An Interagency Roadmap for Methane Hydrate Research and Development

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Office of Fossil Energy

AN INTERAGENCY ROADMAP FOR METHANE HYDRATE RESEARCH AND DEVELOPMENT

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1.0 Executive Summary

An Interagency Roadmap for Methane Hydrate Research and Development is a joint effort of representatives of the U.S Department of Energy (DOE), the U.S. Department of the Interior (including the U.S. Geological Survey [USGS], the Minerals Management Service [MMS], and the Bureau of Land Management [BLM]), the Department of Defense (the Office of Naval Research's, Naval Research Laboratory [NRL]), the Department of Commerce (the National Oceanic and Atmospheric Administration [NOAA]), and the National Science Foundation (NSF). This roadmap outlines a plan of action to fully address the goals of the Methane Hydrate Research and Development Act of 2000 (the MHR&D Act; 30 USC 1902), as amended by Section 968 of Public Law 109-58 (The Energy Policy Act of 2005). This roadmap reflects the MHR&D Act's clear emphasis on determining and realizing hydrate's energy supply potential, while continuing to address important hydrate research questions such as sea floor stability, drilling safety, and environmental issues associated with naturally-occurring methane hydrate. This roadmap is fully consistent with the governmental role of supporting research and development (R&D) in fields with great potential public value that are too high-risk, high-cost, and long-term to be conducted by the private sector alone. This plan: 1) reviews the progress and findings of the first five years of the interagency Methane Hydrate R&D Program (the Program), 2) establishes long-term goals and key intermediate milestones in three primary focus areas, and 3) outlines the overall program structure and management philosophy.

Hydrate science has advanced significantly over the past five years. Closely linked experimentation and numerical modeling have enabled much more confident assessment of hydrate behavior in natural environments. A series of field experiments has revealed the natural complexity and heterogeneity of hydrate systems, confirmed the producability of methane from arctic reservoirs, and documented the existence of concentrated, potentially producible accumulations in marine settings. Furthermore, publication of the "clathrate gun" hypothesis has raised public awareness to the potential relationship between climate change and natural hydrate degassing.

The Program set forth in this roadmap is designed to develop a comprehensive knowledge base and suite of tools/technologies that will, by 2015: 1) demonstrate viable technologies to assess and mitigate environmental impacts related to hydrate destabilization resulting from ongoing "conventional" oil and gas exploration and production (E&P) activities; 2) document the risks and demonstrate viable mitigation strategies related to safe drilling in hydrate-bearing areas; and 3) demonstrate the technical and economic viability of methane recovery from arctic hydrate. By 2025, the Program will: 1) demonstrate the technical and economic viability of methane recovery from domestic marine hydrate; 2) document the potential for and impact of natural hydrate degassing on the environment; and 3) assess the potential to further extend marine hydrate recoverability beyond the initial producible areas.

DOE, as the lead federal agency, will continue to support coordination of methane hydrate R&D within the seven federal agencies listed above through regular meetings of the Interagency Coordination Committee (programmatic managers from here forward referred to as ICC) and the supporting Technical Coordination Team (subject matter experts from here forward referred to as TCT). Furthermore, the cooperating agencies will refocus their efforts towards aligned public outreach so that all program stakeholders can have timely and accurate information on program results and status. DOE, in its role as primary sponsor of extramural R&D, will work to continually review our efforts to ensure program quality and relevance through expanded external peer review. We will cooperate with researchers from around the world to leverage the benefits of significant R&D programs in other countries. Finally, we will manage the Program to ensure that the nation's best talents, including industry, academia, government, and the general public, are brought to bear on this critical issue. The roadmap presented here will secure the United States as a global leader in the science of natural gas hydrate and the technology of hydrate production.

2.0 Background

Methane hydrate is an abundant natural form of clathrate, a unique chemical substance in which molecules of one material (e.g., water) form an open solid lattice that encloses, without chemical bonding, appropriately sized molecules of another material (e.g., methane and related gases). Research during the past two decades has revealed that hydrate exists both as a void-filling material within shallow sediments (both onshore in the Arctic and within deep-water continental shelves) as well as massive deep sea floor "mounds" (often associated with unique chemosynthetic biota). Once thought to be relatively rare in nature, hydrate is now widely considered to store immense volumes of organic carbon, rivaling, if not exceeding, that stored in all the world's oil, natural gas, and coal deposits combined.

A major driver for the Program is the desire to determine and realize the potential for methane hydrate to serve as a future source of energy, both domestically and internationally, for a number of growing economies that currently rely on foreign sources. Furthermore, this vast global methane reservoir is in constant flux, absorbing and releasing gas as it equilibrates to natural changes in pressure, temperature, and geochemical regimes. Understanding the behavior and implications of this dynamic and previously unrecognized component of the natural environment on the carbon cycle, long-term climate, and sea floor stability is an additional critical component of the Program in methane hydrate.

2.1 Collaborating Agencies

This interagency roadmap for methane hydrate R&D was developed by members of the TCT at the request of the ICC (rosters for these two groups are provided in Appendix A). Both groups include representatives of all federal agencies concerned with naturally occurring hydrate: DOE, USGS, MMS, BLM, NSF, NRL, and NOAA.

2.2 Planning Assumptions

The ICC requested the TCT to develop a long-range R&D roadmap that provides a vision of the nature, duration, and sequence of activities needed to achieve the goals of the MHR&D Act. In particular, the ICC wanted a plan that was not limited by historical or anticipated funding levels. Instead, the goal was to describe what would need to be done, (through projects supported by the DOE, other federal or state agencies, or industry) and to then estimate the resources that would be necessary to conduct the work.

This roadmap features the continuation of the Program's current efforts to align major field-based R&D activities with industry, and to conduct this work through project teams to tap the best expertise from industry, universities, the DOE National Laboratories, and federal agencies. This model fits well with DOE's philosophy of advancing technology development through public-private partnerships, and provides government-sponsored research efforts with access to valuable industry expertise, land, and data in a fully cooperative and collaborative mode. However, the TCT recognizes that, even with sufficient federal budgets, progress within cooperative agreements with private partners can be unpredictable and beyond the government's control. Therefore, this plan includes options for conducting critical field R&D projects through direct coordination with state and federal agencies or other means that provide opportunities to accelerate achievement of critical milestones. Prudent use of this approach will further encourage industry involvement in the Program by enabling continued knowledge advancement on hydrate occurrence in nature.

