NATIONAL METHANE HYDRATE MULTI-YEAR R&D PROGRAM PLAN

U.S. Department of Energy
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Federal Energy Technology Center

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NATIONAL METHANE HYDRATE MULTI-YEAR R&D PROGRAM PLAN

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Executive Summary

Methane hydrates represent a potentially enormous natural gas resource. Estimates range as high as 700,000 trillion cubic feet (Tcf) worldwide, many times the estimated total of worldwide conventional resources of natural gas and oil. For the United States, resources are estimated in the range of 100,000 to 300,000 Tcf. If it is determined that the safe production of methane from hydrates is technically feasible and economically viable, the Nation's economic growth would be revolutionized, long-term energy security would be ensured, and environmental quality would be improved.

In its 1997 ***Report on Energy Research and Development for the Challenges of the Twenty-First Century***, the President's Committee of Advisors on Science and Technology (PCAST) included a principal recommendation that the Department of Energy (DOE) Office of Fossil Energy (FE) develop a science-based program with industry and other Government agencies to "understand the potential of methane hydrates worldwide." The PCAST view was that methane hydrates were not being addressed adequately in FE, or in other DOE R&D programs and agencies, and that more emphasis through applicable R&D was needed. The PCAST suggested first-year funding of $5 million, rising to $12 million in the fifth year. The current consensus of DOE and its industry and academic advisors, based upon the additional knowledge acquired in the last year, is that a methane hydrate R&D program of $150 to $200 million over a ten-year period will be needed to accomplish mission goals.

In addition to the PCAST recommendation for an initiative on methane hydrates, draft legislation – U.S. Senate Bill S. 330 and the U.S. House of Representatives companion Bill H.R. 1753, *The Methane Hydrate Research and Development Act of 1999* – promotes the research, identification, and development of methane hydrate resources. This is an authorization bill and thus does not appropriate funds, but these House and Senate actions clearly indicate Congressional support for a National R&D program. The Act is expected to be enacted into law in 1999.

DOE/FE, in collaboration with other agencies, academia, and industry, is poised to implement a program which builds upon the existing knowledge base to investigate and obtain the information necessary to bring methane hydrates into the natural gas resource base. The ***National Methane Hydrate Multi-Year R&D Program Plan*** builds on the 1998 DOE report, ***A Strategy for Methane Hydrate Research and Development,*** is responsive to the PCAST recommendations, and wholly consistent with the FE mission to ensure National energy security through providing an abundant domestic source of natural gas. The Program promotes the introduction of critically needed information, which would not otherwise be available in the marketplace, enabling the private sector to further develop and safely apply the new technologies commercially.

The ***National Methane Hydrate Multi-Year R&D Program Plan*** illustrates how technology is expected to proceed from the current state-of-the-art to the technological level needed to achieve Program goals. The Federal role provides for the coordination, integration, and synthesis of research

efforts needed to: (1) establish an estimate of gas resources from methane hydrate deposits; (2) develop the technology necessary for the commercial production of methane from hydrates; (3) understand and quantify the dual roles of methane hydrates in the global carbon cycle and their relationship to global climate change; and (4) respond to industry concerns regarding the safety and sea floor stability issues and pipeline plugging concerns attributed to methane hydrates which are currently associated with the exploration, production, and transportation of conventional hydrocarbons. The R&D Program is framed as four technology areas which will share data, theoretical concepts, and results. Furthermore, the activities within each technology area will not occur separately nor sequentially; data collection, laboratory experiments, modeling, and field validation will proceed in parallel to promote synergy. Aggressive technology transfer activities, including an on-line database, will stimulate research and serve to monitor and sustain its quality while avoiding duplication of efforts.

The four technology areas are:

(1) Resource Characterization

This key activity includes the work required to prepare, analyze, evaluate, and develop the databases, mapping systems, and models necessary to understand and characterize methane hydrate deposits in the geologic environment, and accurately estimate the methane resource available in hydrate deposits. Much of the information accrued in this activity will also provide the basis for the Global Carbon Cycle and Safety and Sea Floor Stability research areas.

(2) Production

The goal of this activity is to develop the knowledge and technology needed for commercial production of methane from oceanic and/or permafrost hydrate systems by 2015. Specifically, the activity will develop the foundation of basic scientific information necessary for the safe, environmentally responsible, and commercially attractive production of methane from hydrates. Reservoir and process engineering modeling, and economic analyses will be conducted; and conventional recovery technologies, along with novel, innovative alternative recovery technologies will be tested and evaluated.

(3) Global Carbon Cycle

Natural releases of methane from hydrates may add to the atmospheric carbon budget either directly as methane, or indirectly as carbon dioxide, through chemical or biological oxidation. Conversely, utilization of methane from hydrates would provide a vast resource of low-carbon fuel that could displace more carbon-intensive fossil fuels as part of a strategy for reducing atmospheric levels of anthropogenic greenhouse gases. This activity seeks to understand and quantify the dual roles of hydrates in the global carbon cycle and their relationship to global climate change.

(4) Safety and Sea Floor Stability

This activity will be co-developed and integrated with the Resource Characterization effort. Early emphasis will be focused on near-term solutions to the petroleum industry's concerns of both safety and sea floor stability, due to methane hydrate occurrence associated with the exploration, production, and transportation of conventional hydrocarbons. A report, *Advanced Mitigation Recommendations*, will document the findings in this research effort, and offer practical solutions, optimally providing low-cost problem recognition/avoidance solutions. Possible and predictable future trends in global warming effects that could exacerbate safety and/or sea floor stability due to hydrate dissociation will be monitored and activities adjusted accordingly.

The mission of the **National Methane Hydrate Multi-Year R&D Program** is to carry out the research, development, and demonstration necessary to identify and enhance options that could revolutionize 21st century energy markets through the commercial production of methane from hydrates in a safe and environmentally responsible manner.

Acknowledgments

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NATIONAL METHANE HYDRATE MULTI-YEAR R&D PROGRAM PLAN

1. PROGRAM OVERVIEW

1.1 Background

Methane hydrates represent a potentially enormous natural gas resource. The utilization of the methane contained in natural gas hydrates would eliminate concerns regarding the adequacy of domestic energy resources and mitigate global climate change effects by displacing more carbon-intensive fuels with methane. If it is determined that the safe production of methane from hydrates is technically feasible and economically viable, the Nation's economic growth would be revolutionized, long-term energy security would be ensured, and environmental quality would be improved.

Hydrates are clathrate compounds: solid, ice-like materials containing molecules of gas bound in a lattice of water molecules. Methane hydrates are stable under conditions of low temperature and high pressure and thus, are found on ocean slopes at several hundred to several thousand feet deep, and under the permafrost in arctic regions. Developments in the last five years have both broadened and deepened interest in recovering natural gas hydrates as a source of methane gas.

