Methane Hydrate Resource Potential
Associated with the Barrow Gas Fields

Arctic Energy Summit
Anchorage, Alaska
October 2007

Tom Walsh
Pete Stokes
Steve MacRae
Outline

- Introduction
- Geologic Overview
- Hydrate Resource
- Interim Study Results
- Conclusions
- Acknowledgments
North Slope Borough

- 95,000 sq. miles, largest “county” in U.S.
- More land area than state of Idaho
- 7,385 residents (2000 census), nine villages
- Over 15 Billion bbls of oil produced within NSB over last 30 years

- Barrow is the economic, transportation and administrative hub of the NSB
- ~4,500 Barrow residents, consume ~1.3BSCF natural gas/year for heating and power
U.S. Navy Active in NPR-4 in 1940’s
Barrow Arch and Avak Astrobleme

The Barrow Arch
(from Kirschner, et al)

The Avak Astrobleme
(from Kirschner, et al)
Significant Finds in the Barrow Area

- South Barrow #2 - discovery well for the BGF
- Drilled by Navy/ USGS in 1948-49
- First Producing Gas Well in the Arctic
Barrow Gas Fields

- Original exploration by US Navy 1944-49
- Further Investigations by Department of the Interior in the 1970’s
- Congress transfers BGF to North Slope Borough in 1984.
- Local control (NSB) since 1984
Barrow Gas Fields
Walakpa Gas Field

- Identification of Walakpa Gas Field as possible source of gas for Barrow
- Walakpa now provides 80% to 95% of Barrow’s natural gas
- Photo shows drill rig used in development drilling program
Barrow Gas Fields

- **East Barrow Gas Field**
  - Discovered in 1949 by U.S. Navy

- **South Barrow Gas Field**
  - Discovered in 1974

- **Walakpa Gas Field**
  - Discovered 1980 by Husky for U.S. DOI
### AOGCC Pool Statistics

**Barrow Field, South Barrow Gas Pool**

- **Operator:** North Slope Borough
- **Discovery Well:**
  - U.S. Navy
  - S Barrow No. 2
  - Permit #100-024
  - API No. 50-023-10010-00-00
  - Sec. 14, T22N, R18W, UM
  - Depth: 2,505' MD / 2,505' TVD
  - April 15, 1949
- **Status:** Producing
- **Location:** Western Arctic Slope

### Production Statistics

<table>
<thead>
<tr>
<th>Year</th>
<th>Gas (mcf)</th>
<th>Water (bbls)</th>
<th>Disposed Fluids (bbls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative</td>
<td>22,482,501</td>
<td>1,040</td>
<td>0</td>
</tr>
<tr>
<td>2001 Total</td>
<td>42,139</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2002 Total</td>
<td>60,933</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2003 Total</td>
<td>99,671</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2004 Total</td>
<td>69,127</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2003 Rate (/d)</td>
<td>243</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2004 Rate (/d)</td>
<td>189</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
South Barrow Gas Field Prod.
East Barrow Gas Field Pool Stats

AOGCC Pool Statistics

Barrow Field, East Barrow Gas Pool

Operator: North Slope Borough
Discovery Well: U.S. Navy
S Barrow No. 2
Permit #100-024
API No. 50-023-10010-00-00
Sec. 14, T22N, R18W, UM
Depth: 2,505' MD / 2,505' TVD
April 15, 1949

Status: Producing
Location: Western Arctic Slope
Orders:
Complete List
Structure Map
Strat Column

Production:
Prod Chart Prod Report Prod Data

<table>
<thead>
<tr>
<th></th>
<th>Gas (mcf)</th>
<th>Water (bbls)</th>
<th>Disposed Fluids (bbls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative</td>
<td>8,081,817</td>
<td>1,694</td>
<td>0</td>
</tr>
<tr>
<td>2001 Total</td>
<td>85,780</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2002 Total</td>
<td>92,511</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2003 Total</td>
<td>92,659</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2004 Total</td>
<td>100,609</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2003 Rate (/d)</td>
<td>254</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2004 Rate (/d)</td>
<td>276</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
East Barrow Gas Field Prod.
## Walakpa Field Pool Statistics

