H.R. 1753 AND S. 330, METHANE HYDRATE RESEARCH AND DEVELOPMENT ACT OF 1999

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY
AND MINERAL RESOURCES

OF THE

COMMITTEE ON RESOURCES
HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTH CONGRESS

FIRST SESSION

ON

H.R. 1753, THE METHANE HYDRATE RESEARCH AND DEVELOPMENT ACT OF 1999, TO PROMOTE THE RESEARCH, IDENTIFICATION, ASSESSMENT, EXPLORATION, AND DEVELOPMENT OF METHANE HYDRATE RESOURCES, AND FOR OTHER PURPOSES;

S. 330, THE METHANE HYDRATE RESEARCH AND DEVELOPMENT ACT OF 1999, TO PROMOTE THE RESEARCH, IDENTIFICATION, ASSESSMENT, EXPLORATION, AND DEVELOPMENT OF METHANE HYDRATE RESOURCES, AND FOR OTHER PURPOSES

MAY 25, 1999, WASHINGTON, DC

Serial No. 106–32

Printed for the use of the Committee on Resources

Available via the World Wide Web: http://www.access.gpo.gov/congress/house
or
Committee address: http://www.house.gov/resources

U.S. GOVERNMENT PRINTING OFFICE
58–645 ⇆ WASHINGTON : 1999

COMMITTEE ON RESOURCES

DON YOUNG, Alaska, *Chairman*

W.J. (BILLY) TAUZIN, Louisiana
JAMES V. HANSEN, Utah
JIM SAXTON, New Jersey
ELTON GALLEGLY, California
JOHN J. DUNCAN, Jr., Tennessee
JOEL HEFLEY, Colorado
JOHN T. DOOLITTLE, California
WAYNE T. GILCHREST, Maryland
KEN CALVERT, California
RICHARD W. POMBO, California
BARBARA CUBIN, Wyoming
HELEN CHENOWETH, Idaho
GEORGE P. RADANOVICH, California
WALTER B. JONES, Jr., North Carolina
WILLIAM M. (MAC) THORNBERRY, Texas
CHRIS CANNON, Utah
KEVIN BRADY, Texas
JOHN PETERSON, Pennsylvania
RICK HILL, Montana
BOB SCHAFFER, Colorado
JIM GIBBONS, Nevada
MARK E. SOUDER, Indiana
GREG WALDEN, Oregon
DON SHERWOOD, Pennsylvania
ROBIN HAYES, North Carolina
MIKE SIMPSON, Idaho
THOMAS G. TANCREDO, Colorado

GEORGE MILLER, California
NICK J. RAHALL II, West Virginia
BRUCE F. VENTO, Minnesota
DALE E. KILDEE, Michigan
PETER A. DeFAZIO, Oregon
ENI F.H. FALEOMAVAEGA, American Samoa
NEIL ABERCROMBIE, Hawaii
SOLOMON P. ORTIZ, Texas
OWEN B. PICKETT, Virginia
FRANK PALLONE, Jr., New Jersey
CALVIN M. DOOLEY, California
CARLOS A. ROMERO-BARCELO, Puerto Rico
ROBERT A. UNDERWOOD, Guam
PATRICK J. KENNEDY, Rhode Island
ADAM SMITH, Washington
WILLIAM D. DELAHUNT, Massachusetts
CHRIS JOHN, Louisiana
DONNA CHRISTIAN-CHRISTENSEN, Virgin Islands
RON KIND, Wisconsin
JAY INSLEE, Washington
GRACE F. NAPOLITANO, California
TOM UDALL, New Mexico
MARK UDALL, Colorado
JOSEPH CROWLEY, New York
RUSH D. HUNT, New Jersey

Lloyd A. Jones, *Chief of Staff*
Elizabeth Megginson, *Chief Counsel*
Christine Kennedy, *Chief Clerk/Administrator*
John Lawrence, *Democratic Staff Director*

Subcommittee on Energy and Mineral Resources

BARBARA CUBIN, Wyoming, Chairman

W.J. (BILLY) TAUZIN, Louisiana
WILLIAM M. (MAC) THORNBERRY, Texas
CHRIS CANNON, Utah
KEVIN BRADY, Texas
BOB SCHAFFER, Colorado
JIM GIBBONS, Nevada
GREG WALDEN, Oregon
THOMAS G. TANCREDO, Colorado

ROBERT A. UNDERWOOD, Guam
NICK J. RAHALL II, West Virginia
ENI F.H. FALEOMAVAEGA, American Samoa
SOLOMON P. ORTIZ, Texas
CALVIN M. DOOLEY, California
PATRICK J. KENNEDY, Rhode Island
CHRIS JOHN, Louisiana
JAY INSLEE, Washington