The amount of methane in hydrates around the world is estimated to be 700,000 Tcf, many times the estimated total of worldwide conventional resources of natural gas and oil.[1] Domestically, resources are estimated in the range of 100,000 to 300,000 Tcf [2] with major deposits located off the Carolina coasts and in the deep-water portions of the Gulf of Mexico slope, and beneath the permafrost in Alaska. The wide geographical distribution of offshore deposits may provide a source of natural gas for otherwise gas-poor regions. India is planning a multi-year program in hydrates. Japan has undertaken a significant multi-year program to understand the potential of methane hydrates in deposits offshore Japan.

Methane hydrates have been a major research topic for many years. Previous research programs have attempted to quantify the world's methane hydrate resources and find a practical, safe, and environmentally acceptable approach to produce an abundant supply of natural gas from them. The Department of Energy (DOE) Office of Fossil Energy (FE) conducted a multi-agency, academia, and industry methane hydrate research program from 1982 to 1992, funded at levels averaging less than $1 million per year, investing about $8 million total. Although significant progress in hydrate identification and characterization was made, there is still considerable uncertainty as to the quantity, quality, and location of methane hydrate resources in and around the U.S. and worldwide, and judicious ways to make use of them. Many questions remain to be researched, including fundamental thermodynamic and kinetic properties; safety, and the environmental impact of production schemes; the economics of production; and the possible disposal of CO_2 emissions as hydrates in the same vicinity where the methane is produced. Since

termination of that program, limited research activities have continued at the U.S. Geological Survey (USGS), Naval Research Laboratory (NRL), the Ocean Drilling Program (ODP), several universities, and in other countries. Japan initiated, in 1995, a five-year program in hydrates research of over $50 million to determine if methane recovery from their offshore deposits is feasible. This program ends in April 1999, and a second five-year program is currently being planned.

In its 1997 ***Report on Energy Research and Development for the Challenges of the Twenty-First Century***, the President's Committee of Advisors on Science and Technology (PCAST) included a principal recommendation that DOE/FE develop a science-based program with industry, the USGS, Minerals Management Service (MMS), U.S. Environmental Protection Agency (EPA), and the U.S. Department of the Navy to "understand the potential of methane hydrates worldwide." In its review, the PCAST specifically addressed questions related to the appropriateness of Government investments in fossil energy research and development (R&D) and reached the following conclusions:

> "Oil and gas will almost certainly continue to be significant energy sources for the U.S. into the middle of the 21st century. The responsible energy R&D policy will acknowledge that reality and be designed to assure that the U.S. can meet the strategic objectives of enhancing National security, mitigating environmental risk, and providing low-cost energy sources.
>
> Congress and the Administration have, through the budget process, established de facto policies in support of continued fossil fuel use. The PCAST report supports efforts to develop a portfolio approach to energy R&D that stresses the clean use of fossil fuels, as well as development of non-fossil energy sources and energy-efficient technologies. Currently, fossil fuels fulfill over 85 percent of the Nation's energy requirements, and this percentage will likely decline only slowly.
>
> These questions [addressed by the PCAST] suggest an issue of whether Government R&D should fund the production of more oil and gas or the reduction of its use. Clearly, R&D should attack both aspects of the problem. Since it is generally assumed that the economy will grow and require increased energy services, it is important to be able to supply energy at low cost, use it as efficiently as possible, and minimize the environmental impact. More than half of the present U.S. oil supply is imported, and that fraction will increase according to Energy Information Administration (EIA) projections. Without natural gas production, the oil import volume would be much larger. Assuming highly effective oil conservation measures and significant replacement by alternative energy sources, the U.S. will still continue to
> import oil."

PCAST recommended that a National Methane Hydrates program should be a coordinated multi-agency effort in partnership with industry:

> "The research agenda should be formulated with FE leadership, and Energy Research (ER) [now the Office of Science in DOE], the USGS, MMS, EPA, and the U.S. Department of the Navy (NRL), at least, should be involved in the formulation. The Program should be developed jointly with the oil and gas industry. It should also seek strategic ties with key countries. The budget for this Program could start at a few million dollars a year to develop a comprehensive R&D agenda. Carrying out the Program should be the combined efforts of the private sector, other agencies, and the international community."

The PCAST view was that methane hydrates were not being addressed adequately in FE R&D programs, and that more emphasis was needed through applicable R&D. The PCAST suggested an initial funding level of $5 million for Fiscal Year 1999, rising to $11 million in FY 2001, and $12 million in FY 2003. The current consensus of DOE and its industry and academic advisors, based upon the additional knowledge acquired in the last year, is that a methane hydrates R&D program of $150 to $200 million over a ten-year period will be needed to accomplish mission goals.

In addition to the PCAST recommendation for an initiative on methane hydrates, draft legislation – U.S. Senate Bill S. 330 and the U.S. House of Representatives companion Bill H.R. 1753, *The Methane Hydrate Research and Development Act of 1999* – promotes the research, identification, and development of methane hydrate resources. This is an authorization bill and thus does not appropriate funds, but these House and Senate actions clearly indicate Congressional support for a National R&D program. The Act is expected to be enacted into law in 1999.

DOE/FE, with the cooperation of the USGS, MMS, EPA, NRL, the National Science Foundation (NSF), in particular ODP, the National Laboratories, academia, industry, and other collaborating agencies and organizations are poised to implement an R&D program which builds upon the existing knowledge base to investigate and obtain the information necessary to bring methane hydrates into the natural gas resource base. The Program promotes the introduction of critically needed information, which would not otherwise be available in the marketplace, enabling the private sector to further develop and safely apply the new technologies commercially.

The Federal role provides for the coordination, integration, and synthesis of research efforts necessary to: (1) establish an estimate of gas resources from methane hydrate deposits; (2) develop the technology necessary for the commercial production of methane from hydrates; (3) understand and quantify the role of methane hydrates in the global carbon cycle and their relationship to global climate change; and (4) respond to industry concerns regarding the safety and sea floor stability issues and other engineering problems attributed to methane hydrates that

are currently associated with the exploration, production, and transportation of conventional hydrocarbons.

Particular emphasis will be focused on whether the safe production of natural gas from natural gas hydrate deposits is technically and economically feasible. Successful completion of these efforts will:

- Provide a comprehensive database on resources, production possibilities, sea floor stability, safety, and environmental/climate considerations;
- Remove technological barriers preventing resource extraction by 2010;
- Address industry's concerns for safety in such an environment, both for the production of gas from hydrates as well as for the production of conventional resources in hydrate zones;
- Provide guidelines for commercial production of this resource by 2015;
- Ensure national energy security; and,
- Have the U.S. well represented in the global marketplace.

