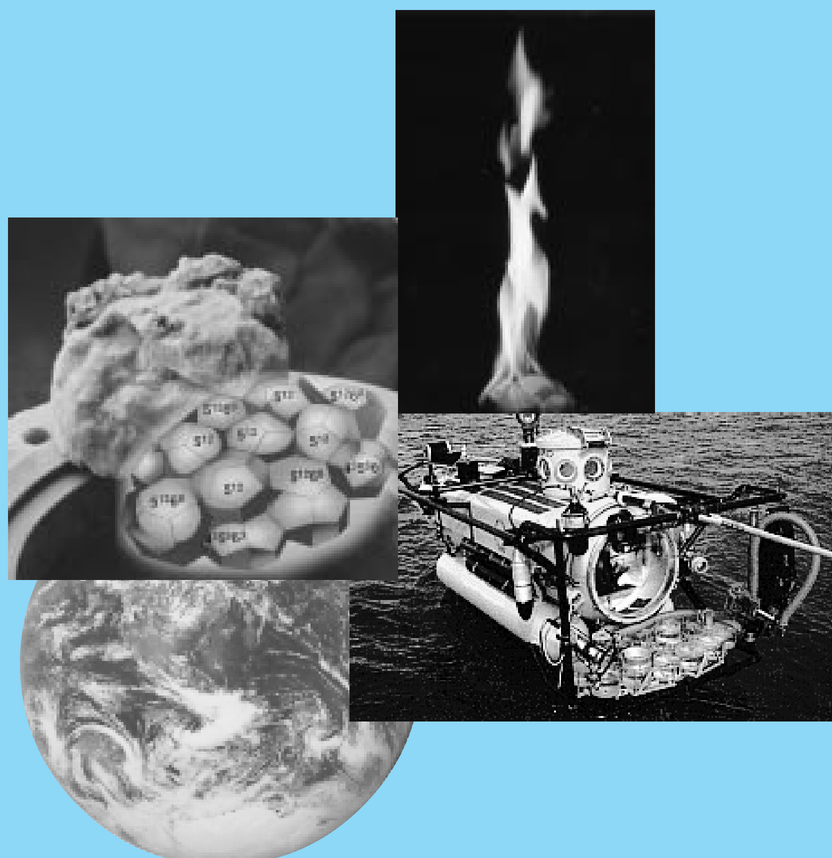
DOE/FE-0378

A STRATEGY FOR METHANE HYDRATES RESEARCH & DEVELOPMENT



U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY

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A STRATEGY FOR METHANE HYDRATES RESEARCH & DEVELOPMENT

U.S. Department of Energy
Office of Fossil Energy
Washington, DC

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METHANE HYDRATES R&D PROGRAM HIGHLIGHTS

~ *ENERGY SUPPLY FOR THE FUTURE* ~

This document sets the foundation for a national program, a 10-year science and technology path that will produce the knowledge and products necessary for commercial production of methane from hydrates by 2015 and will address associated environmental and safety issues. Detailed implementation plans and budgets that are consistent with this document will be subsequently developed.

THIS PROGRAM WILL:

DEFINE a vast, domestic resource in permafrost regions and surrounding waters that is over 100 times greater than the estimated conventional U.S. gas resource of 1,400 trillion cubic feet.

ENABLE the U.S. to meet a substantive natural gas growth in power generation and transportation in the early 21st century, while meeting requirements for cleaner fuels and reduced emissions of CO_2.

ENSURE our energy security, foster U.S. industry global competitiveness, and enhance the value of Federal lands that provide 37 percent of the nation's gas production.

FOCUS on four program goals:

- ***Resource Characterization***
  Determine the location, sedimentary relationships, and physical characteristics of methane hydrate resources to assess their potential as a domestic and global fuel resource.

- ***Production***
  Develop the knowledge and technology necessary for commercial production of methane from oceanic and permafrost hydrate systems by 2015.

- ***Global Carbon Cycle***
  Develop an understanding of the dynamics and distribution of oceanic and permafrost methane hydrate systems sufficient to quantify their role in the global carbon cycle and climate change.

- ***Safety and Seafloor Stability***
  Develop an understanding of the hydrates system in near-seafloor sediments and sedimentary processes, including sediment mass movement and methane release so that safe, standardized procedures for hydrocarbon production and ocean engineering can be assured.

MARSHAL the resources of the petroleum industry, academia, the National Laboratories, and a broad base of government programs with concurrent interests in methane hydrate research. The Department of Energy, Office of Fossil Energy, will develop and manage the program in consultation with a Management Steering Committee:

- DOE Office of Energy Research (ER)
- United States Geological Survey (USGS)
- Minerals Management Service (MMS)
- Naval Research Laboratory (NRL)
- National Science Foundation (NSF)
- Ocean Drilling Program (ODP)
- Natural Gas Supply Association (NGSA)
- Gas Research Institute (GRI)
- American Petroleum Institute (API)

PROMOTE cooperation with the international community, including countries, such as Japan, Canada, and the United Kingdom, who have active methane hydrates R&D programs.

ACKNOWLEDGMENTS

The National Methane Hydrates Program that is outlined in this document has been developed through the cooperative efforts of a multi-agency task force led by Sandra Waisley, Acting Deputy Assistant Secretary for Natural Gas and Petroleum Technology. The task force includes: William Dillon and Timothy Collett, U.S. Geological Survey; Burton Hurdle and Michael Max, Naval Research Lab; Hugh Guthrie and Charles Byrer, Federal Energy Technology Center; Nick Woodward, DOE Office of Energy Research; William Lawson, DOE National Petroleum Technology Office, and Edith Allison, DOE Office of Natural Gas and Petroleum Technology. Rod Malone, who has retired from the Federal Energy Technology Center participated in the early development of the program and Ehsan Khan, DOE Office of Energy Research was formerly on the task force. Experts in methane hydrates from academia and industry assisted in organizing the two national workshops: Peter Brewer, Monterey Bay Aquarium Research Institute; George Claypool, consultant; Wayne Dunlap, Texas A& M University; Arthur Green, Exxon; Gerald Holder, University of Pittsburgh; Arthur Johnson, Chevron; Miriam Kastner, Scripps Institution of Oceanography; Harry Roberts, Louisiana State University; E. Dendy Sloan, Colorado School of Mines; and James Worthington, Kerr-McGee Corporation.

1. INTRODUCTION

As much as 200,000 trillion cubic feet (Tcf) of methane may exist in hydrate systems in the U.S. permafrost regions and surrounding waters (Collett, 1997). This is over a hundred times greater than the estimated conventional U.S. gas resource (1,400 Tcf; Gautier et al, 1995). The volume that may be economically producible is unknown. However, these enormous resources, if proven, have significant implications for U.S. energy security and global environmental issues, particularly global climate change. In addition, because the bulk of these methane hydrates are located on Federal lands, gas production would provide significant resources via royalties and leases.

The U.S. will consume increasing volumes of natural gas well into the 21st century and methane hydrates can contribute to a reliable and low-cost domestic supply. In the near-term, natural gas is expected to take on a greater role in power generation and transportation because of increasing pressure for cleaner fuels and reduced emissions of carbon dioxide (CO_2), particulates, sulfur oxides, and nitrogen oxides. Gas demand is also expected to grow substantially throughout the first half of the 21st century because of an expanded transition role as a transportation fuel or a competitive source of transportation liquid fuel (gas-to-liquids conversion) and hydrogen for fuel cells.

Global energy projections are uncertain because of the potential for marked changes in demand in developing countries, including China, India, and Brazil, and the transitional economies of Eastern Europe and the former Soviet Union. However, it is clear that the U.S. will continue to consume large volumes of natural gas. U.S. consumption is expected to increase from almost 23 Tcf in 1996 to over 32 Tcf in 2020 [Energy Information Administration (EIA), 1997].

What are the Key Issues Constraining Hydrate Development?

A limited understanding of:

- Resource Characterization: geographical distribution and quantities;
- Production: economical, safe, and environmentally acceptable production of natural gas from methane hydrate deposits;
- Global Carbon Cycle: the role of methane hydrates in global carbon and atmospheric methane balances;
- Safety: potential impacts of methane hydrates on the safety of conventional hydrocarbon operations in the Arctic and offshore Gulf of Mexico; and
- Seafloor Stability: the impact of methane hydrate deposits on submarine landslides and sediment collapse features.

Although methane hydrates have been detected around all the U.S. continental margins, only a few areas have been studied in detail. As a result, the methane volumes contained in these deposits are poorly defined. Producers, consumers, and energy policy makers need more accurate resource information for long-term planning.

Only one, and that is debatable, instance of commercial gas production from methane hydrates has been reported. Economic natural gas production can not proceed without development, testing, and field demonstration of specialized production techniques supported by detailed reservoir engineering studies and reservoir and production modeling.

Methane hydrates may play a significant role in global climate change. Methane is a 10-year more potent (by weight) greenhouse gas than CO_2, albeit shorter-lived. Gas hydrates may contain three orders of magnitude more methane than exists in today's atmosphere. Because hydrate breakdown, causing release to the atmosphere, can be related to global temperature increases, gas hydrates may play a role in global climate change.

Hydrates-related sediment collapse is also critical to global climate change because it may represent a major mechanism for transfer of methane to the ocean-atmosphere system. Understanding hydrate–sediment stability is also important for other uses of the seafloor, such as waste disposal and submarine communication cables.

Why A Renewed Interest in Hydrates?

In the past year, a renewed interest in methane hydrates has emerged even to the point of articles appearing in popular science magazines and newspapers. This popular and scientific interest is due to several factors:

- Growing recognition of the need for increased supplies of cleaner domestic fuels by the middle of the 21st century;
- As conventional hydrocarbon production continues in the Arctic and moves into deeper water in the Gulf of Mexico and globally, there is growing evidence of methane hydrates involvement in plugging of wellbores and pipelines, sediment mass movement, blowouts, and well-site subsidence;
- Improved economics for commercial production from hydrates due to proximity to recently developed production and transportation facilities in deepwaters of the Gulf of Mexico;
- Concern about global climate change, most recently heightened by the Kyoto conference,[1] has emphasized the need to understand the role of methane and its hydrate reservoir in global carbon cycles;
- Recent publication of several landmark studies, including the second edition of *Clathrate Hydrates of Natural Gases* (Sloan, 1997), and research results from the Ocean Drilling Program (ODP) study of hydrates on Blake Ridge (Dickens et al, 1997, Paull et al, 1996, and Holbrook et al, 1996); and
- Increased international activity and significant research and development (R&D) expenditures in Japan and India indicate the expectation of commercial production in the not–too–distant future.

A large, long-term R&D effort will be required to turn this potential resource into gas reserves, while developing technologies to assure safe petroleum operations in hydrate areas, and to understand the role of methane hydrates in global climate change. This program plan sets out the foundation for a

[1] Meeting of Parties to the United Nations Framework Convention on Climate Change, Kyoto, Japan, December 1997.

National Methane Hydrates Program, a 10-year R&D program that will produce the knowledge and technology necessary for commercial production of methane from hydrates by 2015 and will address associated environmental and safety issues.

The imperative for embarking on a strong technology program now is supported by recognition of the long times associated with significant change in our energy infrastructure. Research and development often requires one or two decades to yield technology breakthroughs. But, the environmental and economic benefits to be derived from such a program are huge.

1.1 Methane Hydrates Defined

Methane hydrates are methane-bearing, ice-like materials that occur in abundance in marine and Arctic sediments and store immense amounts of methane. They are clathrate (for cage) compounds in which water molecules enclose the gas molecules, allowing high methane concentrations. One unit volume of methane hydrates can contain over 160 volumes of gas and less than one unit of water at surface pressures and temperatures.

Methane hydrates form and are stable at moderately high pressures and low temperatures, conditions found on land in permafrost regions and within ocean floor sediments at water depths greater than about 500 meters. Methane incorporated into the hydrates is generated by microbial production of natural gas in organic rich sediments or may migrate from deeper gas deposits. The hydrate deposits themselves may be several hundred meters thick. The increasing temperature of deeper sediments that precludes hydrate formation limits the bottom of the hydrate zone. Free gas is often found in sediments below the hydrate zone.

Methane hydrates have been detected around most continental margins. Around the U.S., large deposits have been identified and studied in Alaska, the West Coast from California to Washington, the East Coast, including the Blake Ridge offshore from the Carolinas, and in the Gulf of Mexico.

In 1995, the U.S. Geological Survey (USGS) completed its most detailed assessment of U.S. gas hydrate resources using a play analysis method similar to that used for assessment of more conventional U.S. oil and gas resources (Collett *in* Gautier et al, 1995). This study concluded that the U.S. resource is larger by several orders of magnitude than previously thought. U.S. hydrate resources are estimated to range between 112,000 Tcf and 676,000 Tcf (0.95 and 0.05 probability levels). The large range in estimates reflects a high degree of uncertainty because of the lack of detailed information on hydrate concentrations and measurement techniques. The mean value is considered to be about 200,000 Tcf, based on refinements using data from ODP Leg 164 (Collett, 1997) (Figure 1). The offshore hydrate resource is estimated to be 99 percent of the total. (See Appendix 1 for methane hydrate resource distribution.)

