# TOPIC PAPER #24

# HYDRATES

On July 18, 2007, The National Petroleum Council (NPC) in approving its report, *Facing the Hard Truths about Energy,* also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the Task Groups and their Subgroups. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

**These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents but approved the publication of these materials as part of the study process.**

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached Topic Paper is one of 38 such working document used in the study analyses. Also included is a roster of the Subgroup that developed or submitted this paper. Appendix E of the final NPC report provides a complete list of the 38 Topic Papers and an abstract for each. The printed final report volume contains a CD that includes pdf files of all papers. These papers also can be viewed and downloaded from the report section of the NPC website (www.npc.org).

# NATIONAL PETROLEUM COUNCIL

## OIL SHALES AND HYDRATES SUBGROUP
## OF THE
## TECHNOLOGY TASK GROUP
## OF THE
## NPC COMMITTEE ON GLOBAL OIL AND GAS

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# Gas Hydrates

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## I. Executive Summary

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Gas hydrates are found within and under permafrost in arctic regions. They are also found within a few hundred meters of the seafloor on continental slopes and in deep seas and lakes. The reservoir architecture, technology needs, and eventual economic importance of hydrates in arctic and marine environments may be very different. Therefore they are considered separately in this report.

### *A. Arctic Hydrates*

Gas hydrates are found within and beneath permafrost on the North Slope of Alaska, in the Canadian arctic, and in northern Siberia. Some of these accumulations are in areas where there has been significant conventional hydrocarbon development, with associated modern seismic and well-data surveys. In those areas, resources have been quantitatively evaluated. The results suggest that arctic hydrates have the potential to become economically viable sources of natural gas.

The best documented Alaska accumulations are in the Prudhoe Bay-Kuparuk River area, which contains ~30 trillion standard cubic feet of natural gas, about twice the volume of conventional gas found in the Prudhoe Bay field.[1] The proximity to highly developed oilfield infrastructure makes the Prudhoe-Kuparuk accumulation particularly attractive. The absence of a gas pipeline to market implies that the gas is, at present, stranded. However, even without a gas pipeline, this resource is a possible

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[1] Collett TS: "Energy Resource Potential of Natural Gas Hydrates," *AAPG Bulletin* 86 (2002): 1971–1992.

enabler of the development of the nearby Schrader Bluff and Ugnu heavy oil reservoirs, which together amount to about 25 billion bbl of original oil in place.

The main technology barrier is the lack of validated methods for economically viable production of natural gas from hydrate. An arctic site capable of supporting multiyear field experiments would enable significant progress beyond the present state of knowledge.

## B. Marine Hydrates

A widely quoted U.S. Geological Survey estimate predicts that there is twice as much organic carbon in gas hydrate than in all recoverable and unrecoverable conventional fossil fuel resources, including natural gas, coal and oil.[2] Much of this endowment has been thought to be located on continental slopes in close proximity to major energy-consuming nations, see Figure IB.1.[3] However, estimates of hydrate-bound gas abundance have been repeatedly scaled back over the years, though large uncertainties remain.[4]

Worldwide, only a few dozen boreholes have been drilled to assess marine hydrate resources. Most of these boreholes were drilled offshore Japan in 2004,[5] and offshore India in 2006. Comprehensive reports of these campaigns are not yet in the public domain, so there is little public record available to assess the efficacy of exploration paradigms. Thus the main technology barrier is the lack of validated means of reliably finding significant marine gas hydrate resources. A multi-site geological and geophysical exploration program, followed up with a multi-site

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[2] Kvenvolden KA: "Gas Hydrates—Geological Perspective and Global Change," *Reviews of Geophysics* 31 (1993): 173–187.

[3] Kvenvolden KA and Rogers BW: "Gaia's Breath—Global Methane Exhalations," *Marine and Petroleum Geology* 22 (2005): 579–590.

[4] Milkov AV: "Global Estimates of Hydrate-Bound Gas in Marine Sediments: How Much Is Really out There?" *Earth-Science Reviews* 66 (2004): 183–197.
Klauda JB and Sandler SI: "Global Distribution of Methane Hydrate in Ocean Sediment," *Energy & Fuels* 19 (2005): 459-470.

[5] Fujii T et al.: "Modes of Occurrence and Accumulation Mechanism of Methane Hydrate—Result of METI Exploratory Test wells Tokai-oki to Kumano-nada'," *Proceedings of the Fifth International Conference on Gas Hydrates*, Trondheim, Norway (2005).

drilling campaign, is needed to accelerate the assessment of marine gas hydrate as an energy resource.