Coordination of domestic activities with those conducted internationally will help to accelerate development of the knowledge base relative to resource characterization and recovery. In addition, the environmental portion of the Program will complement ongoing research on global carbon cycles and CO_2 sequestration, and will help to ensure a sustainable clean-air environment for the U.S. and the world.

This Program will have a regional focus, which will leverage existing data and petroleum industry experience and infrastructure to reduce costs and accelerate R&D. Onshore Arctic Alaska will be an initial target area for well-logging and production tests; existing industry onshore operations and infrastructure will lower cost and reduce risk. Another primary focus area will be offshore in the Gulf of Mexico, where conventional operations in hydrate-bearing areas stimulate interest in hydrates risk analysis and mitigation technologies. The proximity of hydrates to production and transportation infrastructure in both areas improves the potential economics of methane production, attracting industry interest; industry R&D is likely to focus on drilling hazard and pipeline plugging mitigation. These areas are also targeted because of the volume of existing seismic and well-log data. Global carbon cycle and sea floor stability R&D efforts will be focused offshore on the east and west coasts of the U.S. and the Gulf of Mexico, building on prior studies and regional oceanographic expertise.

The National Methane Hydrate R&D Program subscribes to the PCAST recommendations for a science-based technology program. While its goals relate to the determination of the extent of the methane hydrate resource and the economic commercial production of natural gas from this resource, the basis for achieving these goals is embodied in the scientific understanding of the nature of methane hydrates including their formation, dissociation, structure, and properties. It is through this scientific understanding of methane hydrates that this Program expects to develop to the point of deployment those options for production of natural gas from methane hydrates in a safe and environmentally acceptable manner.

[1] Kvenvolden, Keith A., 1993, "A Primer on Gas Hydrates," The Future of Energy Gases, Ed. David G. Howell, U.S. Geological Survey Professional Paper 1570

[2] Collett, T. S., 1995, "Gas Hydrate Resources of the United States," National Assessment of United States Oil and Gas Resources – Results, Methodology, and Supporting Data, Ed. D. L. Gautier, et al, U.S. Geological Survey Digital Data Series 30.

1.2 National Needs

DOE and its partners promote secure, competitive, and environmentally responsible energy systems that serve the needs of the public by:

- Reducing the vulnerability of the U.S. economy to disruptions in energy supplies;
- Ensuring that a competitive electricity generation industry is in place that can deliver adequate and affordable supplies with reduced environmental impact;
- Increasing the efficiency and productivity of energy use, while displacing more carbon intensive fossil fuels with natural gas;
- Supporting and promoting U.S. energy, environmental, and economic interests in global markets; and
- Carrying out information collection, analysis, and research that will facilitate development of informed positions on long-term energy supply and use of alternatives.

The DOE Gas Hydrates Plan will include major initiatives for DOE to work with the USGS, MMS, the NRL, NSF, ODP, EPA, the National Laboratories, individual universities, university consortiums, and industry to evaluate the production potential of natural gas hydrates in U.S. coastal waters and worldwide. The resource for the U.S. is very large indeed, 50 to 200 times the U.S. resource base. Further, research might well facilitate the sequestration of CO_2 as a hydrate.

1.2.1 Mission

DOE, in partnership with its stakeholders, undertakes and promotes activities and establishes policies to maximize the Nation's ability to supply, transport, and use natural gas to encourage economic growth, enhance National security, and improve the environment. The mission of this Program will be to carry out research development and demonstration activities, which will help identify and enhance options that could revolutionize 21st century energy markets through the production of gas from hydrates.

1.2.2 Vision

The **National Methane Hydrate Multi-Year R&D Program** will enable safe and economic production of natural gas from methane hydrate resources and assessment of the impact on the global carbon cycle of these very large resources. Gas from hydrate deposits, a potentially significant addition to the total natural gas resource base, could become a domestically abundant and reliable source of clean energy that can be a major contributor to the Nation's economic growth, energy security, and environmental quality.

1.2.3 Program Goals and Strategies

The overall goal of natural gas hydrate research is to evaluate and understand the methane hydrate deposits in order to make the resource commercially accessible and to determine their role in the global carbon cycle and seafloor stability. The objectives required to achieve this goal are to: (1) validate the extent of the resource and its reserve potential, (2) develop the exploration and production technology to the proof-of-concept level, (3) quantify the role of hydrates in the global carbon cycle, and (4) understand the impact of hydrates on near-sea floor sediments and sedimentary processes, including sediment mass movement. As outlined in ***A Strategy for Methane Hydrates Research & Development*** (DOE/FE, August 1998), these Program objectives will be achieved through a four-pronged approach:

(1) Determine the location, extent, sedimentary relationships, and physical characteristics of methane hydrate deposits to assess their potential as a domestic and global fuel resource.

(2) Develop the knowledge and technology necessary for commercial production of methane from oceanic and/or permafrost hydrate systems by 2015.

(3) 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.

(4) Develop an understanding of hydrate systems in near-sea floor sediments and sedimentary processes, including sediment mass movement and methane release, so that safe, standardized procedures for hydrocarbon production and ocean engineering can be ensured.

1.2.4 Near-Term Benefits/Products (Within 5 Years)

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

- Assessment of the location and volume of methane hydrate resources for use in energy policy decision making;

- Techniques to mitigate methane hydrate formation in pipelines and production facilities in the Arctic and offshore;

- Practical means to avoid or mitigate the potential hazards of overlying hydrate deposits to conventional oil and gas production in the Gulf of Mexico;
- Improved seismic and other geophysical tools for hydrates identification and characterization for use by the petroleum industry, military, and others;
- Engineering concepts for production of gas from natural gas hydrate deposits;
- Databases containing ocean and atmospheric changes and coupling, for use in enhanced global climate modeling, including thermodynamic data applicable to CO_2 sequestration; and
- Pressure/temperature-controlled biologic sampling devices for low temperature, high pressure environments, which could be a prototype for National Aeronautics and Space Administration (NASA) biologic samplers for the more extreme environments found on the planet Mars.

1.2.5 Mid-Term Benefits/Products (5 to 10 Years)

The Program will yield the following mid-term benefits and products:

- Improved estimates of recovery potential from the natural gas hydrate useful in guiding energy policy and planning;
- Advanced techniques to detect and analyze formation and reservoir systems; and
- New or advanced production technologies, including tests of engineering concepts, for production of natural gas.

1.2.6 Long-Term Benefits/Products (10 to 15 Years)

Long-term, the Program will ultimately lead to an increased supply of cleaner fuel through development of a suite of technologies necessary for commercial production of methane from Arctic and marine hydrates, based on field testing and verification of improved geophysical technologies, production concepts, and reservoir model development for natural gas hydrate recovery.

1.2.7 Technology Transfer

Technology transfer will be aggressively pursued by Government program managers. Program participants will be expected to communicate their results in publications and technical meetings. An on-line database will be established and maintained to facilitate the prompt exchange of information. Aggressive technology transfer activities will stimulate research and serve to monitor and sustain its quality and prevent duplication of efforts.