### Operator: North Slope Borough

**Discovery Well:** Husky Oil

Walakpa No. 1

Permit #100-042

API No. 50-023-20013-00-00

Sec. 09, T20N, R19W, UM

Depth: 3,666’ MD / 3,666’ TVD

February 7, 1980

### Status: Producing

### Location: Western Arctic Slope

### Orders:

- Complete List
- Strat Column

### Production:

<table>
<thead>
<tr>
<th>Production</th>
<th>Prod Chart</th>
<th>Prod Report</th>
<th>Prod Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas (mcf)</td>
<td>Water (bbls)</td>
<td>Disposed Fluids (bbls)</td>
</tr>
<tr>
<td>Cumulative</td>
<td>13,912,605</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>2001 Total</td>
<td>1,347,554</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2002 Total</td>
<td>1,251,033</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>2003 Total</td>
<td>1,235,479</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2004 Total</td>
<td>1,245,4730</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2003 Rate (fd)</td>
<td>3,365</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2004 Rate (fd)</td>
<td>3,412</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Change (%)</td>
<td>1%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Walakpa Gas Field Prod.
Methane Hydrate Potential

• Last Comprehensive Reservoir Study in 1991—Glenn and Allen

• Postulated Presence of Methane Hydrate

• Material Balance Models for East Barrow and Walakpa Fields Lend Support to Possible MH Recharge

• Potential Significant Impact on Local Resource

• Excellent Laboratory for MH Research
Project Objectives

• DOE-NETL/NSB 80-20% Funded Research
• Characterize and Quantify Methane Hydrate Resource Associated With Barrow Gas Fields
• Contribute to Global Research Effort Through Practical Research
• Advance North Slope Borough’s Understanding of It’s Energy Supply
Scope

- Integrated Study (Seismic, Well Log, Production History, Geochem)
- Focus on Barrow Gas Fields—East Field, South Field, Walakpa
- Phased Approach
- Integrate Prior Research Efforts/Current Knowledge
- If Justified, Phase 2 plan is to drill and test dedicated methane hydrate well
Project Tasks

• Phase 1A
  - Prepare Research Management Plan to Guide Study
  - Complete Technology Status Assessment to Define Global and Local Context of Study
  - Gather Data on BGF Temperature and Pressure Gradient, Gas and Fm. Water Composition (legacy data and new collection)
  - Complete Hydrate Stability Modeling

• Phase 1B
  - Perform Reservoir Characterization to Estimate Methane Hydrate Resource Size and Facilitate Dynamic Modeling (Integrate Seismic, Well Logs, Production History, Gas and Water Sample Time-series Analysis)
  - Select Optimum Location for a Dedicated Hydrate Test Well (Hydrate/Gas interface and logistics)

• Phase 2
  - Design, Drill and Production Test a Dedicated MH Well
  - Not Funded Under This Contract
Project Status

- Project start Nov. 14, 2006
- Phase 1A Complete, with positive results from Hydrate Stability
- Phase 1B Initiated August 1, 2007
- Completion of Phase 1B scheduled for March 2008
- Possible Phase 2 to design and drill dedicated hydrate production test and observation well
Generalized Arctic Slope Stratigraphy and Petroleum Systems

Modified after Bird and Houseknecht (USGS)
What Is Required for Methane Hydrate Formation?

- Petroleum System: Reservoir, Gas Source, Migration Path, Trap
- Suitable Temperature and Pressure Regime
- Formation Water
- Critical Timing of All Components

http://doddys.files.wordpress.com/2006/10/petroleum-system.jpg
East Barrow Gas Field HSZ Model

Temp Gradient & Hydrate Stability Zone for E Barrow Wells

- EB Well 15 Mar-07
- 32 Deg Isotherm
- Min Depth Hyd Slab 2.1% Salt
- Max Depth Hyd Slab 10.3% Salt
- Linear (EB Well 15 Mar-07)

Corrected Depth (ft)

Temperature (F)

