Assessment of In-Place Gas Hydrate Resources of the Lower 48 United States Outer Continental Shelf

Natural gas hydrates are ice-like crystalline substances occurring in nature where a solid water-ice lattice accommodates gas molecules (primarily methane, the major component of natural gas) in a cage-like structure known as a clathrate.

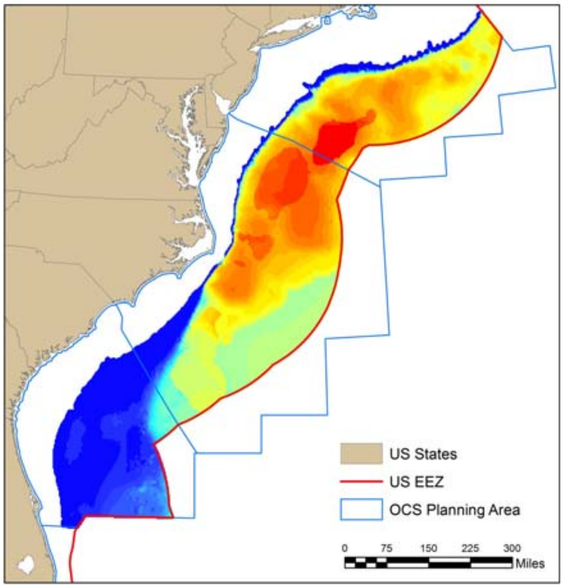
Using a mass balance assessment methodology, the Bureau of Ocean Energy Management estimated a mean of 51,338 trillion cubic feet of in-place gas hydrate resources in the Federal Outer Continental Shelf of the Lower 48 United States.

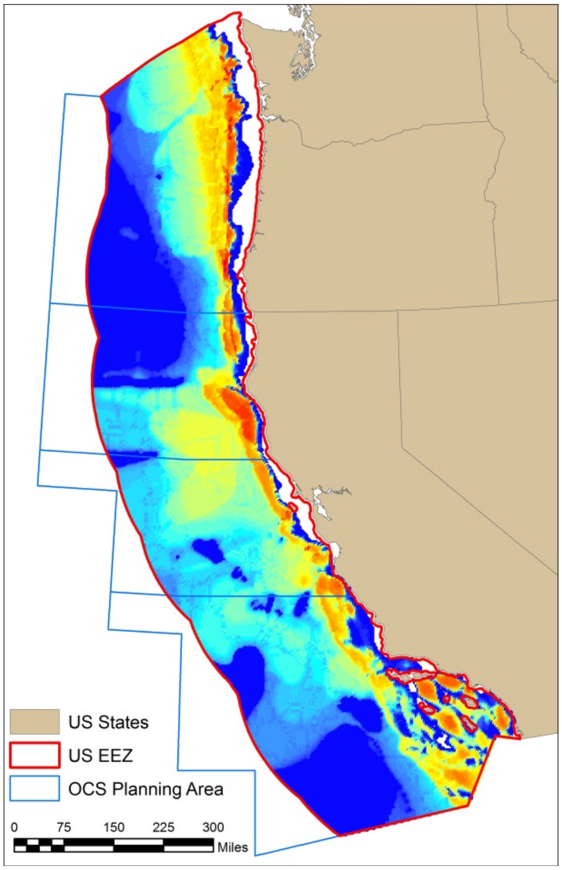
Introduction

This report summarizes the results of the Bureau of Ocean Energy Management (BOEM) assessment of the undiscovered *in-place* gas hydrate resources for those areas of the U.S. Outer Continental Shelf (OCS) adjacent to the Lower 48 states and within the limits of the 200 nautical mile U.S. Exclusive Economic Zone (EEZ; Figures 1a, 1b, 1c). Gas hydrate resources on the U.S. OCS adjacent to Alaska have not yet been assessed in this effort. The OCS comprises that portion of the submerged seabed whose mineral estate is subject to Federal jurisdiction. This assessment represents a comprehensive appraisal of relevant data and information available from a variety of proprietary and non-proprietary data sources.

Gas hydrate resources are assessed as in-place volumes and reported as the amount of natural gas that resides in the form of gas hydrate in any reservoir in the subsurface of the OCS, without regard to technical recoverability. This differs from BOEM's assessments of conventional oil and gas resources (e.g., [BOEM Fact Sheet RED-2011-01b]), where undiscovered oil and gas resources are reported as technically recoverable and economically recoverable volumes. BOEM does not report the larger in-place volume of undiscovered conventional oil and gas resources.

Gas hydrate resources on the OCS are assessed using a spatially-resolved mass balance model that incorporates uncertainty at various levels of model component input. The stochastic nature of the assessment approach provides a range of resources at the model cell level and at levels aggregated to greater geographic extents. More detailed information about the geology and assessment methodology will be made available in separate national and regional assessment reports.