Bill Condit, *Professional Staff*
Mike Henry, *Professional Staff*
Deborah Lanzone, *Professional Staff*

CONTENTS

Statements of Members:

Statements of witnesses:

Additional material supplied:

H.R. 1753, THE METHANE HYDRATE RESEARCH AND DEVELOPMENT ACT OF 1999, TO PROMOTE THE RESEARCH, IDENTIFICATION, ASSESSMENT, EXPLORATION, AND DEVELOPMENT OF METHANE HYDRATE RESOURCES, AND FOR OTHER PURPOSES

S. 330, THE METHANE HYDRATE RESEARCH AND DEVELOPMENT ACT OF 1999, TO PROMOTE THE RESEARCH, IDENTIFICATION, ASSESSMENT, EXPLORATION, AND DEVELOPMENT OF METHANE HYDRATE RESOURCES, AND FOR OTHER PURPOSES

TUESDAY, MAY 25, 1999

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY
AND MINERAL RESOURCES,
COMMITTEE ON RESOURCES,
Washington, DC.

The Subcommittee met, pursuant to notice, at 2:04 p.m., in Room 1324, Longworth House Office Building, Hon. Barbara Cubin [chairwoman of the Subcommittee] presiding.

STATEMENT OF HON. BARBARA CUBIN, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF WYOMING

Mrs. CUBIN. The Subcommittee will please to come to order. Such a huge attendance here.

Forgive me for being a few minutes late.

The Subcommittee on Energy and Minerals meets today to take testimony on two similar bills concerning Federal research and development efforts on gas hydrates—a class of mineral which is a chemical mixture of water and methane gas that can exist in a stable, crystalline form. Other gases, such as propane, are also found in hydrate form, but the predominant gas is methane.

The hydrate chemical structure is conducive to the storage of large volumes of gas. A cubic foot of gas hydrate, when heated and depressurized, can release up to 160 cubic feet of methane. Consequently, any assessment of our domestic natural gas resource is incomplete and woefully understated without reference to methane hydrates. Indeed, the U.S. Geological Survey, together with the Minerals Management Service, estimate the mean undiscovered methane hydrate resource potential to be over 100 times greater than is estimated for conventional natural gas.

Much of this resource lies at the edge of the outer continental shelf and slope in deep water, but significant quantities appear to exist within the permafrost regions at depths as shallow as 200 meters. However, gas hydrates are merely resources, not reserves, because their exploitation is sub-economic at this time, which isn't I guess unlike a lot of conventional gas today because of depressed prices, but that is for another hearing.

The Subcommittee's interest stems from the future potential for leasing of gas hydrates on Federal mineral estate under the OCS Lands Act and onshore in Alaska under the Mineral Leasing Act.

And, if we can convince the Congressional Budget Office to score the revenue potential from such leasing while I am still here in Congress, then I will have some of my very own offsets, and I will share some with you, too.

[Laughter.]

Furthermore, the Federal R&D program envisioned in the bills before us include participation by the U.S. Geological Survey, an agency which is also within our jurisdiction. Both bills modify the charter of the marine mineral research centers established by Public Law 104-325, by way of legislation from this Subcommittee.

I want to welcome our witnesses since they have come from far flung outposts—Honolulu, Hawaii, and Fairbanks, Alaska—well, actually, Fairbanks, Alaska, by way of Kaycee, Wyoming, I have to point out—as well as from Denver, Oxford, Mississippi, and Washington, DC.

Your testimony summarizes the current state of scientific knowledge on the origin, occurrence, and potential for utilization of methane hydrates to help meet America's energy needs and to understand past impacts upon global climate from uncontrolled release of methane from gas hydrates. Also, Congressman Mike Doyle, of Pittsburgh, a member of the House Science Committee which shares jurisdiction over these bills, has asked to testify before us about his sponsorship of H.R. 1753.

I look forward to hearing from all of you about the need for authorizing this important Federal program.

[The prepared statement of Mrs. Cubin follows:]

STATEMENT OF HON. BARBARA CUBIN, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF WYOMING

The Subcommittee on Energy and Minerals meets today to take testimony on two similar bills concerning Federal research and development efforts on gas hydrates—a class of mineral which is a chemical mixture of water and methane gas that can exist in a stable, crystalline (ice) form. Other gases, such as propane, are also found in hydrate form, but the predominant gas is methane. The hydrate chemical structure is conducive to the storage of large volumes of gas. A cubic foot of gas hydrate, when heated and depressurized, can release up to 160 cubic feet of methane. Consequently, any assessment of our domestic natural gas resource is incomplete and woefully understated without reference to methane hydrates. Indeed, the U.S. Geological Survey, together with the Minerals Management Service, estimated the mean undiscovered methane hydrate resource potential to be over one hundred times greater than is estimated for conventional natural gas!

