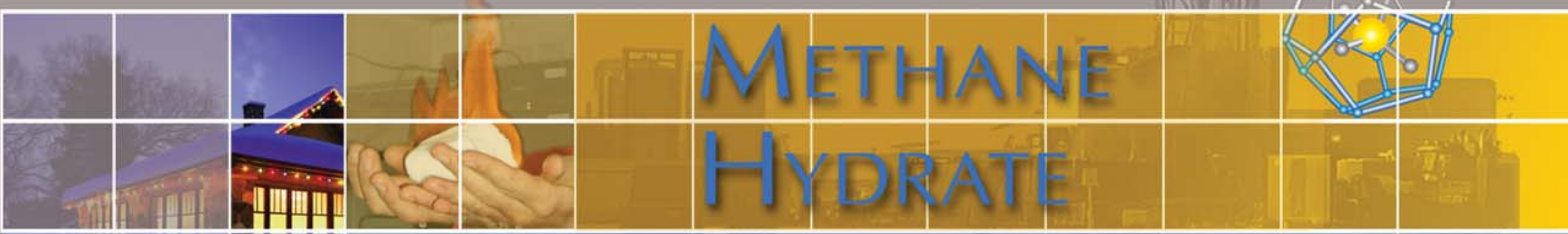
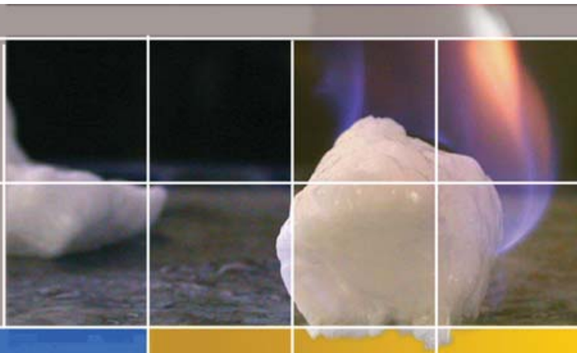


Methane Hydrate

An Overview

Future Energy Within Our Grasp



Methane Hydrate: Future Energy within Our Grasp

Methane Hydrate Comprises an Abundant Energy Resource

Methane hydrate—molecules of natural gas trapped in ice crystals—represents a potentially vast resource that may have as much energy as all the world's other fossil fuels combined. The cost-effective development of hydrate reserves can play a major role both in moderating natural gas price increases and ensuring adequate future supplies for American consumers.

Hydrate science has advanced significantly over the past 10 years, putting the potential for commercial-scale production firmly within our grasp. Closely linked experimentation and numerical modeling have enabled much more confident assessments of hydrate behavior in natural environments. Researchers are addressing important questions such as seafloor stability, drilling safety, and environmental issues associated with naturally occurring methane hydrate.

During the past year, a committee of technical science managers helped DOE develop *An Interagency Roadmap for Methane Hydrate Research and Development*. The roadmap outlines a plan of action to develop a comprehensive knowledge base and suite of tools/technologies that will demonstrate the technical and economic viability of methane recovery from domestic marine hydrate resources within the coming decade.

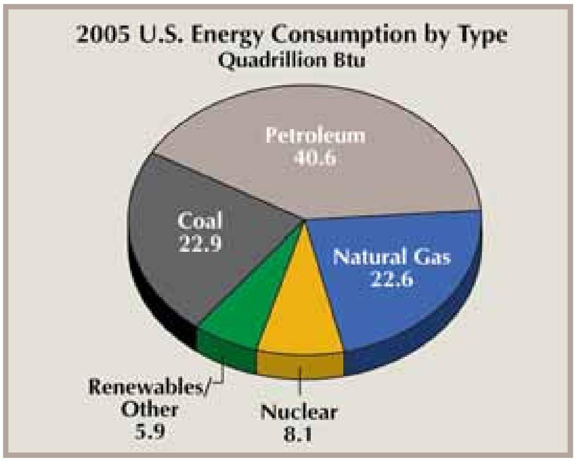
The scientists, researchers, and DOE employees involved in these exciting efforts are proud of the role they are playing in exploring whether and how methane hydrate can supplement America's current energy mix. These initiatives represent advances that will enhance U.S. energy independence and security for generations to come.

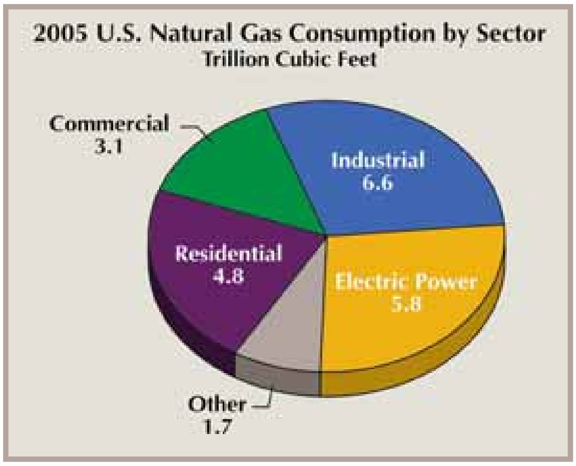
The Growing Need for Natural Gas

Natural gas is an important energy source for the U.S. economy, providing almost 23 percent of all energy used in our Nation's diverse energy portfolio. A reliable and efficient energy source, natural gas is also the least carbon-intensive of the fossil fuels.

Natural gas provides the majority of residential and commercial heating in the United States and fuels approximately 19 percent of the Nation's electricity generation. Total electricity generation from natural gas is projected to increase from about 752 billion kilowatt-hours (kWh) now to more than 930 billion kWh in 2030, according to the Energy Information Administration (EIA).

Natural gas is also a dominant fuel for a wide range of industries, including pulp and paper mills, metals, chemicals, petroleum refining, and stone, clay, and glass manufacturing. It is used in domestic production of fertilizers, chemicals, fabrics, pharmaceuticals, and plastics as a primary feedstock. For many products, viable feedstock alternative do not exist.





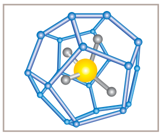
Source: *EIA, Annual Energy Outlook 2007*

Historically, the United States has produced much of the natural gas it has consumed, with the balance imported from Canada through pipelines. According to EIA, total U.S. natural gas consumption is expected to increase from about 22 trillion cubic feet today to 26 trillion cubic feet in 2030—a projected jump of more than 18 percent.