Active involvement of industry in all levels of the Program from program design to joint R&D projects, along with universities and National laboratories, will ensure the rapid adoption of new concepts and technologies. Scientific and technical exchange will also be fostered through periodic conferences and the publication of project results in scientific and technical journals. Noteworthy publications will be posted on the Internet.

1.2.8 R&D Program Elements

The Program's R&D elements rest on the premise that introduction into the marketplace of critically needed information, which would not otherwise be available, will enable the private sector to further develop and apply the new technology, and will lead to the establishment of environmentally acceptable and economically attractive extraction techniques.

The R&D elements of this Program focus on a speculative resource which could contribute to an abundant, environmentally conscientious, and secure future energy supply. The enormous resource potential of natural gas hydrates justifies a high-risk search for breakthrough technologies that can recover this methane. Some research will consist of detailed descriptions of the resource to refine the definition of the constraints that an effective extractive technology will have to overcome.

The Program will have a regional focus, which will leverage existing data and petroleum industry experience and infrastructure to reduce costs and accelerate R&D. Onshore Arctic Alaska will be an initial target area for well-logging and production tests; existing industry onshore operations and infrastructure will provide lower cost and reduced risk. A parallel focus area will be offshore in the Gulf of Mexico, where conventional operations in hydrate-bearing areas have stimulated interest in analysis of hydrate risk to seafloor and facilities stability and mitigation technologies. The proximity of hydrates to the production and transportation infrastructure in the Gulf improves the potential economics of methane production, attracting industry interest. These two areas are also targeted because of the volume of existing seismic and well-log data. The global carbon cycle and sea floor stability R&D efforts will be focused on the east and west coast offshore areas of the U.S. as well as the Gulf of Mexico and Hawaii, building on prior studies and regional oceanographic expertise.

The relative level of effort in the four technology areas and the changes expected in technical emphasis as the Program progresses are depicted in **Figure 1 – R&D Funding Evolution**. 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 Sea floor Stability" areas will receive generally steady funding commitments, reflecting both near-term and long-term research needs. Actual relative funding levels may vary from this chart because periodic reviews of R&D findings and needs will govern future funding.

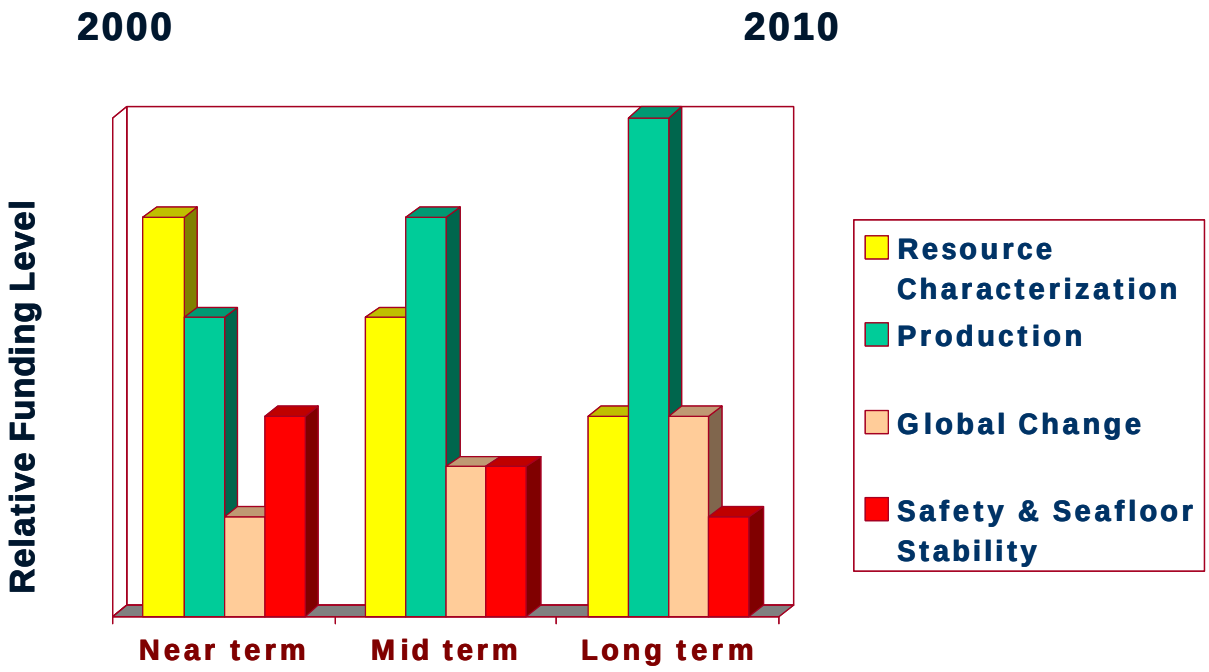

Figure 1 – R & D Funding Evolution

4. R&D ELEMENTS

2.1 Resource Characterization

This key activity will involve the data compilation, field and laboratory studies, and model development necessary to understand and measure natural gas hydrate deposits in the geologic environment and to accurately assess the potential methane resource. This work will provide information to all program areas: resource characterization, production, sea floor stability, and environmental issues.

2.1.1 Resource Assessment (Near-Term)

Collect, organize, and make easily accessible to the research community and policymakers existing data on hydrate properties and occurrence.

2.1.1.1 Historical/Bibliographic/Contractor Information

2.1.1.2 Geologic Information

2.1.1.3 Physical Property Information

2.1.1.4 Location Maps

2.1.2 Laboratory Studies

This work effort will include the adaptation of qualified existing laboratory facilities and development of necessary gas hydrate test facilities.

2.1.2.1 Hydrate Analysis: Provide analysis in the laboratory setting of natural gas hydrate samples recovered from the field and prepared in the laboratory.

2.1.2.2 Crystallography Studies: Increase understanding of hydrate crystallography, its changes with composition, and its potential impact on geologic characteristics, kinetic and thermodynamic data, and production.

2.1.2.3 Pore Water Chemistry

2.1.2.4 Biochemistry of Natural Gas Hydrates

2.1.2.5 Temporal History Studies

2.1.2.6 Geo-Strata Water Movement/Behavior During Gas Hydrate Formation

and Dissociation

2.1.2.7 Thermodynamic Studies in Porous Media

2.1.2.8 Kinetic Studies

2.1.2.9 CO_2 Hydrate Study Results Integration

2.1.3 Field Geophysical, Geochemical, and Microbiological Studies

Development of diagnostic criteria and instrumentation that can aid the explorationist in locating and defining hydrate reservoirs and their geometries.

2.1.3.1 Seismic Interpretation: Studies will be required to update interpretation methods and develop new techniques for both surface and sub-surface geophysics.

