power & energy

features

buried treasure

Geologists estimate that 200,000 trillion cubic feet of natural gas are locked solid in Arctic and offshore ice. Will methane hydrate fuel the future?

by Ray Boswell

What if american dependence on imported energy could be broken? What if, instead of ever-dwindling domestic supplies of oil and natural gas, there was a clean, plentiful fuel source just off shore?

Beginning in the 1970s, some forward-looking researchers have pointed to deposits of methane hydrates as just that sort of resource. But so little was known about these deposits—where they lie, how extensive they are, how easily they can be extracted—that it was impossible to get a true fix on their potential.

Thanks to dedicated research programs—both in the United States and internationally—we are beginning to get answers to these questions. Once thought to be far off in the future, the commercial production of methane from hydrate may now be just around the corner.

Simply put, a methane hydrate is a gas trapped solid in a cage. Methane hydrate is the common term used for the most abundant natural form of clathrate hydrate, solid substances in which host molecules (in this case, water) form a solid lattice that encapsulates, without bonding, appropriately sized guest molecules. Methane hydrate is stable under specific combinations of low temperatures and high pressures, which exist in nature only in sediments under roughly 500 meters or more of water and in certain Arctic continental settings. Under more familiar conditions, such as at room temperature at sea level, methane hydrate quickly dissociates into water and methane. Because of this, it can be studied only by using specialized equipment.

The promise of methane hydrate is this: It is a very efficient storehouse of energy. When dissociated, a single cubic foot of solid hydrate releases as much as 180 cubic feet of methane gas.

Despite a long history of study in the lab, efforts to assess the energy potential of hydrate did not begin in earnest until the research vessel *Glomar Challenger* recovered a massive sample of methane hydrate from deep marine sediments off the coast of Guatemala in 1982. Over the next decade, evidence mounted that methane hydrate could exist in nature in staggeringly large amounts.

Orange chunks of methane hydrate lie exposed on ocean floor. Methane ice worms are thought to feed off bacteria that grow on the hydrate.

In 1995, the U.S. Geological Survey provided the first systematic quantification of the methane volumes in place within hydrates in the United States and bounding continental shelves. Today, following the incorporation of the latest data, this estimate is 200,000 trillion cubic feet. That's equal to 2,000 times the current annual energy consumption in the United States.

Global estimates range across several orders of magnitude, reflecting the uncertainties associated with the limited field data available. Nonetheless, even the most conservative estimates show gas-in-place volumes that are about 10 times greater than all recoverable natural gas of all non-hydrate resources.

But this potential resource is absolutely worthless if it cannot be tapped at a competitive cost.

Although groundbreaking research had already been conducted by USGS, the Naval Research Lab, and others, as recently as 10 years ago very little was known about the nature or behavior of methane hydrate in natural settings. Then, in 1995, the Japanese government launched a major research effort to determine hydrate resource potential. Its aggressive program has included well drilling both at the Mallik site in the Mackenzie Delta of Canada and at Japan's Nankai Trough. The 1998 and 2002 Mallik efforts, in particular, which were conducted as part of a large international consortium, have produced a wealth of public domain data that has been invaluable to hydrate research.

In 2000, the U.S. Congress pumped new life into America's hydrate R&D effort. The Methane Hydrate Research and Development Act substantially increased funding and directed federal agencies involved in hydrate science to work together to better understand methane hydrate.

We are now beginning to reap the fruits of this effort. Five years ago, the ultimate technical—much less economic—recoverability of methane from hydrate reservoirs remained uncertain. Since then, major field studies in the Nankai Trough, Arctic Canada, the waters off Oregon, the Gulf of Mexico, and the Alaskan North Slope, and lab work at the Colorado School of Mines, the USGS lab in Menlo Park, Calif., the Canadian Geological Survey, and elsewhere have brought the picture into sharper focus. It has become clear that production of methane from hydrate is both technically feasible and economically viable in certain settings.

As Nature Made Them

A major difficulty facing laboratory research on naturally occurring hydrate has been the inability to obtain or produce hydrate samples that are representative of natural conditions. This problem is being addressed in two ways. First, new samplers and pressure-retaining core barrels and transport containers are enabling the preservation of samples obtained in the field for later analysis in the lab.