Production of domestic conventional and unconventional natural gas cannot keep pace with demand growth. An increasing amount of imports of liquefied natural gas (LNG) will be required to meet anticipated consumption. The development of new, cost-effective resources such as methane hydrate can play a major role in moderating price increases and ensuring adequate future supplies of natural gas for American consumers.

Development of alternative sources of natural gas, such as methane hydrate, can help to guard against potential supply interruptions or shortages and improve energy security.

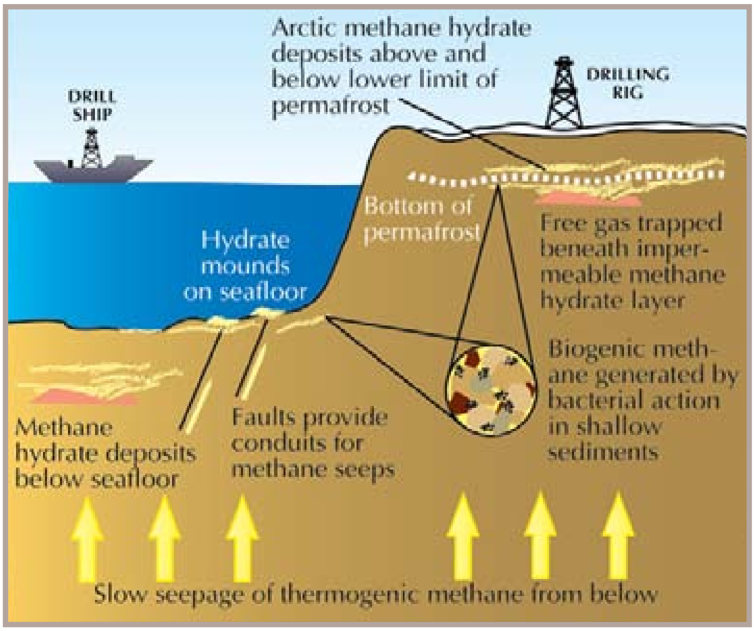
Ice that Burns



Methane hydrate is a cage-like lattice of ice inside of which are trapped molecules of methane, (see image above) the chief constituent of natural gas. If methane hydrate is either warmed or depressurized, it will revert back to water and natural gas. When brought to the earth's surface, one cubic meter (m^3) of gas hydrate releases 164 m^3 of natural gas. While global estimates vary considerably, the energy content of methane occurring in hydrate form is immense, possibly exceeding the combined energy content of all other known fossil fuels.

Types of Hydrate Deposits

Hydrate deposits may be several hundred meters thick and generally occur in two types of settings: under Arctic permafrost, and beneath the ocean floor. Methane that forms hydrate can be both biogenic, created by biological activity in sediments, and thermogenic, created by geological processes deeper within the earth. Thermogenic gases form hydrate that is often associated with conventional oil and gas fields.



Methane hydrate forms at high pressure and low temperature, where sufficient gas is present, and in generally two types of geologic settings: in the Arctic, where hydrate forms beneath the permafrost, and beneath the ocean floor at water depths greater than about 500 meters. The hydrate deposits themselves may be several hundred meters thick.

Methane hydrate has been studied in permafrost areas encompassing the North Slope of Alaska and the Mackenzie River Delta of Canada's Northwest Territories and the Messoyakha gas field of Western Siberia. Well-documented oceanic hydrate accumulations include:

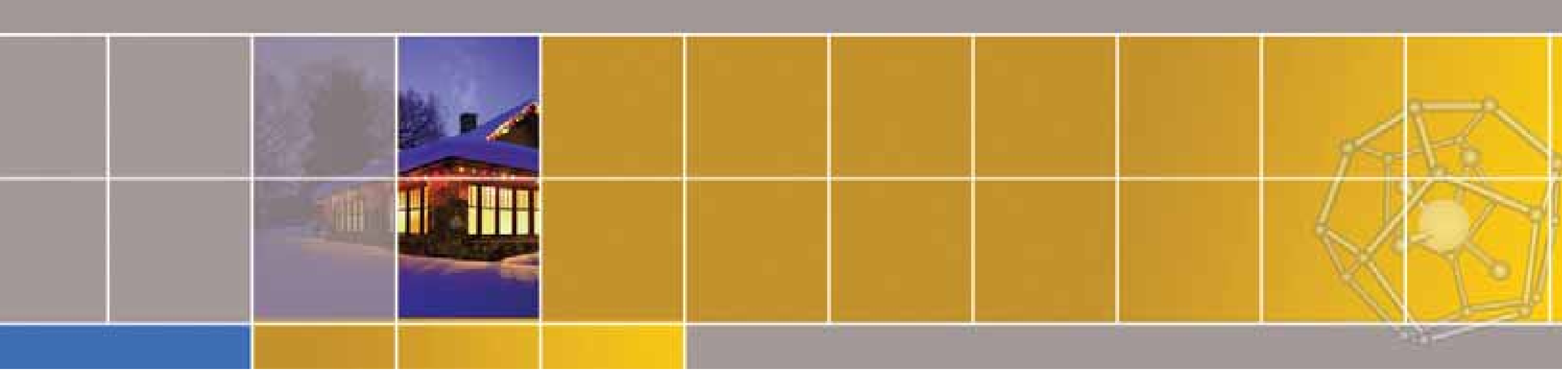
- Blake Ridge, off the eastern coast of North America, near the Carolinas;
- Gulf of Mexico;
- Cascadia margin, off the coast of northern Washington and southern British Columbia, Canada; and
- Japan and India.

Potential Production

Methane hydrate extraction methods that are commercially viable and environmentally acceptable are still being developed but likely will be based on conventional oil and gas production techniques.