2.3 The Nature of Methane Hydrate R&D

As recently as the 1980s, few scientists knew about or studied methane hydrate in nature. Methane hydrate is not stable at sea-level conditions, which necessitated building special instrumentation to recover and preserve natural samples and measure their properties at in-situ conditions. Most hydrate research was related to the issue of flow assurance in oil and gas pipelines. However, by the mid 1990s, researchers were in general agreement that hydrate deposits serve as one of the largest storehouses of organic carbon on the planet. This growth in knowledge was led independently by Russian and American scientists and aided in large part by discoveries from NSF's Deep Sea Drilling Program (DSDP) and Ocean Drilling Program (ODP). Since 2004 the NSF-International effort has been called the Integrated Ocean Drilling Program (IODP).

Although a number of comprehensive field studies have occurred in the past decade, the vast majority of potential global hydrate occurrences remain unsampled. Therefore, there is still much to learn about the details of hydrate occurrence and behavior in nature. The work remaining is wide-ranging, complex, and multi-disciplinary; and includes fundamental work in geology, geophysics, chemistry, hydrology, microbiology, oceanography, physics, and other disciplines. A significant challenge is the requirement for highly specialized tools and facilities for collecting and analyzing samples with minimal disturbance as well as the development of technologies and techniques to remotely sense the existence and concentration of hydrate. In addition, because hydrate occurs in remote and hostile arctic and deepwater environments, additional technical risks and costs, as well as advanced underwater technologies, are associated with studying them.

2.4 The Federal Role in Methane Hydrate R&D

The federal government has a recognized role in addressing key market failures to pursue R&D with the potential to significantly promote the public good. One of the most common examples of such failure is the private sector's common determination that there is no compelling business case for pursuing long-term, high-risk R&D. Methane hydrate research is one area where private investment is not in accord with the potential public benefit, and as a consequence, a federal program is warranted[1].

[1] A parallel example of a high-risk energy-related resource that government supported is coalbed methane. Fifteen years ago, coalbed methane was an unknown resource. With focused research, technological development, and production incentives, coalbed methane now contributes nearly 10 percent of domestic natural gas production.

The collaborating agencies recognize that an integrated program in naturally occurring methane hydrate R&D may lead to enormous public benefits. One outcome will be an improved understanding of our natural environment, providing significant benefits through more informed decision-making on a wide variety of issues ranging from ocean policy to global climate change. Furthermore, successful demonstration of feasible production of methane from gas hydrate will contribute significantly to assuring the long-term supply of natural gas, an environmentally benign fuel whose expanded use promises enormous economic and energy security benefits to the nation and the world. Lastly, while U.S. investment in hydrate research has remained modest over the past five years, international interest has grown rapidly. The governments of Japan and India, in particular, are investing heavily in studies of methane hydrate resource potential. The United States will benefit greatly by remaining the recognized leader in the research, information, and technology that would support this future industry.

2.5 Accomplishments of the First Five Years of R&D under the Act

Throughout the 1980s and 1990s, a solid foundation of knowledge on hydrate properties and processes was developed in U.S. and Canadian laboratories, including the Colorado School of Mines, USGS, NRL, the Geological Survey of Canada, as well as in a series of field expeditions conducted primarily through the ODP and IODP. From 2000 to the present, the Program has worked to build on this knowledge through a variety of research efforts designed to accelerate the determination and realization of hydrate's resource potential and to better understand hydrate's role in the natural environment. Through the efforts of this interagency collaborative program, fundamental advances have been made in remote detection technologies, hazards characterization, field tool development, laboratory characterization of physical properties, reservoir simulation, and many other areas. These accomplishments have benefited, and will continue to benefit, R&D programs in the United States and other nations. The following outlines the more significant contributions derived from efforts funded under the MHR&D Act of 2000.

- The Program's work with BP Exploration (Alaska) Inc. has provided the first direct delineation and characterization of more than a dozen discrete hydrate "prospects" using remote sensing. This characterization, coupled with advances in field-scale reservoir modeling, has enabled the first estimates of the technically recoverable portion of an in-place hydrate resource.

- The work in Alaska, at the USGS and within the various IODP expeditions to which the Program has contributed, has been critical to the development of the Petroleum Systems approach to hydrate assessment and exploration. This approach, which integrates the physics and chemistry of hydrate formation and dissociation into the geologic context of petroleum sources, migration pathways, and reservoirs, will be the foundation of future hydrate exploration. The focus on resource-quality hydrate reservoirs (primarily permeable sandstones), has marked a fundamental shift in focus away from surficial mounds and large-volume/low-concentration deposits encased in mud as the primary targets for the initial evaluation of hydrate as a potential resource.

- A series of field expeditions and sampling cruises to which the Program contributed (including those of ODP and IODP mentioned above, as well as cruises in the Gulf of Mexico by the research vessels *Gyre* and *Marion Dufresne*) have aided in the demonstration that natural methane hydrate systems, like virtually all natural systems, are highly complex, heterogeneous, and dynamic. Once envisioned as occupying broad and continuous "stability zones", the occurrence of hydrate is now known to be a function not only of those factors unique to hydrate systems (necessary temperatures and pressures) but also by highly variable geothermal and geochemical conditions, background pore-water chemistry, gas chemistry, microbial processes, the availability of both gas and water, and the nature of the enclosing sediment.

- The Program's work with the Chevron Joint Industry Project (JIP) indicates that hydrate occurrence within near-surface hydrate-bearing fine-grained sediments can be reasonably determined prior to drilling through evaluation of standard industry seismic data. Furthermore, the project's efforts to date indicate that the likely hydrate concentrations within such sediments of the Gulf of Mexico do not pose a significant drilling hazard to ongoing deepwater exploration.

- The Program's support for numerical modeling has resulted in the creation of a number of sophisticated codes that enable the investigation of hydrate behavior in nature under a wide range of conditions and the comparative analysis of these simulators with international codes. Led by the efforts of the Lawrence Berkeley National Laboratory (LBNL) and the BP Exploration (Alaska) project team, these models are being fully integrated into both the field and laboratory efforts, significantly increasing the relevance and efficiency of both. Recent analyses, which incorporate the findings of the Mallik 2002 consortium's scientific production experiments, have indicated that potential commercial rates are feasible over a wide range of settings. Notably, LBNL's ToughFX/HYDRATE model is now available free of charge to all non-commercial researchers as is the open-source code of an earlier version the model.

- The Program's work with the USGS and the DOE National Laboratory network has created an array of specialized sea floor process simulation reactors that enable meaningful study of the dynamics and nature of methane hydrate under natural pressure and temperature conditions. These efforts, guided in part by a 2005 USGS-hosted workshop on the alignment of hydrate laboratory and modeling work, are now focusing on the most critical data needs, including those dynamic properties that describe the transmission of energy and materials through hydrate-bearing porous media; including: 1) how quickly changes in pressure and temperature are transmitted over meaningful distances, 2) how freely dissociated gas and water move within the changing reservoir, and 3) how dissociation and fluid flow impact the mechanical stability of the reservoir.