Much of this resource lies at the edge of the outer continental shelf and slope in deep water, but significant quantities appear to exist within permafrost regions at depths as shallow as 200 meters. However, gas hydrates are merely resources, not reserves, because their exploitation is sub-economic at this time.

The Subcommittee's interest stems from the future potential for leasing of gas hydrates on Federal mineral estate under the OCS Lands Act and onshore in Alaska under the Mineral Leasing Act. Furthermore, the Federal R & D program envisioned in the bills before us include participation by the U.S. Geological Survey, an agency within our jurisdiction. Also, both bills modify the charter of the marine mineral research centers established by Public Law 104-325, via legislation from this Subcommittee.

I want to welcome our witnesses from far flung outposts—Honolulu, Hawaii and Fairbanks, Alaska as well as from Denver, Oxford, Mississippi and Washington DC. Your testimony summarizes the current state of scientific knowledge on the origin, occurrence, and potential for utilization of methane hydrates to help meet America's energy needs, and to understand past impacts upon global climate from uncontrolled release of methane from gas hydrates. Also, Congressman Mike Doyle of Pittsburgh, a member of the House Science Committee which shares jurisdiction over these bills, has asked to testify before us about his sponsorship of H.R. 1753. I look forward to hearing from all of you about the need for authorizing this important Federal program.

Mrs. CUBIN. And now I recognize our Ranking Member, Mr. Underwood, for any opening statement he might have.

STATEMENT OF HON. ROBERT A. UNDERWOOD, A DELEGATE IN CONGRESS FROM THE TERRITORY OF GUAM

Mr. UNDERWOOD. I thank the Chair, and I thank her for her generosity with the offset.

[Laughter.]

Mrs. CUBIN. Oh, you don't get half.

Mr. UNDERWOOD. Okay.

[Laughter.]

Mrs. CUBIN. Yes, you do.

Mr. UNDERWOOD. I am pleased to join my colleagues on the Subcommittee today as we meet to hear testimony on H.R. 1753 and S. 330, the Methane Hydrate Research and Development Act of 1999.

H.R. 1753 was introduced on May 11, by our colleague, Representative Mike Doyle, of Pennsylvania, who is here this afternoon to explain his bill. H.R. 1753 is a companion measure to S. 330 which has already passed the Senate under unanimous consent on April 19.

I note that we share jurisdiction on this bill with the House Science Committee. The Science Subcommittee on Energy and the Environment held a hearing and reported favorably both bills, as amended, on May 12.

The primary purpose of these bills is to promote the research, identification, assessment, exploration, and development of methane hydrate resources. This is important because one of our most important sources of clean, efficient energy is natural gas. Today, natural gas comes primarily from geological formations in which methane molecules—the primary component of natural gas—exist in the form of gas.

Methane also exists in ice-like formations called hydrates. Hydrates trap methane molecules inside a cage of frozen water. Hydrates are generally found on or under seabeds and under permafrost. While we do not know the extent or amount of methane trapped in hydrates, scientists—some of whom will be testifying today—believe we are talking about an enormous resource.

According to the U.S. Geological Survey, worldwide estimates of the natural gas potential of methane hydrates approach 400 million trillion cubic feet—as compared to the mere 5,000 trillion cubic feet that is known to make up the world's gas reserves. This huge potential illustrates the interest in advanced technologies that may reliably and cost-effectively detect and produce natural gas from methane hydrates.

However, figuring out how to cost-effectively produce energy from hydrates has been problematic, given the adverse and hostile conditions in which they exist. But if methods can be devised to extract methane from these deposits profitably, they may become important sources of fuel in the future.

On a cautionary note, we should be mindful of the fact that, although methane is relatively clean burning, it is still a fossil fuel. So removing it from its safe haven on the ocean floor and burning it will release carbon in the form of carbon dioxide into the atmosphere, which could contribute to greenhouse gas accumulations.

Methane hydrates near offshore oil drilling rigs also pose a threat through subsidence on the ocean floor. For instance, if a drilling rig were hit by shifting or depressurization of the methane hydrates underneath it, the impact on the rig and the workers aboard could be disastrous.

Therefore, it is appropriate that Congress looks carefully at legislation which would promote the research, identification, assessment, exploration, and development of methane hydrates resources.

And I look forward to hearing the testimony of our witnesses today, especially that of our colleague.