Methane hydrate test well, Alaska North Slope

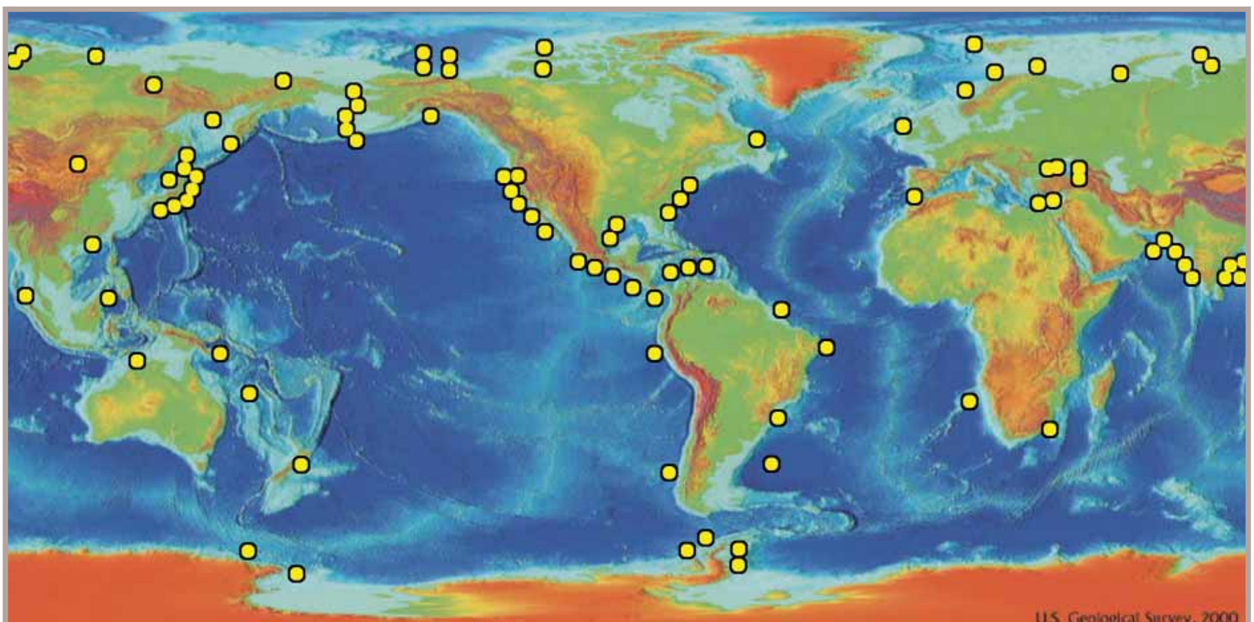
When brought to the earth's surface, one cubic meter (m^3) of gas hydrate releases 164 m^3 of natural gas.



In addition, the presence of hydrate has been inferred from seismic surveys and subsea sampling along most of the continental margins of the world.

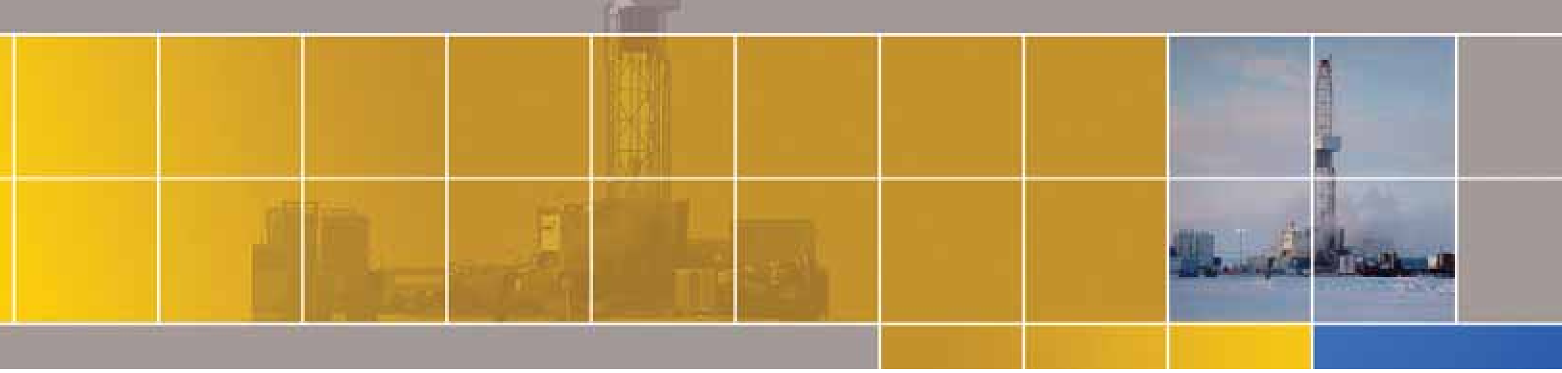
If even a small percentage of the energy contained in methane hydrate can be commercially produced, it could double the volume of clean-burning natural gas, improving U.S. energy security by reducing imports and shifting the world energy balance away from politically unstable regions.

While global estimates vary considerably, the energy of methane occurring in hydrate form is immense, possibly exceeding the combined energy of all other known fossil fuels.



Key: ○ location of known or inferred methane hydrate.

Methane hydrate occurs below permafrost in the Arctic and in subsea sediments of continental margins