- The Program's support for field tool development has enabled significant improvement in field sampling and analysis. Tools such as the Pacific Northwest National Laboratory's (PNNL) hand-held infrared camera and the IODP's Pressure Core Sampler continue to be applied with great benefit in field investigations around the globe. In addition, a device developed by Georgia Tech (in association with the Chevron JIP) has enabled the first measurement of hydrate-sediment mechanical properties on samples kept under continuous in-situ pressure conditions.

- The Program has established valuable collaborations with a wide range of international hydrate R&D programs. The Program has worked with Japan through both direct financial contributions and through support for a range of post-program sample analyses and numerical modeling activities (including Idaho National Laboratory's (INL) microbiological studies of sediments from the Nankai trough, as well as work by several national laboratories in association with the Mallik projects). The Program is currently providing similar support to the USGS' efforts with the government of India. IODP expeditions 204 and 311 were also supported by the Program, primarily with supplemental funding that enabled each program to field complete and state-of-the-art logging, sampling, and analysis equipment. Finally, the Program has provided support to the NRL in the establishment of significant research collaborations with the nations of Chile and New Zealand.

- Over the period from 1999 to 2005, the Program provided financial support and research opportunities to more than 100 students at more than 30 universities and research institutions. During the same period, research funded in whole or in significant part by the Program was reported in approximately 230 published articles and 300 professional presentations at major conferences. A listing of these students and publications can be found on the DOE Web site at: (www.netl.doe.gov/technologies/oilgas/publications/Hydrates/pdf/MHBibliography.pdf)

- In 2004, NOAA organized the first workshop to bring NOAA carbon and climate modelers and measurers together with methane hydrate and oceanic gas experts. The workshop was sponsored by NOAA's Undersea Research Program and Climate Monitoring and Diagnostics Lab, the Program, MMS, USGS, and the Deep Ocean Exploration Institute at Woods Hole Oceanographic Institution. The workshop concluded that the prevailing paradigm that the oceans are an insignificant source of methane input to the atmosphere warrants closer inspection as does the cause-effect relationship of past "spikes" to climate, sea-levels, hydrate occurrence, and slope failures.

In addition to efforts receiving direct support through the DOE's management of the R&D under the MHR&D Act, other efforts conducted by the collaborating agencies in coordination with the ICC and TCT have provided significant benefits to hydrate science as well. The NSF-sponsored marine research expeditions off the Pacific Northwest are landmarks in hydrate R&D, and many other notable NSF-sponsored studies have been conducted. MMS and NOAA have sponsored a series of studies that have greatly advanced understanding the nature of hydrate-related chemosynthetic communities.

Through this work, we now know much more about methane hydrate, both as a physical substance, and as a constituent of the natural environment. However, the remaining challenges are significant. We still do not know the scale of the potentially recoverable share of the in-place resource, particularly in the marine setting, or identified a proven means of remotely detecting and appraising marine accumulations. We also have not conducted a long-term test of a proposed hydrate production technology. The role hydrate plays in the global carbon cycle, in the evolution of the sea floor, or in global climate also remains unclear. Nonetheless, the work accomplished under the first five years of the MHR&D Act has left the United States well-positioned to efficiently address these challenges.

3.0 Goals and Priorities

Over the long-term, methane hydrate R&D under the Program will continue to encompass a wide range of issues. First, there will be a continuing need to conduct fundamental scientific investigations designed to expand our understanding of the occurrence, nature, and behavior of methane hydrate in natural settings. Second, the Program will continue to develop improved tools and technologies as needed for more effective and efficient field sampling, remote hydrate detection and characterization, and modeling of natural hydrate systems. Third, this information and technology will be integrated into a program of research, development, and demonstration that achieves the practical program goals of safe and economic methane production from hydrate while minimizing environmental impacts and improving our understanding of the role of methane in global environmental and climate processes.

3.1 Program Goals

The long-term goals of the Program are to develop a comprehensive knowledge base and suite of tools and technologies that will enable: 1) safe and economic methane production from hydrate while minimizing environmental impacts, and 2) full integration of hydrate science into our understanding of global environmental and climate processes. Specifically, by 2015, the Program will:

- demonstrate viable technologies to assess and mitigate environmental impacts related to ongoing "conventional" oil and gas E&P activities;

- document the risks and demonstrate viable mitigation strategies related to safe drilling in hydrate-bearing areas; and

- demonstrate the technical recoverability and assess the economic recoverability of methane from arctic hydrate.

By 2025, the Program will:

- demonstrate the technical recoverability and assess the economic recoverability of methane from marine hydrate;
- document the potential for and impact of natural hydrate degassing on the environment; and
- assess the potential to further extend marine hydrate recoverability beyond the initial producible areas.

DOE and the ICC member agencies recognize that the nation may have a need for the gas resources that hydrate might provide earlier than these stated milestone dates. Consequently, the Program will investigate every opportunity to supplement current work with projects that promise to shorten the Program's timelines, particularly with respect to: 1) exploratory assessment wells on the outer continental shelf and 2) field production tests in both arctic and marine settings. Options that will be pursued may include working directly with state agencies, international programs, and others with the means and desire to support such efforts.

3.2 Interagency Collaboration

In 2000, the U.S. Congress passed the Methane Hydrate Research and Development Act. This Act authorized DOE to conduct a broad-based program in methane hydrate science and technology development. The lawmakers recognized that other federal agencies, in fulfilling their individual missions, also conducted hydrate-related investigations, and specified that an interagency committee, led by DOE, be created to ensure efficient communication and coordination of activities. The ICC and its technical implementation arm, the TCT, include representatives from seven federal agencies (see Appendix A for current memberships). Both groups meet periodically to inform their colleagues of new findings and emerging opportunities for synergistic research and collaboration, and to provide input to the DOE on draft program plans and other matters. Although final implementation of each agency's programs and budgets are the sole responsibilities of those agencies, each partner to this effort recognizes that continued interagency collaboration is critical to meet the goals of the MHR&D Act. The following paragraphs outline four ways in which collaboration between the agencies has occurred, and provides selected examples of each.

First, the agencies co-fund projects of mutual interest. For example, DOE and USGS contributed funding and expertise to the NSF-sponsored IODP expeditions 204 and 311. While NSF provided the bulk of the U.S. funding, interagency collaborations enabled the IODP to employ the best possible science program, including the further testing and development of pressure-coring and well logging technologies. Similarly, for the past several years, NOAA, MMS, and DOE have jointly funded development and deployment of a sea floor observatory at a hydrate-rich location in the Mississippi Canyon area of the Gulf of Mexico to monitor interactions between the near-seabed hydrocarbon system and the hydrate stability zone.

