Rate : No Hydrates
Cumulative Gas : Base Description
Cumulative Gas : No Hydrates
Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource
Gas Hydrate Field Evaluation - Five Wells -

Case 1 – Gas Hydrate Over Free Gas
50 m gas hydrate, over 10 m free gas

Case 2 – Gas Hydrate Over Water
50 m gas hydrate, over 10 m water
STARS Gas Production

Gas Production Over Time

- Case 1 - High kr
- Case 1 - Low kr
- Case 2 - High kr
- Case 2 - Low kr

Hydrate/gas

Hydrate/water
Internal Rate of Return

Notes:
Frontier Gas Royalties Included
Before Income Tax
No Incentives

Case 1
Gas Hydrate Over Free Gas

Case 2
Gas Hydrate Over Free Water
Unique ANS Motivations to Encourage Production of Gas from Gas Hydrate

- Industry uses of natural gas in northern Alaska:
  - Generate electricity for field operations
  - Miscible gas floods
  - Gas lift in producing oil wells
  - Reinjection to maintain reservoir pressures
  - Steam generation: EOR and viscous oil projects
POLITICAL MOTIVATIONS LEADING TO GAS HYDRATE PRODUCTION

• Government Regulatory and Taxation Policy: Carbon dioxide emissions - tax, Unconventional energy tax credits

• National Security: Concerns over the reliance on imported energy, Trade balance
Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource
Next Steps

Actions Needed

1. Conduct exploratory drilling and production testing by first identifying viable test sites through an improved seismic and geologic understanding of gas hydrates.

2. Work with industry, government, and the international research community to develop the production technology for safe and economic gas hydrate development.
3. Development and calibrate gas hydrate production models through field testing projects – **PILOT TEST**

Long term production rate calculations are critical to evaluating field economics
GAS HYDRATES - THE WORLD'S LARGEST ENERGY RESOURCE

BUT SHOULD I CARE?

• You know Best.....
• Do I export gas to Japan, Korea, India?
• Do I have hydrates within my existing operations?
Reference