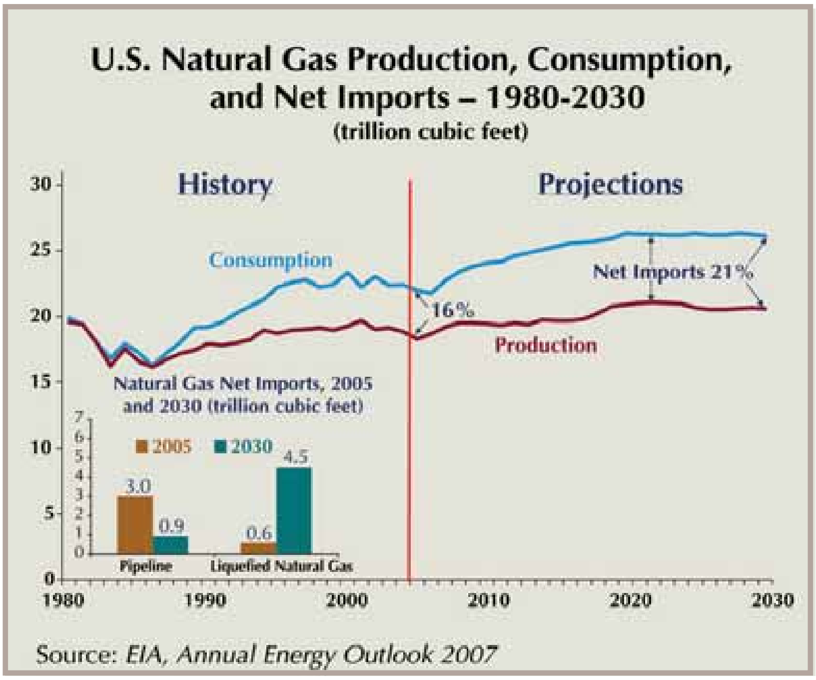


The National Program

Current interest in methane hydrate is based on the need to meet the growing domestic requirement for natural gas. To meet projected demand, net imports of natural gas are forecast to grow from 16 percent of total natural gas supply in 2005 to 21 percent in 2030. Development of alternative domestic sources of natural gas, such as methane hydrate, can help to guard against potential supply interruptions or shortage, and improve energy security.

Scientists have known about methane hydrate for more than a century, starting with research in France as early as 1890, but the resource was not considered a potentially viable energy source until fairly recently. In the 1930s, as natural gas pipelines were extended into colder climates, engineers discovered that hydrate, rather than ice, would form in the lines, often plugging the flow of gas. Viewed as a nuisance, methane hydrate did not gain interest again until the mid-1960s, when a Russian drilling crew discovered natural gas in the "frozen state" or, in other words, methane hydrate occurring naturally. In the 1970s, methane hydrate was found in ocean sediments.

A 10-year, $8 million program established in 1982 at DOE's Morgantown Energy Technology Center (now the National Energy Technology Laboratory, NETL) developed a foundation of basic knowledge about the location and thermodynamic properties of gas hydrate. The program was terminated in 1992, however, when government policy shifted from long-term, high-risk research and development (R&D) to near-term exploration and production R&D. Although DOE funding ceased, work has continued at other government agencies and laboratories,



universities, the Ocean Drilling Program (ODP), and overseas. ODP drilling in 1995 at Blake Ridge, off the coast of the Carolinas, contributed significantly to our understanding of hydrate and its vast potential as an energy source, and stimulated other research.

In 1997, DOE initiated a program to develop the knowledge and technology necessary to allow commercial production of methane from hydrate by 2015, while protecting the environment. Congress authorized funding for this program in 2000 and established requirements for interagency cooperation and external oversights. In addition, the Energy Policy Act (EPAct) of 2005 required the Secretary of Energy to establish a federal advisory panel consisting of experts to review progress and make recommendations for future research directions.

The Interagency Coordinating Committee

The Interagency Coordinating Committee (ICC) actively coordinates joint methane hydrate projects and shares results of research performed by several government agencies. Agencies in the ICC, in addition to DOE, are:

- Department of the Interior (DOI), including U.S. Geological Survey, the Minerals Management Service (MMS), and Bureau of Land Management (BLM);
- Department of Defense, Office of Naval Research, Naval Research Lab;
- Department of Commerce, National Oceanic and Atmospheric Administration (NOAA); and
- National Science Foundation (NSF).

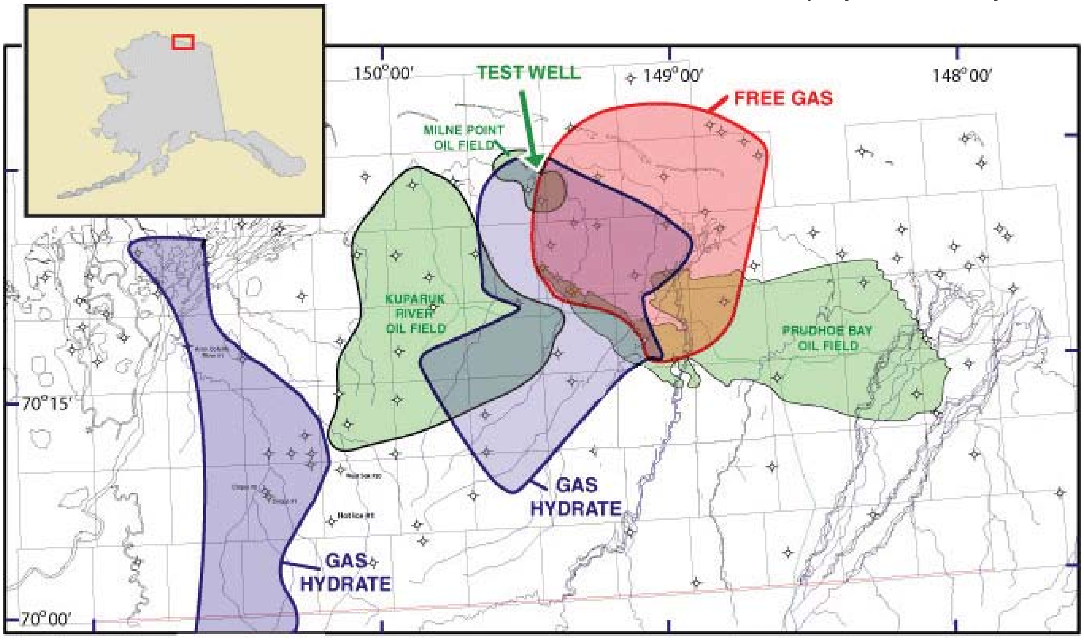
Program Goal — The goal of DOE's methane hydrate program is to provide the knowledge and technologies to fully realize the potential of methane hydrate in supporting our Nation's continued economic growth, energy security, and environmental protection.

Research and Development (R&D)

A major driver for the U.S. R&D Program is the desire to determine and realize the natural gas supply potential of methane hydrate. In addition, methane hydrate represents a highly dynamic and poorly understood component of the natural environment. It is apparent now that this global methane reservoir is in constant flux, absorbing and releasing methane in response to changes in pressure, temperature, and fluid movement. Understanding this flux and its impact on the carbon cycle, long-term climate, and seafloor stability is an additional component of the program.

Defining Natural Gas Production Potential

Worldwide, estimates of the natural gas potential of methane hydrate approach 400 *million* trillion cubic feet—a staggering figure, compared with the 5,500 trillion cubic feet that make up the world's currently proven gas reserves. To pursue the potential of tapping into this vast resource, R&D projects currently center on field



Two field projects are underway on the Alaska North Slope. Shown here is a delineation map of gas hydrate, free gas, and oilfields at Milne Point, with the Milne Point methane hydrate test well identified.