2.1.3.2 Well-Logging: Studies are needed to further evaluate well-logging techniques in both onshore and offshore environments.

2.1.3.3 Geophysical: This work activity will include the collection, preparation, and evaluation of a wide variety of geophysical technologies.

2.1.3.4 Geochemical: These efforts will provide information for evaluating the existence of natural gas hydrates within both onshore and offshore areas.

2.1.3.5 Microbial Processes: This effort will involve generation of methane for hydrates formation, hydrates dissociation, and tracking of released methane.

2.1.3.6 Novel Well-Logging Techniques

2.1.4 Predictive Models

Develop models based on laboratory measurement of physical and chemical properties of natural gas hydrate formation and decomposition.

2.1.4.1 Physical/Chemical Properties: This work effort will require the use of information from physical/chemical tests of laboratory and field samples.

2.1.4.2 Geological Modeling: Develop predictive tools to model where natural gas hydrates are likely to be found.

2.1.4.3 Geophysical Modeling: Model geophysical response of naturally occurring hydrates.

2.1.5 Resource/Reserve Assessment (Mid-Term)

Refined resource estimates will be developed through the evaluation of laboratory and field testing and sampling technologies, both onshore and offshore. The development of reserve estimates requires a more detailed understanding of the natural gas hydrate reservoir and its relationship to the surrounding geologic formations.

2.1.5.1 Reservoir Natural Gas Quality: This element requires development of information on the composition of naturally-occurring gas hydrates.

2.1.5.2 Reservoir Natural Gas Quantity: Work will require development of systems to better quantify the amount of natural gas existing in the hydrate stability zone (HSZ).

2.1.5.3 Associated Free Gas: Research will be required to better understand the relationship between natural gas hydrate deposits and associated free gas.

2.1.5.4 Multi-disciplinary Interaction: Compilation and correlation of geologic, geophysical, and geochemical data.

2.1.6 Economic Validation (Long-Term)

The cost of gas hydrate production will be compared with variations of previous cost parameters to determine the production economics from the wellbore to the marketplace.

2.1.6.1 Production Cost Estimates: Effort will focus on the development of better understanding of the cost associated with the production of natural gas from hydrate formations.

2.1.6.2 Impact of Resource Development: This effort requires the assessment of the location and extent of world gas hydrate formations.

2.1.6.3 Economics: Effort will define economic target identification strategy, determine effects of sediment mass on hydrate occurrence, and define economic targets for both U.S. and global markets.

2.1.6.4 Field Validation: Validate quantitative research data.

2.1.7 Technology Development

Develop and adapt the technologies required to collect, identify, and measure gas hydrates resources.

2.1.7.1 Development and Integration of Seismic, Sonar, and Well-Logging Technologies for Imaging and Measuring Hydrates

2.1.7.2 Development of Pressure/Temperature Controlled Coring

2.1.7.3 Development of Monitoring Sensors and Samplers for Sub-Sea and Sub-Surface Hydrates and Methane Release

GAS HYDRATES PROGRAM PLAN: RESOURCE CHARACTERIZATION

Activities and Sub-elements	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
1) Resource Characterization										
Resource Assessment (Near-Term)										
Historic / Bibliographic / Contractor Information										
Geologic Information										
Physical Property Information										
Location Map										
Laboratory Studies										
Hydrate Analysis										
Crystallography Studies										
Pore Water Chemistry										
Biochemistry and Natural Gas Hydrates										
Temporal History Studies										
Geo-Strata Water Movement and Behavior										
Thermodynamic Studies in Porous Media										
Kinetic Studies										
CO2 Hydrate Study Results Integration										
Field Geophysical, Geochem., & Microbial Studies										
Seismic Interpretation										
Well Logging										
Geophysical										
Geochemical										
Microbial Processes										
Novel Well-logging Techniques										
Model Hydrate Properties										
Physical / Chemical Properties										
Geological Modeling										
Geophysical Modeling										
Resource / Reserve Assessment (Mid-Term)										
Reservoir Natural Gas Quality										
Reservoir Natural Gas Quantity										
Associated Free Gas										
Multi-disciplinary Interaction										
Economic Validation (Long-Term)										
Production Cost Estimates										
Impact of Resource Development										
Economics										
Field Validation										
Technology Development										
Development of Seismic, Sonar, & Well-Logging Technologies										
Development of Pressure/Temperature Controlled Coring										
Dev. of Monitoring Sensors and Samplers for Subsea Hydrates										

Table 1 – Gas Hydrates Program Plan: Resource Characterization

Deliverables and Milestones: Resource Characterization		
Activity	**Deliverable**	**Date**
2.1.1	Create database of historic hydrate research.	**FY01**
2.1.1	Create Atlas of known occurrences/ Depositional Environment Characteristics.	**FY04**
2.1.1	Update Atlas.	**FY06**
2.1.2	Complete laboratory analyses for input into reservoir models.	**FY04**
2.1.2	Update laboratory analyses for input into reservoir models.	**FY09**
2.1.3	Report on status of instrumentation for field application.	**FY04**
2.1.3	Update report on status of instrumentation for field application.	**FY09**
2.1.4	Complete report on geological/geophysical property models and hydrate evaluation.	**FY05**
2.1.4	Update report on geological/geophysical property models and hydrate evaluation.	**FY09**
2.1.5	Update resource and reserve estimates.	**FY06**
2.1.6	Economic Evaluation.	**FY04**
2.1.6	Economic Evaluation update.	**FY09**

Table 2 – Deliverables and Milestones: Resource Characterization

2.2 Production

The goal of the Production activity is to develop the knowledge and technology necessary for commercial production of methane from oceanic and permafrost hydrate systems. Specifically, the Program will:

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

2.2.1 Primary Production Research (Near-Term)

Hydrate production is possible using depressurization, thermal stimulation, solvent injection, and although highly unlikely, physical removal (mining) – a remote possibility. 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 hydrate formation and inhibition that can be adapted to this Program. The Primary Production Research (or near-term) phase will compile and evaluate work done to date and prepare (via information management, model development, and reservoir and economic analyses) a basis for systematic progress toward field test design and field demonstration of the most promising production systems.

2.2.1.1 On-Line Production Database

The database will be maintained and updated at regular intervals and will be accessible to the participating entities over the Internet. It will incorporate drilling and well test results.

2.2.1.1.1 Sample Characterization and Identification of Technology Gaps

2.2.1.1.2 Obtain Input and Update with Drilling/Program Results

2.2.1.2 Physical Process Modeling

Numerical modeling inherently requires the mathematical representation of a physical system. The better the input parameters and assumptions (e.g., thermodynamic properties, phase behavior, rate of heat transfer, formation and dissociation kinetics, mechanisms governing dissociation, and geologic properties) are in a model, the

better the predictive capability of the model. Future program decisions regarding production will rely heavily on the forecasts of numerical reservoir simulations. It is, therefore, imperative that laboratory measurements are comprehensive and that they are rigorously reviewed to provide a robust foundation upon which reliable production models can be constructed.