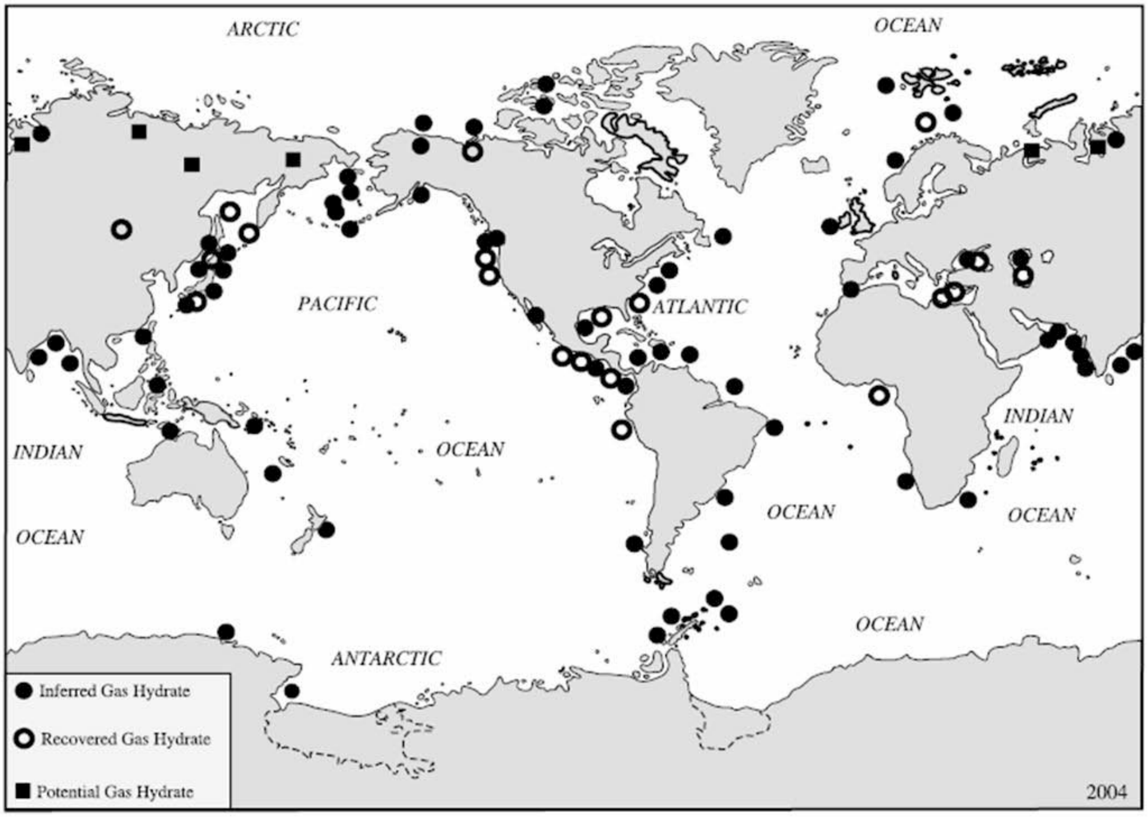


**Figure IB.1. Sites where natural gas hydrate has been recovered or is inferred [Kvenvolden and Rogers, reference 2].**

# II. Overview of Methodology

## A. Recent reports on gas hydrate research and development:

"Natural Gas Hydrates," *Balancing Natural Gas Policy*, Vol. 4, Chap 5, § VII, National Petroleum Council (2003). Available at http://www.npc.org/
"Charting the Future of Methane Hydrate Research in the United States," National Research Council (2004).
"Resources to Reserves: Oil & Gas Technologies for the Energy Markets of the Future," Chapter 4, International Energy Agency (2005).
Alaska Gas Hydrate Planning Workshop Proceedings, Sponsored by Alaska Department of Natural Resources and United States Geological Survey, Anchorage, Alaska (17–18 August 2005).
"An Interagency Roadmap for Methane Hydrate Research and Development," U.S. Department of Energy, Office of Fossil Energy (July 2006). Available at http://www.fossil.energy.gov/programs/oilgas/publications/methane_hydrates/mh_interagency_plan.pdf

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# III. Background

The natural gas hydrate section of the 2003 National Petroleum Council study *Balancing Natural Gas Policy* discussed supply outlook and technology needs in some detail. The present status and future directions of federally sponsored gas hydrate research and development are described in the 2006 Department of Energy interagency roadmap. Both reports are cited in the Overview of Methodology section above. Rather than replicating those studies, this report incorporates them by reference. The emphasis of this report is on the major impediments to the commercial utilization of arctic and marine gas hydrate resources.

