ENGINEERING

Is Gas Hydrate Energy Within Reach?

A new focus of the most recoverable gas hydrate deposits is shortening the timeline for the future production of natural gas from this vast resource.

Ray Boswell

Technological advances have opened up natural gas resources that were previously unobtainable, including deep-water areas (depths >305 m) and unconventional resources, such as coal-bed methane, and gas in shale, that do not readily release their gas to wells. The next resource poised to be delivered is gas hydrates, which form from methane and water at low temperatures and moderate pressures. Gas hydrates occur in permafrost (*1*), but most of this vast resource occurs in marine sediments on the outer continental shelves (*2*). Physical barriers posed by Arctic and deep-water settings, as well as a lack of proven extraction methods, have made them an unexploited resource. However, a series of international field programs in the last 5 years, in conjunction with experimental studies and numerical simulations, show that it should be possible to extract the most favorable gas hydrates—those enclosed in sandy sediments that lay at the apex of the gas hydrate resource pyramid (see the figure)—with existing technologies.

Although recent estimates continue to range over nearly two orders of magnitude (*3*), the global resource of methane in gas hydrate deposits is commonly cited as 20,000 trillion m^3 (*2*). For comparison, annual natural gas use in the United States is just over 600 billion m^3. The carbon stored in gas hydrates may have profound implications for global carbon cycling (*4*) and climate change (*5*). However, it is the potential of gas hydrate to become a major energy resource that is the primary driver for the rapidly accelerating international investment in gas hydrate research, especially by countries with limited hydrocarbon resources.

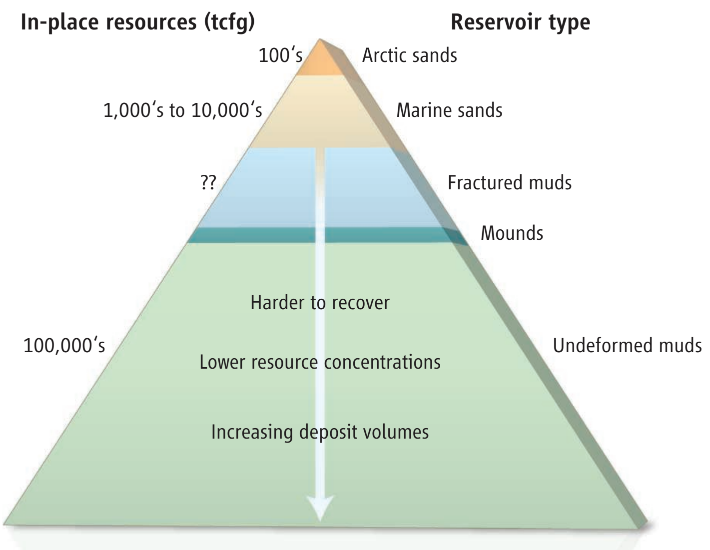
Until the late 1990s, marine gas hydrates were thought to exist primarily in low-permeability, unconsolidated muds. In typical samples, the gas hydrates filled only 10% of the available pore space (*6*), so although the deposits were large, they were lean in gas content. Gas hydrates were also known to occur as large, solid mounds directly on the sea floor, often in association with sea-floor seeps hosting unique benthic marine life (*7*). Because neither of these settings is readily compatible with existing oil and gas production methods, initial production concepts, often invoking mining approaches, faced daunting environmental and economic challenges.

However, the prospects for production from marine gas hydrates greatly improved in 1999, when researchers in Japan discovered extensive gas hydrate deposits in sand reservoirs off the shore of southeastern Japan (*8*). What made these deposits attractive for gas extraction is their permeability, which appears to enable gas hydrate to accumulate to very high concentrations (typically 60 to 90% of the pore space). In addition, the permeability present in sand reservoirs may be the key to producing methane from gas hydrate reservoirs with existing drilling and production technologies.

This new focus on the most prospective gas hydrate deposits brings a highly improved perspective and exploration rationale to the study of gas hydrate resources. Unlike the vast but highly dispersed marine gas hydrates in mud, the sand bodies contain discrete and isolated reservoirs that are richly concentrated. Furthermore, these reservoirs are commonly buried many hundreds of meters below the sea floor and enclosed in a matrix of impermeable sediments that help to prevent the escape of released methane. Therefore, the most prospective gas hydrate deposits are also those that are most effectively buffered from environmental change.

There remain two major near-term challenges that will likely determine whether these sand-enclosed gas hydrates are an exploitable resource. The first is to determine the extent of gas hydrates in sand reservoirs in the marine environment. In the United States, the Minerals Management Service recently estimated that more than 190 trillion m^3 of gas exist in gas hydrate–bearing sand reservoirs in the northern Gulf of Mexico (*9*). This estimate needs to be further confirmed by drilling, but initial results are encouraging. A 21-day expedition to the Gulf of Mexico, completed in April 2009, discovered multiple occurrences of highly saturated gas hydrates in sand reservoirs at two of three sites drilled (*10*).

