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Gas Hydrates: Resource and Hazard

Peter Folger
Specialist in Energy and Natural Resources Policy

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Summary

Solid gas hydrates are a potentially huge resource of natural gas for the United States. The U.S. Geological Survey estimated that there are about 85 trillion cubic feet (TCF) of technically recoverable gas hydrates in northern Alaska. The Minerals Management Service estimated a mean value of 21,000 TCF of in-place gas hydrates in the Gulf of Mexico. By comparison, total U.S. natural gas consumption is about 23 TCF annually. The in-place estimate disregards technical or economical recoverability, and likely overestimates the amount of commercially viable gas hydrates. Even if a fraction of the U.S. gas hydrates can be economically produced, however, it could add substantially to the 1,300 TCF of technically recoverable U.S. conventional natural gas reserves. To date, however, gas hydrates have no confirmed commercial production.

Gas hydrates are both a potential resource and a risk, representing a significant hazard to conventional oil and gas drilling and production operations. If the solid gas hydrates dissociate suddenly and release expanded gas during offshore drilling, they could disrupt the marine sediments and compromise pipelines and production equipment on the seafloor. The tendency of gas hydrates to dissociate and release methane, which can be a hazard, is the same characteristic that research and development efforts strive to enhance so that methane can be produced and recovered in commercial quantities. Gas hydrates have hindered attempts to plug the Deepwater Horizon oil well blowout in the Gulf of Mexico, and may have had some role in contributing to anomalous gas pressure in the wellbore that caused the blowout itself.

Developing gas hydrates into a commercially viable source of energy is a goal of the U.S. Department of Energy (DOE) methane hydrate program, initially authorized by the Methane Hydrate Research and Development Act of 2000 (P.L. 106-193). The Energy Policy Act of 2005 (P.L. 109-58, Subtitle F, § 968) extended the authorization through FY2010 and authorized total appropriations of $155 million over a five-year period. Congress appropriated $15 million for the gas hydrate research and development (R&D) program in FY2009. The Obama Administration requested $25 million for the natural gas technologies program for FY2010, which includes gas hydrate R&D. Congress appropriated $17.8 million for the program in FY2010, which would also fund research and development into unconventional gas production from basins containing tight gas sands, shale gas, and coal bed methane, as well as for gas hydrates.

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Gas hydrates occur naturally onshore in permafrost, and at or below the seafloor in sediments where water and gas combine at low temperatures and high pressures to form an ice-like solid substance.[1] Methane, or natural gas, is typically the dominant gas in the hydrate structure. In a gas hydrate, frozen water molecules form a cage-like structure around high concentrations of natural gas. The gas hydrate structure is very compact. When heated and depressurized to temperatures and pressures typically found on the Earth's surface (one atmosphere of pressure and 70^{o} Fahrenheit), its volume expands by 150 to 170 times. Thus, one cubic foot of solid gas hydrate found underground in permafrost or beneath the seafloor would produce between 150 to 170 cubic feet of natural gas when brought to the surface.

Gas hydrates are a potentially huge global energy resource. The United States and other countries with territory in the Arctic or with offshore gas hydrates along their continental margins are interested in developing the resource. Countries currently pursuing national research and development programs include Japan, India, Korea, and China, among others. Although burning natural gas produces carbon dioxide (CO_2), a greenhouse gas, the amount of CO_2 liberated per unit of energy produced is less than 60% of the CO_2 produced from burning coal.[2] In addition, the United States imports 20% of its natural gas consumed each year.[3] Increasing the U.S. supply of natural gas from gas hydrates would decrease reliance on imported gas and reduce U.S. emissions of CO_2 if domestically produced gas hydrates substitute for coal as an energy source.

Gas Hydrate Resources

There are several challenges to commercially exploiting gas hydrates. How much and where gas hydrate occurs in commercially viable concentrations are not well known, and how the resource can be extracted safely and economically is a current research focus. Estimates of global gas hydrate resources, which range from at least 100,000 TCF to possibly much more, may greatly overestimate how much gas can be extracted economically. Reports of vast gas hydrate resources can be misleading unless those estimates are qualified by the use of such terms as *in-place* resources, technically recoverable resources, and proved reserves:

- The term in-place is used to describe an estimate of gas hydrate resources without regard for technical or economical recoverability. Generally these are the largest estimates.
- Undiscovered technically recoverable resources are producible using current technology, but this does not take into account economic viability.
- Proved reserves are estimated quantities that can be recovered under existing economic and operating conditions.