Figures 1a and 1b. In-place gas hydrate volume distribution for the Atlantic (top) and Pacific OCS (bottom). Red colors indicate maximum accumulations; blue colors indicate minimal accumulations

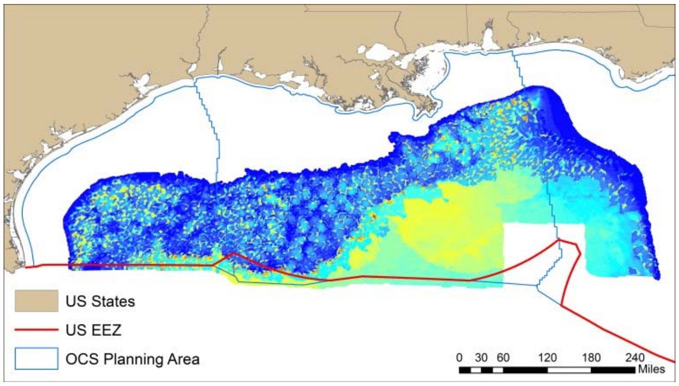


Figure 1c. In-place gas hydrate volume distribution for the Gulf of Mexico OCS, as reported in OCS Report MMS 2008-004. Red colors indicate maximum accumulations; blue colors indicate minimal accumulations.

Commodities Assessed

Natural gas hydrates are ice-like crystalline substances occurring in nature where a solid water lattice accommodates gas molecules (primarily methane, the major component of natural gas) in a cage-like structure, also known as clathrate (Figure 2). Gas hydrates form under conditions of relatively high pressures and relatively low temperatures, such as those found in many of the world's deepwater ocean basins and in some sub-permafrost environs in the Arctic. On most of the U.S. OCS, gas hydrates are stable in water depths in excess of about 1,000 feet, provided that an adequate supply of methane is available and that subsurface temperature and salinity are not excessive.

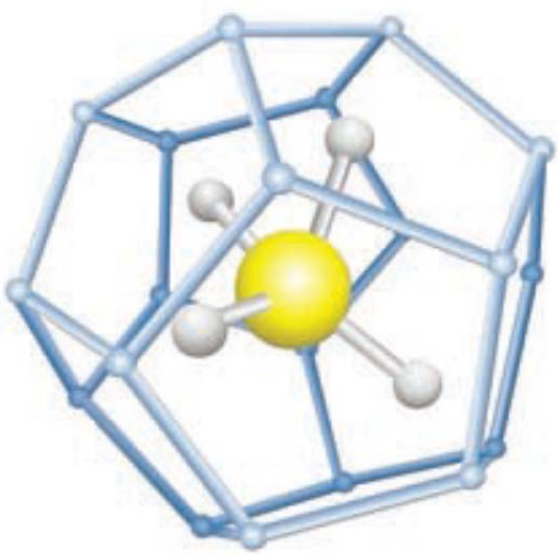


Figure 2. Model of a methane molecule enclosed in water-molecule "cage." (image courtesy NETL)

The only commodity assessed herein is natural gas that occurs in the subsurface as natural gas hydrate, without limitation to the physical nature of the occurrence (pore filling, fracture filling, etc.) or the lithology of the host rock (sandstone reservoir, shale reservoir). All gas volumes in this assessment are reported at atmospheric temperature and pressure in units of trillion standard cubic feet of gas (Tcfg).

Estimates of in-place gas hydrate resources are presented at 95th and 5th percentile levels, as well as at the mean level. This range of estimates corresponds to a 95 percent probability (a 19 in 20 chance) and a 5 percent probability (a 1 in 20 chance) of there being more than those amounts present, respectively. The 95 and 5 percent probabilities are considered reasonable minimum and maximum values, and the mean is the average or expected value.

Methodology

The BOEM gas hydrate assessment model comprises a spatially resolved, cell-based stochastic model structure that utilizes a mass balance approach to calculate the volume of gas hydrate in-place in the subsurface. The assessment model includes three computational modules and an integration module, as well as numerous sub-models that quantify the many components necessary for a working gas hydrate petroleum system. The stochastic model structure allows for the introduction of component uncertainties at many levels throughout the model, resulting in a probabilistic distribution of results. Geologic risk is not introduced at any level in the model.

The modeling approach employed by BOEM for the assessment of in-place gas hydrate resources on the OCS is different than that used by BOEM to assess undiscovered conventional oil and gas resources. Whereas most conventional oil and gas assessments utilize information derived from discovered oil and gas pools in a given play to predict the undiscovered resource potential remaining in that play, the gas hydrate assessment methodology for deep marine settings on the OCS must allow for the paucity of actual field-size information.