[The prepared statement of Mr. Underwood follows:]

STATEMENT OF HON. ROBERT A. UNDERWOOD, A DELEGATE IN CONGRESS FROM THE STATE OF GUAM

I am pleased to join my colleagues on the Subcommittee today as we meet to hear testimony on H.R. 1753 and S. 330, the Methane Hydrate Research and Development Act of 1999. H.R. 1753 was introduced on May 11, by our colleague Rep. Mike Doyle, of Pennsylvania, who is here to explain his bill to us.

H.R. 1753 is a companion bill to S. 330 which has already passed the Senate under Unanimous Consent on April 19. I note that we share jurisdiction on this bill with the House Science Committee. The Science Subcommittee on Energy and the Environment held a hearing and reported favorably both bills, as amended on May 12.

The primary purpose of these bills is to promote the research, identification, assessment, exploration and development of methane hydrate resources. This is important because one of our most important sources of clean, efficient energy is natural gas. Today, natural gas comes primarily from geological formations in which methane molecules—the primary component of natural gas—exist in the form of gas.

Methane also exists in ice-like formations called hydrates. Hydrates trap methane molecules inside a cage of frozen water. Hydrates are generally found on or under seabeds and under permafrost. While we do not know the extent or amount of methane trapped in hydrates, scientists, some of whom will be testifying today, believe we are talking about an enormous resource. According to the United States Geological Survey, worldwide estimates of the natural gas potential of methane hydrates approach *four hundred million trillion* cubic feet—as compared to the mere five thousand trillion cubic feet that make up the world's known gas reserves. This huge potential illustrates the interest in advanced technologies that may reliably and cost-effectively detect and produce natural gas from methane hydrates.

However, figuring out how to cost-effectively produce energy from hydrates has been problematic given the adverse and hostile conditions in which they exist. But if methods can be devised to extract methane from these deposits profitably, they may become important sources of fuel in the future.

On a cautionary note, we should be mindful of the fact that although methane is relatively clean burning, it is a fossil fuel. So removing it from its safe haven on the ocean floor and burning it, will release carbon, in the form of carbon dioxide into the atmosphere, which would contribute to greenhouse gas accumulations.

Methane hydrates near offshore oil drilling rigs also pose a threat, through subsidence on the ocean floor. For instance, if a drilling rig were hit by shifting or depressurization of the methane hydrates underneath it, the impact on the rig and the workers aboard could be disastrous.

Therefore, it is appropriate that the Congress looks carefully at legislation which would promote the research, identification, assessment, exploration and development of methane hydrate resources.

I look forward to hearing the testimony of our witnesses today.

[The text of the bills follows:]

106TH CONGRESS
1ST SESSION

H. R. 1753

To promote the research, identification, assessment, exploration, and development of methane hydrate resources, and for other purposes.

IN THE HOUSE OF REPRESENTATIVES

MAY 11, 1999

Mr. DOYLE (for himself, Mr. CALVERT, and Mr. COSTELLO) introduced the following bill; which was referred to the Committee on Science, and in addition to the Committee on Resources, for a period to be subsequently determined by the Speaker, in each case for consideration of such provisions as fall within the jurisdiction of the committee concerned

---

A BILL

To promote the research, identification, assessment, exploration, and development of methane hydrate resources, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Methane Hydrate Research and Development Act of 1999".

SEC. 2. DEFINITIONS.

In this Act:

(1) CONTRACT.—The term "contract" means a procurement contract within the meaning of section 6303 of title 31, United States Code.

(2) COOPERATIVE AGREEMENT.—The term "cooperative agreement" means a cooperative agreement within the meaning of section 6305 of title 31, United States Code.

(3) DIRECTOR.—The term "Director" means the Director of the National Science Foundation.

(4) GRANT.—The term "grant" means a grant awarded under a grant agreement, within the meaning of section 6304 of title 31, United States Code.

(5) INSTITUTION OF HIGHER EDUCATION.—The term "institution of higher education" means an institution of higher education, within the meaning of section 1201(a) of the Higher Education Act of 1965 (20 U.S.C. 1141(a)).

(6) METHANE HYDRATE.—The term "methane hydrate" means a methane clathrate that—

(A) is in the form of a methane-water ice-like crystalline material; and

(B) is stable and occurs naturally in deep-ocean and permafrost areas.

(7) SECRETARY.—The term "Secretary" means the Secretary of Energy, acting through the Assistant Secretary for Fossil Energy.

(8) SECRETARY OF DEFENSE.—The term "Secretary of Defense" means the Secretary of Defense, acting through the Secretary of the Navy.

(9) SECRETARY OF THE INTERIOR.—The term "Secretary of the Interior" means the Secretary of the Interior, acting through the Director of the United States Geological Survey.

SEC. 3. METHANE HYDRATE RESEARCH AND DEVELOPMENT PROGRAM.

