Gas Hydrates: Resource and Hazard

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January 24, 2011

Congressional Research Service
7-5700
www.crs.gov
RS22990

CRS Report for Congress
Prepared for Members and Committees of Congress

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 Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE, formerly the Minerals Management Service, MMS) 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. An issue for the 112th Congress is whether gas hydrates represent a viable component of the future energy portfolio of the United States, and if federal research and development programs are appropriate and sufficient to meet energy policy goals.

Gas hydrates are both a potential resource and a risk, representing a significant hazard to conventional oil and gas drilling and production operations. If solid gas hydrates dissociate suddenly and release expanded gas during offshore drilling, they could disrupt 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 hindered early attempts to plug the Deepwater Horizon oil well blowout in the Gulf of Mexico and to siphon the leaking oil and gas to the surface. Gas hydrates formed when the leaking natural gas contacted cold seawater at the seafloor. The resulting slurry of gas hydrate crystals clogged pipes and valves leading from the steel box placed atop the leaking well to a vessel at the ocean surface. Given the potential risk associated with developing the resource, and the increased scrutiny on offshore oil and gas development in the wake of the Deepwater Horizon disaster, Congress may consider whether to evaluate the evolving regulatory and safety infrastructure for offshore development to determine if it is appropriate for exploiting gas hydrates offshore.

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 of appropriations through FY2010 for a total of $155 million over a five-year period. Congressional appropriations for FY2010 directed DOE to include no less than $15 million for gas hydrates research and development (R&D). Authorization of appropriations for the methane hydrate R&D expired at the end of FY2010.

For FY2011, the Obama Administration requested no funding for the Natural Gas Technologies program within DOE's Fossil Energy Research and Development account, which included gas hydrates R&D, stating that the move was consistent with Administration policy to phase out fossil fuel subsidies. Instead, the Administration proposed to initiate a new research program in gas hydrates within the DOE Office of Basic Energy Sciences. The Administration's request for the program for FY2011 was $17.5 million.

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Gas hydrates occur naturally onshore in some permafrost regions, 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, the primary component of 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° 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 and 170 cubic feet of natural gas when brought to the surface.[2]

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.[3] In addition, from 2004 to 2009 the United States imported between 16% and 20% of its natural gas consumed each year.[4] 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.

U.S. policy regarding energy resource development is a perennial issue for Congress. Given that gas hydrates offer the possibility of substantially increasing the U.S. supply of natural gas, the 112th Congress may evaluate whether U.S. policies regarding onshore and offshore development are appropriate for the gas hydrate resource. The 112th Congress may also consider the risks of developing gas hydrates, particularly offshore in the Gulf of Mexico, in the wake of the Deepwater Horizon blowout and oil spill. In part, the federal research and development (R&D) program for gas hydrates is aimed at developing knowledge and technology to allow commercial production of methane from gas hydrates and to minimize the risks of developing the resource. Questions for consideration may include: Has the program made progress since the Methane Hydrate Research and Development Act of 2000 (P.L. 106-193) was enacted; and are the funding levels appropriate for the program?

The 112th Congress may also consider market forces in addition to federal involvement in the development of gas hydrates. Together with advances in gas hydrate R&D, the economic viability of gas hydrates 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 of natural gas will likely affect the level and continuity of private-sector investment in commercial production of gas hydrates.

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

[2] Values given below for estimates of gas hydrate resources refer to the quantity of natural gas potentially developed from the solid hydrate, not the actual volume of the gas hydrate in solid form.

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

[4] In 2009, the United States consumed approximately 23 TCF of natural gas, of which 3.75 TCF were imported (87% of the imports came from Canada). See EIA at http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm and http://www.eia.gov/dnav/ng/NG_MOVE_IMPC_S1_A.htm.

Gas Hydrate Resources

There are several challenges to commercially exploiting gas hydrates. How much and where gas hydrates occur 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 using current technology 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 are approximately 2,100 TCF, but proved reserves are only 240 TCF.[5] 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 Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE, formerly the Minerals Management Service, MMS) 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.[6] Despite a lack of a production history and only limited field testing, 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.