1.2 Natural Gas Supply and Demand

Methane hydrate resource estimates are more than a hundred times larger than the resource estimates of other conventional and unconventional gas (exclusive of hydrates) in the U.S. Estimated mean conventional and unconventional technically recoverable U.S. gas resources, plus known reserves onshore, is 1,074 Tcf (Gautier et al, 1995). In 1996, Minerals Management Service (MMS) estimated 338 Tcf of undiscovered conventionally recoverable resources and reserves in the Outer Continental Shelf (OCS), using essentially the same methods as USGS.

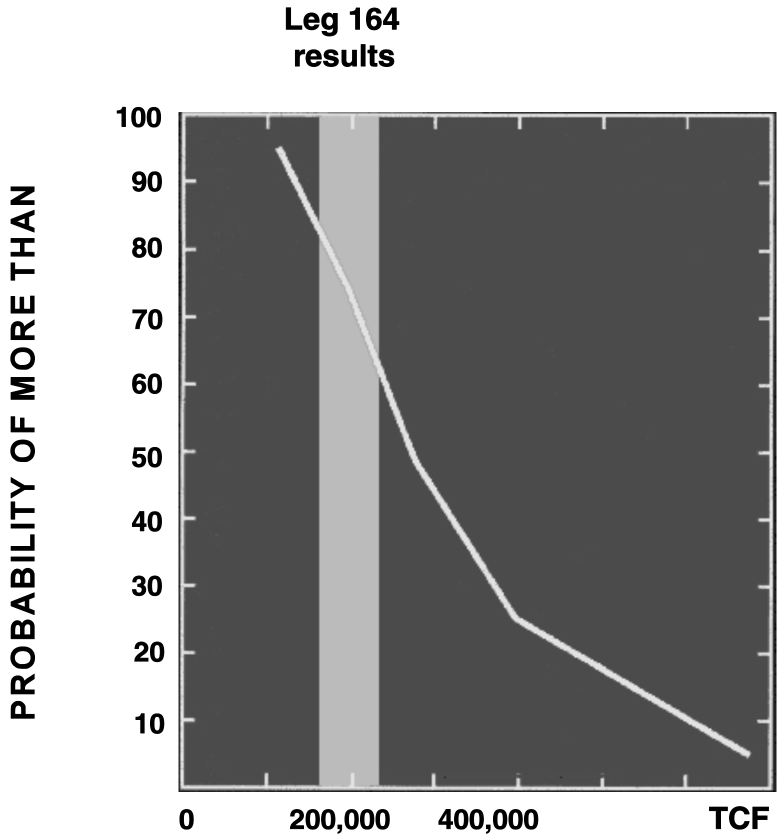
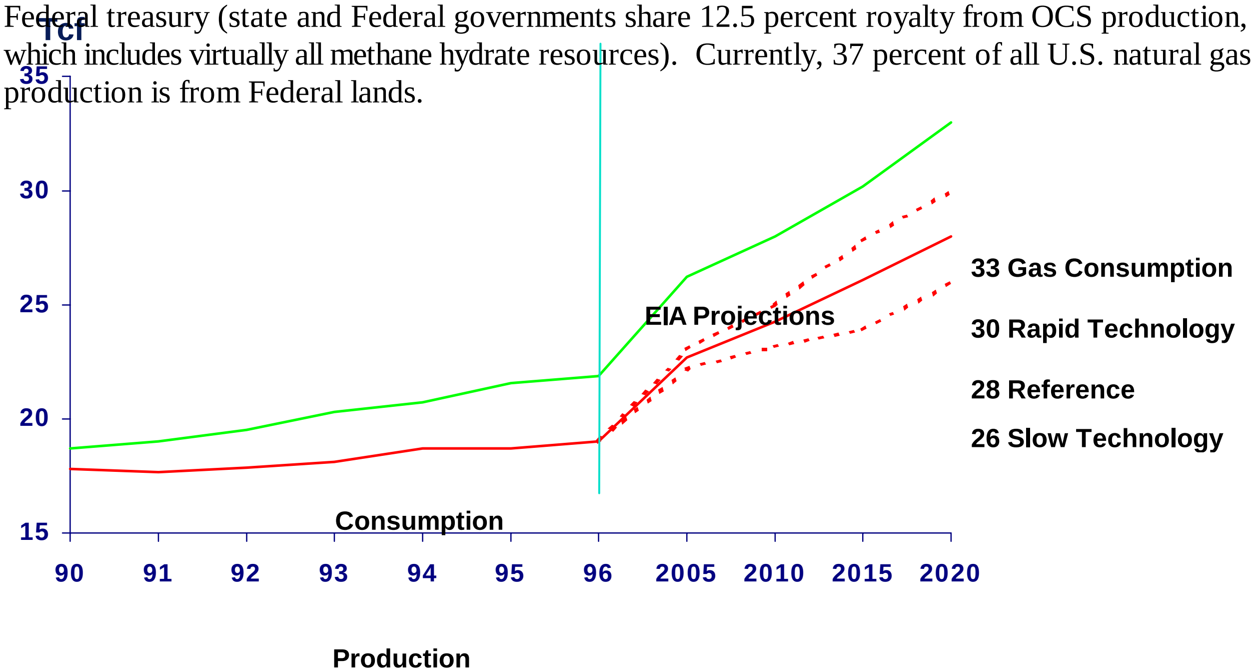


Figure 1. Estimates of Methane in Gas Hydrates and Related Gas Deposits for the U.S.
(T. Collett, 1997. The gray bar shows the best volume estimate.)

The EIA (1997) reference case estimates that U.S. natural gas production will climb from 19 Tcf in 1996 to over 28 Tcf in 2020. However, estimated production will fail to keep up with demand, resulting in an increase in natural gas imports from 2.7 Tcf in 1996 to about 5.3 Tcf in 2020 (see Figure 2).

These projections assume technological advances, driven by increasing demand, will expand reserves and reduce the cost to find and produce natural gas. The EIA reference case assumes current levels of research and technology development by government and industry. EIA estimates (Figure 2) that rapid technological advances provided by expanded R&D will reduce the production deficit. The proposed methane hydrates R&D program will contribute to this accelerated technological advance.

Even if only 1 percent of the estimated 200,000 Tcf methane hydrate resource becomes technically and economically recoverable, the domestic natural gas resource (1,400 Tcf for both onshore and offshore) could be more than doubled. The increased production from this expanded resource could reduce wellhead prices and supplant imports while contributing rental and royalty income to the Federal treasury (state and Federal governments share 12.5 percent royalty from OCS production, which includes virtually all methane hydrate resources). Currently, 37 percent of all U.S. natural gas production is from Federal lands.



Source: Energy Information Administration, Annual Energy Outlook 1998.

Figure 2. Natural Gas Consumption, Production, and Projections

2. FEDERAL ROLE

2.1 What is the Importance of Methane from Hydrates to U.S. Consumers?

Fossil fuels play a vital role in the U.S. economy—$500 billion of our economy goes directly to purchase power and fuels, or about 7 to 8 percent of our Gross Domestic Product. With the Nation expected to increase its energy consumption by over 30 percent by 2020, contribution of fossil fuels to the U.S. energy mix will grow from 85 to 90 percent (EIA, 1997). Oil and gas currently represent 63 percent of the Nation's energy mix and over 99 percent of transportation fuels.

Rising demand for crude oil remains the Nation's most serious energy problem and the EIA (1997) projects that domestic oil demand will grow by over 35 percent by 2020. Meanwhile, continued decline is projected for U.S. oil production, from 6.5 million barrels per day in 1996 to 4.9 million barrels per day in 2020. Furthermore, many analysts believe that although global oil demand will continue to rise, worldwide oil production will peak in the early 21st century[2], setting the stage for price increases and possible supply disruptions.

Conversion of natural gas produced from methane hydrates to liquid transportation fuels using conventional technology, such as Fischer-Tropsch synthesis, or advanced technologies has the potential to reduce our dependence on imported oil.

Significant energy and environmental benefits will also accrue from the use of methane from hydrates for power generation. Natural gas has the lowest carbon emissions of all hydrocarbons. Use of methane hydrates in conjunction with new power generation technologies now being developed by U.S. Department Of Energy's (DOE) Advanced Turbines Program could reduce CO_2 emissions by almost 50 percent.

2.2 Why Should the Federal Government Be Involved?

Federal support can help the U.S. avoid a crisis situation of stagnant energy technology development, brought about by sharp reductions in private sector energy R&D. Energy R&D by the private sector, in virtually every fuel sector, is down nearly a third in just the last three years after a period of steady decline in the 1980s. The Federal fossil energy R&D program is virtually the only remaining national R&D effort emphasizing technologies that are still ten years or more into the future, such as in the methane hydrates and gas-to-liquids programs.

DOE's fossil energy R&D program is developing advanced concepts that are well beyond the timetables and performance goals of private sector R&D. Using Federal R&D investments to make available new technologies 10 to 30 years before they would otherwise emerge from private sector R&D can save consumers billions of dollars, make national environmental choices easier, and strengthen the Nation's energy security. Methane hydrates research, for example, has no immediate economic payoff. Federal R&D is the only way this type of research can be conducted in the U.S.

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[2] Several expert analyses summarized in Edwards (1997) forecast that world crude oil production will peak between the years 2000 and 2030.

Federal R&D can assist U.S. companies maintain their global competitiveness at a time when expanding world markets are creating enormous opportunities and unprecedented competition from other nations. Other nations recognize the trillion-dollar potential of the global energy technology market and are creating public-private partnerships to improve the competitive posture of their technology developers. The U.S. must sustain similar partnerships or risk putting U.S. companies at a disadvantage. Currently, the U.S. is a worldwide leader in sales of equipment and services, with a 40 percent market share or about three billion dollars in revenues per year.

2.3 Stewardship of Public Resources

The Federal Government has a primary role to enhance the value of Federal lands. Currently, 35 percent of domestic gas and 20 percent of domestic oil production come from Federal lands and this contribution is expected to increase in the future. Virtually all the known methane hydrate resources exist in Federal waters of the OCS. The companies developing, producing, and using these resources would pay significant royalties, fees, and taxes. Thus, there is significant incentive for R&D that leads to the efficient utilization of these resources.

2.4 Comprehensive National Energy Strategy

The DOE Comprehensive National Energy Strategy (CNES) (DOE, 1998) defines the government role as improving the operation of competitive markets and addressing the markets' inherent limits. In this context, the Federal Government focuses on promoting increased domestic oil and gas production among other efforts. The CNES concludes that, ultimately, the continued development of new technologies that provide diverse energy sources, improve the efficiency of end use, and reduce the negative environmental effects of energy production and use is the key to maintaining our high quality of life.

The CNES argues that the imperative for embarking on a strong technology program now is reinforced by recognition of the long lead times required for significant change to occur in our energy infrastructure. Research and development often takes one or two decades to yield technology breakthroughs. Moreover, the turnover time for major energy supply and end-use technologies also extends into many decades.

The methane hydrates program will directly contribute to the CNES Goal IV:

> *Expand future energy choices—pursuing continued progress in science and technology to provide future generations with a robust portfolio of clean and reasonably priced energy sources.*

Under Goal IV, this R&D program is proposed as part of Objective 2, Strategy 1: Develop long–term energy technologies that increase energy options, improve overall economics, use resources more efficiently, and reduce adverse impacts of energy supply and use.

2.5 President's Committee of Advisors on Science and Technology

The Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology (PCAST) notes in its 1997 report, "Federal Energy Research and Development for the Challenges of the Twenty-First Century," that fossil fuels will remain the principal energy sources well into the middle of the next century. The panel report states that DOE/industry–supported R&D yields technology that can lead to continued affordable use of fossil fuels, even in a greenhouse–constrained society, moderation of oil imports, and reduced cost to the economy of future oil price shocks. The panel suggests that gas, the transition fuel leading to a renewable energy future, will be a significant strategic energy source for moderating carbon emissions well into the middle of the next century. Gas may have an expanded transition role as a transportation fuel itself or as a competitive source of liquid transportation fuel (gas-to-liquids) and ultimately the least-cost source of hydrogen for transportation, if fuel cells become the power source of choice for advanced, ultra efficient vehicles.

The panel recommends R&D to continue to develop technologies that will expand domestic reserves and reduce the cost of production: "It may be that gas can be produced economically from the methane hydrates on the continental shelf, and this may prove to be a very large new source globally, particularly for some developing countries such as India as well as for the United States."

The panel further recommends that DOE's Office of Fossil Energy (FE) develop a science-based program with industry and other government agencies to understand the potential of methane hydrates worldwide. Research should be conducted on fundamental thermodynamic and kinetic properties, the safety and environmental impact of production schemes, the economics of production and the potential disposal of CO_2 emissions as hydrates in the same vicinity where the methane is produced. DOE research should also contribute to understanding the possibility that climate change can produce hydrate dissociation, which could cause releases of large quantities of methane to the atmosphere.

PCAST suggested that $44 million be allocated for methane hydrates R&D by DOE/FE. The Panel noted that this funding level is not meant to be prescriptive, observing that actual budgets would evolve to more or less than the target suggestion. The panel also noted that any FE initiative should be leveraged by the private sector, other government agencies, and the international community, making the actual spending significantly larger.

2.6 Methane Hydrate Research and Development Act of 1998, S.1418

Senate Bill S.1418, passed by the Senate on July 17, 1998, and referred to the House of Representatives, would authorize work by DOE/FE in consultation with the USGS, National Science Foundation (NSF), and Naval Research Laboratory (NRL), to conduct methane hydrates research for the identification, assessment, exploration, and development of methane hydrate resources. This program plan is consistent with the proposed authorization.