Middle Barrow Sand: -2000' to -2150'
Walakpa Gas Field HSZ Model

Temp Gradient & Hydrate Stability Zone
Walakpa Gas Field

Temperature (F)

Corrected Depth (fts)

Methane Hydrate Stability

Currently Mapped

Walakpa Gas Wells Completions Top: -2000', Base -2600'
Modeled most likely hydrate stability zone depth in East Barrow Field
Modeled most likely hydrate stability zone depth in Walakpa Field
### Hydrate Resource Potential

#### Amount of Area of Hydrates Equivalent to Current Reserves in NSB Gas Fields

<table>
<thead>
<tr>
<th>Field</th>
<th>Estimated Current Reserves, BCF</th>
<th>Equivalent Methane Hydrate Pore Volume, BCF</th>
<th>Porosity</th>
<th>Reservoir Rock Bulk Volume, BCF</th>
<th>Sand Thickness, Ft</th>
<th>Area, Acres, Assuming same H and Phi</th>
<th>Res Temp, Deg F</th>
<th>Res Press, psia</th>
<th>Z</th>
<th>Bg, RCF/SCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walakpa</td>
<td>150</td>
<td>0.9375</td>
<td>22%</td>
<td>4.223</td>
<td>22.2</td>
<td>4366.9</td>
<td>62.8</td>
<td>1037</td>
<td>0.85</td>
<td>0.012114</td>
</tr>
<tr>
<td>S Barrow</td>
<td>9</td>
<td>0.05625</td>
<td>20%</td>
<td>0.281</td>
<td>22.2</td>
<td>290.8</td>
<td>57</td>
<td>663</td>
<td>0.908</td>
<td>0.020016</td>
</tr>
<tr>
<td>E Barrow</td>
<td>8</td>
<td>0.05</td>
<td>20%</td>
<td>0.250</td>
<td>22.2</td>
<td>258.5</td>
<td>43.5</td>
<td>935</td>
<td>0.866</td>
<td>0.013183</td>
</tr>
</tbody>
</table>
Conclusions from Phase 1A

- Temperature Gradients and Hydrate Stability Zone Modeling support Hydrate Stability Zone in East Barrow and Walakpa Fields

- Material Balance studies in East Barrow and Walakpa Field suggest external recharge but with no water production or breakthrough. This could suggest pressure support by methane hydrate dissociation.

- Objectives for Phase 1A of the Study have been met, and support further reservoir study.
Walakpa #1 Synthetic Seismogram

HUSKY OIL NPR OPERAT WALAKPA 1
Wavelet - Ricker
Center Freq - 34.00 Hz
South Barrow Seismic Line (N-S) Through South Barrow #1 Well
South Barrow Seismic Line (W-E) Through South Barrow #6 Well
Walakpa Composite Seismic Line
Brontosaurus to Walakpa #1
Depressurization

- Gas Out
- Impermeable Rock
- Gas
- Dissociated Hydrate
- Free-Gas

- Endothermic heat of dissociation
- Temperature recovery lag time
- Hydrate self-preservation

Thermal Injection

- Gas Out
- Hot Brine or Gas
- Dissociated Hydrate
- Impermeable Rock

- Large energy in Heats Host Rock
- Possible in-situ Electromagnetic

Inhibitor or CO₂ Injection

- Gas Out
- Methanol or CO₂
- Dissociated Hydrate
- Impermeable Rock

- High cost
- PNNL Lab Testing
- Unk. Effectiveness

After Collett, 2000
Messoyakha Field Analog?