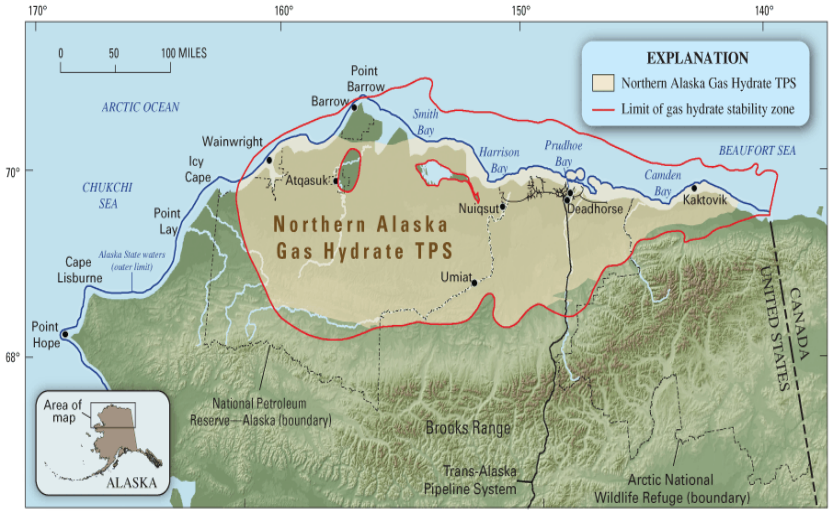
Gas Hydrates on the North Slope, Alaska

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.

[5] These estimates are as of 2007. Global proved reserves of conventional natural gas are over 6,290 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 (global proved reserves reflect the BP Statistical Review estimate at year-end 2007).

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

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.

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.[7] 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, BOEMRE (then MMS) released an assessment of gas hydrate resources for the Gulf of Mexico.[8] The report gave a statistical probability of the volume of undiscovered *in-place* gas hydrate resources, with a mean estimate of over 21,000 TCF. The MMS report estimated how much gas hydrate may occur in sandstone and shale reservoirs, using a combination of data and modeling, but did not indicate how much is recoverable with current technology. The report noted that porous and permeable sandstone reservoirs have the greatest potential for actually producing gas from hydrates, and gave 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.[9]

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

[8] 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 (February 1, 2008), at http://www.mms.gov/revaldiv/GasHydrateFiles/MMS2008-004.pdf.

[9] Ibid., Table 16.

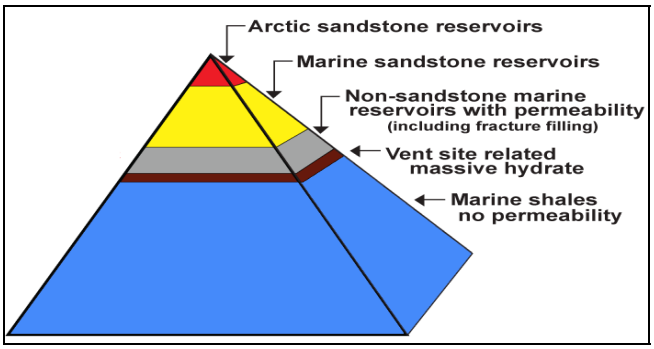
Even for sandstone reservoirs, however, the in-place estimates for gas hydrates in the Gulf of Mexico likely far exceed what may be commercially recoverable with current technology. BOEMRE is planning similar in-place gas hydrate assessments for other portions of the U.S. Outer Continental Shelf (OCS), including Alaska.

In 2009, drilling by a government and industry consortium in the Gulf of Mexico revealed the presence of gas hydrate-bearing reservoir rocks with the potential for producing natural gas using conventional technology.[10] The drilling project identified gas hydrates in sand reservoirs, thick sequences of fracture-filling gas hydrates in shales, and gas hydrates in other types of systems. In a press release, USGS stated that the discovery of the thick, gas-bearing sands provides increased confidence in assessing the energy resource potential of marine gas hydrates.[11]

Gas Hydrates Along Continental Margins

Globally, according to one estimate, the amount of gas hydrate yet to be found offshore along continental margins probably exceeds the amount already identified onshore in permafrost regions by two orders of magnitude.[12] 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.[13] One way to depict the potential size and producibility of global gas hydrate resources is by using a resource pyramid (**Figure 2**).[14] The apex of the pyramid shows the smallest but most promising gas hydrate reservoir—arctic and marine sandstones—which may host tens to hundreds of TCF. The bottom of the pyramid shows the largest but most technically and economically 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.