3. RESEARCH HISTORY

Gas hydrates have been studied for over 100 years. In the 1930s, hydrates were recognized as a production problem for conventional hydrocarbon activities when they were found plugging natural gas pipelines. The U.S. Bureau of Mines published the first definitive study of hydrates in 1946. In 1964, natural gas hydrates were discovered in Siberia and during the 1970s gas derived from hydrates may have been produced in a Siberian gas field, Messoyakha. In the 1970s, they were found by the Deep Sea Drilling Project in ocean sediments and associated with Bottom Simulating Reflectors (BSR), unique seismic reflection patterns caused by the velocity contrast created by free gas trapped below hydrate-bearing sediments. In the 1980s, U.S. studies progressed on several fronts: laboratory studies of physical and chemical properties and the mechanisms of formation and dissociation of hydrates, and studies of the geological, geophysical, and geochemical characteristics of marine and Arctic hydrate formations. A 10-year program, established in 1982, at DOE's Morgantown Energy Technology Center (now the Federal Energy Technology Center, FETC) supported much of this work. DOE-supported studies were instrumental in developing a foundation of basic knowledge about the location and thermodynamic properties of gas hydrates. The DOE-supported program:

- Established the existence of hydrates in Kuparuk Field, Alaska;
- Completed studies of 15 offshore hydrate basins;
- Developed production models for depressurization and thermal production of gas from hydrates;
- Developed preliminary estimates of gas in-place for gas hydrate deposits; and
- Built the Gas Hydrate and Sediment Test Lab Instrument (GHASTLI).

In 1992, the 10-year, eight million dollar program was terminated as government policy shifted from long-term, high-risk R&D to near-term exploration and production R&D. Although DOE funding ceased, work has continued at USGS, NRL, NSF, ODP, universities, other laboratories, and overseas. The 1995 studies of the Blake Ridge, as part of the ODP Leg 164, contributed significantly to our understanding of hydrates. Appendix 2 provides a summary of research activities by state.

Since 1994, FETC has conducted research on CO_2 sequestration, including application of CO_2 hydrates for deep-ocean sequestration. CO_2 hydrates studies will benefit methane hydrates work especially in increased understanding of the thermodynamics and mechanisms of formation and dissociation of hydrates. In addition, research is being conducted in Japan and the U.S. to develop novel combined methane production and CO_2 sequestration techniques that involve displacement of methane from hydrates by CO_2.

DOE's Natural Gas Supply Program provided a small amount of funding in Fiscal Year (FY) 1997 and FY 1998 to support activities in anticipation of program initiation in FY 1999. These include: (1) participation in the production testing and sample analysis of a 1,200-meter deep well in the Mackenzie Delta, Canada, drilled by Japan National Oil Company (JNOC); (2) processing and evaluating seismic data in hydrates regions of the Gulf of Mexico; (3) design of a global database of gas hydrates and related gas deposits; and (4) participation in an industry/university gas hydrates consortium.

4. PROGRAM GOALS AND BENEFITS

The overall objective of the methane hydrates R&D program is to maximize the potential contribution of the huge methane hydrate resources to reliable supplies of a cleaner fuel with reduced impacts on global climate, while mitigating potential hydrates risks for marine safety and seafloor stability. This will be achieved through a four-pronged approach that will answer the questions:

How Much?

Determine the location, sedimentary relationships, and physical characteristics of methane hydrate resources to assess their potential as a domestic and global fuel resource.

How to Produce It?

Develop the knowledge and technology necessary for commercial production of methane from oceanic and permafrost hydrate systems by 2015.

How to Assess Impact?

Develop an understanding of the dynamics and distribution of oceanic and permafrost methane hydrate systems sufficient to quantify their role in the global carbon cycle and climate change.

How to Ensure Safety?

Develop an understanding of hydrates systems in near-seafloor sediments and sedimentary processes, including sediment mass movement and methane release so that safe, standardized procedures for hydrocarbon production and ocean engineering can be assured.

4.1 Near-Term Benefits

Although the major program benefits will be realized 10 to 15 years from the start of the effort, there will be numerous early benefits, for example:

- Understanding of potential hazards of overlying hydrate deposits to conventional production and their mitigation may increase areas of the Gulf of Mexico available to conventional production;
- Techniques to mitigate methane hydrates formation in pipelines and production facilities in the Arctic and offshore;
- Assessments of the location and volume of methane hydrate resources for energy policy decisions;
- Improved seismic and other geophysical tools for use by the petroleum industry, military, and others;
- Improved data on ocean and atmospheric changes for use in global climate modeling;
- Basic thermodynamic data applicable to CO_2 sequestration; and

- Pressure/temperature controlled biologic sampling device for low temperature, high pressure environments could be a prototype for National Aeronautics and Space Administration (NASA) biologic samplers for more extreme environments on the planet Mars.

4.2 Long-Term Benefits

The major long-term benefit will be an increased supply of cleaner fuel through development of a suite of technologies necessary for commercial production of methane from Arctic and marine hydrates. Other long-term benefits will be improved global models of climate change, and detection and mitigation technologies to assure safe hydrocarbon production and ocean engineering in areas underlain by hydrates. Increasingly, refined assessments of U.S. and global hydrate resources will continue to assist energy planners in government and industry. Moreover, this program will help to develop the next generation of scientists and engineers to help assure the Nation's technology leadership.

4.3 Technology Transfer

Technology transfer will be aggressively pursued by government program managers. In addition, grantees will be expected to communicate their results in publications and technical meetings. This technology transfer will stimulate research and serve to monitor its quality.

Active involvement of the industry in all levels of the program, from the program design to joint R&D projects with universities and National Laboratories, will assure the rapid adoption of new concepts and technologies. Scientific and technical exchange will also be fostered through periodic conferences and publication of project results in scientific and technical journals.

5. R&D TO ANSWER TECHNICAL ISSUES

The following "Technology Roadmap" (Figure 3) illustrates in a simplified manner how technology is expected to proceed from the current state-of-the-art to the technological level necessary to achieve the program goals in Resource Characterization, Production, Global Carbon Cycle, and Safety and Seafloor Stability. This roadmap is expected to change as the program proceeds; the early results will determine research directions and activities later in the program.

Although the program is framed as four technology areas, much of the work is interrelated. The four research areas will share data, theoretical concepts, and results. Furthermore, the activities within each technology area will not occur separately or sequentially; data collection, laboratory experiments, modeling, and field validation will proceed in parallel. For example, field and laboratory generated data will provide the basis for computer models and in turn models will be validated using field and laboratory samples.

The program will also have a regional focus, which will leverage existing data and petroleum infrastructure to reduce costs and accelerate R&D. Onshore Arctic Alaska will be the initial target for well logging and production tests; onshore operations and existing industry infrastructure will provide lower cost and reduced risk. The second focus area will be offshore Gulf of Mexico, where

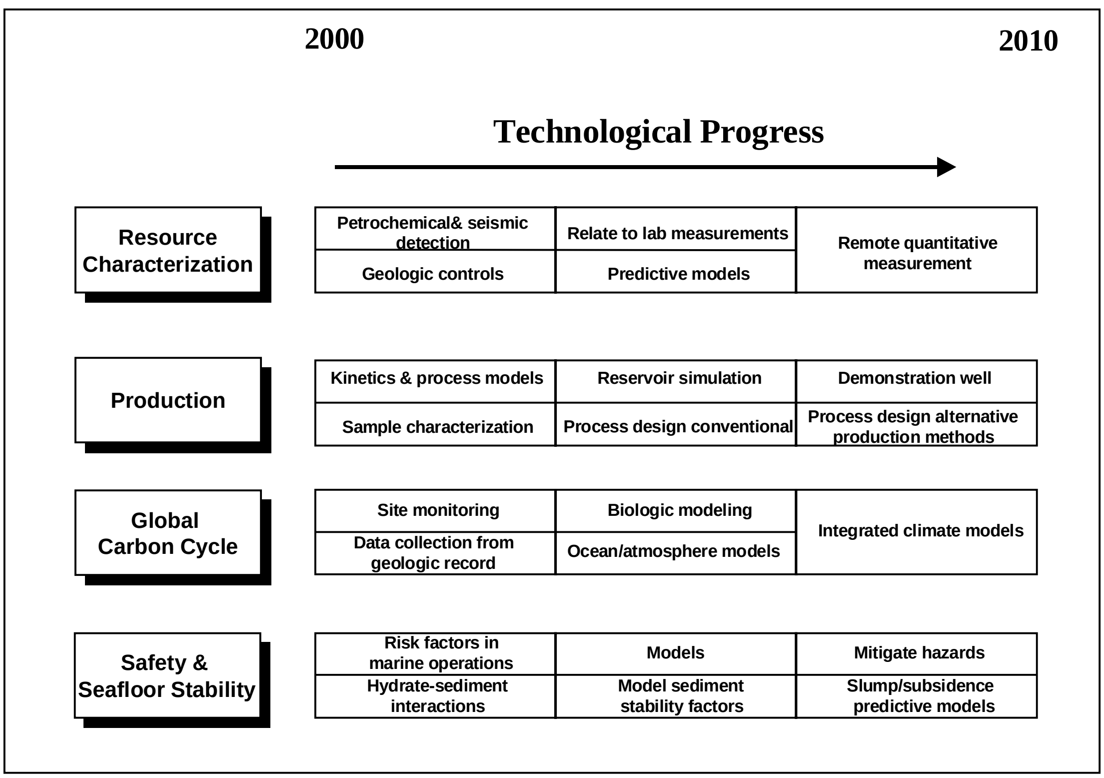

Figure 3. Methane Hydrate Technology Roadmap

recently initiated conventional operations in hydrate-bearing areas stimulate interest in hydrates risk analysis and mitigation technologies. The proximity of hydrates to production and transportation infrastructure improves the potential economics of methane production, attracting industry interest. The areas are also targeted because of the volume of existing seismic and well log data. Global carbon cycle and seafloor stability R&D will be focused on areas offshore of the east and west coasts of the U.S., building on prior studies and regional oceanographic expertise.

Figure 4 shows the relative level of effort in the four technology areas and the changes expected in technical emphasis as the program progresses. Initial work will primarily be focused on Resource Characterization to build the basic understanding necessary in all program areas. Production funding will increase as R&D moves from laboratory and modeling to field tests. Global Carbon Cycle and Safety and Seafloor stability area will receive generally steady funding commitment, reflecting both near-term and long-term research needs.

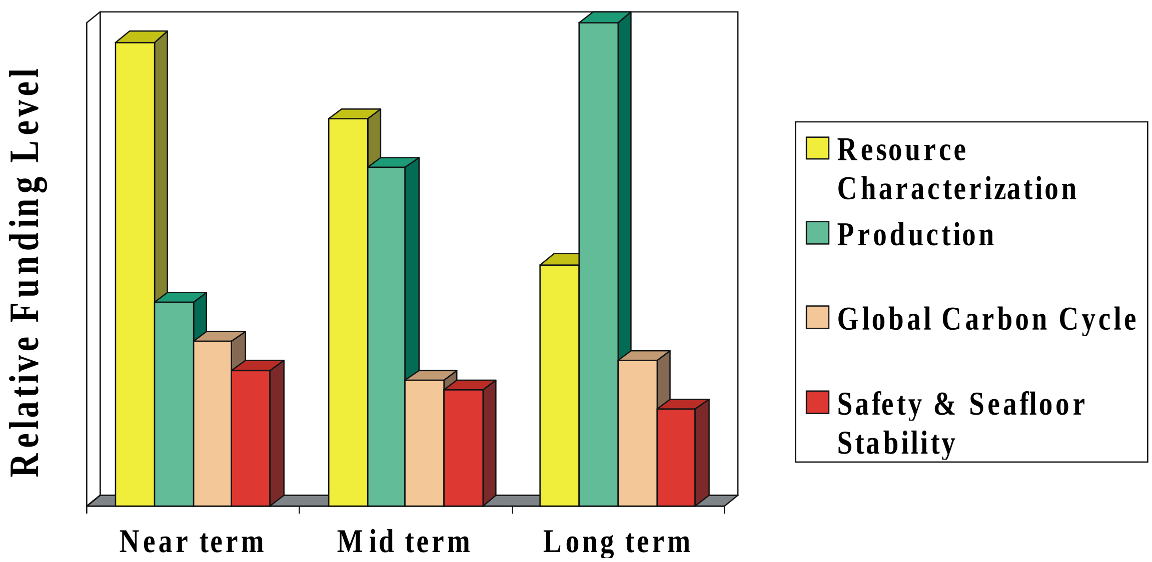

Figure 4. Research and Demonstration Funding Evolution

Research needs and activities necessary to achieve the program goals are described in more detail in the following sections.

5.1 Resource Characterization

5.1.1 ***Goal:*** Determine the location and sedimentary relationships of methane hydrate resources to assess their potential as a domestic and global fuel resource. Specifically, the program should:

- Provide accurate resource estimates necessary for energy planners and policy managers;
- Locate and quantify potentially producible deposits and dispersed deposits that may affect global climate change and define their physical-chemical properties; and
- Provide a foundation of basic information for other R&D areas.

5.1.2 *Research Needs*

The huge range in estimates of hydrates volume points out the lack of understanding of the location, volume, physical character, and methane flux of hydrate deposits in the U.S. and the world.