For every model cell at every trial run, Monte Carlo sampling of uncertain input parameters generates a value for the thickness of the hydrate stability zone (HSZ; the Container module; Figure 3); a value that represents the fraction of the HSZ that can be saturated with gas hydrate (the Concentration module); and a value for the amount of biogenic gas available to charge the HSZ (the Charge module). The volume of gas available is compared to the container space available in the integration module, and the smaller of the two volumes is recorded. While the desired end product of an assessment model run is an in-place volume of gas hydrate resources (reported at surface temperature and pressure), any of the interim calculations and results (such as those of the computational modules) can be reported in either numerical or spatial expressions.

The gas hydrate assessment model was initially developed for application to the Gulf of Mexico (GOM) OCS. The preliminary assessment results for the GOM and a complete description of the model methodology and input parameters are reported in OCS Report MMS 2008-004. While some modifications were incorporated into the original GOM model structure to allow for adaptation to both the Atlantic and

Pacific OCS areas, the overall mass balance modeling approach remains the same. Specific details of the inputs, components, and modeling approach for the Atlantic and Pacific OCS will be available in comprehensive reports to be released at a later date.

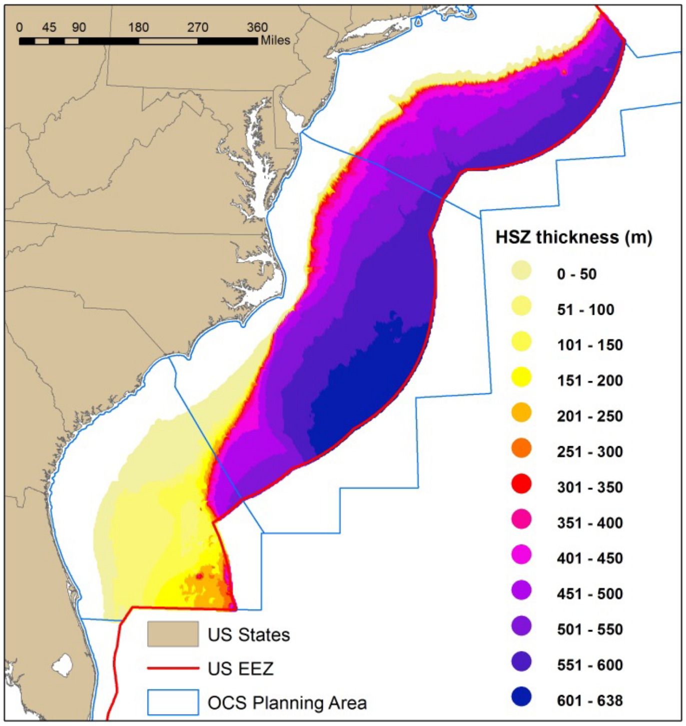


Figure 3. Modeled hydrate stability zone (HSZ) mean thickness for the Atlantic OCS assessment area. Thickness values are in meters.

Assessment Results

This assessment represents a multi-year effort that is still ongoing. The modeling approach allows for a complete disaggregation of the input parameters and modeling components, and provides an opportunity to update the results as more scientific information becomes available and as industry advances this relatively immature energy resource to one that is a closer to a potentially commercial commodity.

In-place gas hydrate volumes are reported separately for the Atlantic OCS, the Pacific OCS, and the Gulf of Mexico OCS (Table 1). The distributed results are not aggregated nor reported at a national level as the differences in modeling approach between the three regions prohibit the allocation of any uniform dependency assumptions across the regions. Thus, the mean results are additive for the three regions and total 51,338 Tcfg in-place, but the P5 and P95 fractiles are reported separately and cannot be summed. Similarly, the range of uncertainty implied by the volume distribution results from the uncertainty of the individual parameters within a region, as well as the dependency assumptions applied in a region.

The results presented here for the GOM OCS remain unchanged from those first reported in OCS Report MMS 2008-004. As previously stated, all results presented here reflect in-place gas volumes only and do not indicate that portion of the resource that may be technically or economically recoverable, as hydrate production technologies are in their infancy and sustained commercial production from gas hydrate reservoirs has not been demonstrated anywhere in the world.

Table 1. BOEM in-place gas hydrate resource volumes for the Atlantic, Pacific, and Gulf of Mexico Outer Continental Shelf. Units are trillion cubic feet; 1 x 10^{12} ft^3. Resource volumes have not been subject to geologic risk.

Region	In-Place Gas Hydrate Resources		
	Gas (Tcfg)		
	95%	Mean	5%
Atlantic OCS	2,056	21,702	52,401
Pacific OCS	2,209	8,192	16,846
Gulf of Mexico OCS	11,112	21,444	34,423

Previous Assessments

The 1995 National Assessment of United States Oil and Gas Resources conducted by the U.S. Geological Survey (USGS) included a comprehensive assessment of the in-place gas hydrate resources of the United States onshore and offshore regions. The stochastic assessment provided a range of gas hydrate resources (113,000 to 676,000 Tcfg) with a mean in-place value for the entire United States reported at 320,000 Tcfg. As with the current BOEM assessment, the 1995 USGS assessment described in-place resources without reference to either technical or economical recoverability.

