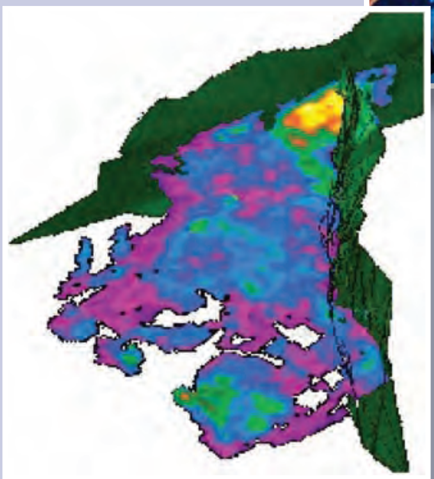
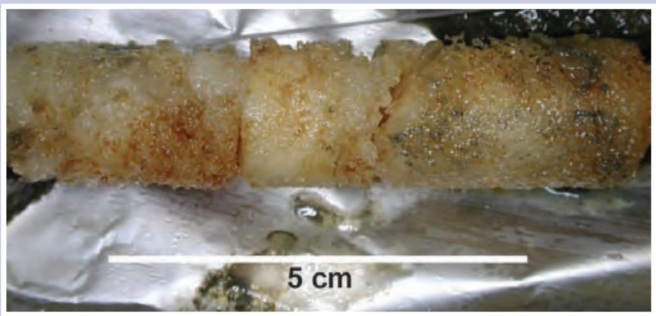
the ENERGY lab

Energy Resource Potential of Methane Hydrate

An introduction to the science and energy potential of a unique resource





NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

Introduction

Natural gas—which is predominantly methane (CH_4)—is recognized as clean burning and an important bridge fuel to a future where renewable energy sources are more common. Methane hydrate—molecules of natural gas trapped in an ice-like cage of water molecules—represents a potentially vast methane resource for both the United States and the world. Recent discoveries of methane hydrate in arctic and deep-water marine environments have highlighted the need for a better understanding of this substance as a natural storehouse of carbon and a potential energy resource.

This document aims to provide a simple but comprehensive explanation of what methane hydrate is, where it is found, its potential as a fuel source, and the current state of methane hydrate research activities. Methane hydrate science has advanced steadily over the past decade, and commercial-scale production of natural gas from methane hydrate deposits is growing more viable at each step. Experimental, modeling, and field-based studies are underway to advance our understanding of this fascinating resource.

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Table of Contents

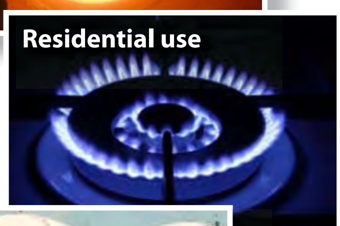
Cover Photos:

Top banner photo is the Mount Elbert well site, in northern Alaska (Courtesy of the Mount Elbert Science Party). Smaller photos include, clockwise from the top: rig floor shot (Courtesy of JIP Leg II Science Team); methane hydrate core recovered from sediments beneath the Indian ocean (Courtesy of NGHP-01 (India) Science Party); hydrate core recovered from sediments beneath the Gulf of Mexico (Courtesy of Ian MacDonald, Texas A & M University); and seismic map (Courtesy of USGS).

The Growing Need for Natural Gas

Natural gas is a relatively clean-burning energy fuel with a wide variety of end-uses.


Cement manufacture


Residential use


Fertilizer plant


Glass manufacture

Mass transit

Most financial advisors agree that a diversified portfolio of investments is a good way to ensure a secure financial future. Similarly, the United States must maintain a diversified energy portfolio, if we are to simultaneously meet growing energy demand, reduce dependence on foreign fuel supplies, and move toward cleaner energy options. Natural gas is poised to play a critical role in helping the nation achieve all three of these goals.

Natural gas currently accounts for nearly a quarter of the U.S. energy supply, and that share is expected to remain roughly constant over the next several decades. Energy demand during this time period is expected to continue growing, in the U.S. and in the world. The Energy Information Administration projects that the U.S. will need to increase its annual production of natural gas by roughly 10% over the next 25 years, in order to keep pace with rising consumption.

Fortunately, domestic natural gas is relatively abundant. The Potential Gas Committee, in their latest assessment, estimated that the U.S. has a total natural gas resource base of about 2,074 trillion cubic feet (Tcf). This figure includes 1,836 Tcf of potential natural gas resources (including probable, possible, and speculative resources) and 238 Tcf of proved reserves. However, as demand for natural gas continues to grow, more supplies will be needed.

Natural gas has many end-uses. It provides fuel for residential heating, and it is the fuel of choice for a wide range of industries, including paper and chemical production, petroleum refining, and glass manufacturing. It is used as a feedstock to produce fertilizers, chemicals, fabrics, pharmaceuticals, plastics, and electric power generation. Total electricity generation capacity from natural gas is projected to increase from 338 gigawatts in 2008 (33 percent of total capacity) to about 454 gigawatts in 2035 (46 percent of total capacity). While the volume of natural gas used to fuel vehicles is comparatively small, it is also growing. The amount of natural gas used for transportation in the U.S. tripled from 1998 to 2008, and it is projected to triple again by 2025.

Natural gas is a relatively clean-burning fuel, and it will continue to be an important part of the country's energy portfolio and is integral to expanded deployment of renewable energy resources.

Over the long term, the development of new natural gas resources such as methane hydrate can play a major role in ensuring adequate future supplies of natural gas and moderating future energy prices for American consumers.

Methane Hydrate Potential as a Fuel Source

The worldwide volume of methane held in methane hydrate is immense. A frequently quoted estimate of the global methane hydrate resource is 20,000 trillion cubic meters, or about 700,000 Tcf. However, only a small portion of this enormous resource is likely to be harvested as an energy fuel.

If existing and new technologies can be applied economically to the development of methane hydrate as a source of natural gas, the U.S. could significantly decrease its reliance on foreign energy supplies. A number of countries that currently import much of their energy could become more self-sufficient.

In 2008, the U.S. Minerals Management Service (now the Bureau of Ocean Energy Management, Regulation and Enforcement or BOEMRE) released a preliminary assessment of the in-place methane hydrate resource in the Gulf of Mexico. This assessment, which does not consider whether the resource is technically or economically recoverable, estimated that there are about 11,000 – 34,000 Tcf of methane in-place in hydrate form in the northern Gulf of Mexico, with a mean value of 21,444 Tcf. The assessment also concluded that about 6,700 Tcf of this resource occur in relatively high-concentration accumulations in sandy sediments—that is, in the sort of reservoirs that would be likely to be producible.

To put these numbers into context, recall that the total U.S. natural gas resource, excluding hydrate, amounts to 2,074 Tcf, based on estimates reported by the Potential Gas Committee. If one-third of the natural gas in-place in methane hydrate in sandy sediments of the Gulf of Mexico becomes technically recoverable, the U.S. could double its total natural gas resource.

The volume of methane has also been calculated for the methane hydrate resource located in sediments within and beneath the permafrost on the North Slope of Alaska. In 2008, the United States Geological Survey (USGS) estimated that there is approximately 85 Tcf of undiscovered, *technically recoverable* natural gas resource within methane hydrate deposits on the North Slope. It is important to recognize that these estimates are continually refined and improved, as researchers obtain new and better information about the location and concentration of methane hydrate through direct sampling, laboratory testing, modeling, and remote detection.