For example, the U.S. Department of Energy's Energy Information Agency (EIA) estimates that total undiscovered technically recoverable conventional natural gas resources in the United States

[1] The terms *methane hydrate* and *gas hydrate* are often used interchangeably, and refer to the methane-water crystalline structure called a clathrate.

[2] U.S. Department of Energy, Energy Information Agency (EIA), at http://www.eia.doe.gov/cneaf/coal/quarterly/co2_article/co2.html.

[3] In 2007, the United States consumed approximately 23 TCF of natural gas, of which 4.6 TCF were imported. See EIA at http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm.

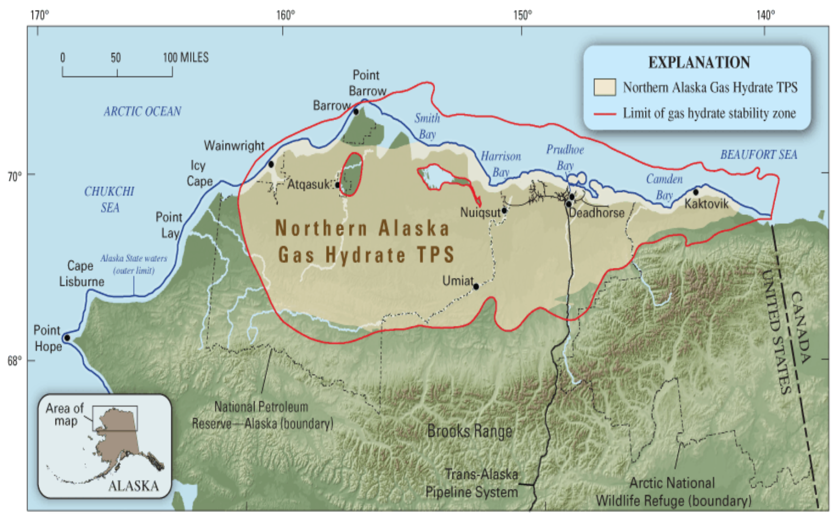
are approximately 1,300 TCF, but proved reserves are only 200 TCF.[4] This is an important distinction because there are no proved reserves for gas hydrates at this time. Gas hydrates have no confirmed past or current commercial production.

Until recently, the Department of the Interior's U.S. Geological Survey (USGS) and Minerals Management Service (MMS) have reported only in-place estimates of U.S. gas hydrate resources. However, a November 12, 2008, USGS estimate of undiscovered technically recoverable gas hydrates in northern Alaska probably represents the most robust effort to identify gas hydrates that may be commercially viable sources of energy.[5] Despite a lack of a production history, the USGS report cites a growing body of evidence indicating that some gas hydrate resources, such as those in northern Alaska, might be produced with existing technology despite only limited field testing.

Gas Hydrates on the North Slope, Alaska

The USGS assessment indicates that the North Slope of Alaska may host about 85 TCF of undiscovered technically recoverable gas hydrate resources (**Figure 1**). According to the report, technically recoverable gas hydrate resources could range from a low of 25 TCF to as much as 158 TCF on the North Slope. Total U.S. consumption of natural gas in 2007 was slightly more than 23 TCF.

Figure 1. Gas Hydrate Assessment Area, North Slope, Alaska



Source: USGS Fact Sheet 2008-3073, Assessment of Gas Hydrate Resources on the North Slope, Alaska, 2008, at http://pubs.usgs.gov/fs/2008/3073/.

Note: TPS refers to total petroleum system, which refers to geologic elements that control petroleum generation, migration, and entrapment.

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[4] These estimates are as of 2006. Global proved reserves of conventional natural gas are over 6,185 TCF. See EIA at http://www.eia.doe.gov/emeu/aer/pdf/pages/sec4_3.pdf and http://www.eia.doe.gov/emeu/international/reserves.html.

[5] USGS Fact Sheet 2008-3073, Assessment of Gas Hydrate Resources on the North Slope, Alaska, 2008, at http://pubs.usgs.gov/fs/2008/3073/.