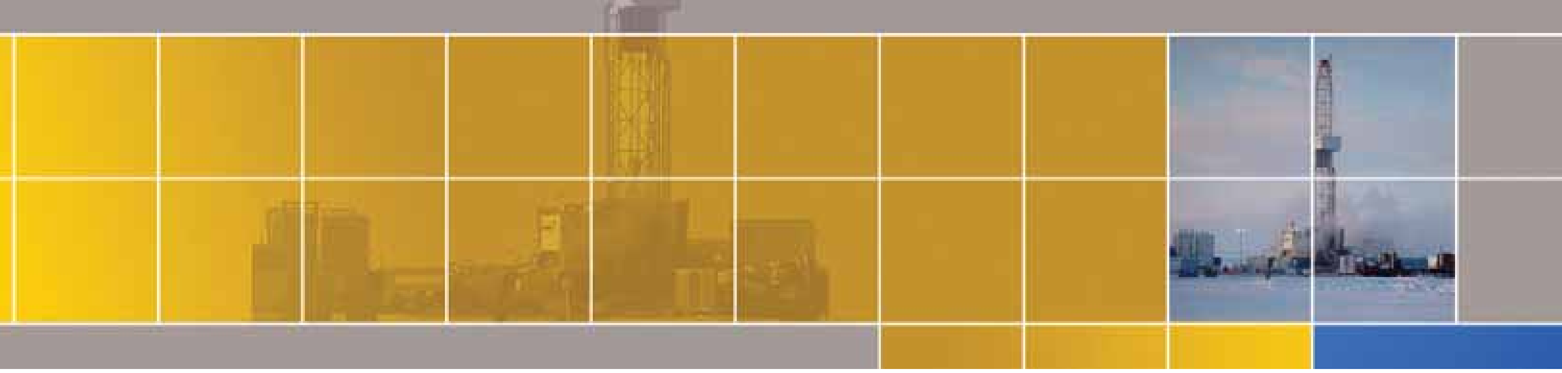
projects in Alaska and the Gulf of Mexico, a cooperative international partnership in India, and development of a computer-based hydrate simulator.

- **Alaska: Two Projects on the North Slope**

DOE and BP have been working for four years to delineate and characterize more than a dozen discrete methane hydrate accumulations within the Milne Point Area, near Prudhoe Bay, on the Alaska North Slope. University of Alaska-Fairbanks, University of Arizona, and U.S. Geological Survey have assisted in the laboratory, geophysical, and modeling studies.

The DOE-BP Alaska project plans drilled a vertical stratigraphic test well in one of the accumulations using an ice pad in Milne Point Field in February 2007 (see map on the preceding page). The stratigraphic test confirmed significant hydrate deposits that have been predicted based on seismic tests, well data, and modeling. A production test may be scheduled based on analysis of the well data.

A second project starting up in the region involves the characterization and quantification of the methane hydrate resource potential associated with the Barrow Gas Fields—three fields located in a permafrost region near Barrow, the main population center and economic hub of Alaska's North Slope Borough. While recent estimates of remaining reserves and current consumption rates indicate the Borough's gas supply should last for more than 150 years, growing demand in Barrow and the expanding distribution of gas and/or power to outlying villages in the Borough is creating pressure on local utilities to increase gas supply. Previous research funded by DOE suggests accumulations of methane hydrate exist within the Barrow area gas fields and could help to meet this growing energy demand in the future.



- **Gulf of Mexico: Deep-Water Drilling**

A partnership enterprise between DOE and Chevron is developing technology and data to assist in the characterization of naturally occurring gas hydrate in the deep water Gulf of Mexico. The project reflects industry's need to better understand the safety issues related to conventional oil and gas operations (drilling, producing, and gathering oil and gas) in areas prone to hydrate occurrence. The ability to safely drill the surface hole, set surface casing, and maintain the integrity of the surface pipe as the entire well is drilled is of primary importance. Information gained from these studies will also help locate and produce potentially commercial hydrate deposits.

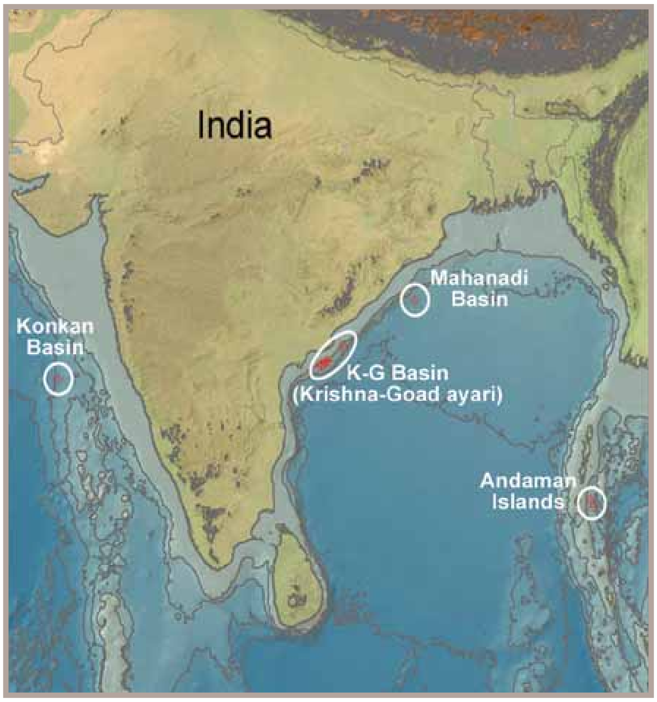
The DOE-Chevron Joint Industry Project (JIP) completed a 35-day cruise in May 2005 to study drilling safety and slope stability issues associated with methane hydrate. The project drilled, logged, and cored two potential hydrate-bearing sites in the Gulf. Data analyses of the 2005 cruise are ongoing, with additional integrated reports planned for release in 2007. In addition, the JIP will continue to pursue improved sampling and analysis technologies in preparation for a potential second field expedition designed to focus on the resource potential of methane hydrate in the Gulf.