The worldwide volume of methane held in methane hydrate is immense and poorly known. Estimates range from 100,000 to more than 1,000,000 Tcf of natural gas.

- ***In-place* methane hydrate resource** – an estimate of the total volume of natural gas contained in methane hydrate deposits
- ***Technically-recoverable* methane hydrate resource** – the portion of the in-place resource that is recoverable using existing technologies, without regard to economics

Methane Hydrate Resource Pyramid

The methane hydrate resource pyramid depicts hydrate resources according to reservoir type, gas recoverability, and estimated total in-place gas quantity. Hydrate resources that are considered to be the most easily recoverable are found at the peak of the pyramid, while those that are the most technically challenging to extract lie at the base. Estimates of the total natural gas resource volume contained in each reservoir type are also indicated. For example, hydrate in arctic sandstone reservoirs contains an in-place gas volume estimated to be in the 100's of Tcf, while hydrate in marine sands is estimated to contain 1,000's to 10,000's of Tcf, and hydrate dispersed through marine muds is estimated to contain 100,000's of Tcf.

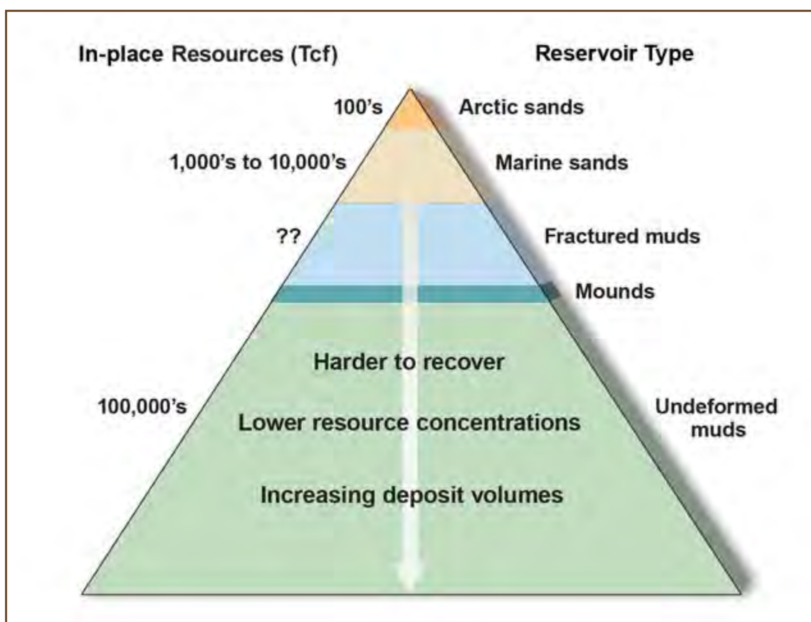
Arctic sandstone reservoirs hold the most promise for near-term recovery of natural gas from methane hydrate, because the hydrate is concentrated in reservoirs with high porosity and permeability. In addition, portions of these reservoirs are located within range of existing oil and natural gas production infrastructure. Hydrate in marine sands is considered more difficult to develop because of higher costs and challenging technical issues associated with deep water exploration and production.

Methane hydrate resource categories farther down the pyramid include hydrate that fills fractures in marine muds, hydrate that occurs as nodules and lenses in fine-grained marine sediments, and hydrate that forms mounds on the seafloor. Each of these deposit types has its own unique challenges

Sample of methane hydrate-saturated sandstone taken from Mt. Elbert Well in Milne Point Unit of Alaskan North Slope. (Courtesy of Mt. Elbert Science Team)

Methane hydrate-saturated coarse-grained sediment taken from core on Alaskan North Slope. (Courtesy of Timothy S. Collett, USGS)

Hydrate-filled fractures found in marine sediment. (Courtesy of the UBGH-01 [Korea] Science Party)



The methane hydrate resource pyramid. (Courtesy of Science Magazine) to those seeking to extract the methane resource. Hydrate extraction from seafloor mounds is problematic, because the mounds are of limited extent, and there is potential for disruption of sensitive sea-floor ecosystems that depend on these deposits. Production of methane hydrate from low-permeability muds has a different set of challenges and would require an entirely new subsea development approach.

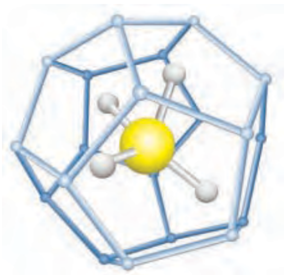
Methane hydrate will most likely be produced first from deposits where the following conditions are met: 1) the hydrate occurs in high concentrations; 2) it occurs in a high-permeability host rock that has good reservoir quality; and 3) the deposit is located in an area with existing infrastructure.

Two near-term challenges will likely determine whether the sand-enclosed methane hydrate near the top of the hydrate resource pyramid becomes an exploitable resource. The first challenge is to more accurately determine the extent of methane hydrate in sand reservoirs in arctic and marine environments. The second challenge is to determine whether such deposits can yield methane gas at the rates necessary to make high-cost arctic or deep-water production commercially viable. Numerical simulations show that production based primarily on reducing pressure could release methane at rates that make commercial production feasible in certain settings. Another possibility is the injection of carbon dioxide (CO_2), which has the potential to displace methane from the hydrate structure and also leave the CO_2 sequestered within the hydrate. Initial studies of these two approaches have been encouraging, but extended production tests of both methods are needed.

Overcoming the challenges to safe, economic development of this resource will require continued research to understand which exploration and production technologies will work best for a given type of hydrate deposit.

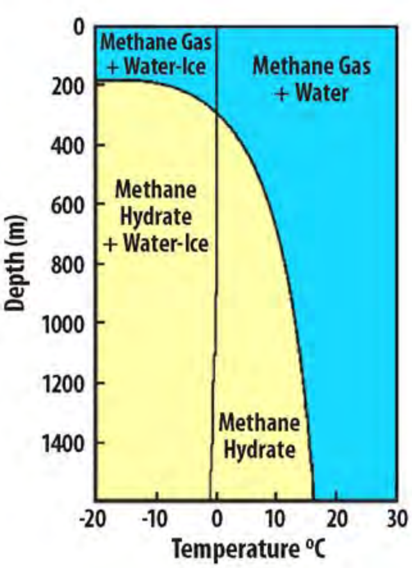
Methane hydrate mound located in the Gulf of Mexico. The hydrate has sediment covering it and has been colored orange by heavier hydrocarbons that have seeped from the seafloor. (Courtesy of Ian MacDonald, Texas A&M University)

Photos showing variety of living creatures that make up ecosystems surrounding methane hydrate mounds found on the seafloor. At left, ice worms live in cavities in a hydrate mound (Courtesy of Ian MacDonald, Texas A&M University); at center, tube worms thrive on a hydrate mound (Courtesy of Gregory S. Boland, Bureau of Ocean Energy Management, Regulation, and Enforcement); at right, clams cluster around a hydrate mound. (Courtesy of National Oceanic and Atmospheric Administration).



Model of a methane molecule enclosed in water-molecule "cage."

Methane hydrate dissociating with the methane ignited – "burning ice." (Courtesy of National Research Council Canada)



Methane hydrate stability diagram.

Ice That Burns

What is Methane Hydrate?