Second, each agency actively incorporates the findings and expertise of others agencies' work into its programs. For example, USGS works to maintain a database of Alaska North Slope hydrate-relevant well data has been an invaluable resource to DOE-funded projects in Alaska. Likewise, USGS has actively followed and supported DOE-funded work to produce hydrate numerical simulation capabilities, and has informed its priorities for work in its Menlo Park and Woods Hole laboratories to those identified data needs. As another example, an ongoing MMS project to assess the technically recoverable resources in the marine settings has benefited greatly from USGS expertise, and has produced a valuable interpretation of existing Gulf of Mexico hydrate-related information (including a detailed determination of the existence of sandstone reservoirs within the hydrate stability zone) that will be extremely useful inputs into future stages of DOE-funded hydrate expeditions in the Gulf of Mexico.

Third, DOE directly funds other agencies to conduct work in support of its program when those agencies have unique abilities to provide critical data needs. Examples include funding to USGS and NRL to conduct both field and laboratory research in support of the Gulf of Mexico JIP. Such contributions have also been very useful in supporting international collaborations, including DOE funding to augment the ongoing USGS effort with the government of India as well as funding to NRL to conduct initial geophysical and geochemical surveys with the governments of Chile and New Zealand.

Fourth, the collaborating agencies have been invaluable in providing technical expertise to the development of R&D plans. The best example is this document, which has been prepared by the interagency TCT, approved by the ICC, and submitted to the Federal Advisory Committee for comment. Furthermore, as noted in section 4.3, the collaborating agencies have been very responsive to DOE's requests for technical comment/review on proposals received under DOE solicitations, and for peer reviewers of ongoing DOE research efforts.

3.3 External Scientific Oversight and Review

DOE and ICC member agencies recognize the soundness of the recommendations of the National Research Council (2004 Report: *Charting the Future of Methane Hydrate Research in the United States*) and the requirements of the MHR&D Act for expanded use of external expert opinion in the selection and management of projects. This review is achieved through external merit reviews of ongoing projects, external review of proposals for new projects under DOE solicitations, and ongoing consultation with the Federal Advisory Committee (see Appendix B).

An initial peer review of ongoing activities, which focused on selected efforts within the DOE National Laboratory system, was successfully conducted in January of 2006 using a panel of six external experts from industry, academia, and government agencies (U.S. and Canada). This review resulted in additional strategic funding for needed studies and equipment enhancements. A similar review of the full program portfolio is expected for the fall of 2006. Such reviews will be repeated at least once every two years and include all significant ongoing R&D efforts.

Evaluation of proposals for R&D projects received under the DOE's 2005 Methane Hydrate solicitation were subject to initial external scientific review from a panel of six reviewers representing the collaborating agencies. DOE evaluation of proposals received under the 2006 solicitation was similarly augmented by reviews provided by a group of 18 external expert reviewers, including representatives from industry, academia, and federal agencies.

Finally, in keeping with the requirements of the MHR&D Act, DOE will commission a comprehensive review of the Program by the National Research Council in Fiscal Year (FY) 2007 for submission to Congress in FY2009.

3.4 International Collaboration

DOE understands the outstanding value and contributions that collaboration with international hydrate R&D efforts has provided to the Program. In particular, USGS and NRL have done exceptional work in building U.S.-International scientific collaboration on hydrate. The DOE-led interagency Program will continue to build on this foundation through support to cooperative efforts with international R&D programs and researchers when opportunities arise. The agencies will also enable, to the extent possible and practical, the opportunities for foreign parties to observe and participate in domestic hydrate field programs.

In the near-term, USGS and DOE will work to increase the chances for success in the impending exploration program in India, and will encourage cooperative post-cruise studies that seek to integrate the findings of such programs into the existing body of hydrate knowledge. The agencies will similarly look to expand collaborative opportunities with Japan, and will continue nurturing ties built through cooperative ventures such as Mallik 2002 and an ongoing collaborative effort (with DOE, USGS, and others) to compare hydrate reservoir simulators. Work with international organizations, such as the Asia Pacific Economic Cooperation Forum (APEC), IODP and with nations such as Korea, China, Chile, Russia, New Zealand, Australia, the European Union, and others will also be actively pursued through continued sponsorship for international hydrate workshops and significant cooperative studies such as those developed by NRL.

3.5 Data Dissemination

Critical to a collaborative effort such as the interagency Program is the efficient dissemination of information. One avenue is through the publication of DOE's quarterly newsletter, *Fire in the Ice.* Also, the Program will continue to ensure that its researchers and research partners publish their results in peer-reviewed journals and regularly participate in professional conferences. Lastly, in 2006, the DOE signed an Interagency Agreement with the National Institutes for Standards and Technology (NIST) to develop a searchable, web-based national Methane Hydrate database in association with the international CODATA gas hydrate effort. Going forward, DOE will encourage/require research partners to contribute research findings to this national database as part of their research efforts.

3.6 Provide Educational and Training Opportunities for New Scientists

Over the past five years, institutions of higher education have played a major role in the Program, both in support to the Program's industry-led field projects, as well as in individual competitively awarded R&D projects. DOE and the ICC member agencies will expand this commitment to provide educational and training opportunities to the next generation of energy scientists by establishing a formal, competitive, merit-based fellowship program. The fellowship program will recognize and provide full support to at least two "National Methane Hydrate R&D Program Fellows" per year. The Program's ongoing accomplishments in this regard will be featured in our annual report to Congress.

3.7 Public Outreach

Critical to the ultimate success of this Program will be the acceptance and understanding of this potential new resource by the public. Although initial hydrate resources may come from established oil and gas production areas (Alaska, the Gulf of Mexico), full realization of methane hydrate's resource potential may mean tapping areas that currently lack an industry presence. Furthermore, methane hydrate has been linked to past episodes of rapid climate change raising credible concerns over the behavior of hydrate during potential extraction. Therefore, the Program needs to demonstrate and communicate that it is responsibly addressing these topics and honestly and fully sharing the facts on issues of rightful concern to the public.

To improve the availability of information on methane hydrate beyond the scientific community, DOE will work with the ICC member agencies to: 1) provide through its Web sites (and promote the existence of) information, graphics, videos, and other materials in a format designed for use by educators (K–12) on hydrate-related issues; 2) conduct a series of public lectures and/or prepare articles for the non-technical press on the fundamentals and implications of methane hydrate science; and 3) carry out other activities, such as agency newsletters and media laboratory or field site visits, that expand the awareness and understanding of methane hydrate issues and potential.

4.0 Major Program Elements

The following provides descriptions of the types of activities and areas of investigation that will enable achievement of the interagency Program's long-term goals.