Tubeworms and mussels on top of a hydrate mound. The yellowish methane hydrate provides a source of methane for the mussels living on top of them. A little farther from the hydrate, we see lots of tubeworms growing. They may be connected to the hydrate too, since the microbes in the sediment that turn seawater sulfate into sulfide need methane for energy. (Photo courtesy of NOAA)

- **India: Cooperative International Study**

DOE provided scientific expertise and specialized equipment for a three-month, multinational expedition to measure and core methane hydrate deposits in four basins off the coasts of India and the nearby Andaman Islands. The expedition, which was completed in August 2006, drilled or cored 39 holes at 21 sites and recovered approximately 2,850 meters of core. Hundreds of hydrate samples have been preserved for additional laboratory study. DOE and the Directorate General of Hydrocarbons, India, plan to exchange information and analyses, conduct joint studies and projects, and exchange scientific and technical personnel.

In addition to scientists from India, the expedition research team included representatives from DOE/NETL, U.S. Geological Survey, National Science Foundation, Woods Hole Oceanographic Institution, the Idaho and Pacific Northwest National Laboratories, six U.S. universities, the Geological Survey of Canada, and others. This cooperation will increase understanding of the geologic occurrence and the potential for methane production from natural gas hydrate in India, the United States, and Canada.



A multinational expedition retrieved core samples in four basins off the coasts of India and the Andaman Islands

Fostering International Research

DOE co-sponsored the 5th International Gas Hydrate Workshop in Edinburgh, Scotland, in October 2006. The workshop showcased recent research around the world and provided an opportunity for researchers to develop international collaborations.

- **Hydrate Reservoir Simulator**

The computer simulator *TOUGH+/HYDRATE* was developed by Lawrence Berkeley National Laboratory and released in 2005. The simulator can be used to predict hydrate formation and dissociation from the molecular to the reservoir scale. It can also be run by industrial operators to simulate large-scale production, using actual field data. Free program licenses have been granted to 25 non-commercial organizations in 11 countries.

JOIDES Resolution IODP drill ship

NETL and USGS are guiding a collaborative, international effort to compare methane hydrate reservoir simulators. The intentions of the effort are: (1) to exchange information regarding gas hydrate dissociation and physical properties enabling improvements in reservoir modeling, (2) to build confidence in all the leading simulators through exchange of ideas and cross-validation of simulator results on common datasets of escalating complexity, and (3) to establish a depository of gas hydrate-related experiment/production scenarios with the associated predictions of these established simulators that can be used for comparison purposes.

Understanding Naturally Occurring Hydrate Fluctuation

DOE is working in cooperation with other government agencies and university researchers to learn more about the properties and geologic behavior of naturally occurring hydrate. Current field activities are taking place off the coast of Victoria Island, British Columbia, and in the Gulf of Mexico. Additional laboratory work is being done to develop an accurate model for use in identifying hydrate formations with commercial production potential.

- **British Columbia: Integrated Ocean Drilling Program**

An ocean drilling expedition off the coast of Victoria Island, British Columbia, sought to understand how hydrate forms and how it affects the sediment properties in certain geologic settings. Conducted in September and October 2005 aboard the *JOIDES Resolution* (pictured on previous page), the Integrated Ocean Drilling Program (IODP) Expedition 311 studies will also help explain the role of methane hydrate in global climate change.

The expedition collected more than 1,200 meters of sediment and hydrate core, including 43 pressure cores. Pressure cores are necessary to preserve collected hydrate at *in situ* conditions while it is being lifted from the seafloor to the ship's research labs.

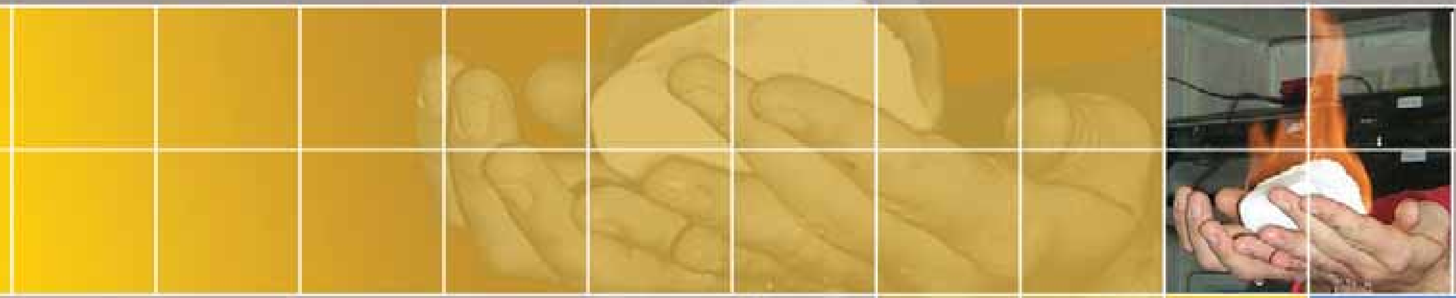
While the National Science Foundation is the primary sponsor of IODP, DOE provided supplemental funding to this effort. The additional funds enabled the expedition to develop and use innovative pressure coring and sample analysis technologies.

- **Gulf of Mexico: Seafloor Monitoring**

Methane hydrate formations on or near the seafloor may vary in extent over a span of months. These changes have implications for possible shifts in seafloor sediment, which could damage facilities—including production platforms, subsea wellheads, and pipelines—and for the potential release of methane to the atmosphere.

A project jointly funded by DOE/NETL, the Minerals Management Service (MMS), and the National Oceanic and Atmospheric Administration (NOAA) will enable DOE and its university research partners to monitor changes in gas hydrate at a seafloor observatory currently

Johnson SeaLink submersible



being installed in the Gulf of Mexico. Developed by a consortium of 15 academic groups headed by The University of Mississippi, the observatory will allow continuous collection of data within the hydrate stability zone and provide a platform from which to monitor the interactions between hydrate, seafloor sediments, the water column, and the atmosphere.

The observatory, which coincides with an area of extensive conventional oil and natural gas industry activity, will be constructed across Mississippi Canyon Block 118 in water depths of approximately 850 meters. The manned submersible *Johnson SeaLink* (pictured on previous page) began deploying some of the monitoring equipment for the observatory in September 2006.