A clathrate is a chemical compound in which molecules of one material (the "host") form a solid lattice that encloses molecules of another material (the "guest"). Methane hydrate is a naturally-occurring clathrate in which a host lattice of water-ice encloses guest molecules of methane. Methane, made of one carbon atom and four hydrogen atoms, is the simplest hydrocarbon molecule and the primary component of natural gas.

In methane hydrate, the gas molecules are not chemically bound to the water molecules but instead are trapped within their crystalline lattice. The resulting substance looks remarkably like white ice, but it does not behave like ice. When methane hydrate is "melted," or exposed to pressure and temperature conditions outside those where it is stable, the solid crystalline lattice turns to liquid water, and the enclosed methane molecules are released as gas. This process, called dissociation, can be demonstrated by lighting a match next to a piece of methane hydrate; the heat from the match will cause the hydrate to dissociate, and the methane molecules will be ignited as they are released. This results in the curious spectacle of what appears to be burning ice.

Methane hydrate is a material very much tied to its environment—it requires very specific conditions to form and remain stable. Pressure, temperature, and availability of sufficient quantities of water and methane are the primary factors controlling methane hydrate formation and stability, although geochemistry and the type of sediment also play a part. If the pressure and temperature are just right, free methane gas and water will form solid methane hydrate.

The adjacent graph is a phase diagram showing the pressure and temperature ranges where methane hydrate is stable. The horizontal axis shows temperature, increasing from left to right, and the vertical axis shows depth of burial, increasing from top to bottom. Because fluid pressure increases with depth below the surface of the earth or the ocean, depth serves as a proxy for fluid pressure in hydrate phase diagrams. The curved line between the blue and yellow areas is the methane hydrate phase boundary. Above this boundary, temperatures are too warm, and pressures are too low for methane hydrate to form, so methane can only be present as a gas. Below this boundary, solid methane hydrate is able to form and remain stable, because temperatures are sufficiently low, and fluid pressures are sufficiently high to sustain the solid phase.

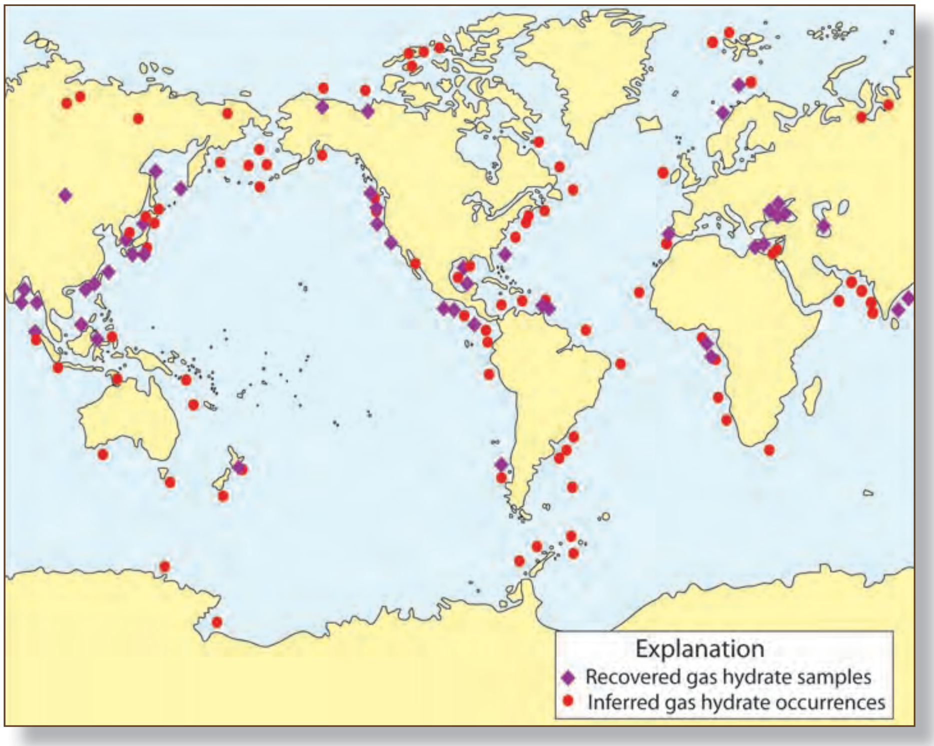
Other factors can affect the stability of methane hydrate. For example, higher salt content in pore water within sediments can restrict hydrate formation, just like road salt keeps ice from forming on highways. Elevated salinity has the effect of shifting the hydrate phase boundary to the left—essentially requiring colder temperatures to form hydrate. Similarly, the presence of small amounts of gases other than methane, such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), or heavier hydrocarbons such as ethane (C_2H_6) can act to shift the phase boundary to the right, so that hydrate can form at higher temperatures.

Because methane hydrate can only remain solid at low temperatures and high pressures, it is difficult to recover methane hydrate samples intact, whether the samples are collected from the seafloor or from deeply buried sediments. As soon as a sample is brought to the Earth's surface, it will follow a pressure-temperature path on the graph that is upwards and towards the right across the phase boundary. Dissociation of the hydrate into water and methane will occur, unless the sample is maintained during retrieval, or quickly pressurized or refrigerated after retrieval to keep it within the hydrate stability envelope.

Methane hydrate is a fairly concentrated form of natural gas. When dissociated at normal surface temperature and pressure, one cubic foot of solid methane hydrate will release about 164 cubic feet of methane gas. This is one of the reasons people are interested in methane hydrate as a potential source of methane for energy supply.

Where is Methane Hydrate Found?

Methane hydrate is known to occur in both terrestrial and marine environments. Terrestrial deposits have been found in polar regions, hosted in sediments within and beneath the permafrost, while marine occurrences have been found mainly in sediments of the Earth's outer continental margins. These are the natural settings where methane and water are present, and where pressure and temperature conditions are suitable to form and sustain hydrate.



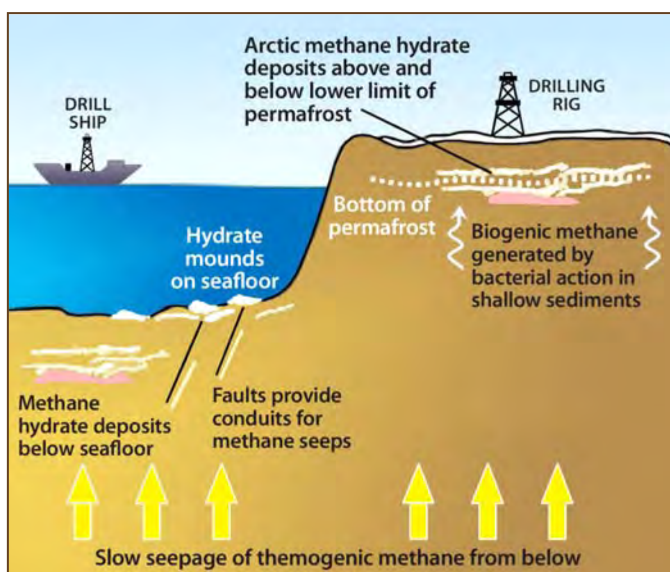
Location of sampled and inferred gas hydrate occurrences worldwide.
(Map courtesy of Timothy S. Collett, USGS)

> Methane hydrate is known to occur in both terrestrial and marine environments—where methane and water are present, and where pressure and temperature conditions are just right to form and sustain hydrate.