(a) IN GENERAL.—

(1) COMMENCEMENT OF PROGRAM.—Not later than 180 days after the date of enactment of this Act, the Secretary, in consultation with the Secretary of Defense, the Secretary of the Interior, and the Director, shall commence a program of methane hydrate research and development.

(2) DESIGNATIONS.—The Secretary, the Secretary of Defense, the Secretary of the Interior, and the Director shall designate individuals to carry out this section.

(3) MEETINGS.—The individuals designated under paragraph (2) shall meet not later than 120

days after the date on which all such individuals are designated and not less frequently than every 120 days thereafter to—

(A) review the progress of the program under paragraph (1); and

(B) make recommendations on future activities to occur subsequent to the meeting.

(b) GRANTS, CONTRACTS, COOPERATIVE AGREEMENTS, INTERAGENCY FUNDS TRANSFER AGREEMENTS, AND FIELD WORK PROPOSALS.—

(1) ASSISTANCE AND COORDINATION.—The Secretary may award grants or contracts to, or enter into cooperative agreements with, institutions of higher education and industrial enterprises to—

(A) conduct basic and applied research to identify, explore, assess, and develop methane hydrate as a source of energy;

(B) assist in developing technologies required for efficient and environmentally sound development of methane hydrate resources;

(C) undertake research programs to provide safe means of transport and storage of methane produced from methane hydrates;

(D) promote education and training in methane hydrate resource research and resource development;

(E) conduct basic and applied research to assess and mitigate the environmental impacts of hydrate degassing (including both natural degassing and degassing associated with commercial development); and

(F) develop technologies to reduce the risks of drilling through methane hydrates.

(2) COMPETITIVE MERIT-BASED REVIEW.—Funds made available under paragraph (1) shall be made available based on a competitive merit-based process.

(c) CONSULTATION.—The Secretary may establish an advisory panel consisting of experts from industry, institutions of higher education, and Federal agencies to—

(1) advise the Secretary on potential applications of methane hydrate; and

(2) assist in developing recommendations and priorities for the methane hydrate research and development program carried out under subsection (a)(1).

(d) LIMITATIONS.—

(1) ADMINISTRATIVE EXPENSES.—Not more than 5 percent of the amount made available to carry out this section for a fiscal year may be used by the Secretary for expenses associated with the administration of the program carried out under subsection (a)(1).

(2) CONSTRUCTION COSTS.—None of the funds made available to carry out this section may be used for the construction of a new building or the acquisition, expansion, remodeling, or alteration of an existing building (including site grading and improvement and architect fees).

(e) RESPONSIBILITIES OF THE SECRETARY.—In carrying out subsection (b)(1), the Secretary shall—

(1) facilitate and develop partnerships among government, industry, and institutions of higher education to research, identify, assess, and explore methane hydrate resources;

(2) undertake programs to develop basic information necessary for promoting long-term interest in methane hydrate resources as an energy source;

(3) ensure that the data and information developed through the program are accessible and widely disseminated as needed and appropriate;

(4) promote cooperation among agencies that are developing technologies that may hold promise for methane hydrate resource development; and

(5) report annually to Congress on accomplishments under this section.

SEC. 4. AMENDMENTS TO THE MINING AND MINERALS POLICY ACT OF 1970.

Section 201 of the Mining and Minerals Policy Act of 1970 (30 U.S.C. 1901) is amended—

(1) in paragraph (6)—

(A) in subparagraph (F), by striking "and" at the end;

(B) by redesignating subparagraph (G) as subparagraph (H); and

(C) by inserting after subparagraph (F) the following:

"(G) for purposes of this section and sections 202 through 205 only, methane hydrate; and";

(2) by redesignating paragraph (7) as paragraph (8); and

(3) by inserting after paragraph (6) the following:

"(7) The term 'methane hydrate' means a methane clathrate that—

"(A) is in the form of a methane-water ice-like crystalline material; and

"(B) is stable and occurs naturally in deep-ocean and permafrost areas.".

SEC. 5. AUTHORIZATION OF APPROPRIATIONS.

There are authorized to be appropriated to the Secretary of Energy to carry out this Act—

(1) $5,000,000 for fiscal year 2000;

(2) $7,500,000 for fiscal year 2001;

(3) $10,000,000 for fiscal year 2002;

(4) $10,000,000 for fiscal year 2003; and

(5) $10,000,000 for fiscal year 2004.

Amounts authorized under this section shall remain available until expended.

SEC. 6. SUNSET.

Section 3 of this Act shall cease to be effective after the end of fiscal year 2004.