- **Laboratory Studies: Geomechanics**

The mass of carbon held in sediments below the seafloor is a significant element of the earth's carbon cycle; however, estimates of this mass and the rate at which it can accumulate in or dissipate from sediments vary widely. A new study, launched in September 2006 with DOE funding, will provide mechanisms for observing the co-existence of gas and hydrate in ocean sediments. Led by the University of Texas at Austin and the Massachusetts Institute of Technology (MIT), the project will enable researchers to develop a model for interpreting seismic and borehole log data to determine the quantity of carbon held in the hydrate stability zone. This theoretical sediment model will be used to compare virtual sediment geometries with real gas hydrate reservoir characteristics described in field study literature, eventually leading to better identification of hydrate formations with commercial development potential.

Global Climate Change

Methane enters the atmosphere from a number of sources, both natural and anthropogenic (those related to human activities). The methane hydrate reservoir appears to have the capability of both storing and suddenly releasing free methane into the ocean when environmental conditions are suitable.

If this methane somehow enters the atmosphere, it acts as a very powerful greenhouse gas (gasses that trap solar radiation). While methane hydrate sequesters methane on and under the seafloor, if released to the air in sufficient quantities, the methane has the potential to contribute to global

climate change. The magnitude and likelihood of a major methane release event from hydrate production are not yet known, although several naturally occurring releases throughout geologic history are suspected, dating as far back as 60 million years.

An important goal of the methane hydrate program is to collect sufficient data by 2015 to define the rates of methane flux from the sediments to the water column and, ultimately, to the atmosphere. By 2025, the program goal is to develop a comprehensive knowledge base and suite of analytical tools will enable an improved understanding of the potential for, and impact of, natural hydrate degassing on the environment.

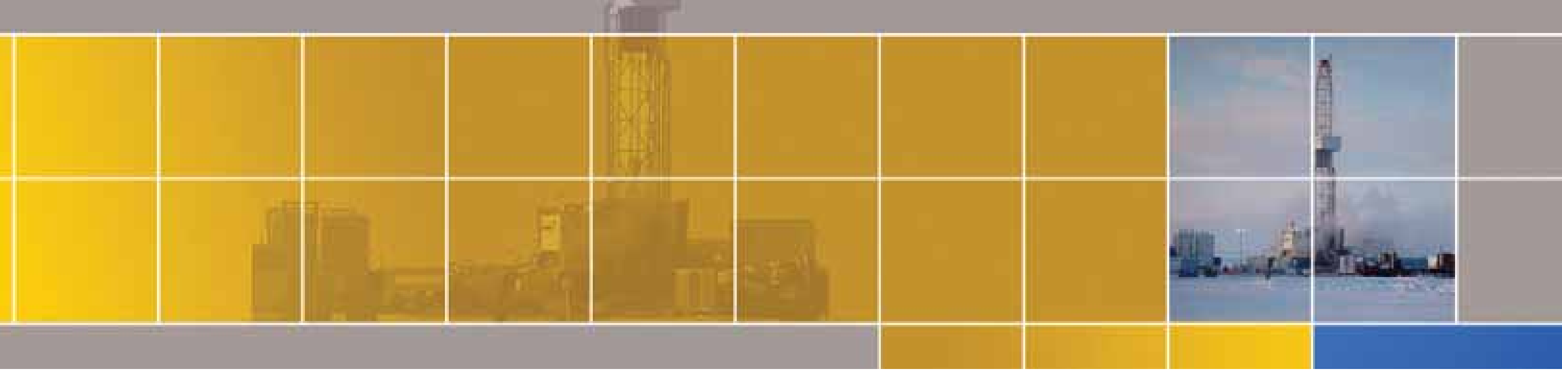
In the nearer term, DOE is funding a research project being conducted by the Woods Hole Oceanographic Institution to investigate the link between methane hydrate and climate in sediments from the southeastern Bering Sea. An expedition to the Umnak Plateau region in 2002 collected a series of sediment cores for investigation into the climate history of the region.

Drilling and seismic observation offshore of Umnak Plateau in the Aleutian Basin have led the researchers to conclude that the entire region off southwest Alaska probably has enormous stores of methane hydrate. By retrieving core samples from varying water depths in the region, the Woods Hole scientists believe they have the potential to develop a three-dimensional picture of possible methane hydrate dissociation. Regardless of the potential to commercially produce methane from the region, this cutting-edge research will enable scientists to better understand the earth's historical periods of warming and climate change.

Methane and Carbon Dioxide (CO_2) Sequestration Research

Since 1994, NETL has conducted research on CO_2 sequestration, including application of CO_2 hydrate for deep-ocean sequestration. CO_2 hydrate studies will benefit methane hydrate work, especially in increased understanding of the thermodynamics and mechanisms of formation and dissociation of hydrate.

Research is also being conducted in Japan and the United States to develop novel combined methane production and CO_2 sequestration techniques that involve displacement of methane from hydrates by CO_2 injection.