The methane that is captured in the methane hydrate may have been formed by biogenic or thermogenic processes. *Biogenic* methane is the common by-product of bacterial ingestion of organic matter. This is the same process that produces methane in swamps, and it occurs continually within buried sediments all around the globe. Biogenic processes are capable of producing vast amounts of methane and are considered to be the dominant source of the methane trapped in hydrate accumulations in shallow seafloor sediments.

Thermogenic methane is produced by the combined action of heat and pressure over a long period of time on buried organic material. Over time and with deep burial, organic-rich source beds are literally pressure-cooked, with the result being the production of large quantities of oil and natural gas. Along with the oil, the natural gas (largely methane, but also larger molecules like ethane, propane, and others) slowly migrates upward due to its relative buoyancy. Where sufficient quantities of gas reach the zone of hydrate stability, this gas is able to combine with water in the sediments to form methane hydrate.

Given the pressure-temperature relationship found in deep marine environments, it might seem that hydrate could accumulate anywhere in ocean-bottom sediments where water depth exceeds about 400 meters. However, very deep sediments are generally not thought to contain large quantities of hydrate. The reason is that very deep oceans lack the high biologic productivity needed to create the organic matter that generates methane, and they lack the rapid sedimentation rates needed to deeply bury the organic matter. These conditions do exist along the continental margins—areas where the continental shelf transitions to the deep ocean. As a result, this is where large quantities of methane hydrate are thought to exist in the marine environment.



Methane hydrate can form in arctic and marine environments.

Methane Hydrate and Global Climate

As discussed above, methane hydrate deposits hold immense volumes of methane, primarily stored in sediments of the Earth's outer continental margins and polar regions. The total amount of carbon stored in these deposits amounts to many thousands of gigatons and far exceeds the quantity of carbon that currently resides in the atmosphere. In addition, methane is itself a potent greenhouse gas, remaining in the atmosphere for about a decade before it is converted to carbon dioxide. Clearly, methane hydrate has a significant role in the global carbon cycle, and it is gaining recognition as an important player in global climate processes and climate change.

Beyond these basic assertions, many questions remain. What is the best estimate for how much methane resides in methane hydrate accumulations throughout the world? What is the natural methane flux from methane hydrate deposits in marine and non-marine environments? How sensitive are marine hydrate deposits to warming of ocean waters? How stable are continental shelf hydrate deposits in polar regions, and how much do they contribute to observed methane releases?

In recent years the U.S. Department of Energy (DOE) has stepped up efforts to address these and other questions. Experts from universities and national laboratories are working to quantify methane flux from hydrate in a variety of settings and to define the potential impacts of methane hydrate formation and dissociation on the global carbon cycle. Scientists are also studying natural consumption of methane by microbes in marine waters, to determine how much methane makes its way upward through the water column and to the atmosphere. Ongoing studies are also underway to improve maps of the distribution and concentration of hydrate deposits in particular geological settings. Data and results from such studies will enable methane hydrate to be more accurately incorporated into global climate models.

On an international level, DOE program representatives are participating in a new initiative launched by the United Nations Environment Program, Global Outlook on Methane Gas Hydrates. This initiative has wide-ranging objectives, with an overall emphasis on evaluating methane hydrate as a potential energy resource for future development. Some supporting goals are to better understand the links between natural methane hydrate systems and the global carbon cycle, to understand the sensitivity of natural hydrate occurrences to likely climate-change scenarios, and to assess potential methane release to the atmosphere from possible future development activities related to methane hydrate.

Photo Credit NASA

Producing Methane from Hydrate

Substantial energy resources may be available from methane hydrate deposits using largely conventional drilling and production technologies.

Producing natural gas from methane hydrate will require that we find economical methods for safely extracting the methane, while minimizing environmental impacts. Some progress has been made in this area, but much remains to be understood.

Most natural gas is produced from conventional gas accumulations by drilling a well into the reservoir rock, casing the well with pipe, perforating the pipe to allow the gas to flow into the wellbore, placing a string of tubing inside the casing, and then extracting the gas up the tubing, sometimes with the aid of a pumping system. In some cases, natural gas flows freely up the tubing without the aid of a pumping system, because of high pressure in the reservoir. Natural gas flows from the reservoir rock into the well and up the tubing, as long as the pressure at the bottom of the well is lower than the pressure in the reservoir.

Production of methane from hydrate deposits in sandstone or sandy reservoirs is likely to be approached in a similar manner. As pressure in the well bore is reduced, free water in the formation moves toward the well, causing a region of reduced pressure to spread through the formation. Reduced pressure causes the hydrate to dissociate and release methane. Subsequent removal of water and gas causes a further reduction in pressure and further dissociation and methane production. One complication is that hydrate dissociation is an endothermic process—meaning it is a process that uses heat. So, a natural consequence of dissociation is cooling and potential re-freezing of adjacent portions of the reservoir. To be successful, a methane hydrate production strategy must include sufficient depressurization to cause the hydrate to dissociate and, in some cases, the addition of localized heating to overcome the natural tendency of the hydrate in the reservoir to return to its stable, frozen state.

Numerical simulations conducted in both the United States and Japan have shown that conventional well bores penetrating sand reservoirs can be used effectively to dissociate methane hydrate and gather the released methane at rates that make commercial production a possibility. In other words, substantial energy resources may be available from methane hydrate deposits using largely conventional drilling and production technologies.

Methane hydrate wells will be more complex than most gas wells due to a number of technical challenges, including: maintaining commercial gas flow rates with high water production rates; operating at low temperatures and low pressures in the wellbore; controlling formation sand production into the wellbore; and ensuring the structural integrity of the well. Technologies exist to address all of these issues, but their implementation will add to overall development costs for producing natural gas from hydrate.

In addition to these technical challenges, production of natural gas from methane hydrate would need to be carried out with attention to the potential environmental impacts and safety concerns associated with this unique resource. Any future development would need to use techniques that minimize the release of methane to the atmosphere, and development activities in both arctic and marine settings would need to be carried out in ways that maximize protection of these environments.

The degree of environmental impacts in the Arctic—including effects on surface water, groundwater, wildlife, and tundra plants—depends on the production and development strategies that are used. In some cases, it may be possible to select a hydrate well site where an existing pad, road, power lines, and other infrastructure are already present, owing to prior development. In other cases, it may be necessary to develop new pads or new roads to accommodate a producing well at a new site. In sensitive areas, smaller drilling platforms may be used to reduce the drilling footprint, and exploration and production activities may be curtailed during the caribou calving season to minimize impacts on wildlife. In addition, a gas pipeline or other gas transportation strategy must be developed to move the gas to market.

Significant scientific work must be completed before methane hydrate can be considered a producible natural gas resource. Critical tasks include identifying sites that are suitable for methane hydrate production testing and validating reservoir quality and well performance through extended field testing. Such testing must demonstrate that methane can be produced safely from hydrate deposits, at commercial rates, over extended time periods, and with minimal environmental impacts.

As with oil or conventional gas production, hydrate field development must be achieved using methods that minimize negative impacts on the environment.