2.2.1.2.1 Sample Review and Lab Measurements

2.2.1.2.2 Develop Production Models

2.2.1.3 Preliminary Reservoir Engineering

Preliminary reservoir engineering will focus on known hydrate deposits and their reservoir characteristics; the study will also initiate development of improved analyses and test designs which will support subsequent field testing and system demonstration.

2.2.1.3.1 Onshore Site Selection and Test Design

2.2.1.3.2 Offshore Site Selection and Drilling Criteria Specification

2.2.1.4 Preliminary Production Modeling and Demonstration Design

Sub-elements within this activity form the beginning of information gathering for production model development.

2.2.1.4.1 Analyze Prior/Collaborative Production Test Results

2.2.1.4.2 Preliminary Pilot Facility Development

2.2.1.5 Preliminary Commercial and Alternative Methods Evaluation

Sub-elements include the initial information gathering for current state-of-the-art production systems and for system design for future field testing. Results of this activity will feed the more complex system and economic studies anticipated for the mid- and long-term portions of the Program. This activity provides some of the earliest production information for improved model development and more complex production test planning.

2.2.1.5.1 State-of-the-Art and Innovative Production Methods Evaluation

2.2.1.5.2 Sample Collection & Production Testing of Onshore Well

2.2.2 Reservoir Simulation and Process Design (Mid-Term)

Mid-term studies focus on preparation for drilling hydrate and free-gas zones, emphasizing refinement of drilling techniques, development of field test models, and calibration of well and remote sensing data. This work involves integrated system development and supports follow-on long-term work, where additional drilling and testing will validate models, confirm findings, and develop the techniques necessary for commercial production.

2.2.2.1 Reservoir Engineering

This activity combines current process model results with reservoir modeling to support an effective process for site selection and production test design.

2.2.2.1.1 Select Offshore Sites

2.2.2.1.2 Develop Field Test Reservoir Model

2.2.2.1.3 Pilot Reservoir Studies for Model Verification

2.2.2.2 Commercial/Alternative Process Design

The focus of this activity is to test instrumentation and processes for optimization of field test design and implementation. It also provides the first detailed study of potential alternative production systems for further improving production economics.

2.2.2.2.1 Develop Downhole Instrumentation for Logging Deposits

2.2.2.2.2 Establish Alternative Production Technology

2.2.2.2.3 Preliminary Economic Analysis

2.2.3 Production Testing: Demonstration Well & Alternative Production Evaluation (Long-Term)

The focus of long-term studies will be to validate models, confirm findings, and develop the best techniques necessary for commercial production.

2.2.3.1 Process Model Validation

This activity focuses on the later stage of model development and validation with

increased emphasis on field test planning and forecasting.

2.2.3.1.1 Calibrate Model with Field Results

2.2.3.1.2 Predict Demonstration Well Results

2.2.3.2 Evaluation of Commercial Potential of Demonstration Well Sites

This activity utilizes the best models and knowledge gathered to date to assist industry partners in optimizing the site selection and testing of (a) demonstration well(s).

2.2.3.2.1 Drill Sampling Wells to Evaluate Potential Demonstration Sites

2.2.3.2.2 Technical and Economic Analyses of Demonstration Wells

2.2.3.2.3 Demonstration Well Site Selection Assistance

2.2.3.2.4 Support for Industry – Design, Construction, and Testing of Demonstration Well

2.2.3.2.5 Demonstration Production Analysis

2.2.3.3 Evaluate Program Accomplishments

This activity summarizes the Production activity results for entry into the Project information database. It also should provide the "blueprint" for industry efforts for further commercial hydrate production efforts and define any additional areas for potential optimization of production economics.

2.2.3.3.1 Select Novel Technology Facility Fabricator

2.2.3.3.2 Technical and Economic Analysis of Demonstration Well

2.2.3.3.3 Final Calibration of Production Model

GAS HYDRATES PROGRAM PLAN: PRODUCTION

Activities and Sub-elements	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
2) Production										
Primary Production Research (Near-Term)										
On-Line Production Database										
Sample Characterization & Ident. of Technology Gaps										
Obtain Input and Update with Drilling/Program Results										
Physical Process Modeling										
Sample Review and Lab Measurements										
Develop Production Models										
Preliminary Reservoir Engineering										
Onshore Site Selection & Test Design										
Offshore Site Selection & Drilling Criteria Specification										
Preliminary Production Modeling and Demo. Design										
Analyze Prior/Collaborative Production Test Results										
Prelim. Pilot Facility Development										
Preliminary Commercial & Alternative Methods Evaluation										
State-of-the-Art and Innov. Prod. Methods Evaluation										
Drill Exploratory Onshore Well										
Reservoir Simulation and Process Design (Mid-Term)										
Reservoir Engineering										
Select Offshore Sites										
Develop Field Test Reservoir Model										
Pilot Reservoir Studies for Model Verification										
Commercial/Alternative Process Design										
Develop Downhole Instrumentation for Logging Deposits										
Establish Alternative Production Technology										
Preliminary Economic Analysis										
Prod. Testing: Demo. Well & Alt. Prod. Evaluation (Long-Term)										
Process Model Validation										
Calibrate Model with Field Results										
Predict Demonstration Well Results										
Evaluation of Commercial Potential of Demo. Well Sites										
Drill Sampling Wells to Evaluate Potential Demo. Sites										
Tech. and Economic Analyses of Potential Demo. Wells										
Demonstration Well Site Selection Assistance										
Support for Industry Demonstration Well										
Demonstration Production Analysis										
Evaluate Program Accomplishments										
Select Novel Technology Facility Fabricator										
Tech. and Economic Analysis of Industry Demo. Well										
Final Calibration of Production Model										

Table 3 – Gas Hydrates Program Plan: Production

Deliverables and Milestones: Production		
Activity	**Deliverable**	**Date**
2.2.1	Design for onshore well test.	**FY01**
2.2.1	Onshore well data collection and production test.	**FY03**
2.2.1	Engineering and geological analyses of results from prior and collaborative field tests, and identification of technology gaps for subsequent program planning.	**FY05**
2.2.1	Computerized, experimentally tested, laboratory-scale model for thermally controlled production of gas by depressurization.	**FY07**
2.2.1	Computerized, experimentally tested, laboratory-scale model for production of gas by injection of thermal fluid.	**FY07**
2.2.2	Geological and reservoir models for field test.	**FY04**
2.2.2	Preliminary economic analyses.	**FY04**
2.2.2	Complete development of new instrumentation for downhole logging.	**FY04**
2.2.2	Advanced laboratory-scale production models.	**FY07**
2.2.3	Complete reservoir studies for verification of reservoir model.	**FY08**
2.2.3	Make predictions for demonstration-well results.	**FY09**
2.2.3	Complete advanced reservoir model, calibrated with field results.	**FY10**
2.2.3	Assistance with Industry Demonstration-well (designed, tested, and completed).	**FY10**
2.2.3	Technical and economic analyses of demonstration well (completed and disseminated to all stakeholders).	**FY10**

Table 4 – Deliverables and Milestones: Production

2.3 Global Carbon Cycle

Natural releases of methane from hydrates add to the atmospheric carbon budget, either directly as methane, or indirectly as carbon dioxide through chemical or biological oxidation. On the other hand, utilization of this resource would provide additional low-carbon fuels that could be part of a strategy for reducing atmospheric levels of anthropogenic greenhouse gases. This activity seeks to understand and quantify the dual roles of hydrates in the global carbon cycle and their relationship to global climate change.