4.1 Periodic Resource Assessment

The Program will promote the regular evaluation of methane hydrate resources and resource assessment methodologies in order to inform the public of the in-place and likely technically recoverable resources of methane in hydrate deposits. These activities will continue to be coordinated by the Department of the Interior (USGS, BLM, and MMS). Updates to the initial 1995 USGS in-place assessment of methane within gas hydrates are currently underway by USGS, BLM and MMS, and will culminate with the first systematic national estimates of technically recoverable natural gas resources from hydrate by 2008. Given the state of data on hydrate distribution, volumes, and potential productivity, these estimates will need to be continuously refined as data come available.

4.2 Collection and Management of Existing Data

Integral to this work is the continued development and maintenance of comprehensive databases of hydrate-relevant data (occurrences, temperature and pressure gradients, fluid salinities, gas compositions, reservoir lithologies, direct and indirect indication of hydrate in well logs and seismic data, etc.) culled from public (and private, when possible) oil and gas drilling records from the Gulf of Mexico, the Alaska North Slope, and elsewhere. DOE will continue to support the efforts of USGS, BLM, and MMS to collect such data and to integrate them into databases that are available to the collaborating agencies and other researchers.

4.3 "Wells/Data of Opportunity"

The Program will seek opportunities to partner with industry to collect new data from ongoing oil and gas exploration, including remote sensing data and specialized shallow logging in wells drilling to deeper conventional targets ("wells of opportunity"). This approach has provided useful data on the Alaska North Slope, and has the promise of providing similar benefits in the Gulf of Mexico.

4.4 Field R&D Programs

Field studies, although both costly and risky, must be continued and accelerated to provide samples for analysis, to more fully reveal the range of methane hydrate occurrences, to ground-truth predictive/diagnostic tools, and to provide means for testing alternative production strategies under natural conditions. In the near-term, work to advance the characterization of the resource potential of methane hydrate on the Alaskan North Slope will continue. An initial field test in cooperation with industry is expected by late 2006. The Program will continue to work with industry and other interested parties to enable the initiation of an extended production test in a well-characterized reservoir by 2007. Additional field tests in other arctic settings will be needed to test different combinations of production methodologies, well bore designs, and geologic settings. Field efforts should conclude with a multi-well pilot test in cooperation with industry partners that will establish the field-scale economic potential of hydrate production.

The lessons learned from research in the Arctic and from collaboration with international partners will be applied to domestic marine settings, primarily the Gulf of Mexico. Initially at least, the pursuit of hydrate in the deep ocean will proceed in the same way as in the Arctic, by seeking out the quality sandstone reservoirs that appear to be prerequisites for well-based extraction at viable rates. Therefore, in the near-term, the program will work with the established Chevron JIP in the Gulf of Mexico to survey existing data to select, survey, drill, and characterize one or more locations with confirmed or high-potential occurrence of hydrate-saturated sandstones. Several such tests, including one or more extended well production tests, will be required.

In addition to resource aspects, the periodic, natural dissociation of hydrate, particularly at the up-dip margins of hydrate stability where the pressure-temperature conditions never stray far from the phase boundaries, can greatly weaken the strata of continental shelves leading to large-scale submarine slope failure. One such hydrate-related slope failure off Norway, the Storrega slide, is associated with tsunami deposits in Scotland more than 20 meters high. The frequency and mechanisms for these slope failures are very poorly understood and merit new and comprehensive field studies.

4.5 Numerical Simulation

Determining the behavior of hydrate in nature requires validated numerical simulations of methane hydrate responses to natural and induced phenomena. A variety of models of different nature and scale will be needed for both developing the most effective drilling, production, and completion strategies for marine or arctic hydrate and determining hydrate's role in global environmental processes. In the near-term, DOE and USGS will continue to pursue the international code comparison effort to advance the leading hydrate reservoir simulation models. Similarly, DOE, NRL, and NOAA will continue to pursue means to integrate hydrate-related data into leading oceanic and global climate modeling efforts.

4.6 Experimental Studies

In 2005, an external scientific review found that the DOE National Laboratory System can be a very cost-effective means to provide critical data to the research community. In addition, the Program supports a variety of cooperative R&D efforts with industrial and academic laboratories. The Program will continue to utilize this expertise, and will work to foster communication between experimentalists, numerical modelers, and the Program's academic and industrial research partners. The Program will continue to conduct regular external merit reviews to ensure that work: 1) employs sound scientific principals, 2) avoids unproductive redundancies, and 3) targets the most pressing data needs. Among the data needs that are likely to be given high priority in the near-term are determining the mode and distribution of hydrate in porous media, the ability of hydrate-bearing sediments to transmit pressure-temperature perturbations, the nature of relative permeability, phase saturations and resulting fluid flow in hydrate reservoirs, methane production and migration rates in the subsurface, the significance and fate of methane released into the water column, and others.

4.7 Remote Sensing/Exploration Technologies

The Program will continue to pursue research that enables discriminating among the different rock-physics models of hydrate occurrence, as well as improved data acquisition and interpretation methodologies. Advanced multi-component seismic and other technologies (resistivity profiling, etc.) have the potential to contribute to the detection and characterization of methane hydrate by measuring changes in the physical properties of marine sediments in which hydrate is present. This ability is a necessary element in fully understanding the occurrences and concentrations of hydrate in the marine environment and will form the basis of future hydrate exploration technologies.

4.8 Field Sampling Tool Development

The Program will support, through our program with the Chevron JIP, promising concepts for new and better tools for obtaining, retrieving, and analyzing natural hydrate/sediment samples under uninterrupted in-situ pressure and temperature conditions. In addition, the Program will also pursue opportunities to minimize the amount of sample disturbance by bringing analytical devices as close to the reservoir as possible, through both remotely deployed, down-hole in-situ analyses, and through mobile laboratories.

4.9 Sea Floor Observatory

NOAA, MMS, and DOE will work to complete installation and support the ongoing operation and maintenance of a permanent sea floor observatory in the Gulf of Mexico. This observatory will be the first of a series of regional domestic stations designed to monitor real-time interactions between the water column, near-sea floor sediments, and the hydrate stability zone. NRL will seek collaborators in the development of this network and will continue its history of cooperation in similar ventures internationally, most notably in Canada (the Neptune Program) and Europe.

4.10 Improved Deep Marine Characterization Tools

The Program will support the development of improved tools for analysis of deep-marine hydrate occurrences and the distribution, rates, and analysis of fluid and gas flux from the sea floor into the water column. The Program will also pursue opportunities to develop and test tools that enable in-situ, interactive measurements of methane bearing strata, either at the surface or in boreholes.