Studying Methane Hydrate

The scientific study of methane hydrate has gained momentum over the past ten years, resulting in significant improvements in our understanding of natural hydrate systems. Recent studies in the U.S. have resulted in major steps forward in understanding the domestic methane hydrate resource. Meanwhile, international efforts in Japan, India, and elsewhere have helped to define the global hydrate resource. Current efforts in the U.S. are focused on testing the producibility of methane from hydrate, enhancing our ability to remotely detect and characterize hydrate occurrences, and improving our understanding of methane hydrate-climate interactions.

Early studies of methane hydrate date back to the early 1800s, but for more than a century the substance was considered to be only a laboratory curiosity.

Early Studies of Methane Hydrate

Scientific research into the nature of methane hydrate dates back to the early 1800s, when scientists first created synthetic hydrate in a physical chemistry laboratory. For decades after that, hydrate was created and tested in laboratory experiments, but it was not expected to be encountered in the natural world. Then, in the 1930s, hydrate was observed forming in natural gas pipelines, in some cases blocking the flow of gas. This spurred a new phase of scientific work focused on developing techniques to inhibit gas hydrate formation in pipelines.

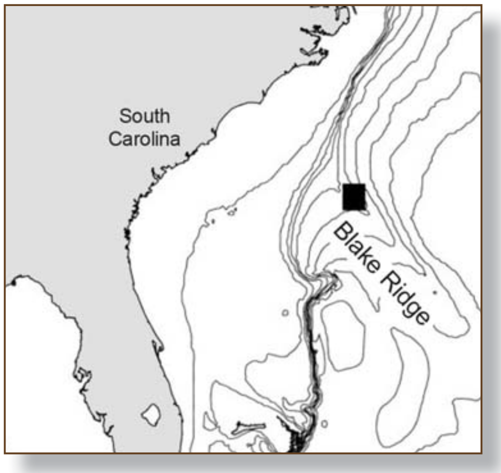
Methane hydrate was first discovered in the natural world in the 1960s, in subsurface sediments of the Messoyahka gas field of the Western Siberian basin. In the 1970s, hydrate was observed in well samples from the North Slope of Alaska, and in seafloor sediments collected from the bottom of the Black Sea. These initial findings were followed by a major hydrate discovery in the early 1980s, when the Deep Sea Drilling Program recovered hydrate-bearing cores, including a 1-meter sample of nearly pure hydrate, from sediments off the coast of Guatemala. These discoveries led to the realization that methane hydrate was not just a laboratory curiosity or industrial nuisance. Methane hydrate began to be viewed as a potentially widespread, natural storehouse of methane.

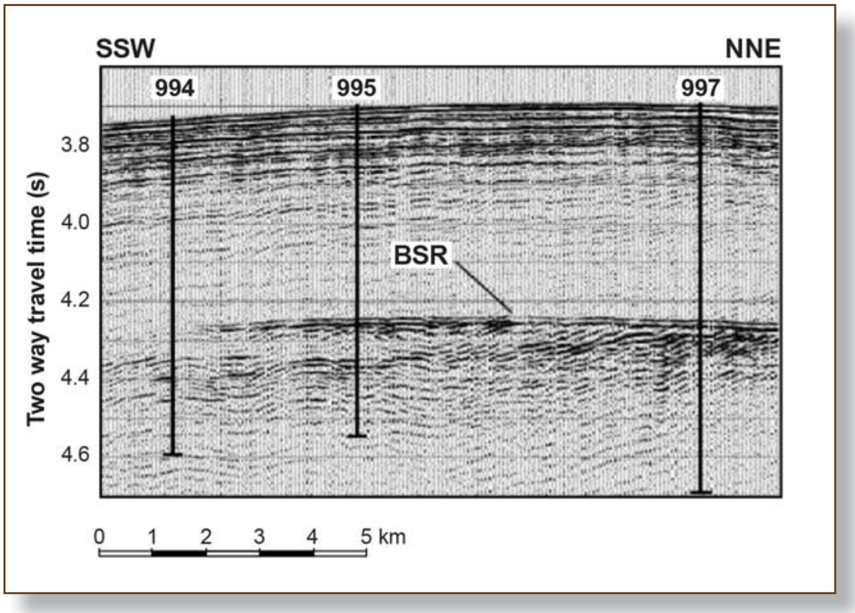
An Era of Hydrate R&D is Born

In 1982 the U.S. launched a national R&D program dedicated to the study of naturally occurring methane hydrate. During the first phase of this program, from 1982-1992, the U.S. carried out research on the physical and chemical properties of methane hydrate, and the USGS focused on characterizing sub-permafrost hydrate trends on the North Slope of Alaska. In 1995, the USGS completed the first systematic assessment of gas hydrate resources in the U.S., and they estimated that the volume of gas in the nation's hydrate greatly exceeded all our known conventional gas resources.

Scientists recognized the need to field test hydrate resource estimates. In 1995, the first dedicated scientific effort to investigate marine methane hydrate was carried out by the Ocean Drilling Program (ODP), with an expedition to the Blake Ridge area, off the coast of South Carolina. Scientists drilled through prominent bottom simulating reflections (BSRs), which were observed in seismic profiles and thought to be indicative of hydrate in the subsurface. Scientists found lower than expected concentrations of methane hydrate in the Blake Ridge area.

This was followed by additional field testing in 1998 and 1999, when methane hydrate research wells were drilled at the Mallik site in the Canadian Arctic and in the Nankai Trough off the coast of Japan. Wells drilled at these sites showed high concentrations of methane hydrate, with saturations as high as 80 percent in Nankai Trough sandstones. This contrasted sharply with the dispersed, low-saturation accumulations identified in the Blake Ridge area.





Map and seismic profile across the Blake Ridge showing a strong bottom simulating reflector (BSR) thought to be an indicator of methane hydrate. Numbers mark ODP boreholes. (Map and section courtesy of Steve Holbrook, University of Wyoming)

Renewed interest in methane hydrate as a potential energy source resulted in a reinvigorated national program in the U.S., launched in 1998 and continuing up to the present day. In 2000, the U.S. government signed into law the "Methane Hydrate Research and Development Act of 2000," which mandated that the DOE lead the national methane hydrate R&D program and utilize the talents of federal, private, and academic organizations to carry out the program goals. The program was extended under the "Energy Policy Act of 2005." DOE continues to coordinate with the Bureau of Land Management (BLM), Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE), National Oceanic and Atmospheric Administration (NOAA), Naval Research Laboratory (NRL), National Science Foundation (NSF), and USGS, to maximize collaboration on hydrate R&D activities and ensure a comprehensive program of research.

The DOE program mission is to advance the scientific understanding of naturally-occurring methane hydrate, such that its resource potential can be fully understood and realized. Specific goals are to confirm the scale, nature, and producibility of the resource, mainly through drilling and coring programs complemented by numerical simulation and laboratory experimentation. The program also aims to develop tools and knowledge needed to understand and control the impact of methane hydrate on seafloor stability and to develop a more robust understanding of the role methane hydrate plays in geohazards and in global environmental processes.

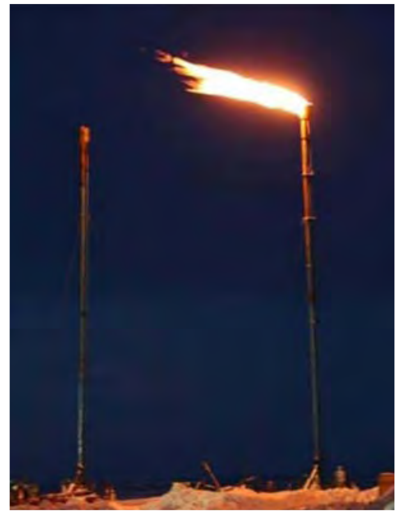
The DOE program mission is to advance the scientific understanding of naturally-occurring methane hydrate, such that its resource potential can be fully understood and realized.