Just as important are newly developed pressure cells and other tools that allow scientists to replace analogue materials or bulk samples of synthesized hydrate with more representative samples and study them under conditions that mimic nature. For example, scientists at the Pacific Northwest National Lab and the Lawrence Berkeley National Lab are using technologies such as resident ultrasound spectrometry and computed tomography X-ray scanning to look inside hydrate-sand samples and study the details of hydrate dissociation. Similarly, work at the USGS's Woods Hole laboratory and at Brookhaven National Lab is enabling the direct measurement of the physical properties of hydrate-bearing sediments down to silt size.

Scientists are now developing the means to use the latest technology, such as CT scanners, Raman spectrometers, nuclear magnetic resonance imaging, and even full core-analysis laboratories in the field. These devices are greatly improving the efficiency of high-cost field operations, as well as reducing the uncertainties that surround the analyses of transported samples.

An international team of researchers at the Mallik site in the Northwest Territories drilled three 3,900-foot wells during the winter of 2002. They found that gas production from hydrate was technologically feasible.

For much of the history of hydrate research, the primary signal for assessing the occurrence of hydrates in marine environments was the presence on 2-D seismic reflection profiles of bottom-simulating reflectors—known as BSRs—and other anomalous features such as amplitude "blanking." BSRs were interpreted to indicate the transition from hydrate to free gas and water with depth. Areas lacking BSRs were assumed to possess no hydrate.

Today, however, it is widely accepted that hydrate can occur without BSRs and the presence of a BSR provides virtually no information on the distribution or concentration of hydrate. Therefore, geophysicists are turning their attention to the use of 3-D seismic data, where available, to directly detect hydrate presence from its effect on the mechanical properties of the enclosing sediments.

Through work at the Mallik site and elsewhere, we also have a good sense of the physical form hydrates take within sediments. Researchers are now in general agreement that hydrates most often occur as discrete grains that form within pores and act as part of the framework of the sediment, rather than as grain coatings or cements. This finding is critical to improving the interpretation of well log, reflection seismic data, and a variety of other reservoir parameters.

In addition to progress in physical sampling and characterization, researchers have been able to create richer, more robust models that can help predict the behavior of hydrate reservoirs under natural conditions. Validated with data from the 2002 testing at Mallik, the ToughFX/Hydrate model produced by Lawrence Berkeley National Laboratory in California allows simulation of hydrate dissociation and resultant fluid flows under currently contemplated production scenarios. In addition, researchers working with the U.S. Department of Energy and BP Alaska on the Alaskan North Slope have successfully conducted industry-standard, field-scale reservoir simulations of discrete gas hydrate prospects.

These strands are coming together in Alaska, where geologists are discovering hydrate deposits and developing plans to exploit them. Researchers working in association with the DOE, the USGS, and BP Alaska are applying 3-D seismic and conventional well log data to fully identify, characterize, and evaluate gas hydrate and associated free gas potential within the area of the Milne Point oil field on the Alaskan North Slope. This work has identified more than a dozen unique, delineated, and potentially drillable hydrate prospects.

Economic Viability

Work at the Mallik site in the Canadian Arctic over the past seven years has definitively established that production of methane from hydrates can occur using existing well-based technologies. Furthermore, based on the results of the scientific production response tests conducted at Mallik in 2002, it is now believed that depressurization can result in significant and economically viable volumes and rates of methane production. Research reported at a major petroleum geology conference in September 2004 indicates that, by leveraging existing infrastructure, production can be economical at gas prices on the order of $4 to $6 per thousand cubic feet.

Over the past half-decade of extensive laboratory and field work, we have learned that hydrate systems are highly complex and heterogeneous, challenging earlier concepts that were informed by notions of broad, continuous, and uniform hydrate stability zones. This new appreciation for the complexities of natural hydrates is a key step in reclassifying hydrates from a vaguely defined "resource of the future" to a recognized part of the nation's energy portfolio.