Of the mean estimate of 85 TCF of technically recoverable gas hydrates on the North Slope, 56% is located on federally managed lands, 39% on lands and offshore waters managed by the state of Alaska, and the remainder on Native lands.[6] The total area comprised by the USGS assessment is 55,894 square miles, and extends from the National Petroleum Reserve in the west to the Arctic National Wildlife Refuge (ANWR) in the east (**Figure 1**). The area extends north from the Brooks Range to the state-federal offshore boundary three miles north of the Alaska coastline. Gas hydrates might also be found outside the assessment area; the USGS reports that the gas hydrate stability zone—where favorable conditions of temperature and pressure coexist for gas hydrate formation—extends beyond the study boundaries into federal waters beyond the three-mile boundary (**Figure 1**).

Gas Hydrates in the Gulf of Mexico

On February 1, 2008, the MMS released an assessment of gas hydrate resources for the Gulf of Mexico.[7] The report gives a statistical probability of the volume of undiscovered *in-plac*e gas hydrate resources, with a mean estimate of over 21,000 TCF. The MMS report estimates how much gas hydrate may occur in sandstone and shale reservoirs, using a combination of data and modeling, but does not indicate how much is recoverable with current technology. The report notes that porous and permeable sandstone reservoirs have the greatest potential for actually producing gas from hydrates, and gives a mean estimate of over 6,700 TCF of sandstone-hosted gas hydrates, about 30% of the total mean estimate for the Gulf of Mexico.[8] Even for sandstone reservoirs, however, the in-place estimates for gas hydrates in the Gulf of Mexico likely far exceed what may be commercially recoverable with current technology. The MMS is planning similar in-place gas hydrate assessments for other portions of the U.S. Outer Continental Shelf (OCS), including Alaska.

Gas Hydrates Along Continental Margins

Globally, the amount of gas hydrate to be found offshore along continental margins probably exceeds the amount found onshore in permafrost regions by two orders of magnitude, according to one estimate.[9] With the exception of the assessments discussed above, none of the global gas hydrate estimates is well defined, and all are speculative to some extent.[10] One way to depict the potential size and producibility of global gas hydrate resources is by using a resource pyramid (**Figure 2**).[11] The apex of the pyramid shows the smallest but most promising gas hydrate

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[6] USGS presentation, Timothy S. Collett, October 2008, at http://energy.usgs.gov/flash/AlaskaGHAssessment_slideshow.swf.

[7] U.S. Department of the Interior, Minerals Management Service, Resource Evaluation Division, "Preliminary evaluation of in-place gas hydrate resources: Gulf of Mexico outer continental shelf," OCS Report MMS 2008-004 (Feb. 1, 2008), at http://www.mms.gov/revaldiv/GasHydrateFiles/MMS2008-004.pdf.

[8] Ibid., table 16.

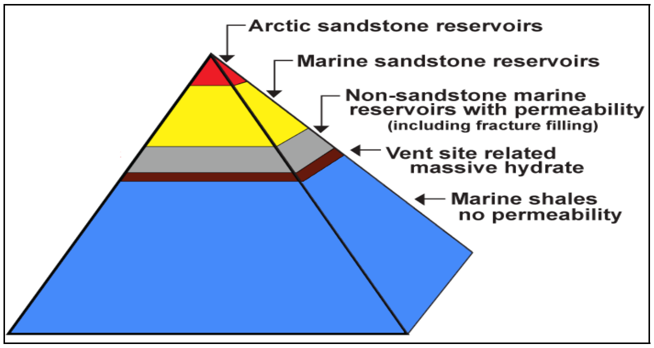
[9] George J. Moridis et al., "Toward production from gas hydrates: current status, assessment of resources, and simulation-based evaluation of technology and potential," 2008 SPE Unconventional Reservoirs Conference, Keystone, CO, February 10, 2008, p. 3, at http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/reports/G308_SPE114163_Feb08.pdf.

[10] Ibid.