Seismic, well logging, and other geophysical technologies tailored to shallow methane hydrate deposits are needed to locate and quantify the gas content of methane hydrate deposits. Although BSRs have been identified in many marine and Arctic areas around the world, the volumes of hydrates and underlying free gas associated with BSRs are poorly known. The presence of hydrates in the absence of BSRs is also not well defined.

An unknown amount of the global gas hydrates inventory may be technically and economically recoverable. For hydrates to be an exploitable resource, localized concentrations must exist; locating these areas requires improved understanding of methane migration and trapping. Free gas trapped below hydrates may be a resource. However, little is known about the gas saturation, thickness, and areal extent of such deposits.

There is a need for basic core, seismic, well logs, geochemical, and microbiological data from marine, Arctic, concentrated, and dispersed deposits. Hydrate-sediment interactions based on laboratory and field studies are not well defined, especially the relationships between hydrates physical and chemical characteristics and geophysical measurements, seismic, well logs, and oceanic and sediment chemistry. Incorporation of methane hydrate dynamics into global climate change modeling has not been performed.

Quantifying hydrate reservoirs, in both concentrated deposits, the primary subject of research to date, and dispersed deposits is required. New collection, measurement, and monitoring technologies are required to support the needed research, including, for example: deep-towed seismic arrays, ocean–bottom seismic sensors, pressure coring devices, and borehole geophysical, measurement, and sampling devices.

5.1.3 *Program Activities*

1. Resource assessment:
    a. Develop databases of the location of dispersed and concentrated (potential production) sites, seismic data, well test data, hydrates-related slumps and slides, and physical properties, as well as for international R&D tracking
    b. Develop and apply seismic and other geophysical imaging including deep-towed arrays, ocean bottom seismic sensors, acquisition and processing techniques applicable specifically to hydrates, and side scan sonar
    c. Collect marine and Arctic measurements and samples using pressure/temperature cores and monitoring technology
    d. Conduct shallow detection studies, including well logging sample collection and geothermal and geochemical measurements
    e. Multi-disciplinary integration of geologic, geophysical, and geochemical data

2. Quantify the resource and define geologic, chemical, physical, and biologic controls on hydrates location and formation/dissociation:

   a. Structure and stratigraphy

   b. Gas source

   c. Flux — hydrology, traps, and microbial systems

   d. Rock properties — porosity, permeability, shear modulus, and correlation with well logs

   e. Hydrate properties in-situ — pressure, temperature, concentration, sediment properties, and gas/sediment properties below the hydrates stability zone

3. Define and model physical and chemical properties:

   a. Laboratory studies

      i Develop a reproducible laboratory replicates of naturally-occurring hydrates

      ii Thermodynamics, kinetics, and crystallography

      iii Geochemistry

      iv Microbial processes involved in hydrates formation and dissociation, and the fate of released methane

      v Acoustic and physical properties correlation

      vi CO_2 hydrates study results integration

   b. Predictive modeling

      i Hydrates equilibrium

      ii Methane flux

4. Field validation — monitoring and ongoing testing of research results

5. Technology development — develop and adapt seismic, sonar, and well logging technology for imaging and measuring hydrates; develop pressure/temperature controlled coring; develop sensors and samplers for monitoring subsea hydrates and methane release; and, construct a laboratory with high pressure, low temperature cells to produce and study hydrates formation and dissociation. These technologies will be made available to industry and to the research community.

5.2 Production

5.2.1 ***Goal:*** Develop the knowledge and technology necessary for commercial production of methane from oceanic and permafrost hydrate systems by 2015. Specifically, the program will:

- Develop a foundation of basic scientific information necessary for production;
- Conduct reservoir and process engineering and economic analysis;
- Develop and test conventional recovery technologies; and
- Evaluate alternative recovery technologies.

5.2.2 *Research Needs*

Study of the Blake Ridge, offshore of the Carolinas, showed substantial amounts of hydrates but at low concentrations, representing only about two percent of bulk volume. More concentrated deposits need to be located and characterized.

There is one disputed instance of commercial gas production with replenishment from hydrates, in Messoyakha field, Siberia, during the 1970s. However, the hydrates contribution to methane production is unclear, based on recent studies.

Hydrates production is possible using depressurization, thermal stimulation, and solvent injection. However, much work remains to document and field test these techniques for commercial–scale production.

Industry experience in Arctic production and worldwide transportation of conventional hydrocarbons has provided information on hydrates formation and inhibition that can be adapted to this program.

5.2.3 *Program Activities*

1. Basic studies for production:
   a. Characterization of field samples, laboratory replication, and determining fundamental kinetics, heat and mass transfer parameters
   b. Physical process and economic models
   c. Well data evaluation
2. Reservoir engineering:
   a. Site identification
   b. Reservoir modeling
   c. Conventional/advanced drilling technologies evaluation and modification
   d. Economic analysis
   e. Process design
3. Conventional technologies:
   a. Well tests of increasing complexity

   b. Pilot plant validation of technologies
   c. Proof-of-concept well test
   d. Economic and process evaluation of test well

4. Evaluate alternative production technologies:
   a. Develop down-hole instrumentation
   b. Evaluate applicable technologies from mining and coalbed methane industries
   c. Evaluate chemical and gas stimulation techniques

5.3 Global Carbon Cycle

5.3.1 ***Goal:*** Develop an understanding of the dynamics of oceanic and permafrost methane hydrate systems sufficient to quantify their role in the global carbon cycle, climate change, sediment mass movement, and methane release.

5.3.2 *Research Needs*

Historically, methane hydrates research has emphasized concentrated deposits. However, dispersed occurrences exposed at the seafloor may also play a major role in methane release. These deposits may be the most immediately susceptible to change during global warming. Furthermore, landslides and seafloor collapse can abruptly release large volumes of methane that is trapped below the gas hydrate zone.

Little is currently known about the processes or volumes involved in global perturbations from gas hydrates decomposition on the seafloor. The stability of gas hydrates during global warming and the environmental consequences of a significant methane release are poorly understood.

The locations at which gas hydrates exist at the sediment surface is known at only a few locations. Furthermore, which of these exposures is susceptible to contemporary change is unknown. In spite of a few documented sites, the process of seafloor hydrate decomposition is poorly known.

The fate of methane in seawater has not been quantified. Seawater in contact with the atmosphere contains an equilibrium amount of methane. Much lower methane levels, however, are recorded in deep oceanic waters due to microbial oxidation. Most attempts to model the early geologic history of atmospheric methane do not yet incorporate gas hydrates.

5.3.3 *Program Activities*

1. Identify mechanisms and processes of hydrates flux on the seafloor:
   a. Site monitoring, including development of new measurement tools and protocols
   b. Determining impact of global warming on hydrates dissociation
   c. Identifying processes that cause seafloor mass movement and release of methane trapped below the gas hydrate zone

2. Evaluate and model consequences of methane release from hydrates:
   a. Ocean/atmosphere studies

   b. Biological studies

3. Determine methane release in the geologic record:

   a. Compilation of existing data and seek evidence using new methane proxies

   b. Applying data to climate and ocean models

4. Integrate modern and geologic data into climate models

5.4 Safety and Seafloor Stability

5.4.1 ***Goal:*** Develop an understanding of the hydrates system in near-seafloor sediments and sedimentary processes, including sediment mass movement and methane release, so that safe, standardized procedures for hydrocarbon production and ocean engineering can be established.

5.4.2 *Research Needs*

Arctic and marine hydrates are known to cause problems during drilling and production of conventional hydrocarbons. Difficulties include gas release during drilling, blowouts, casing collapse, and well-site subsidence. These problems are generally the result of dissociation of gas hydrates caused by the heat of circulating drilling fluids or flow of warm production fluids. Pipelines carrying warm fluids may suffer loss of support due to underlying hydrates. Research is needed to accurately document drilling and production problems caused by gas hydrates and to develop techniques to avoid or mitigate hazards. Correlation of hazard evidence with gas hydrates occurrence and a determination of the quantities of hydrates that constitute a hazard are also required.

Long term impacts on seafloor stability and safety due to methane production from hydrates must also be investigated. It is not known if hydrates production will cause subsidence.

Natural seafloor collapse, apparently caused by gas hydrate processes with subsequent mass movements (e.g., slides, faults), is likely to release methane to the ocean/atmosphere system and may threaten seafloor structures. Although there is circumstantial evidence implicating gas hydrates in triggering seafloor landslides, the historical record of mass movements has not been mapped and the mechanisms are unknown. Although free gas below hydrates is inferred from seismic data, it has not been determined whether hydrate deposits can seal high-pressure gas accumulations and influence seafloor stability.

5.4.3 *Program Activities*

1. Assess safety in conventional hydrocarbon production and transportation:

   a. Determine risk factors

   b. Develop models and predictive tools

   c. Develop mitigation techniques

2. Investigate the potential for seafloor subsidence from hydrates production:

   a. Integrate sediment/rock property and production models

   b. Develop subsidence mitigation technologies

3. Investigate seafloor stability:

   a. Model gas pressure/volumes below hydrates stability zone

   b. Determine faulting and fracturing of hydrate seals

   c. Study processes of seafloor mass movement caused by gas hydrate

6. PROGRAM MANAGEMENT

To accomplish the necessary R&D activities and achieve the program goals, a diverse set of engineering and scientific disciplines is required. Figure 5 below illustrates many of the disciplines necessary for a complex integrated program, and highlights the fact that each of these disciplines will contribute to more than one program goal.

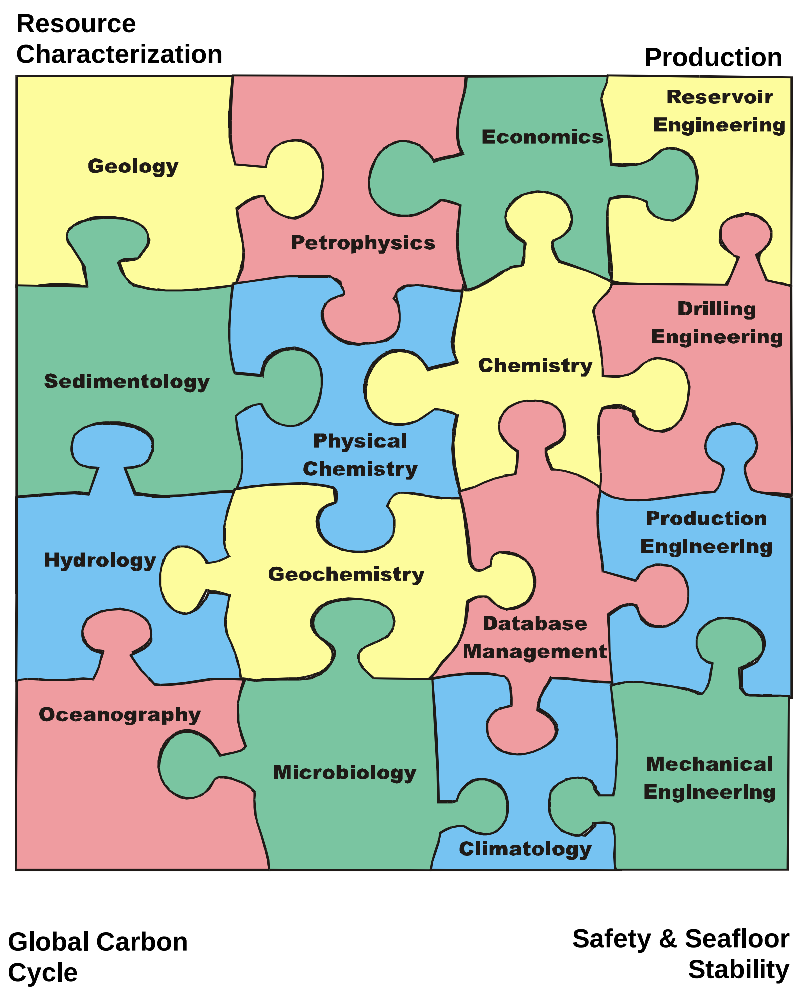

Figure 5. Disciplines, Skills, and Capabilities Required by a Methane Hydrates Program

Significantly, no single organization or agency can provide this spectrum of capabilities. To effectively address this technological complexity, the methane hydrates program will marshal the resources of the petroleum industry, academia, National Laboratories, and a broad base of government programs with concurrent interests in methane hydrates research. Figure 6 shows the planned program management structure.