Greater than 90 percent of the mean resources assessed by the USGS in 1995 are located in deep marine settings that comprise the majority of the U.S. OCS. Mean results from the 1995 USGS assessment are reported by OCS area as follows (all units Tcfg): Atlantic Ocean Province - 51,831; Gulf of Mexico Province - 38,251; Pacific Ocean Province - 61,071.

Compared to the 1995 USGS results, the 2012 BOEM assessment reflects a lower resource volume in each OCS area. While some of the gross differences are simply a reflection of the variations in modeling approach, the consistent reduction in volume across all regions is likely a result of downward revisions in specific modeling components based on information gained from recent gas hydrate field programs.

Major Field Programs

In the last decade, significant advances in understanding the distribution, characterization, and production potential of gas hydrate reservoirs have taken place through the execution of several successful field programs. BOEM has been an active participant in the U.S. Department of Energy's (DOE) multi-phased Gulf of Mexico Gas Hydrate Joint Industry Project

(JIP) since it began in 2001. The JIP recently confirmed the presence of high concentration gas hydrate accumulations in sand reservoirs at several locations in the GOM during the Leg II drilling and well logging campaign conducted in 2009. It is anticipated that additional efforts at these sites will include the collection of pressure cores (returning gas hydrate samples to the surface while maintaining in situ temperature and pressure conditions), acquisition of multicomponent and high resolution seismic data, and utilization of borehole methods for short-term production testing.

In the Arctic regions of North America, several advanced field projects are under way to characterize production potential from gas hydrate reservoirs in a permafrost environment. A joint effort in 2008 led by Canadian and Japanese researchers at the Mallik well site located in the Mackenzie Delta, Northwest Territories of Canada, obtained sustained gas flow to the surface from a gas hydrate reservoir. Under carefully controlled conditions over a six day period, a stepwise reduction in bottomhole pressure stimulated gas flow rates that averaged 70,000 - 100,000 ft^3 per day. At the Mount Elbert well site in the Milne Point area of the Alaskan North Slope, a joint effort led by BP Alaska Exploration, DOE, and the USGS completed a gas hydrate test well in 2007. In addition to confirming the validity of pre-drill seismically-based predictions of gas hydrate occurrence, fluid and reservoir flow-properties data were obtained through the deployment of a wireline formation testing tool in the well. Additional phases of this project may include long-term production testing.

A third Arctic project is underway with the Spring 2012 completion of the Ignik Sikumi #1 gas hydrate field trial well from an ice pad in the Prudhoe Bay Operating Unit on the North Slope of Alaska. In this production test, a mix of nitrogen and carbon dioxide was injected into the wellbore and gas flow from a methane hydrate reservoir was established. Overall, the well produced for 30 days during the 38-day flow-back period, with peak rates as high as 175,000 ft^3 per day and cumulative gas production approaching one million standard cubic feet. The CO2 exchange project is a joint effort between DOE and ConocoPhillips, with additional support from the Japan Oil, Gas and Metals National Corporation (JOGMEC).

List of Terms

Gas hydrate: natural gas hydrates are ice-like crystalline substances occurring in nature where a solid water-ice lattice accommodates gas molecules (primarily methane, the major component of natural gas) in a cage-like structure known as a clathrate.

Hydrate stability zone (HSZ): zone of appropriately high pressure and low temperature where methane gas and water will form solid methane hydrate. On the U.S. OCS these conditions are generally present in water depths that exceed 1,000 feet. In the absence of extreme changes in subsurface temperatures, the HSZ will increase in thickness as water depth increases.

In-place resource: an estimate of the total volume of natural gas contained in methane hydrate deposits, without regard to individual accumulation size or technical recoverability.

Technically recoverable resource: the portion of the in-place resource that is recoverable using existing technologies, without regard to economics. Technically recoverable gas hydrate resources are not assessed in this report.

Selected References

Minerals Management Service, 2008, Preliminary evaluation of in-place gas hydrate resources: Gulf of Mexico Outer Continental Shelf. OCS Report MMS 2008-004.

Boswell, R., Collett, T.S., Frye, M., Shedd, W., McConnell, D.R., and Shelander, D., 2012, Subsurface gas hydrates in the northern Gulf of Mexico, Journal of Marine and Petroleum Geology 34, 4-30.

Collett, T.S., 1995, Gas hydrate resources of the United States, in Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 National assessment of United States oil and gas resources on CD-ROM: U.S. Geological Survey Digital Data Series 30.

For Further Information

Supporting geological studies, previous assessment results, and methodologies used by BOEM for resource assessment can be found on BOEM's web site, *www.boem.gov.*

For further information on this study please contact:

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