Documents describing the Federal methane hydrate program and the interagency research team. These reports can be found at www.netl.doe.gov/methanehydrates.

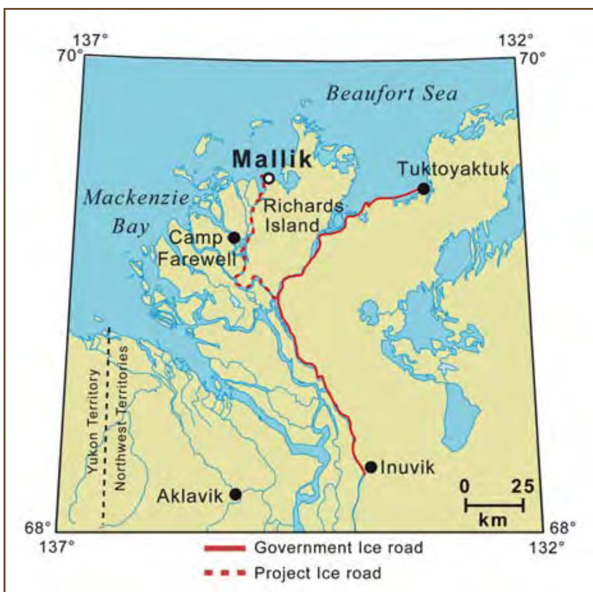
Recent Field Studies

Early conceptual models of methane hydrate occurrence were oversimplified and tended to see hydrate occurring throughout a broad and continuous stability zone that could be tracked by BSRs. It became apparent from early field studies that methane hydrate occurrence is, in fact, complex and can be highly variable from one site to another and even within a particular site. Recent field studies have been aimed at providing the ground-truth needed to test seismic and log-based predictions of hydrate occurrence, and testing production approaches in targeted reservoirs.

In 2002, an international consortium, led by Japan and Canada and including the U.S., conducted short-duration production testing at the Mallik site and demonstrated, for the first time, that methane could indeed be produced from hydrate. During the same time, the Ocean Drilling Program undertook ODP Leg 204 off the Oregon coast and found high concentrations of methane hydrate in an area known today as Hydrate Ridge. A few years later, in 2005, the International Ocean Drilling Program carried out IODP Leg 311, which included conventional coring and pressure-coring at four sites off the coast of Vancouver Island. Methane hydrate was found to occur preferentially in coarser grained sediments in this area.



Natural gas flare at Mallik site during 2008 well test using depressurization technique. (Courtesy of Natural Resources Canada and Japan Oil, Gas, and Metals National Corporation)



Location of Mallik well in Canada's Northwest Territories. (Photo and map courtesy of USGS)

In 2007 and 2008, Japanese and Canadian researchers returned to the Mallik site to conduct a longer-duration production test in a hydrate-bearing interval near the bottom of the methane hydrate stability zone. A six-day pressure drawdown test resulted in sustained, stable gas flow from hydrate. The success of this production test was a major step forward in verifying the producibility of methane from hydrate.

In recent years, the U.S. has been collaborating with international partners on hydrate research projects. In 2006, the DOE and USGS provided scientific leadership and technical support for India's multi-site logging and coring expedition in the Indian Ocean. In 2007, the U.S. participated in China's logging and coring research expedition in the South China Sea, and in 2007, DOE participated in a Korean logging and coring expedition in the Ulleung Basin, East Sea, Korea. Data collected in the course of these field efforts have confirmed earlier suspicions that hydrate saturation is closely linked to reservoir quality.

DOE and USGS scientists have participated in a number of recent international scientific expeditions to study methane hydrate in marine settings. These photos were taken during excursions led by India (at left), China (above), and Korea (below). (Photos courtesy of Kelly Rose, NETL)

Major U.S. Field Projects

Three major field research projects are currently underway in the U.S.—one offshore project to study marine hydrate in the Gulf of Mexico, and two onshore projects to study methane hydrate beneath the permafrost in northern Alaska.

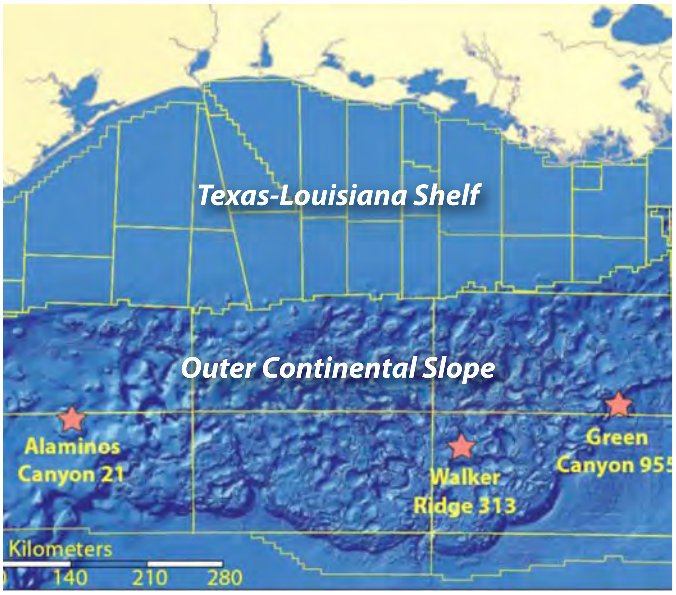
The Gulf of Mexico Joint Industry Project (JIP) is a cooperative research program between the DOE and an international consortium of industry partners led by Chevron. The overall objective of the project is to develop technology and acquire data to aid in the characterization of methane hydrate accumulations in the deep water Gulf of Mexico. During 2009, the project team completed a successful drilling and logging expedition (JIP Leg II) to carefully selected sites in the Gulf of Mexico. Seven wells were drilled at three different locations, and these included the deepest gas hydrate research wells in the world. Drilling and logging results demonstrated the presence of gas hydrate at high saturations in reservoir quality sands at two of the three locations drilled, thus confirming the effectiveness of the methane hydrate prospecting methodology.

Two wells drilled in Walker Ridge Block 313 encountered gas hydrate in high saturations in multiple sand layers, with layer thicknesses up to 50 feet. Drilling at two sites also found gas hydrate filling fractures in finer-grained sediments above the primary targets. Two of the wells drilled in Green Canyon Block 955 encountered extensive sand layers filled with gas hydrate, and one well penetrated a 100-foot-thick sand-rich zone with gas hydrate in high saturations. Finally, two wells drilled in Alaminos Canyon Block 21 confirmed pre-drill predictions of gas hydrate in low saturations throughout shallow sand layers.

The 2009 drilling and logging expedition met its scientific objectives and resulted in a wealth of high-quality geological data from gas hydrate-bearing sediments in the Gulf of Mexico. Results of this drilling program have led to improved techniques for hydrate detection, characterization, and sampling in a marine setting. Individual test wells confirmed the existence of resource-quality methane hydrate at selected sites, and the JIP is now in the process of analyzing the data gathered and selecting candidate well locations for another expedition to further delineate the hydrate resource.