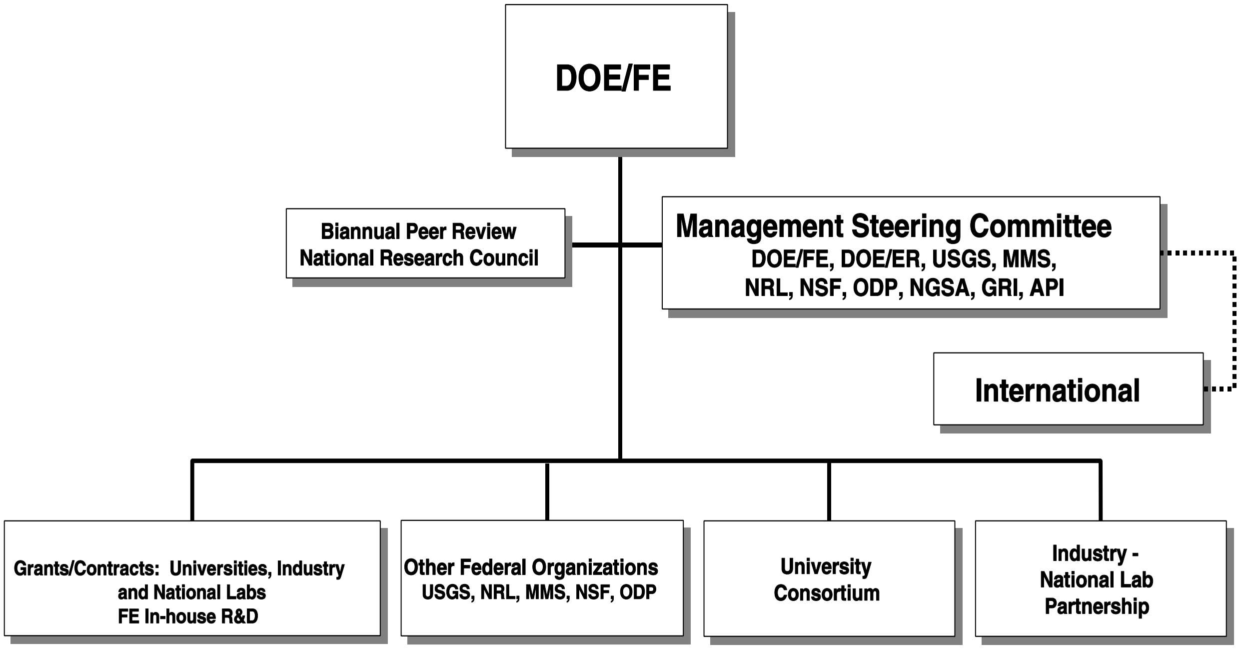

Figure 6. Management Structure of the Methane Hydrates Program

6.1 DOE/Fossil Energy

As shown in the organization chart, DOE/FE will have the primary responsibility for program management. DOE/FE will develop and manage the program in consultation with USGS, NRL, NSF, and the Management Steering Committee.

6.2 Management Steering Committee

This Committee comprises government and private organizations that finance methane hydrates research and/or will use the products of the program:

- DOE/FE, USGS, NSF, NRL, and MMS will be conducting R&D using program and internal funds.
- Industry will have multiple roles in the program: financing and participating in R&D, and testing and implementing research results and new technology. Industry will be represented on the Management Steering Committee by three organizations: Gas Research Institute (GRI), American Petroleum Institute (API), and Natural Gas Supply Association (NGSA).
- NSF and DOE's Office of Energy Research (ER) will participate in the Management Steering Committee. Because these programs fund basic research in geoscience, oceanography, climatology, and microbiology that is applicable to methane hydrates, participation in the Committee will strengthen communication and coordination between basic and applied research related to methane hydrates.

- ODP, which is funded through NSF and a 17-nation international partnership, will be a major source of ocean drilling and sampling of hydrates.

The Management Steering Committee will:

- Define program goals and responsibilities;
- Monitor R&D progress;
- Ensure that work under the methane hydrates program will complement other work conducted by Federal, state and commercial organizations;
- Maintain a dialogue with private sector organizations;
- Periodically review program direction, program accomplishments and the relationship of the program to natural gas market conditions;
- Assure that funding from multiple agencies will not be redundant and will be consistent with each program's mission; and
- Coordinate with International groups conducting hydrates R&D.

The proposed "Methane Hydrate Research and Development Act of 1998," S.1418, would require the Secretaries of Energy, the Interior, and Defense, and the Director of the NSF or their designees to meet quarterly to review the program progress and make recommendations on future activities. If this legislation is adopted, the Management Steering Committee may provide the mechanism for interagency consultation.

6.3 International Cooperation

Japan, India, Canada, United Kingdom, Germany, Brazil, Norway, and Russia currently have active methane hydrates R&D programs. DOE and the Management Steering Committee will explore opportunities to leverage the program effort through cooperative work with these countries. These will probably take the form of Memorandum of Understanding (MOU) between government agencies of the two countries. The Department of Natural Resources of Canada and DOE already have a MOU for cooperation in energy research and development that would allow methane hydrates cooperation. In addition, other Federal agencies and National Laboratories are expected to support join international efforts.

Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES), a 17-nation international partnership that supports ODP, will enhance international scientific cooperation.

Japan is expected to spend about $90 million over five years on methane hydrates production research to meet energy security goals. As part of the Japanese effort, Japan National Oil Company drilled a gas hydrates well in the Mackenzie Delta, Canada, in February-March 1998. DOE and USGS researchers participated in experiments at the well and are currently studying samples collected there.

India has earmarked $56 million for a multi-year gas hydrates program to collect and interpret new seismic data and develop new production technologies. India, through the Gas Authority of India, Ltd. (GAIL) and the Indian Institute of Technology, has also initiated a program to offer offshore leases for methane production from hydrates. Indian officials have expressed their intention to fund gas hydrates work by NRL, USGS, DOE National Laboratories, and other U.S. scientists.

6.4 Peer Review

Biannual peer review will be implemented in order to assure that R&D projects represent high quality science, are cost effective, and achieve intended objectives. A biannual independent peer review process will be conducted through the National Research Council (NRC). For its review, the NRC is expected to draw on the expertise of the academic, government, and industry research community as well as several of its scientific boards, including Energy and Environmental Systems, Ocean Studies, Earth Sciences and Resources, and Marine Boards.

6.5 Implementing Organizations

6.5.1 *Federal Energy Technology Center (FETC)*

Consistent with existing FE management structure and procedures, FETC will have the primary responsibility for developing implementation plans, monitoring project performance, and tracking program milestones for funds appropriated to DOE/FE.

FETC will also fund critical elements of the program that are not appropriate to the other implementing organizations, for example: National Laboratories and universities to conduct basic scientific studies such as geochemistry, microbiology, or global change; and, ODP support for shipboard laboratory modifications or funding for a dedicated hydrates cruise.

FETC staff will conduct small amounts of in-house R&D for physical/chemical resource characterization and basic production studies.

6.5.2 *Other Federal Organizations*

Federal agencies and organizations, including the USGS, NRL, and MMS, will receive program funds through interagency transfer from DOE/FE to conduct aspects of the R&D program. The Department of the Interior and Naval Research Laboratory are also expected to fund program activities. Other government agencies, such as the Cold Regions Research and Engineering Laboratory (CRREL), the National Oceanic and Atmospheric Administration (NOAA), and NASA, who conduct R&D that is related to hydrates, may become involved in the program.

The Navy's historic interest in marine methane hydrates has focused on the impact of hydrate deposits on sonar propagation, the potential impact on seafloor mounted instrumentation and engineering artifacts, and the potential of hydrates as a fuel. NRL is expected to conduct resource characterization and seafloor stability R&D. The Navy may make available information of the location and acoustic/geophysical properties of hydrates to other researchers.

The Energy Resources Program of the USGS has historically conducted geological and geophysical assessments of global and U.S. hydrate resources and characterization of Arctic hydrate deposits, while the Coastal and Marine Geology Program has focused on hydrates distribution, processes of concentration, geochemistry, and relationships to seafloor stability. These two groups are expected to continue research in these areas using internal and DOE funding.

MMS has historically funded hydrates research regarding safety and flow assurance associated with conventional hydrocarbon operations. In the future, MMS expects to expand its research to include resource assessments needed for future lease tract evaluation, as hydrates production becomes a reality in Federal waters.

6.5.3 *University Consortium*

A university-affiliated foundation or institute will be chosen to coordinate academic hydrates R&D and administer the consortium. This organization will also manage and disseminate data, organize seminars, and facilitate communication between research affiliates, industry members, and other parts of the hydrates program. The consortium will include industry members, who will pay an annual fee, and qualified academic institutions. An Industry Review Board, with the assistance of a Science Advisory Board, will prioritize research needs, issue requests for proposals, and rank proposals for DOE selection.

6.5.4 *Natural Gas and Oil Technology Partnership*

The partnership is an industry-driven program that aims through collaborative projects to develop advanced technologies, including advanced computation, for improved natural gas and oil recovery. The partnership was formed in 1988 and has since expanded to include 125 companies, 16 universities, and all nine multi-purpose National Laboratories, in four technology forums: Oil and Gas Recovery; Diagnostics and Imaging; Drilling, Completion, and Stimulation; and Environment.

Hydrates R&D projects jointly proposed by industry and one or more National Laboratories will be reviewed and ranked by industry within one of the four existing technology areas. DOE/FE will select projects to be funded.

6.6 Industry Involvement

Until recently, industry research has focused on preventing hydrates formation in wellbores and pipelines. The 1995 National Petroleum Council study of "RD&D Needs of the Oil and Gas Industry," lists hydrates deepwater prevention as one of 35 high priority research needs. The recommendation for Federal R&D is based on a combination of expected large impact on industry operations and the low probability that the technology will be made available commercially.

Industry has generally considered methane production from hydrates as too improbable to justify active research. However, recent research progress, combined with production and transportation facilities in the deep Gulf of Mexico in areas containing hydrates, have caused industry to reconsider hydrates for gas supply. Details regarding the companies involved and the number of ongoing or planned projects are unknown at this time.

Industry will be represented on the Management Steering Committee by three organizations: the Natural Gas Supply Association, representing integrated and independent companies that produce and market domestic natural gas; American Petroleum Institute (API), the major petroleum trade association; and the Gas Research Institute (GRI), the research, development, and commercialization organization of the natural gas industry.

6.7 Government Performance and Results Act of 1993

DOE will assure that the program is managed and its results monitored in conformance with the requirements of the Government Performance and Results Act of 1993 (GPRA). The purpose of this Act is to reduce waste and inefficiency and increase customer satisfaction in Federal programs. The GPRA calls for development of five-year strategic plans: a comprehensive mission statement linked to ongoing operations, general goals and objectives and how they will be achieved, a description of key external factors that could affect achievement of these goals, and annual program evaluations to be used in establishing or revising goals and objectives.

6.8 Stakeholder Input

Stakeholder input into this plan has come primarily from two DOE-sponsored workshops. The first workshop on "The Future of Methane Hydrates Research and Resource Development" was held in Denver, Colorado, on January 21-22, 1998. Over 100 senior scientists and managers from industry, academia, National Laboratories, government agencies, and international organizations attended the meeting. The objective of this meeting was to gather expert opinions on research needs and priorities as a preliminary step to developing a program plan.

The second workshop, conducted on May 12, 1998, in Washington, DC, reviewed the draft program plan and discussed organizational and budget issues.

An Internet site dedicated to methane hydrates R&D will be developed by DOE together with the NGSA and the International Centre for Gas Technology Information. It will be used to obtain stakeholder input as well as enhance communication among the diverse community of hydrates researchers and technology users.

Stakeholder input will continue throughout the program through peer review of research proposals and program accomplishments. Presentation of research results will occur regularly at DOE–sponsored meetings and meetings of technical associations such as American Geophysical Union, American Association of Petroleum Geologists, and Society of Petroleum Engineers.

7. BUDGET

PCAST suggested that $44 million be allocated over five years by DOE/FE on methane hydrates R&D, while noting that this funding level was strictly a suggestion and not meant to be prescriptive. Actual program budgets will be derived from detailed implementation plans developed subsequent to this document. As the program proceeds, out-year budgets will evolve, based on early research results.

7.1 Cost Sharing

In addition to DOE/FE funding, the program will be supported by a variety of cost sharing mechanisms:

- Industry is expected to expand its support of university and National Laboratory research and loan wellbores and other facilities for sample collection, monitoring, or production testing. The proportion of industry cost sharing will increase as technology development approaches commercialization.
- Seismic and other subsea data originally acquired for oil and gas prospecting may be made available for reinterpretation of shallow horizons of interest for hydrates. Additionally, shallow seismic data may be collected during seismic surveys for deep targets.
- Other Federal agencies, including USGS, MMS, and NRL, are expected to continue to fund work by their agencies that contributes to this program's objectives.
- Organizations such as NSF and DOE/ER should continue to support basic research such as seismic, well logging, oceanography, and marine geology applicable to, but not directly focused on, methane hydrates.
- Universities and oceanographic institutions are expected to contribute faculty salaries and overhead expenses to program work.