Messoyakha field, Siberia, gas production and reservoir pressure. Bottom blue curve is intermittent and variable historical gas production, top curve is observed reservoir pressure, middle curve is expected reservoir pressure given the production history. The unexpected increase in reservoir pressure is interpreted to indicate recharge from disassociating hydrates. (Makogon, 1995)

Messoyakha field, Siberia, gas production and reservoir pressure. Bottom blue curve is intermittent and variable historical gas production, top curve is observed reservoir pressure, middle curve is expected reservoir pressure given the production history. The unexpected increase in reservoir pressure is interpreted to indicate recharge from disassociating hydrates. (Makogon, 1995)

Messoyakha field, Siberia, gas production and reservoir pressure. Bottom blue curve is intermittent and variable historical gas production, top curve is observed reservoir pressure, middle curve is expected reservoir pressure given the production history. The unexpected increase in reservoir pressure is interpreted to indicate recharge from disassociating hydrates. (Makogon, 1995)

After Krason and Findley, 1992

Intermittant and variable historical gas production, top curve is observed reservoir pressure, middle curve is expected reservoir pressure given the production history. The unexpected increase in reservoir pressure is interpreted to indicate recharge from disassociating hydrates. (Makogon, 1995)

Intermittant and variable historical gas production, top curve is observed reservoir pressure, middle curve is expected reservoir pressure given the production history. The unexpected increase in reservoir pressure is interpreted to indicate recharge from disassociating hydrates. (Makogon, 1995)

Intermittant and variable historical gas production, top curve is observed reservoir pressure, middle curve is expected reservoir pressure given the production history. The unexpected increase in reservoir pressure is interpreted to indicate recharge from disassociating hydrates. (Makogon, 1995)

Thermo-cross section, Messoyakha field (modified from Makogon, 1995). Free gas underlies the hydrate interval. Explanation of pressure recovery might include one or more of these alternatives:

1. Disassociating hydrates (responding to decreased pressure after production) recharge free gas zone.
2. A strong water drive restores reservoir pressure during shut-in period.
3. Low permeability reservoir sands require time to rebuild pressure.

Given the limited data available for Messoyakha field, I feel it is unconfirmed the pressure increase reflects disassociating hydrates. It is a possibility, but unproven in my opinion and caution is advised. Some reservoir pressure modeling may shed more light on this issue.

East Barrow Field Decline?

East Barrow Field
P/Z vs. CUMULATIVE PRODUCTION
PRA 2007 Reserves Study

1988 A&C Est of ultimate recoverable = 5.7 BCF

2007 PRA Pressure EB #'s 14 & 21

1996 A&C Pressure EB #'s 14 & 21

A&C 1988 Report
A&C 1996 Data
PRA 2007 Data
Phase 1B Achievements:

• Comprehensive literature and data search completed, extensions anticipated

• Produced water sample collection and analysis from E.B. #14 well completed

• Barrow Area Seismic Data loaded to Seismic Workstation

• Well Log Interpretation in progress

• Seismic well ties and interpretation of Walakpa lines nearly complete
Study Challenges:

• Thin pay seismic interpretation, very mixed well and seismic dataset

• Depletion Mechanism:
  • Will dissociation occur in reservoir through pressure depletion?
  • Will wellbore/reservoir freeze?
  • Will Fm. Water overrun well?
Conclusions:

• Great opportunity for NSB and Hydrate Research Community

• Significant Potential Social, Economic and Scientific Impact

• Excellent Natural Laboratory
Participants

DOE-NETL
NSB
PRA
UAF

Advisory Committee

Acknowledgements

- **North Slope Borough**
  - Steve MacRae, Kent Grinage

- **DOE-NETL**
  - Robert Vagnetti, Ray Boswell

- **USGS**
  - Tim Collett

- **ASRC**
  - Richard Glenn, Bob Hunter

- **UAF**
  - Shirish Patil, Abhijit Dandekar, Praveen Singh
Backup Slides
BASC and Barrow

- A collaboration between the community of Barrow and the scientific community
- Primarily Supported by the NSF
- Also accommodates many non-NSF funded research projects
BASC Facilities

- BARC
- Field Work Support Equipment
- Laboratory Space
- Dormitory Space
- BASC designated as a remote campus of University of Alaska, Fairbanks for IT support
Alignment of Objectives

- BGF is tied to existing gas transmission and distribution infrastructure.
- Practical application and testing of production techniques, with significant potential contribution to global hydrate resource research.
- May enable the NSB to regionalize the utility infrastructure (either gas transmission or power transmission) thereby serving other remote arctic communities.