[11] Roy Boswell and Timothy S. Collett, "The Gas Hydrate Resource Pyramid," Fire in the Ice, Methane Hydrate R&D Program Newsletter, Fall 2006, pp. 5-7, at http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/newsletter/newsletter.htm.

reservoir—arctic and marine sandstones—which may host tens to hundreds of TCF. The bottom of the pyramid shows the largest but most technically challenging reservoir—marine shales.

Figure 2. Gas Hydrate Reservoir Pyramid



Source: Roy Boswell and Timothy S. Collett, "The Gas Hydrate Resource Pyramid," Fire in the Ice, Methane Hydrate R&D Program Newsletter, Fall 2006.

Sandstones are considered superior reservoirs because they have much higher permeability—they allow more gas to flow—than shales, which can be nearly impermeable. The marine shale gas hydrate reservoir may host hundreds of thousands of TCF, but most or all of that resource may never be economically recoverable. It is likely that continued research and development efforts in the United States and other countries will focus on producing gas hydrates from arctic and marine sandstone reservoirs.

Gas Hydrate Hazards

Gas hydrates are a significant hazard for drilling and production operations.[12] Gas hydrate production is hazardous in itself, as well as for conventional oil and gas activities that place wells and pipelines into permafrost or marine sediments. For activities in permafrost, two general categories of problems have been identified: (1) uncontrolled gas releases during drilling; and (2) damage to well casing during and after installation of a well. Similar problems could occur during offshore drilling into gas hydrate-bearing marine sediments. Offshore drilling operations that disturb gas hydrate-bearing sediments could fracture or disrupt the bottom sediments and compromise the wellbore, pipelines, rig supports, and other equipment involved in oil and gas production from the seafloor.[13]

Problems may differ somewhat between onshore and offshore operations, but they stem from the same characteristic of gas hydrates: decreases in pressure and/or increases in temperature can cause the gas hydrate to dissociate and rapidly release large amounts of gas into the well bore during a drilling operation.

Oil and gas wells drilled through permafrost or offshore to reach conventional oil and gas deposits may encounter gas hydrates, which companies generally try to avoid because of a lack of

[12] Timothy S. Collett and Scott R. Dallimore, "Detailed analysis of gas hydrate induced drilling and production hazards," Proceedings of the Fourth International Conference on Gas Hydrates, Yokohama, Japan, April 19-23, 2002.

[13] George J. Moridis and Michael B. Kowalsky, "Geomechanical implications of thermal stresses on hydrate-bearing sediments," Fire in the Ice, Methane Hydrate R&D Program Newsletter, Winter 2006.

detailed understanding of the mechanical and thermal properties of gas hydrate-bearing sediments.[14] However, to mitigate the potential hazard in these instances, the wells are cased—typically using a steel pipe that lines the wall of the borehole—to separate and protect the well from the gas hydrates in the shallower zones as drilling continues deeper. Unless precautions are taken, continued drilling may heat up the sediments surrounding the wellbore, causing gas from the dissociated hydrates to leak and bubble up around the casing. Once oil production begins, hot fluids flowing through the well could also warm hydrate-bearing sediments and cause dissociation. The released gas may pool and build up pressure against the well casing, possibly causing damage.[15] Some observers suggest that exploiting the gas hydrate resources by intentionally heating or by depressurization poses the same risks—requiring mitigation—as drilling through gas hydrates to reach deeper conventional oil and gas deposits.[16]

Gas Hydrates and the Deepwater Horizon Oil Spill in the Gulf of Mexico

On April 20, 2010, a well drilled by the Deepwater Horizon semisubmersible oil platform "blew out," igniting a fire on board the platform, which eventually sank. The blowout has resulted in an uncontrolled leak of oil and gas from the broken off pipe, or "riser," that led from the top of the well to the drilling platform. In one of the early attempts to plug the well, a heavy steel and concrete box was lowered atop the leaking riser in an attempt to capture the oil and gas and siphon it to the surface. The attempt failed because hydrates clogged the valves and pipes leading to the surface from the steel box as methane converted from a gas phase to solid phase methane hydrate.

The Deepwater Horizon had drilled an "ultradeep" exploratory well in the Gulf of Mexico in approximately 5,000 feet of water. At 5,000 feet below the surface, seawater is approximately 40° F (4.4° C), and the pressure is approximately 2,500 pounds per square inch (psi). Gas hydrates are stable at that depth and pressure, and can form as long as sufficient quantities of natural gas and water are present—as was the case for the Deepwater Horizon blowout.