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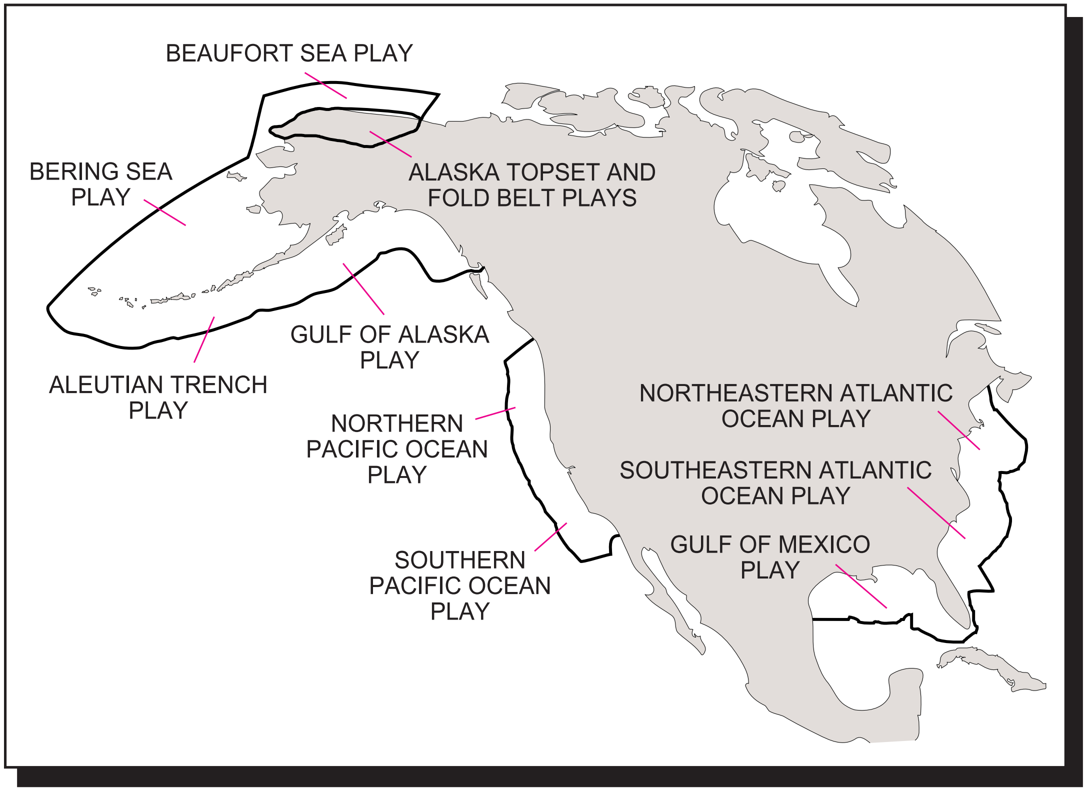
ACRONYMS AND ABBREVIATIONS

API	American Petroleum Institute
BSR	Bottom Simulating Reflector
CNES	Comprehensive National Energy Strategy
CO_2	Carbon Dioxide
CRREL	Cold Regions Research and Engineering Laboratory
DOE	Department of Energy
EIA	Energy Information Administration
ER	DOE Office of Energy Research
FE	DOE Office of Fossil Energy
FETC	DOE Federal Energy Technology Center
FY	Fiscal Year
GAIL	Gas Authority of India, Ltd.
GHASTLI	Gas Hydrate and Sediment Test Lab Instrument
GPRA	Government Performance and Results Act of 1993
GRI	Gas Research Institute
JNOC	Japan National Oil Company
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
MMS	Minerals Management Service
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NGSA	Natural Gas Supply Association
NOAA	National Oceanic and Atmospheric Administration
NPC	National Petroleum Council
NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
ODP	Ocean Drilling Program
OCS	Outer Continental Shelf
PCAST	President's Committee of Advisors on Science and Technology
R&D	Research and Development
S.1418	The Methane Hydrate Research and Development Act of 1998
TCF	Trillion Cubic Feet
USGS	United States Geological Survey

APPENDIX 1

USGS RESOURCE ESTIMATES

USGS Estimates of the United States In-Place Gas Resources Within Gas Hydrates



Plays	Mean Estimates (Trillion cubic feet, Tcf)	Percentage of Total U.S. Resource
Atlantic Ocean Province	**51,831**	**16.1**
– Northeastern Atlantic Ocean Play	30,251	9.4
– Southeastern Atlantic Ocean Play	21,580	6.7
Gulf of Mexico Province	**38,251**	**12.0**
– Gulf of Mexico Play	38,251	12.0
Pacific Ocean Province	**61,071**	**19.1**
– Northern Pacific Play	53,721	16.8
– Southern Pacific Play	7,350	2.3
Alaska Offshore Province	**168,449**	**52.6**
– Beaufort Sea Play	32,304	10.0
– Bering Sea Play	73,289	23.0
– Aleutian Trench Play	21,496	6.6
– Gulf of Alaska Play	41,360	13.0
OFFSHORE PROVINCES TOTAL	**319,602**	**99.8**
Alaska Onshore Province	**590**	**0.20**
– Topset Play–State Lands & Waters	105	0.034
– Topset Play–Federal Waters	43	0.013
– Fold Belt Play–State Lands & Waters	414	0.13
– Fold Belt Play–Federal Waters	28	0.011
ONSHORE PROVINCES TOTAL	**590**	**0.20**
UNITED STATES TOTAL	**320,192**	**100**

APPENDIX 2

STATE R&D SUMMARIES

Alaska: Methane Hydrate Research

Recent Projects

<u>Organization</u>: North Slope Borough, Barrow, Alaska; U.S. Department of Energy

Activity Summary: Researchers evaluated methane hydrate potential of the Walakpa gas field, a shallow gas field located near Barrow, Alaska, by analyzing reservoir geology and production test data.

Contact: Richard K. Glenn, Phone: (907) 852-0395

<u>Organization</u>: South Dakota School of Mines & Technology, Department of Geological Engineering, Rapid City, South Dakota

Activity Summary: Researchers investigated the feasibility of utilizing electromagnetic heating for disassociating solid gas hydrates trapped under high reservoir pressure and permafrost conditions.

Contact: M.R. Islam, Phone: (605) 394-2461

<u>Organization</u>: U.S. Geological Survey, Denver, Colorado

Activity Summary: Assessed the geologic parameters responsible for controlling the occurrence of gas hydrates (e.g., formation temperature, pore pressure, gas chemistry, pore water salinity, availability of gas and water, and the presence of reservoir rocks and seals) and estimated the U.S. gas hydrate accumulations in the onshore and offshore regions of the U.S., including permafrost-associated deposits of the Northern Hemisphere.

Contact: Timothy Collett, Phone: (303) 236-5731, e-mail: tcollet@usgs.gov

<u>Organization</u>: U.S. Geological Survey, Menlo Park, California

Activity Summary: USGS examined the geologic characteristics of the Eocene Formation of the Bering Sea Basin linked to regional-scale tectonism of Alaska, and assessed potential implications for energy gas resources and the accumulations of massive hydrate deposits.

Contact: David W. Scholl, Phone: (650) 329-4762; Patrick E. Hart, Phone: (650) 329-5160

<u>Organization</u>: University of Alaska, Fairbanks, Alaska

Activity Summary: Researchers investigated the effects of inhibitors on hydrate decomposition rate, and characterized gas hydrate resources on the North Slope of Alaska, including measurement and modeling of gas hydrate phase equilibrium and determination of zones of hydrate stability.

Contact: Vidyadhar Kamath, Phone: (907) 474-7748, e-mail: ffvak@aurora.alaska.edu

<u>Organization</u>: Westport Technology Center, Houston, Texas

Activity Summary: This project identified drilling hazards associated with gas hydrates production in the Cascade Field, a small field located on the southeastern edge of the Milne Point Unit in Alaska.

Contact: M. Yousif, Phone: (713) 245-7685, e-mail: mhyousif@shellus.com

California: Methane Hydrate Research

Recent Projects

Organization: Chevron Petroleum Technology Co., La Habra, California

Activity Summary: This research involved investigation of technical challenges in the areas of hydrate formation and inhibition, multiphase flow measurement, corrosion control, and multiphase flow.

Contact: Emrys Jones, Phone: (562) 694-7730, e-mail: emry@chevron.com

Organization: Monterey Bay Aquarium Research Institute, Moss Landing, California

Activity Summary: This preliminary case study investigated the relationship between gas hydrates and global climate change, and examined sea floor and water column in the Eel River Basin, offshore of northern California. The video imagery recorded a site actively venting gas. The temperature and age data indicated the susceptibility of the site to climate variability, which could affect the stability of the gas hydrates.

Contact: Peter G. Brewer, Phone: (408) 775-1706, e-mail: brpe@mbari.org

Organization: Stanford University, Stanford, California

Activity Summary:

- Two micromechanical models of hydrate deposition were examined using the amplitude versus offset seismic technique to estimate the amount of gas hydrates in the pore space and determine the permeability of the hydrated sediment.
- Researchers conducted a theoretical and experimental investigation of rock physics and intergranular characteristics of gas hydrates to understand the seismically discovered phenomenon of bottom simulating reflectors.

Contact: Amos Nur, Phone: (650) 723-0839, e-mail: nur@pangea.stanford.edu

Organization: U.S. Department of Energy, National Labs, Industry Partners, Universities

Activity Summary: Researchers are focusing on developing advanced seismic techniques: 1) Oak Ridge National Laboratory (ORNL) is benchmarking various computational tools for a 3-D seismic analysis for accuracy and efficiency using existing models; 2) Lawrence Livermore National Laboratory (LLNL) is evaluating miniature seismic sensors for use in microboreholes and wellbore tubing annuli to improve reliability of the microgeophone and accelerometer to 10,000 feet and 162 °F; 3) Lawrence Berkeley National Laboratory (LBNL) and LLNL are developing techniques to interpret vertical seismic profiles and other well logs to determine formation pressures and acoustic velocities ahead of the bit; 4) LBNL is developing and testing the full capability of performing marine magnetotelluric (MT) surveys in the Gulf of Mexico for the exploration and delineation of hydrocarbon reservoirs beneath salt structures; and 5) LBNL is examining *in-situ* thermodynamic conditions at which methane hydrates remain stable in the oceanic environment, and developing a new technique for monitoring the formation of xenon clathrate hydrates using NMR spectroscopy.

Contact: Tom Schmidt (ORNL), Phone: (423) 574-4977; Norman Goldstein (LBNL), Phone: (510) 486-5961; Tom Whitsett (LLNL), Phone: (713) 464-6961

Organization: U.S. Geological Survey, Menlo Park, California

Activity Summary:

- Determined the role of gas hydrates in global climate change and their potential as a fuel resource, reviewed subaquatic gas hydrate occurrences in polar and oceanic regions, and evaluated their geological effects on the sediment properties using fluid-movement models.
- Synthesized large-volume, low-porosity, cohesive polycrystalline clathrate aggregates with a uniform fine grain size and random crystallographic grain orientation using laboratory apparatus.

Contact: Keith Kvenvolden, Phone: (650) 329-4196, e-mail: kk@octopus.ior.usgs.gov; Laura Stern, Phone: (650) 329-4811

Colorado: Methane Hydrate Research

Recent Projects

Organization: Colorado School of Mines, Golden, Colorado

Activity Summary:

- 25 years of physico-chemical hydrate science and engineering studies currently performed by a team of 15 hydrate researchers (students and professors) have resulted in over 100 refereed publications, including two books.
- The 1998 second edition of *Clathrate Hydrates of Natural Gases* by E. Dendy Sloan, (Marcel Dekker, Inc.) provides an historical overview of clathrate hydrates, examines future research trends, reviews hydrate properties and summarizes applications of clathrate hydrates in the earth and in natural gas production and processing.
- Investigated phase equilibria data, phase diagrams, and thermodynamic studies of time-independent hydrate properties (heat of dissociation, heat capacity, and thermal conductivity.)
- Developed statistical thermodynamic models for structure-H hydrates.
- Completed measurements and modeling of single hydrate crystal growth, and inhibition.
- Conducted laboratory experiments and models of massive hydrate formation and gas production from hydrate in both pipelines and reservoir sediments.
- Patented kinetic method and chemicals for preventing hydrate formation in pipelines in deepwater or in land masses in the winter. Tested 1500 chemicals and conducted 3 years of chemical synthesis.
- Developed method for hydrate inhibition in drilling fluids.
- Initiated and developed Raman spectroscopic method for hydrate structure determination and for determining time dependent kinetics. Expanded the use of NMR spectroscopy with advice of National Research Council of Canada.
- Current research funding is by a Colorado School of Mines consortium of 10 energy companies (drilling muds and kinetic inhibition), with additional funding by the National Science Foundation (structure-H, Raman and NMR spectroscopy) and the DeepStar Consortium (hydrate dissociation models).

Contact: E. Dendy Sloan, Jr., Phone: (303) 273-3723, e-mail: esloan@gashydrate.mines.edu

Organization: U.S. Geological Survey, Denver, Colorado

Activity Summary:

- This assessment included a systematic resource appraisal of in-place natural gas hydrate resources of the U.S. onshore and offshore regions, including geochemical parameters that control the occurrence of gas hydrates.
- Researchers developed a model that utilizes seismic data to estimate the amount of *in-situ* gas hydrates in deep marine sediments.

Contact: Timothy Collet, Phone: (303) 236-4731, e-mail: tcollett@usgs.gov

Florida: Methane Hydrate Research

Recent Projects

Organization: Stanford University, Stanford, California

Activity Summary: This research tested seismic data from the Blake Outer Ridge, offshore of Florida to explore the origin of the bottom simulating reflectors (BSRs).

Contact: Jack Dvorkin, Phone: (415) 725-9296; Amos Nur, Phone: (650) 723-0839, e-mail: nur@pangea.stanford.edu

Organization: U.S. Geological Survey, Woods Hole, Massachusetts; U.S. Naval Research Laboratory, Stennis Space Center, Mississippi

Activity Summary: Researchers determined factors that control gas hydrate concentration and investigated the faulting of gas-hydrate bearing marine sediments off the southeastern coast of the U.S. In addition, two buried zones of faulting were identified.

Contact: William Dillon, Phone: (508) 457-2224, e-mail: bdillion@nobska.er.usgs.gov;
J. Gettrust, Phone: (601) 688-5475, e-mail: gettrust@nrlssc.navy.mil

Organization: U.S. Naval Research Laboratory, Washington, D.C.