Preliminary scientific results of the JIP Leg II expedition are available to the public in a series of initial reports posted on NETL's web site at: www.netl.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/JIPLegII-IR. These reports include a Technical Summary,

Results of this drilling program have led to improved techniques for hydrate detection, characterization, and sampling in a marine setting.

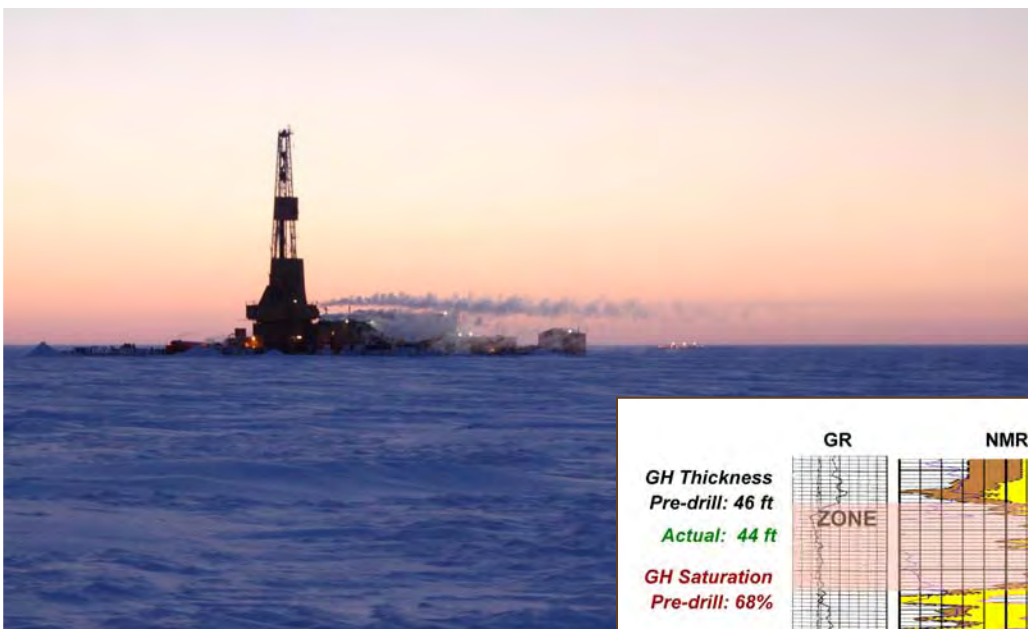


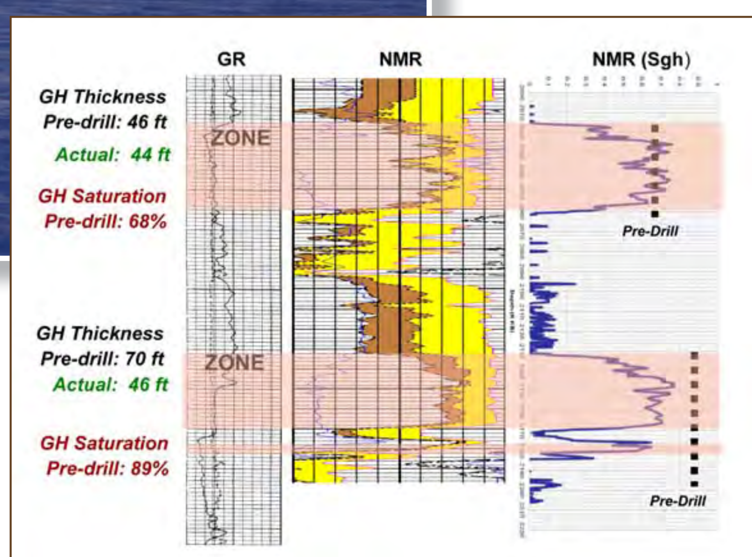
Location of sites drilled during JIP Leg II in the Gulf of Mexico. Bathymetry data illustrate complex geomorphology of outer slope region. (Courtesy of JIP Science Team)

Operational Summary, Logging-While-Drilling Methods, Site Summaries for Walker Ridge 313, Green Canyon 955, and Alaminos Canyon 21, Logging-While-Drilling Operations and Results, and Pre-Drill Site Evaluation and Selection Reports.

The DOE has also been collaborating with the USGS, BP, and a team of participants from industry, government, and academia to evaluate and test the producibility of methane from hydrate in Arctic Alaska, where recent assessments by the USGS estimate 85 Tcf of undiscovered, technically recoverable gas resources within methane hydrate accumulations. The ultimate goal of the project is to conduct long-term testing to evaluate the response of naturally-occurring gas hydrate to controlled pressure reduction. The Mount Elbert stratigraphic test well, drilled in 2007, confirmed the existence of 60-75% hydrate saturation within reservoir quality sands in targeted stratigraphic intervals. A short-term downhole test confirmed the ability of the formation to release gas through depressurization, the first time this had been accomplished on the North Slope.

Another Arctic Alaska project, led by ConocoPhillips, is planning to conduct a field experiment in the Prudhoe Bay region to test a CO_2-CH_4 exchange approach to methane production from hydrate. Carbon dioxide would be injected into a methane hydrate reservoir, where the CO_2 molecules would be exchanged *in situ* for methane molecules, releasing methane for production. If successful, this approach could lead to a synergistic approach to CO_2 sequestration and methane production from hydrate.





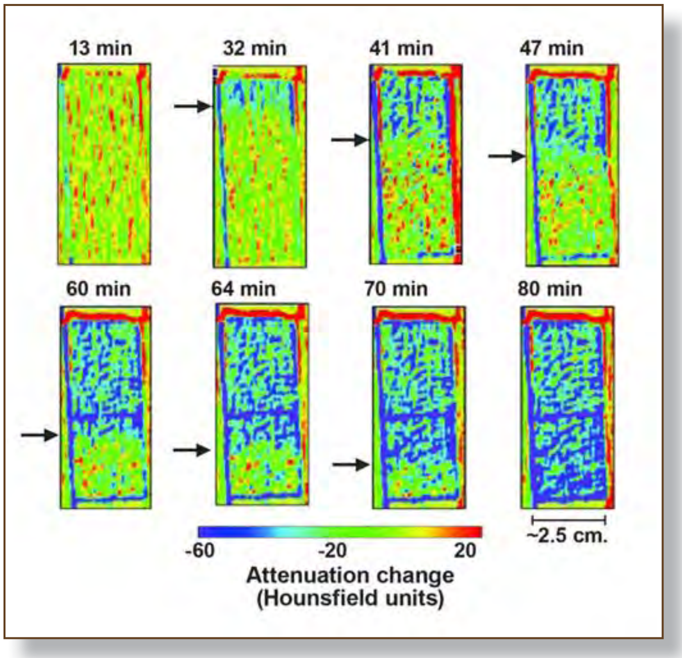
Logs from Mt. Elbert test well in Milne Point field near Prudhoe Bay on the Alaskan North Slope. The gamma ray (GR) and nuclear magnetic resonance (NMR) logs show that pre-drilling estimates of formation thickness and methane hydrate gas saturation (Sgh) based on seismic data were very accurate, supporting the conclusion that seismic exploration tools could be used to prospect for methane hydrate deposits. (Courtesy of Mt. Elbert Science Team)

Experimental and Modeling Studies

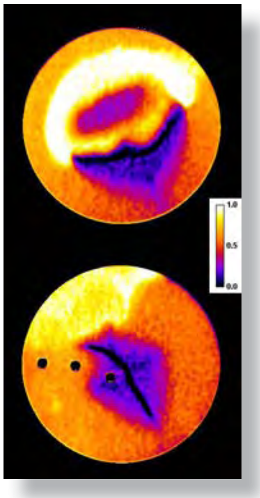
The national methane hydrate R&D program also includes laboratory and modeling studies. The experimental efforts are aimed at improving our understanding of physical and chemical controls on hydrate formation, behavior, and dissociation, and developing techniques for 3D-imaging of hydrate in natural core specimens and synthetic hydrate/sediment samples. Modeling activities are centered on optimizing existing computer codes for simulating methane hydrate reservoir behavior. The codes are tested using reservoir and production data acquired in the field and laboratory. These codes have grown significantly more reliable and useful in recent years, as experimental and field results have been continually incorporated to update the codes.