○

I

106TH CONGRESS
1ST SESSION

S. 330

IN THE HOUSE OF REPRESENTATIVES

APRIL 27, 1999

Referred to the Committee on Science, and in addition to the Committee on Resources, for a period to be subsequently determined by the Speaker, in each case for consideration of such provisions as fall within the jurisdiction of the committee concerned

---

AN ACT

To promote the research, identification, assessment, exploration, and development of methane hydrate resources, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Methane Hydrate Research and Development Act of 1999".

SEC. 2. DEFINITIONS.

In this Act:

(1) CONTRACT.—The term "contract" means a procurement contract within the meaning of section 6303 of title 31, United States Code.

(2) COOPERATIVE AGREEMENT.—The term "cooperative agreement" means a cooperative agreement within the meaning of section 6305 of title 31, United States Code.

(3) GRANT.—The term "grant" means a grant awarded under a grant agreement, within the meaning of section 6304 of title 31, United States Code.

(4) INSTITUTION OF HIGHER EDUCATION.—The term "institution of higher education" means an institution of higher education, within the meaning of section 102(a)(1) of the Higher Education Act of 1965.

(5) METHANE HYDRATE.—The term "methane hydrate" means a methane clathrate that—

(A) is in the form of a methane-water ice-like crystalline material; and

(B) is stable and occurs naturally in deep-ocean and permafrost areas.

(6) SECRETARY.—The term "Secretary" means the Secretary of Energy.

(7) SECRETARY OF DEFENSE.—The term "Secretary of Defense" means the Secretary of Defense, acting through the Secretary of the Navy.

(8) SECRETARY OF THE INTERIOR.—The term "Secretary of the Interior" means the Secretary of the Interior, acting through the Director of the United States Geological Survey.

(9) DIRECTOR.—The term "Director" means the Director of the National Science Foundation.

SEC. 3. METHANE HYDRATE RESEARCH AND DEVELOPMENT PROGRAM.

(a) IN GENERAL.—

(1) COMMENCEMENT OF PROGRAM.—Not later than 180 days after the date of enactment of this Act, the Secretary, in consultation with the Secretary of Defense, the Secretary of the Interior, and the Director, shall commence a program of methane hydrate research and development.

(2) DESIGNATIONS.—The Secretary, the Secretary of Defense, the Secretary of the Interior, and the Director shall designate individuals to carry out this section.

(3) MEETINGS.—The individuals designated under paragraph (2) shall meet not later than 120 days after the date on which all such individuals are

designated and not less frequently than every 120 days thereafter to—

(A) review the progress of the program under paragraph (1); and

(B) make recommendations on future activities to occur subsequent to the meeting.

(b) GRANTS, CONTRACTS, AND COOPERATIVE AGREEMENTS.—

(1) ASSISTANCE AND COORDINATION.—The Secretary may award grants or contracts to, or enter into cooperative agreements with, institutions of higher education and industrial enterprises to—

(A) conduct basic and applied research to identify, explore, assess, and develop methane hydrate as a source of energy;

(B) assist in developing technologies required for efficient and environmentally sound development of methane hydrate resources;

(C) undertake research programs to provide safe means of transport and storage of methane produced from methane hydrates;

(D) promote education and training in methane hydrate resource research and resource development;

(E) conduct basic and applied research to assess and mitigate the environmental impacts of hydrate degassing (including both natural degassing and degassing associated with commercial development); and

(F) develop technologies to reduce the risks of drilling through methane hydrates.

(2) CONSULTATION.—The Secretary may establish an advisory panel consisting of experts from industry, institutions of higher education, and Federal agencies to—

(A) advise the Secretary on potential applications of methane hydrate; and

(B) assist in developing recommendations and priorities for the methane hydrate research and development program carried out under subsection (a)(1).

(c) LIMITATIONS.—

(1) ADMINISTRATIVE EXPENSES.—Not more than 5 percent of the amount made available to carry out this section for a fiscal year may be used by the Secretary for expenses associated with the administration of the program carried out under subsection (a)(1).

(2) CONSTRUCTION COSTS.—None of the funds made available to carry out this section may be used for the construction of a new building or the acquisition, expansion, remodeling, or alteration of an existing building (including site grading and improvement and architect fees).

(d) RESPONSIBILITIES OF THE SECRETARY.—In carrying out subsection (b)(1), the Secretary shall—

(1) facilitate and develop partnerships among government, industry, and institutions of higher education to research, identify, assess, and explore methane hydrate resources;

(2) undertake programs to develop basic information necessary for promoting long-term interest in methane hydrate resources as an energy source;

(3) ensure that the data and information developed through the program are accessible and widely disseminated as needed and appropriate;

(4) promote cooperation among agencies that are developing technologies that may hold promise for methane hydrate resource development; and

(5) report annually to Congress on accomplishments under this section.