Activity Summary: Researchers determined the characteristics of hydrate-trapped gas, and investigated means of recovering methane gas while maintaining the integrity of the hydrate cap.

Contact: Michael Max, Phone: (202) 404-1124, e-mail: max@qur.nrl.navy.mil

Georgia: Methane Hydrate Research

Recent Projects

<u>**Organization**</u>**:** Georgia Institute of Technology, Atlanta, Georgia

Activity Summary: *In-situ* temperature measurements were taken to depths of 415 meters below sea floor in methane hydrate-bearing sediments on the U.S. Atlantic offshore. The results indicated that temperatures at the bottom simulating reflector (BSR) were anomalously low.

Contact: Carolyn Ruppel, Phone: (404) 894-0231, e-mail: cdr@piedmont.eas.gatech.edu

<u>**Organization**</u>**:** Stanford University, Stanford, California

Activity Summary: The research involved testing of marine seismic data from the Blake Outer Ridge, offshore of Georgia. Detailed velocity and amplitude versus offset analysis of these data were used to explore the origin of bottom simulating reflectors.

Contact: C. Ecker, Phone: (415) 723-6006, e-mail: christin@kana.stanford.edu

<u>**Organization**</u>**:** U.S. Geological Survey, Woods Hole, Massachusetts

Activity Summary: USGS researchers developed geological maps showing the inferred distribution of natural gas hydrate in the offshore region from Georgia to New Jersey. This represents the first attempt to map volumes of gas hydrates.

Contact: William P. Dillon, Phone: (508) 457-2224, e-mail: bdillion@nobska.er.usgs.gov

Hawaii: Methane Hydrate Research

Recent Projects

<u>Organization</u>: University of Hawaii, Honolulu, Hawaii

Activity Summary: This activity focused on the investigation of the origin of bottom simulating reflectors and geophysical evidence gathered from offshore area of northwest United States under the Ocean Drilling Program.

Contact: Mary E. Mackay, Phone: (808) 956-4777, e-mail: mackay@soest.hawaii.edu

Idaho: Methane Hydrate Research

Recent Projects

Organization: U.S. Department of Energy, Idaho National Environmental & Engineering Laboratory, Idaho Falls, Idaho

Activity Summary:

- Idaho National Environmental & Engineering Laboratory is currently investigating techniques of methane production from marine sediments. The research involves microbiology and physical chemistry aspects of controlling subsea formation of methane and methane hydrates, and focuses on methanogens from the Nankai Trough. Future studies will utilize McKenzie River Delta core samples.
- Researchers are assessing production potential and investigating characteristics of natural gas hydrate accumulations at the Mallik Well in the Mackenzie Delta Area of Canada.
- Research is underway to develop new and adapting existing sensor packages for subsurface applications involving shallow soil/groundwater systems. The sensor systems being developed have acoustic, optic, electrical, magnetic, and ultrasonic features.
- Researchers are developing analytical models to understand the physical and chemical properties of subsurface gas hydrate deposits.

Contact: Richard E. Rice, Phone: (208) 526-1992, e-mail: rrr@inel.gov

Louisiana: Methane Hydrate Research

Recent Projects

Organization: Haliburton Energy Services, New Orleans, Louisiana

Activity Summary: Researchers investigated options for conducting safer hydraulic workovers in gas wells, including controlling blowout preventer environments, selecting proper elastomers, and preventing hydrate formation.

Contact: Ray Lawson, Phone: (713) 624-3400

Organization: Louisiana State University, Baton Rouge, Louisiana

Activity Summary:

- Under the National Oceanic and Atmospheric Administration's National Undersea Research Program, researchers have gathered and analyzed geotechnical, bacterioplankton, and carbon isotope fractionation data from the Green Canyon 185 and Mississippi Canyon 929 sites.
- Refined and calibrated the surface amplitude extraction method for 3-D seismic interpretation of sea floor geology to establish a new standard for evaluating geohazards from sensitive benthic communities.
- Researchers determined the growth rate and potential production of bacterioplankton in cold hydrocarbon seeps located along the Louisiana coast.

Contact: H.H. Roberts, Phone: (504) 388-2964, e-mail: harry@antares.csi.lsu.edu; P.A. Larock, Tel: (504) 388-6308

Organization: Shell Deepwater Development, Inc., New Orleans, Louisiana

Activity Summary: The occurrence and distribution of active petroleum vents and slicks were identified in the Gulf of Mexico. This research determined that their occurrence and distribution were strongly influenced by the local geological framework, especially the presence of vertical migration pathways into shallow sediments.

Contact: Alan S. Kornacki, Phone: (504) 728-6275, e-mail: kornacki@shell.com

Organization: Texaco; Deepstar Consortium; Minerals Management Service

Activity Summary: This research was initiated in 1992 to investigate the feasibility of using long offset subsea tie-backs with shallow water platforms to develop deep-water tracts in the Gulf of Mexico. It includes developing pipeline blockage removal technology, hydrate plug decomposition systems, and flow assurance techniques.

Contact: Paul R. Hays, Phone: (713) 432-3172

Organization: Texas A&M University, College Station, Texas

Activity Summary: Researchers mapped a belt of sea floor involving oil seeps and chemosynthetic communities across the Upper Continental Slope, offshore of Louisiana, at depths ranging from 1,000–2,000 meters. Oil-stained sediments and thelmogenic gas hydrates were recovered using piston cores and research submarines.

Contact: Roger Sassen, Phone: (409) 862-2323, e-mail: sassen@gerg.tamu.edu

Organization: Tulane University, New Orleans, Louisiana

Activity Summary: Investigated principles of hydrate formation through novel applications of enzyme catalysis and preparation of advanced materials.

Contact: Vijay T. John, Phone: (504) 865-5883

Massachusetts: Methane Hydrate Research

Recent Projects

Organization: Massachusetts Institute of Technology, Cambridge, Massachusetts

Activity Summary: Researchers investigated options for CO_2 sequestration in deep oceans and assessed potential deleterious effects of hydrate formation that could clog discharge nozzles or impede mass transfer from an unconfined release.

Contact: E.E. Adams, Phone: (617) 253-6595

Organization: U.S. Geological Survey, Woods Hole, Massachusetts

Activity Summary:

- Seismic velocities were measured in three drill holes through a gas hydrate deposit on the Blake Ridge, offshore of South Carolina. Results indicated the existence of substantial free gas beneath the bottom simulating reflectors (BSRs).
- Laboratory tests were conducted to further enhance understanding of the processes by which concentrated gas hydrates and deposits at the Blake Ridge were formed. Analytical tools were developed (e.g., acoustic models) to add recognition to resource analysis of offshore hydrate deposits. Seismic reflection profiles of the Ocean Drilling Program (ODP) Blake Ridge sites were collected using seismic sources to image the zone of gas hydrate stability.
- Occurrences of *in-situ* marine hydrate deposits off the U.S. eastern continental margin, using remote sensing techniques, were identified and their distribution mapped.
- Researchers examined the impact of shear waves on methane hydrate-bearing sediments using a combined walkaway-vertical seismic profile (W-VSP) and ocean bottom seismometer (OBS) experiment. The experiment was conducted during the Ocean Drilling Program at the Blake Ridge.
- Researchers conducted laboratory tests to study the formation and decomposition characteristics of gas hydrates at sea-floor pressures and temperatures, to better understand the interrelationships of natural factors in marine environment.
- This research tested gas hydrates in marine sediment by modeling *in-situ* hydrate-forming conditions in the laboratory and by percolating gas upward through a pressurized test specimen of sediment.

Contact: William P. Dillon, Phone: (508) 457-2224, e-mail: bdillon@nobska.er.usgs.gov

Mississippi: Methane Hydrate Research

Recent Projects

Organization: Mississippi State University; U.S. Department of Energy

Activity Summary: Mississippi State University determined the feasibility of utilizing gas hydrates as a storage mechanism and developed a storage facility conceptual design.

Contact: Rudy Rogers, Phone: (601) 325-5106

Organization: Naval Research Laboratory, Stennis Space Center, Mississippi

Activity Summary:

- Researchers gathered high resolution, multi-channel seismic data using the Deep Towed Acoustic/Geophysics System. The data highlighted growth faults of the crest of the Blake Ridge, which extended through the hydrate stability zone.
- Researchers developed a mass balance model to estimate the thickness of sediment that would be required to act as the source of biogenic methane and water in an enclosed massive hydrate.

Contact: Warren T. Wood, Phone: (601) 688-5311, e-mail: warren.wood@nrlssc.navy.mil; Joseph F. Gettrust, Phone: (601) 688-5475, e-mail: gettrust@nrlssc.navy.mil

Organization: Naval Research Laboratory, Washington, D.C.

Activity Summary:

- Identified problems associated with commercial exploitation of hydrates, including constant danger of blow-outs from oceanic gas hydrate reservoirs that are only shallowly buried (less than 1.5 km) in the seabed in water depths over 2 to 3 km. The research suggested exploring extraction strategies that focus on adapting mining methodologies for the hydrate-methane conversion process prior to utilizing modified conventional gas recovery procedures.
- Performed an analysis of high resolution seismic data collected by the Deep-Towed Acoustic/Geophysics System from the Blake Outer Ridge. The data enabled the extent and the hydrate content of the hydrate-bearing sediments to more precisely than had been possible with conventional geophysical systems.

Contact: Michael D. Max, Phone: (202) 404-1124, e-mail: max@qur.nrl.navy.mil

Organization: Marine Minerals Technology Center, University of Mississippi, University, Mississippi

Activity Summary:

- Developed a single-channel reflection method for quantifying lateral variations in bottom simulating reflector (BSR) reflectivity, and tested the method on gas hydrate data collected off the coast of Costa Rica. The results are to be presented at the European Geophysical Society Meeting in April, 1998.
- Prepared a comparison of single-channel processing vs. full wave form inversion for the determination of lateral variations in BSR strength. The results are to be presented at the Offshore Technology Conference in May, 1998.
- Together with the U.S. Geological Survey, the Marine Minerals Technology Center (MMTC) is planning to conduct a cruise in June, 1998 to a known gas hydrate area in the Gulf of Mexico for the purpose of testing and comparing conventional multichannel seismic data with those of very rapidly digitized single-channel seismic data.
- In cooperation with the Center for Applied Isotope Studies (University of Georgia) Atlanta, Georgia, the MMTC is designing and constructing a Gamma Isotope Mapping System to be used on a towed underwater vehicle for the conduct of geochemical studies in gas hydrate areas.
- Plans are being made for a December, 1998 cruise to test vertical arrays in the water column and seafloor 4-component arrays (hydrophone and 3 component geophones). This will be an international collaboration, with participants from Russia and India. Plans are also underway for the establishment of a permanent monitoring station in the DeSoto Canyon.

Contact: Thomas M. McGee, Phone: (601) 232-7320; e-mail: tmm@mmri.olemiss.edu

New Mexico: Methane Hydrate Research

Recent Projects

<u>**Organization**</u>**:** U.S. Department of Energy, Los Alamos National Laboratory, Industry Partners

Activity Summary: Los Alamos National Laboratory is developing an advanced technology for 3-D pre-stack depth migration by improving methods for imaging and visualization. This breakthrough technology would decrease time required for obtaining images, and would acquire better images of sedimentary layers in the Gulf of Mexico.

Contact: Earl Whitney, Phone: (505) 667-3687, e-mail: whitney@lanl.gov

<u>**Organization**</u>**:** U.S. Department of Energy, Sandia National Laboratories, Deepstar Consortium, Industry Partners

Activity Summary: Sandia National Laboratories, in conjunction with the Deepstar Consortium, is developing computational methods for structural analysis and material selection of deepwater risers for petroleum production in hydrate-bearing areas in the Gulf of Mexico. Another project at Sandia involves developing new capabilities for seismic imaging of complex underground structures. Sandia is also developing an advanced seismic source applicable to hydrate-bearing areas.

Contact: David Borns, Phone: (505) 844-7333, e-mail: djborns@sandia.gov

New York: Methane Hydrate Research

Recent Projects

<u>Organization</u>: Brookhaven National Laboratory, Upton, New York

Activity Summary:

- Developed novel catalysts to attain atom-economical conversion of natural gas hydrates to energy liquids to compete with the baseline energy delivery efficiency of liquefied natural gas.
- Performed crystal growth and low-temperature neutron diffraction studies of clathrate hydrates to establish thermodynamic stability of clathrate phases and understand relevant dynamic and static disorders in the structure.

Contact: Devinder Mahajan, Phone: (561) 344-4985, e-mail: dmahajan@bnl.gov

<u>Organization</u>: Columbia University, New York City, New York

Activity Summary: Researchers estimated the magnitude and distribution of potential oceanic methane hydrates in the world's oceans based on two major theories of gas hydrate formation: (a) *in-situ* bacterial production, and (b) pore-fluid expulsion models. Investigated also were the conditions that control gas hydrate formation during pipeline transport at low temperatures.

Contact: V. Gornitz, Phone: (212) 678-5566, e-mail: ccvmg@nasagiss.giss.nasa.gov

<u>Organization</u>: Cornell University, School of Chemical Engineering, Ithaca, New York; Gas Research Institute, Chicago, Illinois

Activity Summary: Researchers investigated the fundamental science underlying hydrate formation and inhibition mechanisms using computer simulation techniques. *In-situ* spectroscopic techniques were combined with computer simulation to study the reorientations of water clusters and redistribution of H-bond energies during ice/hydrate formation.