In recent years, the DOE program has increased its emphasis on global climate studies, and a number of projects are underway to examine the relationship between methane hydrate formation/dissociation and global climate. Experts from national laboratories and universities are working to incorporate methane flux from hydrates into global climate models and to define potential impacts of methane hydrate on the global carbon cycle.

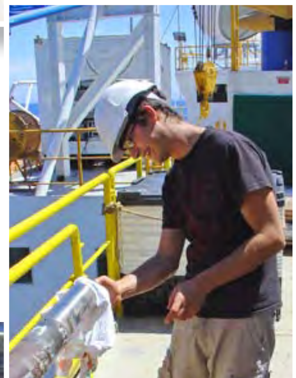
NETL researcher operates the X-ray CT scanner to observe methane hydrate formation in sandy sediments. (Courtesy of Yongkoo Seol, NETL)



Images from CT scanning equipment that reveal attenuation changes as the dissociation front (at arrow) progresses from top to bottom through a methane hydrate-saturated sediment sample over time. (Courtesy of Yongkoo Seol, NETL)

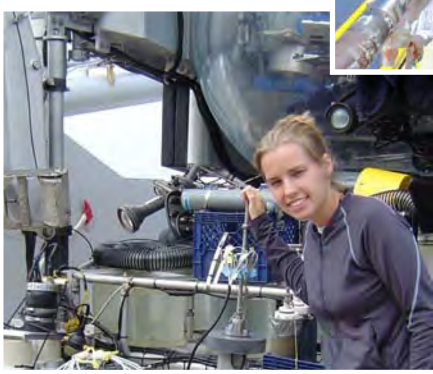


X-ray CT images showing methane hydrate (bright region) and water-depletion (black zone) resulting from methane hydrate formation in sand. (Courtesy of Yongkoo Seol, NETL)



Monica Heintz–University of California at Santa Barbara (above)

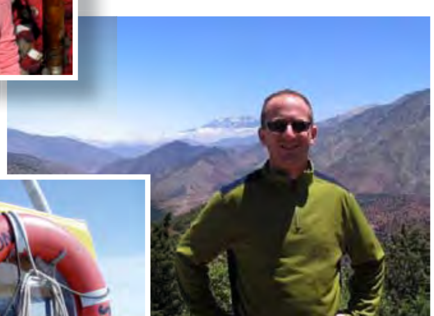
Evan Solomon–Scripps Institution of Oceanography (at right)

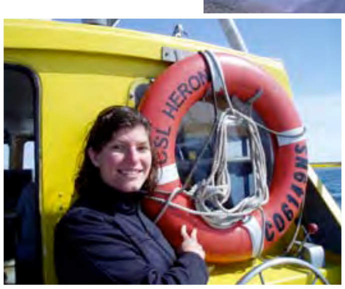


Laura Lapham–Florida State University (above)

Ann Cook–Columbia University (at left)

Hugh Daigle–Rice University (below)





Laura Brothers–USGS Woods Hole (at left)

Research Fellowships

In 2007, NETL initiated the Methane Hydrate Research Fellowship, to support highly qualified doctoral and post-doctoral students engaged in leading-edge hydrate research. Fellowships have been awarded to six promising researchers: Monica Heintz of the University of California at Santa Barbara; Evan Solomon of SCRIPPS Institution of Oceanography; Laura Lapham of Florida State University; Ann Cook, of Columbia University; Hugh Daigle of Rice University; and Laura Brothers of USGS – Woods Hole Oceanographic Institution. These individuals have led research projects on a variety of topics including methane flux from the seafloor to the atmosphere, gas hydrate distribution in ocean basins, and numerical modeling of fluid flow in hydrate-bearing sediments. These fellowships have been highly successful in supporting talented, young scientists and welcoming them into the hydrate R&D community.

A Robust and Balanced Program

The DOE has striven to manage a methane hydrate research program that is well balanced and focused on the knowledge gaps in several key areas: resource characterization, production potential, global environmental impacts, and potential safety hazards. The National Research Council (NRC), in its 2010 review of the program, found that DOE's "overall management of the Program has been consistent and effective." Further, the NRC found that "the positive impact the Program is having on raising the profile of and interest in methane hydrate as a potential energy resource, and the rate at which the Program is moving toward the goal of achieving production of methane from methane hydrate accumulations are all commendable."

In its existing portfolio, DOE continues to focus on the objectives supported by the NRC review; "to develop a comprehensive knowledge base and suite of tools and technologies that will enable: 1) safe and economic methane production from hydrate while minimizing environmental impacts, and 2) full integration of hydrate science into our understanding of global environmental and climate processes."

How to Learn More

There are a number of places to find additional information about methane hydrate research being conducted by the DOE, other U.S. government organizations, universities, and international entities.

- The U.S. Department of Energy's National Energy Technology Laboratory (NETL) maintains a methane hydrate website that is a centralized storehouse of information on the topic. Here you can find summaries of current and past R&D projects, an up-to-date bibliography of methane hydrate research papers, and galleries of photos from methane hydrate field studies. This information is available at: www.netl.doe.gov/methanehydrates

  This NETL website contains two reports with detailed information on the U.S. methane hydrate R&D program. The "Interagency Coordination on Methane Hydrates R&D" describes the federal program, and "Interagency Roadmap for Methane Hydrate R&D" summarizes the research priorities of the interagency effort.

  Also, on this website is a link to Fire in the Ice, the methane hydrate research newsletter published quarterly by NETL. Current and past issues of the free newsletter are available at: http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/newsletter/newsletter.htm
- Information on the U.S. Geological Survey's methane hydrate research is available at: http://woodshole.er.usgs.gov/project-pages/hydrates/
- Information on the U.S. Naval Research Laboratory's methane hydrate research is available at: http://www7430.nrlssc.navy.mil/7432/hydrates/index.htm
- Information on the U.S. Bureau of Ocean Energy Management, Regulation and Enforcement's methane hydrate research is available at: http://www.boemre.gov/eppd/sciences/esp/hydrates/
- Information on HYDRATECH, a methane hydrate research project supported by the European Commission, has information available at: http://www.hydratech.bham.ac.uk/
- Information on the United Nations Environment Program's Global Outlook on Methane Gas Hydrates is available at: http://www.methanegashydrates.org/

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