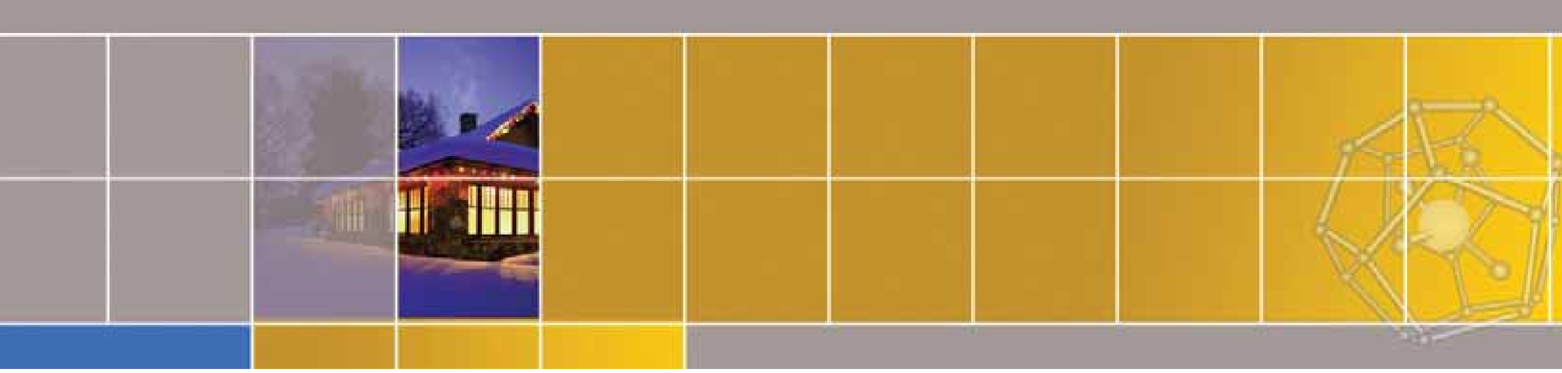
Research Fellowships

DOE's NETL has initiated a new academic research fellowship program designed to support the development of methane hydrate science. The two-year fellowships are made available to support work toward M.S. and Ph.D. degrees, or in a post-doctoral appointment. The National Academy of Science administers recruitment and competitive selection of the fellowships.

NETL's Methane Hydrates Fellowship Program is designed to maintain three to five fellowships at any point in time, supporting work that prepares the individuals to apply hydrate science either in practical applications in industry or in further academic research.

While DOE research contracts made directly with universities fund the work of graduate students and professors, many students are also funded through subcontracts to universities made by DOE's major industrial partners. For example, in the planning and analysis phases of the DOE-BP Alaska North Slope project (see p. 8), BP utilized nearly two-thirds of DOE's funding for tapping into student and faculty talent at the Universities of Arizona and Alaska-Fairbanks for much of the foundational geological and engineering support needed by the project. The Gulf of Mexico Joint Industry Project led by Chevron (see p. 9) has similarly utilized university support, through contracts with Rice University, Georgia Tech, and Scripps Institute of Oceanography.

An international hydrate research team and crew aboard the Research Vessel *Vidal Gomez* in the open sea offshore Chile



To Learn More

DOE distributes information about methane hydrate research through its Web sites, www.fossil.energy.gov and www.netl.doe.gov, which include detailed information about all research and development projects, and publishes a quarterly newsletter, *Fire in the Ice*.

In order to provide easy, Internet-based access to research data, DOE is funding development of a distributed, international gas hydrate database through CODATA, the International Council for Science: Committee on Data for Science and Technology, Task Group on Data on Gas Hydrate.

A bibliography of all reports and publications resulting from DOE methane hydrate research is available at the NETL methane hydrate Web site, www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrate/maincontent.htm.

The quarterly *Fire in the Ice* newsletter updates readers on methane hydrate research

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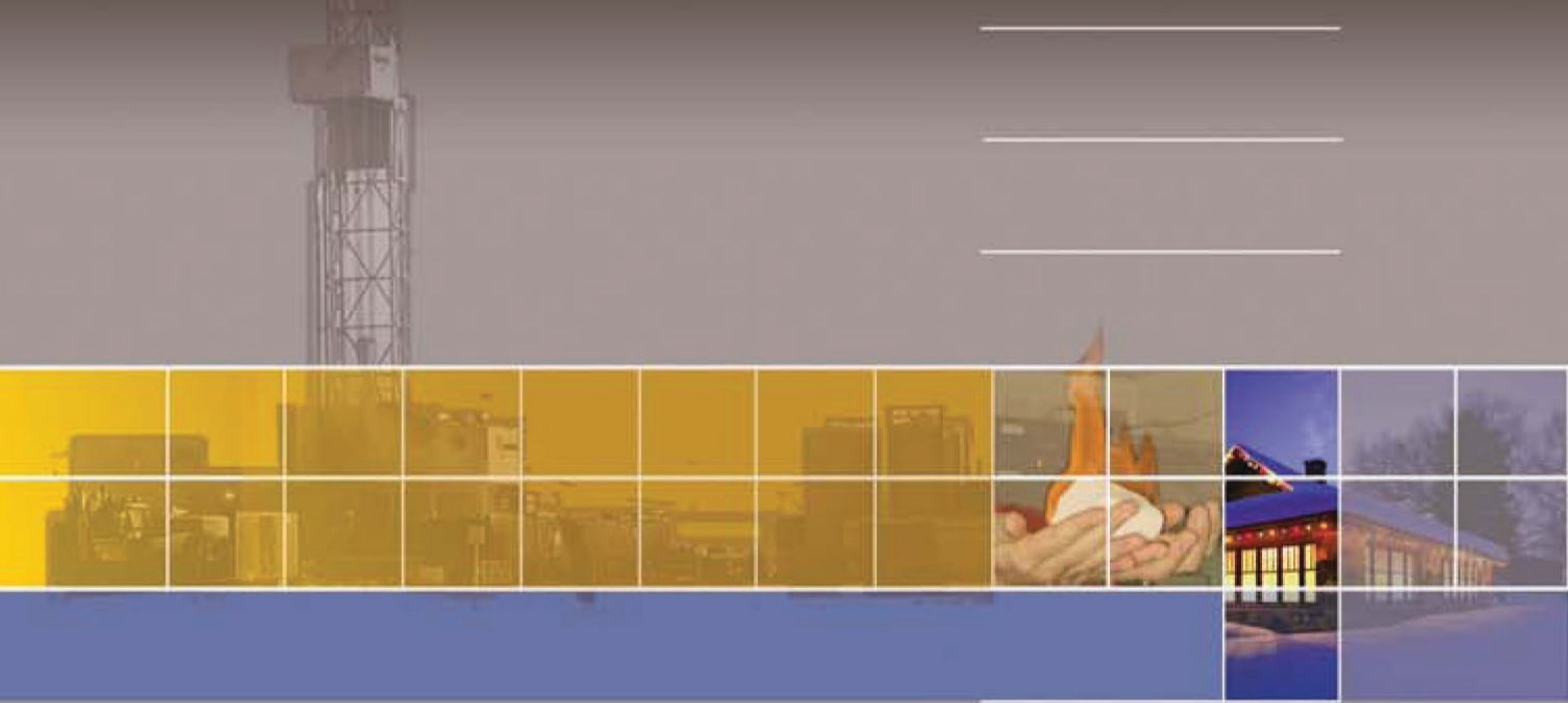

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