Indeed, gas hydrates may have had some role in the original blowout. If a sufficient amount of methane were present in the seafloor sediments, gas hydrates could have formed at the temperatures and pressures in the sediments 1,000 or perhaps 1,500 feet below the seafloor at the Deepwater Horizon drill site (depending on the geothermal gradient—how rapidly the earth changes temperature with depth in that part of the Gulf of Mexico). As discussed in the text of this report, drilling and well completion activities may have disturbed hydrate-bearing sediments, resulting in depressurization or heating that could have caused the hydrate to dissociate into a gas. If the gas were able to enter the wellbore through some defect in the casing or cement, it may have contributed to the anomalous gas pressure inside the wellbore that led to the April 20 blowout. Pending an analysis of the causes for the blowout, however, it is currently unknown whether gas hydrates were involved.

Sources: personal communication, Carolyn Ruppel, Gas Hydrates Project, U.S. Geological Survey, Reston, VA, May 17, 2010; MMS Report 2008-004, Preliminary Evaluation of In-Place Gas Hydrate Resources: Gulf of Mexico Outer Continental Shelf.

Gas Hydrate Research and Development

A goal of the DOE methane hydrate research and development (R&D) program is to develop knowledge and technology to allow commercial production of methane from gas hydrates by 2015.[17] Since the Methane Hydrate Research and Development Act of 2000 (P.L. 106-193) was

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[14] Moridis and Kowalski (2006).

[15] Collett and Dallimore (2002).

[16] Personal communication, Ray Boswell, Manager, Methane Hydrate R&D Programs, DOE National Energy Technology Laboratory, Morgantown, WV, Nov. 5, 2008.

[17] DOE methane hydrate R&D program, at http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/ (continued...)

enacted, DOE has spent $102.3 million through FY2009, or approximately 67% of the $152.5 million authorized by law. The Omnibus Appropriations Act, 2009 (P.L. 111-8), provided $20 million in FY2009 for natural gas technologies R&D, which included $15 million for gas hydrates R&D. The Obama Administration requested $25 million for the natural gas technologies program in FY2010, or half of the $50 million authorized for methane hydrates R&D by the Energy Policy Act of 2005 (P.L. 109-58). Congress appropriated $17.8 million for natural gas technologies in FY2010, giving DOE direction to fund research into unconventional gas production from basins containing tight gas sands, shale gas, and coal bed methane, as well as for gas hydrates.[18] The gas hydrate R&D program is authorized through FY2010 under current law.

The DOE program completed a Gulf of Mexico offshore expedition in May 2009 and an Alaska production test in the summer of 2009. The Gulf of Mexico program was aimed at validating techniques for locating and assessing commercially viable gas hydrate deposits.[19] In Alaska, a two-year production test is expected to provide critical information about methane flow rates and sediment stability during gas hydrate dissociation.[20] Results from the two-year test in Alaska may be crucial to companies interested in producing gas hydrates commercially. Both projects have international and industry partners.

Researchers identify a need to better understand how geology in the permafrost regions and on continental margins controls the occurrence and formation of methane hydrates.[21] They underscore the need to understand fundamental aspects—porosity, permeability, reservoir temperatures—of the geologic framework that hosts the gas hydrate resource to improve assessment and exploration, to mitigate the hazard, and to enhance gas recovery.

Together with advances in R&D, economic viability will depend on the relative cost of conventional fuels, as well as other factors such as pipelines and other infrastructure needed to deliver gas hydrate methane to market. Additionally, price volatility will likely affect the level of private sector investment in commercial production of gas hydrates.

Author Contact Information

Peter Folger
Specialist in Energy and Natural Resources Policy
pfolger@crs.loc.gov, 7-1517

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MethaneHydrates/rd-program/rd-program.htm.

[18] See H.Rept. 111-278.

[19] See DOE, National Energy Technology Laboratory, “Fire in the Ice,” Summer 2009, at http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/Newsletter/MHNewsSummer09.pdf.

[20] See http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/projects/DOEProjects/Alaska-41332.html.

[21] Collett and Dallimore (2002); Moridis and Kowalski (2006).