4.11 Integration at All Levels

The Program expects that all the major program elements will be integrated together, as appropriate, to maximize the benefit to research. This is particularly necessary for interpreting coincident measurements from field, laboratory, and modeling experiments.

5.0 Long-Range R&D Roadmaps

Three draft roadmaps are presented. The first two roadmaps describe steps required to enable production of methane from arctic and marine deposits respectively. The third covers activities that will lead to an understanding of methane hydrate's role in the global environment and climate processes.

With regard to production, the Program recognizes that we must confirm the extent and nature of marine resources and develop the technology to produce methane from them in order for hydrate to fulfill its potential as a paradigm-shifting future energy source. To achieve this goal, we intend to pursue a program of R&D that proceeds along two paths. Research on the demonstration of technologies for hydrate prospect drilling and production should continue to focus, in the near-term, on the more accessible arctic accumulations. The highest priority will be the completion of a series of extended well production tests that employ a variety of alternative production/stimulation scenarios and well designs across a relevant range of geologic/reservoir conditions. These tests will not only help deliver incremental resources on the North Slope, but will cost-effectively provide the natural laboratory needed to determine the producability of naturally-occurring hydrate enclosed in permeable reservoirs. At the same time, the near-term research related to marine hydrate will focus on an extensive exploratory well drilling campaign designed to ground truth developing marine exploration technologies and determine the scale of the potentially producible marine hydrate resources. As soon as feasible, the most promising hydrate production technologies developed in the Arctic will be translated and modified for the sandstone reservoirs in the marine environment.

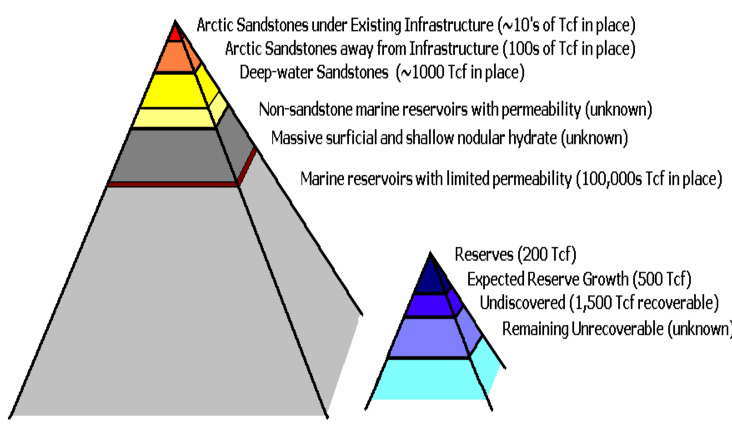

Fig. 1: *A methane hydrate resource pyramid (left) compared to a similar depiction for non-hydrate resources. Values are orders of magnitude estimates only (in trillions of cubic feet, Tcf).*

This approach will result in a steady advance of understanding downward through the hydrate "resource pyramid". Our first target will be the tens of Tcf present within a large number of structurally complex, but well-characterized and geologically favorable hydrate-bearing sandstones known to exist under the Prudhoe Bay infrastructure on the North Slope. Assuming favorable results, additional testing will target hundreds of Tcf of resource across the broader Alaska North Slope region. These findings will then inform efforts to tap potentially thousands of Tcf of methane bound in hydrate in marine sandstone reservoirs. Looking further, fundamental engineering and scientific breakthroughs will be required to access tens of thousands of Tcf held within dispersed, fine-grained, and low-concentration marine deposits such as those documented at the Blake Ridge.

5.1 Arctic Resources

The roadmap for R&D resulting in demonstration of the commercial viability of methane production calls for an integrated program of field study, laboratory investigations, and numerical modeling. An initial milestone is the completion, by 2008, of the Department of the Interior's (DOI) initial regional assessment of in-place and technically recoverable resources across the broader Alaska North Slope. Current expectations are that this assessment will be informed by at least one scientific well test within the "Eileen Trend" (greater Prudhoe Bay region) to ground-truth seismic resource

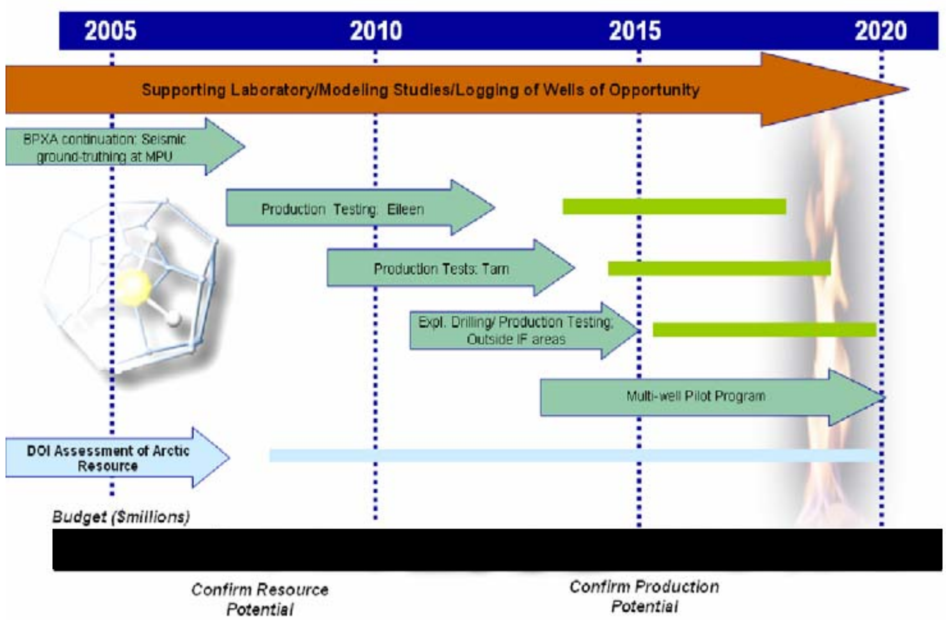

Fig. 2: *R&D roadmap leading to confirmation of the economic potential of methane production from arctic hydrate.*

delineation technologies and test critical assessment parameters. The test well will also serve to provide additional data to support selection of the most appropriate sites for initial long-term production testing. The Program will continue to pursue opportunities to enable this testing to begin at the earliest possible time.

The initial production test at Prudhoe will be a long-term test (at least 18 months) and will likely focus on reservoir depressurization with supplemental down-hole heating as needed to sustain production. During this period, additional projects to determine the need and appropriate sites for additional Alaska North Slope production testing will be initiated. A second long-term test, building upon the findings of the first and targeting additional permutations of stimulation method, well design, and reservoir character is targeted for initiation by 2009 with completion no later than 2013. A third test may be conducted if necessary to resolve remaining issues or to define additional resources throughout the Alaska North Slope, with completion planned by 2015.