During the next five years, the national methane hydrate research program will direct much of its effort to field and laboratory studies designed to accelerate the commercial production of methane from hydrate in Alaska. It will also pursue the difficult task of appraising the recoverable potential of marine hydrates. A key focus of the effort will be to establish whether hydrate occurs in sufficient quality and quantity to ultimately provide a significant contribution to the nation's future energy supply.

Clearly, unless the much more voluminous and technically challenging marine deposits can be accessed, this answer is likely to be "no." The hydrate resource in Arctic sediments does not look to be great enough by itself. Ongoing work by the Minerals Management Service to assess hydrate resources in the Gulf of Mexico will be a major step toward getting an answer.

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There's much work to be done in other areas as well. For geologists, many issues, such as the mechanical strength and thermal conductivity and compressibility of hydrate-bearing sediments, remain poorly understood. Of critical importance will be the refinement of current methods to estimate the rate and progression of hydrate dissociation, as pressure and temperature conditions change in different geochemical environments and in various sediment types and textures. Similarly, we need to refine our current understanding of how hydrate occurrence and dissociation affects the relative permeability, phase saturations, and resulting fluid flow in hydrate reservoirs.

Much like the production of conventional gas, hydrate development will begin with the highest-quality deposits and slowly expand to more challenging settings. And, as with conventional resources, success will depend on the ability to appraise large regions and efficiently find these "sweet spots."

With respect to marine hydrates in particular, this will be a major technological challenge. Conceptual models of hydrate formation that provide insight into why hydrate forms in some places and not in others will have to improve. Then, exploration for marine hydrates will fully integrate these models with heat flow measurement and geochemical indicators of methane flux. Testing these interpretations against data collected in the field will be ongoing as more sites are analyzed.

Additional production tests, although both costly and risky, must be conducted to test the effectiveness of predictive and diagnostic tools—and to provide the means of refining alternative production strategies. The selection of sites and the interpretation of results will be supported by the use of numerical simulators that will constantly be incorporating new field and lab-derived data on the nature and behavior of hydrate in natural settings.

It has now been demonstrated that the production of methane from hydrate is technically possible and, in certain settings, economically feasible. Now, research has to determine how extensive the producible hydrate resource is.

Although it is not where the bulk of the in-place resource lies, productivity will first be demonstrated in the Arctic because those deposits are better defined and of higher quality than marine hydrates. Then that knowledge will be applied to marine settings. In the United States, the offshore work will likely occur first in the Gulf of Mexico, where oil and gas industry data, infrastructure, and experience can be leveraged to provide collaborative R&D opportunities.

No one doubts that producing gas from hydrates poses enormous technical challenges, in addition to the high cost of deep-water operations: The marine hydrate resource remains poorly defined, and may exist largely as diffuse, discontinuous, and low-concentration deposits within fine-grained, low-permeability sediments. The ability, at least initially, to reliably detect coarser-grained reservoirs within the zone of hydrate stability, and to appraise hydrate saturations within those units, will be critical.

What's more, a number of critical public-interest questions need to be addressed before any exploitation of hydrates can begin. What, for example, does this global methane reservoir mean for our understanding of the global carbon cycle and global climate? How does it react to natural changes in the environment and how might it respond to human activities? How does it impact the stability of deep-water continental shelves and slopes, particularly where instability poses a hazard to oil and gas exploration?

Despite these challenges, the U.S. Department of Energy, the U.S. Geological Survey, the Minerals Management Service, the National Oceanic and Atmospheric Administration, the National Science Foundation, the Naval Research Lab, and other organizations are cooperating on this effort. All the parties recognize that methane hydrate research will provide enormous public benefits. Fundamentally, the work will yield an improved understanding of the natural environment and provide knowledge for more informed decision-making on issues ranging from ocean policy to global climate change.

Beyond that, the successful demonstration of feasible production of methane hydrate will add greatly to assuring the long-term supply of natural gas, an environmentally friendly fuel with enormous economic and energy security benefits to the nation. Ultimately, the success of this effort will contribute significantly to the expanded diversification of global energy supply and the associated adjustment of the global balance of energy power.

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