Contact: Jeffrey L. Savidge, Phone: (773) 399-8333

<u>Organization</u>: Lamont Doherty Earth Observatory, Palisades, New York

Activity Summary: Researchers characterized *in-situ* elastic properties of hydrated sediments to understand their seismic signature, and conducted downhole sonic log and vertical seismic profile experiments at three sites on the Blake Outer Ridge offshore of the Carolinas.

Contact: Gilles Guerin, Phone: (914) 365-8674, e-mail: gilles2ledo.columbia.edu

North Carolina: Methane Hydrate Research

Recent Projects

Organization: Texas A&M University, College Station, Texas

Activity Summary: Direct measurements were made of *in-situ* methane resource stored as gas hydrates and free gas in a sediment sequence from the Western Atlantic Ocean. The results indicated substantial quantities of methane (approximately 15GT of carbon) stored as solid gas hydrate with an equivalent or greater amount occurring as free gas in the sediments below the hydrate zone.

Contact: P. Wallace, Phone: (409) 845-0879

Organization: U.S. Geological Survey, Denver, Colorado

Activity Summary: A downhole logging program determined *in-situ* physical properties of gas hydrate-bearing sediments, specifically, conducting downhole-log analyses of the volume of gas within the gas hydrate and estimating accumulations at Blake Ridge, offshore of the Carolinas.

Contact: Timothy Collett, Phone: (303) 236-5731, e-mail: tcollett@usgs.gov

Organization: University of North Carolina, Chapel Hill, North Carolina

Activity Summary:

- Ocean Drilling Program research examined the potential of biogenic methane in offshore Carolina sediment and investigated the *in-situ* characteristics of natural gas hydrates in marine sediments. Potential sources of biogenic methane in marine gas hydrates formation in the offshore Carolina sediments were examined. The results indicated that recycling and upward migration of methane was an essential mechanism in forming gas hydrates.
- Marine pore-water sulfate profiles measured in piston cores were used to estimate methane flux toward the sea floor and detect anomalous methane gradients within sediments overlying a major gas hydrate deposit.
- Researchers examined sediment core samples from a gas hydrate field located on the southern Carolina Rise and inner Blake Ridge. The results reaffirmed the relationship between sea-level lowstands and frequency of sea-floor slumping on continental margins containing gas hydrates.
- Acoustic tests were conducted in a water column at Blake Ridge associated with active chemosynthetic biological communities to examine sea floor venting characteristics of microbial gases.

Contact: Charles K. Paull, Phone: (919) 962-0687, e-mail: paull@email.unc.edu

Oregon: Methane Hydrate Research

Recent Projects

Organization: California State University, Long Beach, California

Activity Summary: Isotopic compositions of carbonate cements were used to infer the composition of historical pore fluids at two ODP sites with gas hydrates offshore of the Oregon Coast.

Contact: J.C. Sample, Phone: (562) 985-4809

Organization: Oregon State University, Corvallis, Oregon

Activity Summary:

- Under the National Oceanic and Atmospheric Administration's National Undersea Research Program, the researchers are evaluating geochemical consequences of gas hydrate formation in sediments of the Cascadia accretionary prism by examining: 1) processes that occur above the gas-hydrate sealed strata away from actively venting sites; 2) mechanisms and consequences of hydrate decomposition at actively venting sites; and 3) spatial and temporal variability of hydrate decomposition.
- The researchers analyzed the results of several video surveys taken by a remotely operable vehicle of gas hydrates and fluid venting off Oregon at water depths of 550 meters.

Contact: M. Torres and J. McManus, Phone: (541) 737-3281; R.W. Collier, Phone: (541) 737-4367, e-mail: rcollier@oce.orst.edu

Organization: Scripps Institution of Oceanography, LaJolla, California

Activity Summary: Seismic bottom simulating reflectors (BSRs) were drilled at two sites off Oregon and Vancouver Island to measure geological parameters and investigate occurrence of gas hydrates. Bacterial populations were quantified at four Ocean Drilling Program (ODP) sites off the West Canadian/American Coast to investigate occurrence of gas hydrates in the sediments.

Contact: Miriam Kastner, Phone: (619) 534-2065, e-mail: mkastner@ucsd.edu

Organization: University of California, Santa Cruz, California

Activity Summary: This research focused on offshore Oregon to determine stability of gas hydrate sediments by measuring the variations in temperature gradient and identifying structures that were tectonically active.

Contact: J.C. Moore, Phone: (408) 459-2574

Pennsylvania: Methane Hydrate Research

Recent Projects

Organization: Pennsylvania State University, State College, Pennsylvania;
Gas Research Institute, Chicago, Illinois

Activity Summary: Techniques were developed for predicting the effects of pipeline hydraulics on hydrate behavior by determining the effects of low concentrations of polymers, polypeptides, and other compounds on controlling hydrate formation.

Contact: Jeff Savidge, Phone: (773) 399-8333

Organization: U.S. Department of Energy, Federal Energy Technology Center, Pittsburgh, Pennsylvania; University of Pittsburgh, Pittsburgh, Pennsylvania

Activity Summary:

- Evaluated the technical feasibility of long-term deep ocean sequestration (disposal) of liquid CO_2 and possible formation of ice-like CO_2 clathrate hydrate.
- Developed a mathematical model to investigate the effect of hydrate formation on the fate of CO_2 droplets discharged into the ocean under hydrate-forming conditions.

Contact: Robert P. Warzinksi, Phone: (412) 892-5863, e-mail: warzinski@fetc.doe.gov; Gerald D. Holder, Phone: (412) 624-9809, e-mail: holder@engrng.pitt.edu

Organization: University of Pittsburgh, Pittsburgh, Pennsylvania

Activity Summary:

- Research involved laboratory investigation of the kinetics of hydrate formation at the interface of gas-water systems. The results showed that kinetics of hydrate formation depend on the interfacial area, temperature, and gas shear rate at the hydrate-forming interface.
- Researchers conducted laboratory experiments and developed engineering models for controlling hydrate formation and dissolution of hydrates, waxes, asphaltenes, and diamondoids in natural gas under flow conditions found in subsea pipelines.

Contact: Gerald D. Holder, Phone: (412) 624-9809, e-mail: holder@engrng.pitt.edu

South Carolina: Methane Hydrate Research

Recent Projects

<u>Organization</u>: Stanford University, Stanford, California

Activity Summary: The goal of this investigation was to provide a theoretical tool (e.g., a rock physics-based synthetic seismic model) for quantifying the amount of gas hydrate and free gas near a bottom simulating reflector (BSR) at Blake Ridge, offshore of the Carolinas.

Contact: Christine Ecker, Phone: (415) 723-6006, e-mail: christin@kana.stanford.edu

<u>Organization</u>: University of South Carolina, Columbia, South Carolina

Activity Summary: Sediments of a Pliocene—Quaternary distal turbidite sequences were cored at four closely Ocean Drilling Program (ODP) drill sites in offshore Carolinas, and several hydrate samples were collected and analyzed.

Contact: T. Shaw, Phone: (803) 777-5263, e-mail: shaw@chem.scarolina.edu

<u>Organization</u>: Woods Hole Oceanographic Institute, Woods Hole, Massachusetts

Activity Summary: The mass of methane present as hydrate and free gas on the Blake Ridge, offshore of South Carolina was estimated using vertical seismic profiles. Seismic velocities measured in three drill holes through a gas deposit indicated the existence of substantial amounts of free gas 250 meters beneath the hydrate zone.

Contact: I.A. Pecher, Phone: (508) 457-2310, e-mail: ipecher@usgs.gov

Texas: Methane Hydrate Research

Recent Projects

Organization: Deepstar Consortium, American Gas Association and Gas Research Institute

Activity Summary: The objective of this research was to conduct tests to better understand the problem of hydrate blockages and the coating of flowlines, and to find solutions to minimize such occurrences.

Contact: James Chitwood, Phone: (713) 432-3116

Organization: George Claypool (retired, Mobil ODP Safety Panel), Lakewood, Colorado

Activity Summary: Researchers investigated the influence of water solubility, phase equilibria, and capillary pressure on methane hydrate occurrence in sediments. The results indicated that the amount of methane dissolved in marine sediment pore water was larger than that present as gas hydrate.

Contact: George Claypool, Phone: (303) 237-8273, e-mail: geclaypool@aol.com

Organization: Rice University, Houston, Texas

Activity Summary: Researchers investigated samples of water and methane/propane gas (96% CH_4) in the metastable/nonequilibrium region of a hydrate formation/decomposition process by combining macroscopic and microscopic hydrate experiments.

Contact: R. Kobayashi, Phone: (713) 527-3507

Organization: Texaco, Inc., E&P Technology Department, Houston, Texas

Activity Summary: Laboratory and field tests have shown the feasibility of replacing the classic inhibitors (methanol and ethylene glycol) with kinetic inhibitors. Although kinetic inhibitors have limitations, they have shown to be effective in preventing the formation of hydrate plugs in field situations. This effort investigated a novel process for preventing hydrate formation in petroleum production and transportation systems.

Contact: Phil K. Notz, Phone: (713) 954-6135, e-mail: notzp@texaco.com

Texas (continued)

<u>Organization</u>: Texas A&M University, College Station, Texas

Activity Summary:

- Investigated factors that are responsible for large gas hydrate plugs in gas and oil pipelines during the periods of long shut-ins. Examined the properties of hydrate and hydrate-saturated sediments, and role of surrounding conditions in their formation.
- Performed laboratory tests using a research submarine on the Gulf of Mexico continental slope to precipitate gas hydrate for the first time in deep sea environment using natural starting materials.
- Performed a detailed thermodynamic analysis using the finite-element method to validate a laboratory experiment involving a hot conductor buried in the hydrate rich soil.
- Investigated the nature and extent of gas hydrates in shallow sediments on the upper continental slope from the perspective of global climate change research, offshore production and understanding of the global carbon cycle.
- Prepared a video survey documenting oceanographic influences of sea floor gas hydrates with respect to their formation and disassociation in the northern Gulf of Mexico.
- Completed measurements of three-phase, four-phase, and five-phase equilibrium regions involving crystalline structures of methane hydrates.

Contact: Roger Sassen, Phone: (409) 862-2323, e-mail: sassen@gerg.tamu.edu

<u>Organization</u>: University of Texas, Austin, Texas

Activity Summary: The research activity involved utilization of the spectral analysis of surface waves (SASW) method, a non-intrusive seismic technique, for evaluating the stiffness in shear of seafloor soils as a function of depth in the Gulf of Mexico.

Contact: S.G. Wright, Phone: (512) 471-4929

<u>Organization</u>: Westport Technology Center International, Houston, Texas

Activity Summary: The research involved a novel experimental method for screening hydrate kinetic inhibitors and characterization of the nucleation process using laser light scattering technique for hydrate formation. A laboratory study was conducted to determine the effect of low concentration methanol and ethylene glycol on the hydrate formation process. A mathematical model was developed to predict the decomposition rate of a hydrate plug under various depressurization scenarios.

Contact: M.H. Yousif, Phone: (281) 560-3242, e-mail: myhyousif@shellus.com

Washington: Methane Hydrate Research

Recent Projects

Organization: California State University, Long Beach, California

Activity Summary: Researchers used isotopic compositions of carbonate cements to infer the composition of historical pore fluids at two Ocean Drilling Program (ODP) sites with gas hydrates offshore Washington Coast.

Contact: J.C. Sample, Phone: (562) 985-4809

Organization: Tempress Technologies, Inc., Kent, Washington

Activity Summary: This company developed a low-cost system for drilling and characterizing accumulations of gas hydrates on continental margins. The system successfully mapped the gas concentrations in the sediment to a total depth of 1,500 meters.

Contact: Jack Kolle, Phone: (253) 395-9276, e-mail: jkolle@tempressteels.com

Organization: University of California, Santa Cruz, California

Activity Summary: Researchers focused on offshore Washington to determine stability of gas hydrate sediments by measuring variations in temperature gradient and identifying structures that were tectonically active.

Contact: J.C. Moore, Phone: (408) 459-2574

West Virginia: Methane Hydrate Research

Recent Projects

<u>Organization</u>: U.S. Department of Energy, Federal Energy Technology Center, Morgantown, West Virginia

Activity Summary:

- Developed a model to determine the sensitivity of seismic responses to gas hydrate and associated free gas saturation within marine sediments. Performed an assessment of the usefulness of seismic shear waves in characterizing hydrate saturation, including a review of potential complications in seismic modeling procedures.
- Conducted a numerical investigation to evaluate the influence of hydrate production on ground movements near the wellbore and surrounding area. The computer simulations were based on theories of continuum mechanics, thermodynamics of hydrate production, principles of rock mechanics, and geomechanics.
- Studied hydrates by using remote sensing approach afforded by seismic-reflection profiles. The seismic methods used in this project were newly developed, although seismic profiles previously had been used to identify marine hydrate occurrences in a non-quantitative way.
- Researched information relative to geology and geography of onshore and offshore deposits of gas hydrates in the U.S., specifically reviewed the status of research performed on gas hydrates involving geology of gas hydrates and their diagnostic characteristics.
- Collected, evaluated, and validated seismic profile data (e.g., acoustic velocity, resistivity) relative to gas hydrates in the Gulf of Mexico.

Contact: Charles W. Byrer, Phone: (304) 285-4547, e-mail: cbyrer@fetc.doe.gov