2.3.1 Mechanisms and Processes of Hydrate Flux (Near- to Mid-Term)

This work seeks to quantify the North American hydrate mass, that would be susceptible to global perturbations, and by extrapolation, provide an estimate of the susceptible hydrate mass worldwide. Information from the Resource Characterization activity (2.1) will be integrated into this effort. Mechanisms and processes that lead to destabilization of hydrates would also be determined. This would primarily include hydrates that exist in the upper stability margins in both oceans and permafrost regions.

2.3.1.1 Evaluation of Dispersed Hydrates

Hydrates that are finely dispersed in oceanic or permafrost sediments have little or no economic value, but may constitute the largest part of the hydrate mass and the part that is most susceptible to global warming. The goal is to assess their abundance and distribution, and characterize their physical and chemical composition.

2.3.1.2 Site Monitoring

Natural laboratory sites would be identified, implemented, and maintained throughout the Program to study areas where hydrates are susceptible to global warming. They would be located at natural hydrate outcrops and areas associated with venting of gases in the ocean and in permafrost regions that are expected to warm if global temperatures continue to rise.

To complete these studies, new tools, procedures, and models will need to be developed.

2.3.1.3 Impact of Climate Change on Hydrate Stability

The relationships between global warming and the stability of both dispersed and concentrated hydrate deposits will be determined by modeling and experimentation.

2.3.1.4 Sea Floor Stability and Release of Trapped Free Gas

The potential for catastrophic releases of free gas trapped below hydrate zones will be assessed and the role of dispersed hydrates in these events determined. These results will be used to broaden the scope of the other sea floor assessments obtained in this Program.

2.3.2 Consequences of Methane Release from Hydrates (Mid- to Long-Term)

The fate of methane released from hydrates will be assessed by observation and experimentation. Atmospheric, oceanic, and coupled models that incorporate these results will be developed or improved.

2.3.2.1 Oceanic/Atmospheric Studies

The fate of methane released into the ocean water column or into permafrost sediments will be determined.

2.3.2.2 Biological Studies

Biological factors impacting the conversion of methane to CO_2 will be investigated.

2.3.2.3 Application to Atmospheric, Ocean, and Climate Models

2.3.3 Methane Release in the Geologic Record (Near- to Mid-Term)

Most attempts to model the geologic history of the atmosphere have not incorporated hydrates. The impact of hydrates on atmospheric concentrations of greenhouse gases in the geologic past will be assessed and the information used to evaluate their current and future potential involvement in global change scenarios.

2.3.3.1 Compilation of Existing Data

2.3.3.2 Development of New Proxies

Hydrates do not leave a direct geologic marker. Better proxies will be sought to allow indirect inference of their existence in the geologic record.

2.3.3.3 Application to Ocean and Climate Models

2.3.4 Integrated Model Development (Long-Term)

The results of all work on this activity will be incorporated in state-of-the-art models to provide better understanding of the impact of hydrates on the global carbon cycle.

2.3.4.1 Combine Data into Integrated Models

The data obtained from actual hydrate studies and from the geologic record will be incorporated in integrated atmospheric, climatic, ocean, and terrestrial models concerned with the global carbon budget and flux.

2.3.5 Greenhouse Gas Mitigation (Near- and Long-Term)

The utilization of methane from hydrates has the potential for reducing the rate of carbon input into the atmosphere. This activity will assess the anticipated benefits and impacts. The ability of sediments to sequester CO_2 as a hydrate during or after methane removal will also be determined. Effects on sediment stability will also be determined. Both tasks will involve an initial assessment at the beginning of the Program and a final assessment after information has been gathered in the other program areas.

2.3.5.1 Environmental Benefits and Impacts

A full life cycle analysis and economic analysis will be performed on the hydrate production process. Accurate greenhouse gas mitigation potential will be determined.

2.3.5.2 CO_2 Storage Options

The potential for sequestering $CO_{2,}$ either during or after hydrate production, will be assessed and the greenhouse gas mitigation potential estimated.

GAS HYDRATES PROGRAM PLAN: GLOBAL CARBON CYCLE

Activities and Sub-elements	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
3) Global Carbon Cycle										
Mechanisms and Processes of Hydrate Flux (Near- to Mid-term)										
Evaluation of Dispersed Hydrates										
Site Monitoring										
Measurement and Protocol Development										
Impact of Climate Change on Hydrate Stability										
Seafloor Stability and Release of Trapped Free Gas										
Consequences of Methane Release from Hydrates (Mid- to Long-Term)										
Ocean/Atmospheric Studies										
Biological Studies										
Application to Ocean and Climate Models										
Methane Release in the Geologic Record (Near- to Mid-Term)										
Compilation of Existing Data										
Development of New Proxies										
Application to Ocean and Climate Models										
Integrated Model Development (Long-Term)										
Use Modern and Geologic Data in Ocean and Climate Models										
Greenhouse Gas Mitigation (Near- and Long-Term)										
Environmental Benefits and Impacts										
CO_2 Storage Options										

Table 5 – Gas Hydrates Program Plan: Global Carbon Cycle

Deliverables and Milestones: Global Carbon Cycle		
Activity	**Deliverable**	**Date**
2.3.1	Implement first natural laboratory monitoring site.	**FY01**
2.3.1	Report on the North American hydrate mass susceptible to global climate change.	**FY04**
2.3.1	Report on the stability of both dispersed and concentrated hydrates with respect to global climate change.	**FY04**
2.3.1	Publish estimate of worldwide hydrate mass susceptible to global climate change.	**FY05**
2.3.2	Report on the fate of methane released from oceanic and permafrost hydrates.	**FY07**
2.3.2	Development of new or improved ocean/atmospheric and climate models completed.	**FY09**
2.3.3	Report compilation of existing geologic data.	**FY02**
2.3.3	Report describing new proxies for hydrates relative to the geologic data.	**FY03**
2.3.3	Report on application of revised geologic data in ocean/atmospheric and climate models.	**FY07**
2.3.4	Report on integration of modern and geologic data into new ocean/atmospheric and climate models.	**FY09**
2.3.5	Provide initial assessment on the greenhouse gas mitigation potential of using methane from gas hydrates.	**FY01**
2.3.5	Provide initial assessment on sequestering CO_2 in gas hydrate containing sediments.	**FY03**
2.3.5	Complete final assessments on greenhouse gas mitigation potential and CO_2 storage options associated with gas hydrate production.	**FY09**