[10] USGS press release, "Significant Gas Resource Discovered in U.S. Gulf of Mexico," May 29, 2009, at http://www.usgs.gov/newsroom/article.asp?ID=2227&from=rss_home.

[11] Ibid.

[12] 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.

[13] Ibid.

[14] 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.

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 conventional oil and gas drilling and production operations.[15] 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 detailed understanding of the mechanical and thermal properties of gas hydrate-bearing sediments.[16] 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.[17]

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.[18] 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 wellbore during a drilling operation.

Gas hydrate production is hazardous in itself. 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. Some observers suggest that exploiting the gas hydrate resources by intentional heating or by depressurization poses the same risks—requiring mitigation—as drilling through gas hydrates to reach deeper conventional oil and gas deposits.[19]

[15] 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.

[16] Moridis and Kowalski (2006).

[17] Collett and Dallimore (2002).

[18] 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.

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

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 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. (For reference, the pressure at sea level, corresponding to one atmosphere, is approximately 14.7 psi.)

The final report from the Deepwater Horizon Commission on the disaster mentioned the risk from methane hydrates to deepwater drilling, citing the possibility of disturbing hydrate-bearing sediments during drilling. The report did not, however, indicate that hydrates in the marine sediments had any role in causing the blowout and loss of well control.

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*; National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, *Deep Water: the Gulf Oil Disaster and the Future of Offshore Drilling*, Report to the President, January 2011.

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.[20] The Methane Hydrate Research and Development Act of 2000 (P.L. 106-193) first authorized appropriations for the program of $5 million in FY2001 and increased annual authorization levels to $12 million by FY2005. The Energy Policy Act of 2005 (P.L. 109-58) authorized appropriations from FY2006 through FY2010 totaling $155 million for the program over five years. Since P.L. 106-193 was enacted, DOE has spent $102.3 million on the R&D program through FY2009. In FY2010, Congress appropriated $17.8 million for natural gas technologies, and directed DOE to include no less than $15 million for gas hydrates R&D.[21] Authorization of appropriations for the program expired at the end of FY2010.

For FY2011, the Obama Administration requested no funding for the Natural Gas Technologies program within DOE's Fossil Energy Research and Development account, which included gas hydrates R&D, stating that the move was consistent with Administration policy to phase out fossil fuel subsidies.[22] Instead, the Administration proposed to initiate a new research program in gas hydrates within the Office of Basic Energy Sciences. In the Administration proposal, the program would study fundamental scientific questions about methane hydrates, and would conduct controlled *in situ* depressurization and physical, thermal, and chemical stimulation experiments in

[20] DOE methane hydrate R&D program, at http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/rd-program/rd-program.htm.

[21] See Committee Print on H.R. 1105/P.L. 111-8 Books 1&2, House Committee on Appropriations, Book 1, Division C, at http://www.gpoaccess.gov/congress/house/appropriations/09conappro2.html.

[22] U.S. Department of Energy, FY2011 Congressional Budget Request, volume 3, February 2010, p. 703, at http://www.cfo.doe.gov/budget/11budget/Content/Volume%203.pdf.

the Arctic. The program would also collect *in situ* core samples from sediments in the Gulf of Mexico. The Administration's request for the program for FY2011 was $17.5 million.

It could be argued that the proposed program's emphasis on understanding basic scientific questions about gas hydrates responds to needs identified by gas hydrate researchers. For example, researchers have identified a need to better understand how geology in the permafrost regions and on continental margins controls the occurrence and formation of methane hydrates.[23] 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.

It is unclear whether the Administration will implement the new program in 2011. Funding for the federal government provided in P.L. 111-322 as a continuing resolution for FY2011 does not address the proposed shift in program funding from the Fossil Energy R&D account to the Office of Science. Appropriations under P.L. 111-322 extend through March 4, 2011.

Additional Reading

T. Collett et al., eds., *Natural Gas Hydrates—Energy Resources Potential and Associated Geologic Hazards*, American Association of Petroleum Geologists, AAPG Memoir 89, 2009.

National Research Council, *Realizing the Energy Potential of Methane Hydrate for the United States*, National Academies Press, Washington, DC, 2010, at http://www.nap.edu.

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