SEC. 4. AMENDMENT TO THE MINING AND MINERALS POLICY ACT OF 1970.

Section 201 of the Mining and Minerals Policy Act of 1970 (30 U.S.C. 1901) is amended—

(1) by redesignating paragraphs (6) and (7) as paragraphs (7) and (8), respectively;

(2) by inserting after paragraph (5) the following:

"(6) The term 'methane hydrate' means a methane clathrate that—

"(A) is in the form of a methane-water ice-like crystalline material; and

"(B) is stable and occurs naturally in deep-ocean and permafrost areas."; and

(3) in paragraph (7) (as redesignated by paragraph (1))—

(A) in subparagraph (F), by striking "and" at the end;

(B) by redesignating subparagraph (G) as subparagraph (H); and

(C) by inserting after subparagraph (F) the following:

"(G) methane hydrate; and".

SEC. 5. AUTHORIZATION OF APPROPRIATIONS.

There are authorized to be appropriated such sums as are necessary to carry out this Act.

Passed the Senate April 19, 1999.

Attest: GARY SISCO,
Secretary.

Mrs. CUBIN. Thank you, Mr. Underwood.

And I guess I have to admit it is really easy to share those offsets when we will probably both die of old age before the CBO gives us a score on that.

I would like introduce our first witness, the Honorable Michael F. Doyle from Pennsylvania.

Welcome.

STATEMENT OF HON. MICHAEL F. DOYLE, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF PENNSYLVANIA

Mr. DOYLE. Thank you very much, Madam Chairman, and Ranking Member Mr. Underwood, and all of my colleagues on the Committee, for holding this important hearing today.

I know that for some of my colleagues, as I have worked on this issue in the Science Committee, methane hydrates must have seemed like a very obscure subject, and I would like to commend your Committee for seeing beyond that and giving this esoteric issue the attention it deserves.

In short, methane hydrates are little-known, but have a huge potential as a new energy resource. Methane hydrates are defined as methane in a crystalline, highly-pressurized form, and are found both on the ocean floor and in some ares of the Arctic permafrost. As a potential energy source, methane hydrates are present on Earth in more than double the quantities of existing fossil energy supplies worldwide.

At the same time, methane hydrates pose a threat to us as well, for their potential to depressurize and enter the atmosphere, contributing to greenhouse gas accumulations.

Methane hydrates located on the sea floor underneath offshore oil drilling rigs could pose an even greater, near-term threat. If an oil drilling rig were hit by a massive shifting or depressurization of the methane hydrates in the sediment at the bottom of the ocean underneath it, the impact on the rig and the workers aboard could be disastrous.

For all of these reasons, methane hydrates definitely deserves further study at this time.

My staff and I have had the pleasure of working a little bit with the chairman's staff on my bill, H.R. 1753. This legislation would further define and extend the current interagency program for research into methane hydrates.

My bill follows, for the most part, on Senator Akaka's bill, S. 330, with a few changes, primarily the institution of merit review of research proposals.

In the Science Committee, I have been pleased to be able to work with members from both sides of the aisle on this issue, including my friend, Chairman of the Science Energy and Environment Subcommittee, Ken Calvert, who I believe previously served as Chairman of the Energy and Mineral Resources Subcommittee. And I would like to continue that unbroken string of cooperation across the aisle. As your Committee continues consideration of methane hydrates, I would like, at some point, to resume the discussions I have had with the Committee staff about changes to the text, if necessary, and any other way I might enlist your support.

In the Science Committee, I was pleased to see the bill receive a favorable report from the subcommittee on May 12. And along with my colleagues on both sides of the aisle, I am looking forward to a full committee mark at some point soon.

Just this morning on the Science Committee, I was assured by Jim Sensenbrenner, chairman of the committee, that reporting my bill from the full committee and moving it to the floor on the suspension calendar is one of the options he is looking at, as we work to complete consideration of this issue.

The research program is run by the Department of Energy, specifically the Federal Energy Technology Center. The FETC, as it is called, has convened working groups to develop “straw-man” proposals that outline a methane hydrates research program, and program management staff at the center plans to enter work agreements with scientists at USGS, the Naval Research Lab, the DOE national labs, marine mineral researchers in Mississippi, Hawaii, Alaska, and other States, and other agencies, academic centers, and companies with relevant expertise.

For this reason, appropriated funds are expected to be directed to DOE, though I understand there may be some ambiguity on this question that we can clear up as the bill moves closer to floor consideration.

As I mentioned before, this is a rather esoteric subject. Bob Kripowicz, whom I have worked with for a long time, and other witnesses here today, are far more expert than I am on this subject. But if you have any questions that I can answer specific to my legislation, or the differences between it and Senator Akaka’s bill, I would be happy to hear them.