Table 6 – Deliverables and Milestones: Global Carbon Cycle

2.4 Safety and Sea Floor Stability

This activity will be co-developed and integrated with the Resource Characterization effort (Section 2.1). Early emphasis will be focused on near-term solutions to industry concerns of both safety and sea floor stability, due to natural gas hydrate occurrence associated with the exploration, production, and transportation of conventional hydrocarbons. These preliminary models will be upgraded in the mid-term to incorporate subsurface hydrate data obtained from early stage hydrate production modeling efforts (Section 2.2). Findings will be documented in a report on Advanced Mitigation Recommendations, which would conclude the Government's principal research effort to define safety and sea floor stability problems and offer practical solutions (if possible, offering low-cost problem recognition/avoidance solutions.) Field demonstration and testing of both safety and sea floor stability mitigation technology is envisioned as a cooperative/co-funded effort with the oil and gas industry, to be conducted if no other alternative is deemed feasible in 2.4.2. Possible and unpredictable future trends in global warming effects, that could exacerbate safety and/or sea floor stability due to hydrate dissociation, will be monitored and activities adjusted accordingly.

2.4.1 Basic Research in Safety and Sea Floor Stability (Near-Term)

Basic research will consist primarily of determining the risk factors associated with natural gas hydrate occurrence as related to conventional exploration, production, and transportation of hydrocarbons in the offshore marine environment. Data useful to modeling the safety and sea floor stability associated with the production of gas hydrates will be gathered during this period and included in the mid-term modeling effort of 2.4.2.

2.4.1.1 Safety/Risk Factor Research

Research establishing the risk factors associated with natural gas hydrate occurrence will be broadened to include worldwide offshore experiences and concerns. Database development, as above, will be integrated with Resource Characterization (Section 2.1). Model development will be specific to this problem and focused on rapid development of preliminary models (first year).

2.4.1.1.1 Develop Database of Hydrates-Related Safety Issues/ Incidents Worldwide

2.4.1.1.2 Develop Preliminary Models and Predictive Tools

2.4.1.1.3 Develop Preliminary Mitigation Recommendations

2.4.1.2 Sea Floor Stability Research

As with the Safety/Risk Factor Research (Section 2.4.1.1 above), Sea Floor Stability Research will incorporate worldwide data from industry experience and ongoing Geological and Geophysical studies of phenomena (sea floor faulting, slumping, etc.) believed to have occurred due to natural forces associated with hydrate deposits in the offshore environment.

2.4.1.2.1 Geological/Geophysical Studies

2.4.1.2.1.1 Integrate Studies with Resource Characterization Effort (Section 2.1)

2.4.1.2.1.2 Develop Preliminary Sea Floor Stability Models

2.4.2 Advanced Safety and Sea Floor Stability Model Development (Mid-Term)

The emphasis of this effort will be to develop the models that will forward the overall research effort to enable development of specific techniques/technology to mitigate problems defined by the collective industry experience as determined in 2.4.1 above.

2.4.2.1 Gas Hydrates Safety/Risk Factor Research Model Development

2.4.2.1.1 Develop Advanced Sea Floor Stability Models

2.4.2.1.2 Develop Advanced Mitigation Recommendations

2.4.3 Development and Field Demonstration/Testing of Safety and Sea Floor Stability Mitigation Techniques (Long-Term)

The goal of this effort is the development and testing of specific techniques/ technology to mitigate both problems of conventional hydrocarbon exploration, production, and transportation associated with gas hydrates, and problems associated with production of natural gas from gas hydrate deposits in the offshore environment. (Note: It is conceivable that this activity would be made minimal or unnecessary by a strategy that emphasizes awareness of defined safety solutions and avoidance of sea floor stability problems as determined in Section 2.4.2 above. It would continue only if there is no other option.)

2.4.3.1 Development of Sea Floor Safety Technology

2.4.3.1.1 Field Testing of Safety Technology

2.4.3.2 Development of Sea Floor Stability Mitigation Technology

2.4.3.2.1 Field Testing of Sea Floor Stability Mitigation Technology

GAS HYDRATES PROGRAM PLAN: SAFETY AND SEAFLOOR STABILITY

Activities and Sub-elements	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
4) Safety & Seafloor Stability										
Basic Research in Safety and Seafloor Stability (Near-Term)	High level research------- Low Level research------									
Safety/Risk Factor Research										
Devel. Database of Safety Issues/Incidents										
Devel. Preliminary Models and Predictive Tools										
Devel. Preliminary Mitigation Recommendations										
Seafloor Stability Research	High level research------- Low Level research									
Geological/Geophysical Studies										
Integrate Studies (w/Resource Characterization in 1)										
Develop Prelim. Seafloor Stability Models										
Advanced Safety & Seafloor Stability Model. Devel. (Mid-Term)										
Gas Hydrates Safety/Risk Factor Research Model Devel.										
Develop Advanced Seafloor Stability Models										
Develop Advanced Mitigation Recommendations										
Development & Field Demon./Testing of Safety and Seafloor										
Stabilty Mitigation Techniques (Long-Term)										
Development of Seafloor Safety Technology										
Field Testing of Safety Technology										
Development of Seafloor Stability Mitigation Tech.										
Field Testing of Seafloor Stability Mitigation Tech.										

Table 7 – Gas Hydrates Program Plan: Safety and Sea Floor Stability

Deliverables and Milestones: Safety and Sea Floor Stability		
Activity	**Deliverable**	**Date**
2.4.1	Complete basic research in safety and sea floor stability.	**FY05**
2.4.1	Completion of database of safety issues/incidents.	**FY00**
2.4.1	Completion of preliminary models and predictive tools.	**FY02**
2.4.1	Completion of preliminary mitigation recommendations.	**FY04**
2.4.2	Complete advanced safety and sea floor stability model development.	**FY07**
2.4.2	Complete development of advanced mitigation recommendations.	**FY07**
2.4.3	Complete development and field demonstration/testing of safety and sea floor stability mitigation techniques.	**FY09**
2.4.3	Complete field testing of safety technology.	**FY09**
2.4.3	Complete field testing of sea floor stability mitigation technology.	**FY09**

Table 8 – Deliverables and Milestones: Safety and Sea Floor Stability