## *A. Arctic Hydrates*

Arctic hydrate reservoirs are potentially high quality sources of natural gas. Figure IIIA.1 shows the location of an important accumulation in the Prudhoe-Kuparuk region on the North Slope of Alaska, and Table IIIA.1 summarizes its petrophysical characteristics. Other reservoirs exist elsewhere on the North Slope of Alaska, in northern Canada, and in Siberia. Some important arctic hydrate accumulations have good porosity and good gas saturation, and are predominantly found in coarse sands that have high intrinsic permeability. Overlying permafrost may provide a low-permeability barrier to gas leakage during extraction. These factors are favorable for production.

One of the few fields in which gas production has been attributed to hydrates is the Messoyakha gas field in West Siberia. About one-third of the gas produced in this field was estimated to come from hydrates, but that estimate has been called into doubt.[6] The field is now inactive.

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[6] Collett TS and Ginsberg GD: “Gas Hydrates in the Messoyakha Gas Field of the West Siberian Basin—A Re-examination of the Geologic Evidence,” *International Journal of Offshore and Polar Engineering* 8 (1998): 22–29.

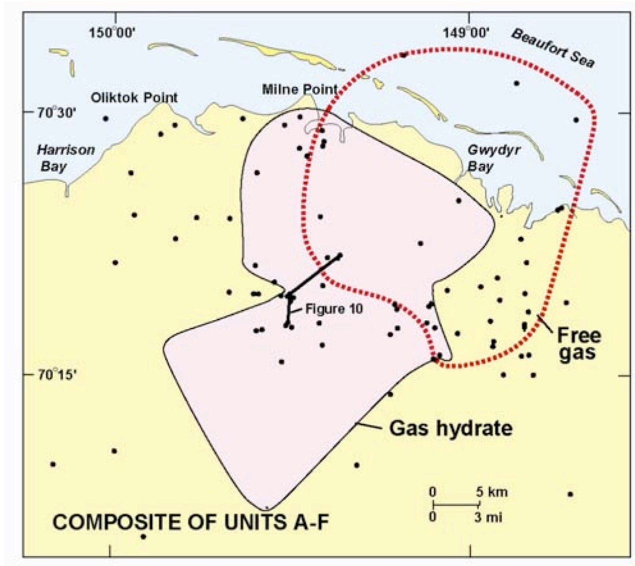


**Figure IIIA.1. Eileen gas hydrate trend (pink-shaded area) and underlying free gas (dotted red perimeter) on the North Slope of Alaska [Collett, reference 1].**

**Table 1.** Estimated Volume of Gas Within the Downhole Log-Inferred Gas Hydrate Occurrences

| Site/Well Identification | Depth of Log-Inferred Gas Hydrates (m) | Thickness of Hydrate-Bearing Zone (m) | Average Sediment Porosity (%) | Average Gas-Hydrate Saturation (%) | Volume of Gas within Hydrate per km² (m³) |
|---|---|---|---|---|---|
| Northwest Eileen State-2 Drill Site: | | | | | |
| Unit C | 651.5–680.5 | 29.0 | 35.6 | 60.9 | 1,030,904,796 |
| Unit D | 602.7–609.4 | 6.7 | 35.8 | 33.9 | 133,382,462 |
| Unit E | 564.0–580.8 | 16.8 | 38.6 | 32.6 | 346,928,811 |
| | | | Total for Northwest Eileen State-2 | | 1,511,216,069 |

**Table IIIA.1. Estimated volume of gas within the downhole log-inferred gas hydrate occurrences [Collett, reference 1].**

A heavily monitored gas hydrate production experiment was carried out in 2002 at the Mallik site in the Mackenzie Delta, Northwest Territories.[7] During a period of a week, both depressurization and thermal stimulation were used to produce gas from hydrate. Although a technical success, the experiment was too brief to serve as a guide to reservoir-scale production. Two longer and even more heavily monitored tests, led by the Japan Oil, Gas, and Metals National Corporation (JOGMEC), are

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[7] Dallimore SR and Collett TS: "Scientific Results from the Mallik 2002 Gas Hydrate Production Research Well, Mackenzie Delta, Northwest Territories, Canada," *Bulletin* 585, Geological Survey of Canada, Ottawa (2005).

scheduled for the same site during the winters of 2006–2007 and 2007–2008. It is unclear how much information from these tests will be made public.

The U.S. Department of Energy and BP drilled a survey well on the North Slope of Alaska in early 2007, and may conduct production tests in Winter 2008.