With the scale and nature of the technically recoverable resource well documented, the Program will then determine the merits of working further with industry to conduct a field-scale, multi-well pilot production program to establish the commercial viability of stand-alone hydrate production. This project will be completed by 2020, at which time large-scale federal involvement in this segment of the Program is expected to end.

5.2 Marine Resources

The interagency Program recognizes that significant methane production from marine hydrate accumulations is essential to meet the goals of the MHR&D Act. By 2008, an initial DOI assessment (MMS and USGS) of the scale of that resource, (potentially ground-truthed by a second leg of resource-directed drilling within the Chevron JIP), will be completed. Before 2010, a second leg of exploratory drilling will be initiated in the Gulf of Mexico, and will drill and evaluate locations identified through maturing remote sensing technologies. An initial production test in the marine environment will begin by 2012 with a second test shortly after, resulting in the confirmation of marine hydrate technical recoverability by 2015. Assuming full or partial success, additional production tests may be needed to further refine production technologies, including potential multi-well pilot-scale testing. By 2020, the parameters for commercial productivity of Gulf of Mexico hydrate will be understood. Outside the Gulf, the Program will pursue the delineation of high-potential areas in other U.S. coastal areas through remote sensing and drilling programs as necessary. By 2025, assuming success in earlier stages, the Program will complete analyses and other data collection activities to assess the potential for expanding the technically recoverable marine hydrate resource beyond permeable sandstone reservoirs to include other, non-sandstone accumulation. A recommendation of the prospects for (and related environmental impacts of) such extraction, including the appraisal of non-well based methods, will be provided.

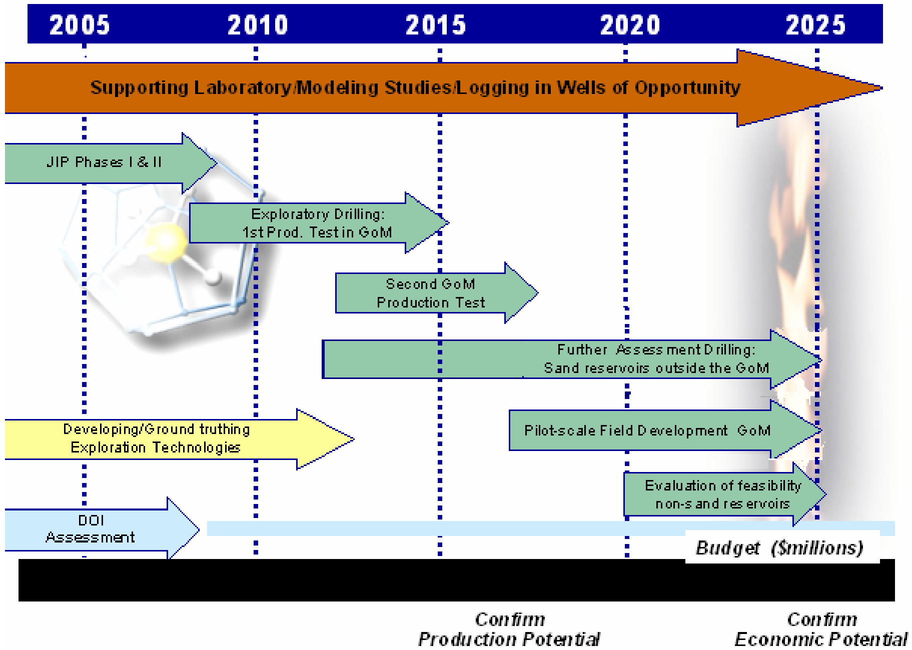

Fig. 3: *R&D roadmap leading to confirmation of the economic potential of methane production from marine hydrate.*

5.3 Hydrate and Its Role in the Natural Environment

The global hydrate reservoir holds vast volumes of methane in close proximity to the sea floor, raising several important questions about the role of hydrate relative to: 1) global climate change; 2) the stability of the sea floor, both under structures on deep shelves and upon slopes; 3) ocean carbon modeling; and 4) their associated chemosynthetic communities. To address these questions, the Program will collect data in both the marine and arctic environments to enable: 1) developing predictive models of methane generation, oxidation, and migration, as well as natural hydrate formation and dissociation; 2) measuring and interpreting the timing, magnitude, distribution, and ultimate fate of past methane releases; 3) determining background fluxes of gases between sea floor sediments, hydrate, the water column, and the atmosphere; 4) numerical modeling of the impacts among hydrate-related phenomena, global carbon cycling, and climate change; 5) an improved understanding of E&P related impacts to ecosystems associated with gas hydrates and identification of methods to minimize those impacts; and 6) studying hydrate's role in the development and stability of continental shelves and slopes.

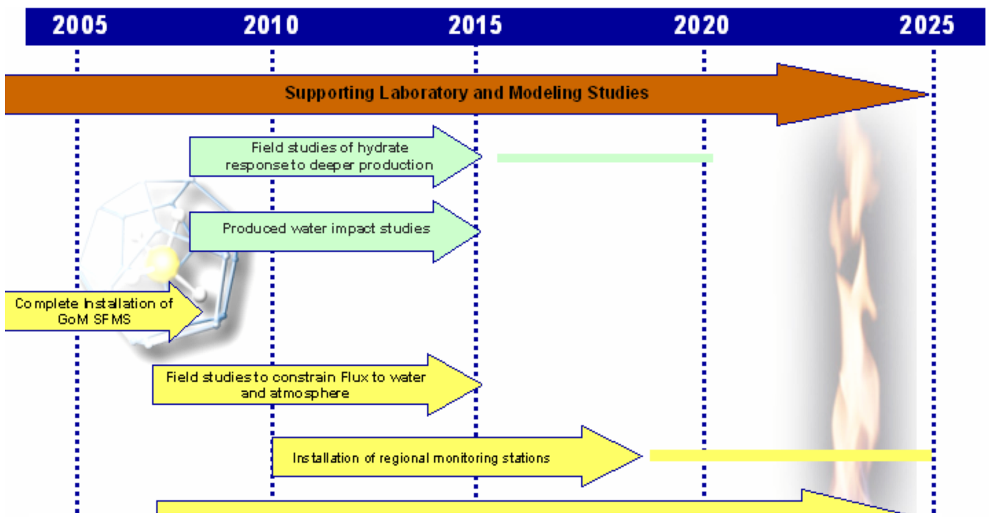

Fig. 4: R&D roadmap leading to a full understanding of the role methane hydrate plays in the natural environment.