The second challenge is whether such deposits yield gas at the rates necessary to make expensive deep-water production commercially viable. The most promising production method reduces pressure in the well bore. Water in the formation moves toward the well, causing a region of reduced pressure to spread rapidly throughout the formation. Reduced pressure initiates gas hydrate dissociation and methane release. The viability of this approach was confirmed during a 6-day production test com-



The gas hydrate resource pyramid. The various components of the total gas hydrate resource are arranged, with those most readily recovered at the top. Current research, focusing on sand-hosted gas hydrates at the top of the pyramid, shows large potential resources that are recoverable with existing technology. These findings may provide insight into the nature and resource potential of the more challenging resources that occur at the base of the pyramid. Current best estimates of resource volumes are in trillions of cubic feet of gas (tcfg); 100 ft^3 = 2.83 m^3. [Modified from (*18*)]

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pleted in April 2008 by the governments of Japan and Canada at the Mallik site in the Canadian Northwest Territories (*11*). Numerical simulations (*12*) show that production based primarily on reducing pressure by pumping could release methane at rates that make commercial production feasible in certain settings. Another production possibility enabled by sand reservoirs is the injection of carbon dioxide (CO_2), which has the potential to displace methane from at least half of the hydrate structure cavities (*13*) and also leave the CO_2 sequestered within the hydrate structure. Initial studies of these two approaches have been encouraging (*12*, *14*), but extended production tests of both methods are needed. Such testing, currently in the planning stages for sites in Alaska, will be needed to help prepare for marine production tests, which are still several years away.

The new focus on sandy deposits enables the first assessments of resource volumes that are recoverable with existing technology (*15*). These resource volumes are substantially smaller than those that have previously framed the gas hydrate resource debate. However, these new estimates, which indicate volumes of hundreds of trillions of cubic meters, are still substantial, are more firmly grounded in scientific information obtained in the field, and are far more relevant to the energy resource issue.

This focus does not mean that the larger resource at the bottom of the pyramid will always be out of reach. Recently, gas hydrate deposits more than 150 m thick were discovered in fine-grained sediments offshore India (*16*) and Korea (*17*). The typically low filling of the pore space by gas hydrate is substantially augmented in these deposits by pervasive networks of gas hydrate–filled veins and fractures. The total resource represented by these fractured clay reservoirs is not yet known, but could be substantial. However, a number of engineering challenges must be overcome to enable production from such unconsolidated and practically impermeable sediments.

Exploitation of even the most promising gas hydrate reservoirs requires substantial technological and economic hurdles to be overcome. However, many of these issues, such as geomechanical complications caused by the unconsolidated nature of sand in the reservoirs, are now being successfully addressed in existing oil and gas fields. Solving these issues would provide a new and potentially vast global resource to meet mid- and long-term energy demands. Gas hydrates may offer an important "bridging" fuel that will help ease the transition to the sustainable energy supplies of the future.

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GENETICS

More Than Just a Copy

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Several dog breeds owe their short legs to a gene duplication event based on reverse transcription of RNA.

How do new gene functions arise? The importance of gene duplication for the emergence of new gene functions, and hence for the origin of evolutionary innovations, was already recognized in the early 1930s by geneticists J. B. S. Haldane (*1*) and H. J. Muller (*2*), and later popularized by S. Ohno (*3*). In this view, the occurrence of a second copy of a gene provides unique raw material for evolutionary diversification: One of the two duplicate gene copies is preserved to maintain the original gene function, whereas the other is free to accumulate mutations, potentially yielding a gene with new functional properties. A large body of data has provided incontestable support for this early hypothesis (*4*). On page 995 in this issue (*5*), Parker *et al*. provide a new paradigm for gene duplication with implications regarding the evolution of new gene functions.

Until recently, DNA-mediated gene duplication was considered the main underlying mechanism—that is, duplication occurs by recombination of chromosomal segments containing the gene during meiosis (cell divisions that occur during the production of gametes) (see the figure). But gene duplication can also occur through a process called retroposition or retroduplication (*6*), in which a mature messenger RNA (mRNA) that is transcribed from a gene is then "reverse transcribed" into a complementary DNA copy, which gets inserted into the genome (see the figure). Unlike the parental "source" gene, which contains introns, a "retrocopy" that is produced from a mature mRNA (in which introns have been spliced out) contains only the parental exons. These intronless retrocopies were long thought to be doomed to decay and were routinely classified as processed pseudogenes because of the expected lack of regulatory elements and the presence of deleterious mutations in many copies. Nevertheless, individual functional retrocopies (so-called retrogenes) have been discovered since the late 1980s (*7*), and the genomics era facilitated their discovery and characterization on a larger scale. Often their functions were found to be related to the germ line, but retrogenes were also shown to affect other functions, such as in the courtship behavior of flies (*6*).

Parker *et al*. provide a new example of a retrogene with important functional consequences. The authors aimed to uncover the molecular basis of the short-, curved-leg trait (chondrodysplasia) that is characteristic of several common dog breeds such as the dachshund. In fact, leg length is a primary aspect of interbreed variation and is therefore particu-

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