## B. Marine Hydrates

Subsea gas hydrates have been thought to comprise the preponderance of hydrate to be found in the geosphere. Moreover, they are to be found much closer to markets than are arctic hydrates, see Figure IB.1. Promising accumulations have been thought to exist off the east, west, and Gulf coasts of the United States, as well as offshore Japan, India, China, and other important energy-consuming nations. Originally estimated to be 10,000 times larger than the global conventional gas endowment, most recent estimates are smaller, though large uncertainties persist. Figure IIIB.1 compares historic and current estimates of total hydrate-bound gas[8] to proved reserves of conventional gas.[9] Since recoverability of gas from gas hydrate is unknown, it is impossible to say how hydrate-bound gas reserves might compare to conventional reserves. However, it is important to note that the fossil fuel significance of marine gas hydrate rests less on its gross global abundance then on the existence of high quality, economically producible reservoirs close to energy-consuming nations desirous of increasing their domestic production of gas.

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[8] Milkov, reference 4.
Klauda and Sandler, reference 4.
[9] "World Proved Reserves of Oil and Natural Gas, Table," Energy Information Agency (Posted November 9, 2004).

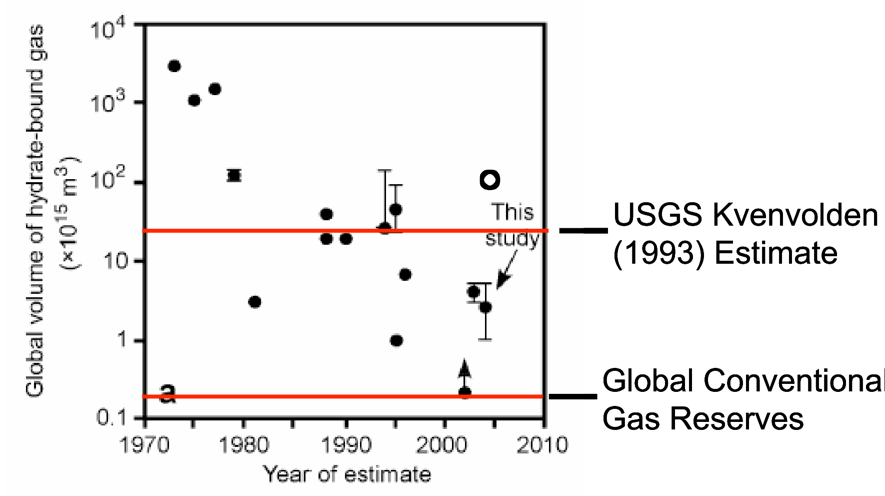


**Figure IIIB.1. Estimates of global gross volume of hydrate-bound gas (solid dots) [Milkov, reference 4], including the most recent estimate (open circle) [Klauda and Sandler, reference 4]. These are compared to global proved reserves of conventional gas (lower horizontal line) [EIA, reference 9]. [Modified from Milkov, reference 4.]**

There have been a number of hydrate-related drilling programs in North American waters, but none of them has had the primary objective of defining the fossil fuel resource base. Ocean Drilling Program investigations at a number of sites, including Blake Ridge offshore South Carolina, Hydrate Ridge offshore Oregon, and the Cascadia Margin offshore Vancouver were funded in part by the National Science Foundation, and were not tasked to find economically significant reservoirs of gas hydrate. The Department of Energy sponsored a scientific drilling program at Keathley Canyon and Atwater Valley in the Gulf of Mexico, with the primary objective of developing techniques to ensure the safety of drilling to deepwater conventional petroleum targets. Thus the nature, and even the existence, of economically exploitable gas hydrate reservoirs in U.S. waters is an open question.

There have been major drilling campaigns in the Nankai Trough offshore Japan in 2004, and in several widely spaced sites offshore India in 2006. Unlike the US-led efforts, these programs had the specific objective of assessing the fossil fuel potential of gas hydrate. Resource estimates from these campaigns are not in the public domain, and therefore this summary does not draw on, nor necessarily apply to, those areas. However, these programs serve in some respects as models of national resource assessment.

# IV. Tables of advances

## A. Advances that might be in commercial use by 2010

- None.

## B. Advances that might be in commercial use by 2020

- Production methods for arctic reservoirs developed through field tests and reservoir simulation.
- Broad-based exploration and delineation of gas hydrate resources in U.S. waters.

## C. Advances that might be in commercial use by 2030

- Production methods for marine gas hydrates.