In accordance with the MHR&D Act, the Program will focus on assessing the potential for, and mitigating the impacts of, hydrate degassing in response to human activities (primarily oil and gas E&P) as well as assessing the potential for and impacts of natural hydrate degassing. These two components are discussed separately below.

Environmental impacts associated with natural degassing: The Program will complete the installation of a gas hydrate sea floor observatory in the Gulf of Mexico, by 2008. The gas hydrate sea floor observatory will allow continuous collection of data within the hydrate stability zone and provide a platform which to monitor the interactions between hydrates, sea floor sediments, the water column, and the atmosphere. Additionally, the Program will seek out opportunities to participate in other ongoing and future international gas hydrate sea floor observatories. By 2015, the Program's goal is to collect sufficient data to constrain the rates of methane flux from the sediments to the water column and ultimately, to the atmosphere. By 2025, a comprehensive knowledge base and suite of analytical tools will enable an improved understanding of the potential for, and impact of, natural hydrate degassing on the environment. In addition, this work will similarly address the relationship between hydrates, natural changes in pressure and temperature, and the general stability of the continental shelf and slope.

Environmental impacts associated with E&P activities: The Program will work to integrate studies of the potential for and environmental impacts of hydrate degassing induced by drilling and production of hydrocarbons (either deeper conventional oil and gas or hydrate-related gas) into its production-related field programs. Additionally, the Program will focus on developing methods to reduce environmental impacts for E&P activities on the biological communities associated with near-surface hydrate deposits. Developing technologies and procedures to limit incidental dissociation and/or mitigate the hazards related to drilling, producing, or gathering oil and gas will be integrated as appropriate into ongoing projects supported by the Program. Standalone cooperative efforts with industry to monitor hydrate bearing strata before, during, and after conventional drilling will be pursued, both in the marine and arctic environments. In either setting, opportunities to conduct 4-D seismic surveys to measure progressive changes in shallow sediment characteristics before and after drilling is highly recommended. In the Arctic, field projects to test recoverability will be designed, as possible, to address issues such as the disposal or use of produced water and the maintenance of the geomechanical stability of the permafrost.

6.0 Concluding Remarks

This document has presented the structure, goals, and management philosophy for the DOE-led interagency Program in natural methane hydrate. This plan is currently in draft form, and will be revised as we continue to solicit the opinions of various stakeholders. This long-range roadmap will form the framework for a detailed five-year plan that is required by Congress in 2007.

Subsequently, this plan will be revisited annually to reflect the continuing progress of the Program. Additional workshops to solicit broad external stakeholder input on the Program multi-year plan will be held as needed, with a second workshop scheduled for no later than FY 2010.

Appendix A: The Interagency Coordination Committee and Technical Coordination Team

Interagency Coordination Committee:

- James Slutz, Chairman, Department of Energy / Office of Fossil Energy
- Edith Allison, Program Manager, Department of Energy / Office of Fossil Energy
- Nicholas Douglas, Department of the Interior / Bureau of Land Management
- Bilal Haq, National Science Foundation
- Robert Labelle, Department of the Interior / Minerals Management Service
- Brenda Pierce, Department of the Interior / United States Geological Survey
- Richard Spinrad, Department of Commerce / National Oceanic and Atmospheric Administration
- Bhakta Rath, Department of Defense / Naval Research Laboratory

Technical Coordination Team:

- Ray Boswell, Chairman, Department of Energy / National Energy Technology Laboratory
- Roger Amato, Department of the Interior / Minerals Management Service
- Richard Coffin, Department of Defense / Naval Research Laboratory
- Timothy Collett, Department of the Interior / U.S. Geological Survey
- George Dellagiarino, Department of the Interior / Minerals Management Service
- Robert Fisk, Department of the Interior / Bureau of Land Management
- Joseph Gettrust, Department of Defense / Naval Research Laboratory
- Bilal Haq, National Science Foundation
- Deborah Hutchinson, Department of the Interior / U.S. Geological Survey
- Kimberly Puglise, Department of Commerce / National Oceanic and Atmospheric Administration
- Pulak Ray, Department of the Interior / Minerals Management Service
- Kelly Rose, Department of Energy / National Energy Technology Laboratory

Appendix B: External Scientific Oversight

The following non-DOE scientific experts have provided input into program planning, evaluation, and project selection in FY2005 and FY2006.

A. External Review Panel evaluated project proposals received in response to the FY2005 Methane Hydrate solicitation:

- William Waite, U.S. Geological Survey
- Ed Dlugokencky, National Oceanic and Atmospheric Administration
- Roger Amato, Minerals Management Service
- Dirk Herkoff, Minerals Management Service
- David Twichell, U.S. Geological Survey

B. Merit Review panel for the January 2006 review of selected projects underway within DOE National Laboratories

- Timothy Collett, U.S. Geological Survey
- J. Carlos Santamarina, Georgia Institute of Technology
- E. Dendy Sloan, Colorado School of Mines
- William Waite, U.S. Geological Survey
- Scott Wilson, Ryder Scott Petroleum Engineers
- Fred Wright, Geological Survey of Canada

C. External scientific review panel evaluated project proposals received in response to the FY2006 Methane Hydrate solicitation:

- Roger Amato, Minerals Management Service
- George Claypool, Retired
- Timothy Collett, U.S. Geological Survey
- William Dillon, Hydrate Energy International
- John Dunne, National Oceanic and Atmospheric Administration
- Patrick Hart, U.S. Geological Survey
- Bruce Herman, Minerals Management Service

- James Howard, ConocoPhillips
- Robert Hunter, ASRC Energy Services
- Robert Kleinberg, Schlumberger-Doll Research
- Timothy Kneafsey, Lawrence Berkeley National Laboratory
- Carolyn Koh, Colorado School of Mines
- George Moridis, Lawrence Berkeley National Laboratory
- Mike Smith, Minerals Management Service
- William Waite, U.S. Geological Survey
- Mark White, Pacific Northwest National Laboratory
- Joseph Wilder, University of Akron

D. The Federal Advisory Committee

- Peter Brewer, Monterey Bay Aquarium Research Institute
- Richard Charter, National OCS Coalition
- Nader Dutta, Schlumberger
- Arthur Johnson, Hydrate Exploration International
- Emrys Jones, Chevron
- Miriam Kastner, Scripps Institute of Oceanography
- Devinder Mahajan, Brookhaven National Laboratory
- Stephen Masutani, University of Hawaii
- E. Dendy Sloan, Colorado School of Mines
- Robert Swenson, Alaska Department of Natural Resources
- Jean Whelan, Woods Hole Oceanographic Institute
- Scott Wilson, Ryder Scott Petroleum Engineers
- Robert Woolsey, University of Mississippi
- Kimberly Juenger, World Energy Systems, Inc.