Details of the implementation of these broad objectives may be found in:

"Natural Gas Hydrates," *Balancing Natural Gas Policy*, Vol. 4, Chap 5, § VII, National Petroleum Council (2003). Available at http://www.npc.org/

"An Interagency Roadmap for Methane Hydrate Research and Development," U.S. Department of Energy, Office of Fossil Energy (July 2006). Available at http://www.fossil.energy.gov/programs/oilgas/publications/methane_hydrates/mh_interagency_plan.pdf

# V. Discussion

## A. Arctic Hydrates

In the absence of a gas pipeline, arctic gas hydrate is a stranded resource. Pipeline planning, which is of necessity conservative, has not incorporated the possibility that hydrate may contribute to arctic gas production at some point in the future. However, arctic gas hydrate could have a role in producing the abundant Ugnu and Schrader Bluff heavy oil resources of the North Slope.

Generically there are three ways to destabilize gas hydrate in order to produce free gas from it. These are heating, depressurization, and chemical inhibition. Reservoir simulators have been developed to predict the efficacy of these techniques, singly or in combination.[10] Although consistent with each other, the simulators have yet to be validated by field test data. While the upcoming Canadian and Alaskan tests are good next steps, the limited-term production tests envisioned will yield a less-than-definitive understanding of how to produce natural gas from hydrate reservoirs. If the development of other unconventional gas resources (e.g. tight gas sands, shale gas, and coalbed methane) is any guide, novel production practices will need to be devised.

There are several strong arguments in favor of a long-term gas hydrate production test facility in an arctic area:[11]

- Because there are a number of ways of destabilizing hydrate, multiple tests will be required to identify the best technique or combination of techniques.
- Reservoir simulations suggest that these tests will need to be of long duration (a year or more) in order to properly assess the success of a technique.[12]

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[10] Masuda Y, Kurihara M, Ohuchi H, and Sato T: "A Field-Scale Simulation Study on Gas Productivity of Formations Containing Gas Hydrates," Proceedings of the Fourth International Conference on Gas Hydrates, Yokohama, Japan (19–23 May 2002).
Moridis GJ: "Numerical Studies Of Gas Production From Methane Hydrates," *Society of Petroleum Engineers Journal* (December 2003): 359–370.

[11] Alaska Gas Hydrate Planning Workshop, Proceedings, Sponsored by Alaska Department of Natural Resources and United States Geological Survey, Anchorage, Alaska (17-18 August 2005).

[12] Masuda, et al., reference 10.
Moridis, reference 10.

- There are many advantages to drilling multiple wells from a single pad. These include the possibility of experimenting with multiple production techniques in a single formation, doing multiple production tests simultaneously, and using closely spaced monitor wells to track reservoir properties over time.

An excellent model is the systematic development of heavy oil production techniques used to exploit the Cold Lake field in Alberta. Over a period of years, Exxon ran more than two dozen pilot projects on contiguous acreage. As a result, Exxon has been able to rapidly ramp up its heavy oil production throughout the field.[13]

Production tests in the arctic can also serve as an early and relatively low-cost indicator of how the potentially larger marine hydrate resources might be produced. While the architecture of marine deposits is at present a matter of speculation, and may differ from that of arctic reservoirs, elements of arctic production technology are likely to be transferable to marine settings.

## B. Marine Hydrates

The most significant offshore drilling campaigns directed to finding economically significant gas hydrate deposits are being conducted by the national energy authorities of Japan and India. The results of these campaigns are not in the public domain. China has recently announced a $100 million program of hydrate exploration. The state-owned oil companies of Malaysia and Korea have signaled their intention to explore for hydrate in their territorial waters.

With its abundant gas seeps in deep water, the Gulf of Mexico is probably the most promising marine gas hydrate province in U.S. waters.[14] However, there has been no hydrate exploration activity there. A small number of hydrate-related wells

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[13] Gallant RJ and Dawson AG: "Evolution of Technology for Commercial Bitumen Recovery at Cold Lake," Proceedings of the Fourth UNITAR/UNDP International Conference on Heavy Crude and Tar Sands, Edmonton, Ontario, Canada (7-12 August 1988).
[14] Milkov AV and Sassen R: "Economic Geology Of Offshore Gas Hydrate Accumulations And Provinces," *Marine and Petroleum Geology* 19 (2002): 1–11.

were drilled in Keathley Canyon and Atwater Valley lease blocks in 2005, primarily to investigate drilling safety. This work was sponsored by DOE, and Chevron was the lead contractor.

To achieve an assessment of marine gas hydrate resources, the U.S. government would need to adopt the model used by the governments of Japan and India: an exploration and drilling campaign encompassing, for example, twenty sites dispersed over a significant geographical area. In 2007 the Minerals Management Service will announce a methodology for selecting hydrate exploration sites, which could serve as a basis for this program.