I also have one further thing to add to my testimony, as submitted.

With methane and other gas hydrates located in the Arctic permafrost, throughout the oceans, and particularly at the bottom of such ocean features as the Marianas Trench, which is located near Guam, and with the Japanese planning to drill for hydrates this year in a similar trench, the Nankei Trough, off the southeast of Japan, a field hearing on methane hydrates might well be in order.

I understand that there is some interest in the Committee in a field hearing on the subject of manganese nodules on the ocean floor, and I would certainly lend my support and work to make a field hearing on that subject and methane hydrates a success.

With that, I conclude my testimony, and I am happy to answer any questions the Committee have.

And thank you very much, Madam Chairman.

[The prepared statement of Mr. Doyle follows:]

STATEMENT OF HON. MIKE DOYLE, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF PENNSYLVANIA

I would like to thank Madam Chairman Cubin, the Ranking Member, Mr. Underwood, and my colleagues on the Committee for holding this important hearing today. I know for some of my colleagues, as I’ve worked this issue on the Science Committee, “methane hydrates” must have seemed like a very obscure subject, and I would like to commend your Committee for seeing beyond that, and giving this esoteric issue the attention it deserves.

In short, methane hydrates are little-known, but have a huge potential as a new energy resource. Methane hydrates are defined as methane in a crystalline, highly pressurized form, and are found both on the ocean floor and in some areas of the

Arctic permafrost. As a potential energy source, methane hydrates are present on earth in more than double the quantities of existing fossil energy supplies worldwide.

At the same time, methane hydrates pose a threat to us as well, for their potential to depressurize and enter the atmosphere, contributing to greenhouse gas accumulations.

Methane hydrates located on the sea floor underneath offshore oil drilling rigs could pose an even greater, near-term threat. If an oil drilling rig were hit by a massive shifting or depressurization of the methane hydrates in the sediment at the bottom of the ocean underneath it, the impact on the rig and the workers aboard could be disastrous.

For all these reasons, methane hydrates definitely deserve further study at this time.

My staff and I have had the pleasure of working a little bit with the Chairman's staff on my bill, H.R. 1753. This legislation would further define and extend the current inter-agency program for research into methane hydrates. My bill follows for the most part on Senator Akaka's bill, S. 330, with a few changes, primarily the institution of merit review of research proposals.

In the Science Committee I have been pleased to be able to work with Members from both sides of the aisle on this issue, including my friend the Chairman of the Science Energy and Environment Subcommittee, Ken Calvert, who I believe has previously served as the Chairman of the Energy and Mineral Resources Subcommittee. I'd like to continue this unbroken string of cooperation across the aisle. As your Committee continues consideration of methane hydrates, I would like at some point to resume the discussions I had with the Committee's staff about changes to the text, if necessary, and any other way I might enlist your support. In the Science Committee I was pleased to see the bill receive a favorable report from the subcommittee on May 12, and along with my colleagues on both sides of the aisle. I'm looking forward to a full Committee mark at some point soon.

The research program is run by the Department of Energy, specifically the Federal Energy Technology Center. The FETC, as it's called, has convened working groups to develop "straw-man" proposals that outline a methane hydrates research program, and program management staff at the Center plan to enter work agreements with scientists at USGS, the Naval Research Lab, the DOE national labs, marine minerals researchers in Mississippi, Hawaii, Alaska, and other states, and other agencies, academic centers, and companies with relevant expertise. For this reason, appropriated funds are expected to be directed to DOE, though I understand there may be some ambiguity on this question that we can clear up as the bill moves closer to floor consideration.

As I mentioned before, this is a rather esoteric subject. Bob Kripowicz, whom I've worked with for a long time, and the other witnesses here today are far more expert than I am on this subject. But if you have any questions I can answer specific to my legislation, or the differences between it and Senator Akaka's bill, I'd be happy to hear them.

Mrs. CUBIN. Thank you, Congressman.

I don't have any questions of the Congressman.

Mr. Underwood?

Mr. UNDERWOOD. Well, thank you very much, and now that you have clarified that there is the potential for methane hydrates being near Guam, I am for this legislation.

[Laughter.]

Mrs. CUBIN. It does make a difference, doesn't it?

Mr. UNDERWOOD. Does make a difference.

[Laughter.]

Thank you.

Mr. DOYLE. I think a field hearing in Guam is in order.

Mr. UNDERWOOD. I think that field hearing in Guam is a great idea.

[Laughter.]

Along with a manganese nodule.

[Laughter.]

Mrs. CUBIN. Thank you very much for your testimony.

Mr. UNDERWOOD. Thank you.

Mrs. CUBIN. Thank you for being here.

Now I will introduce our first panel of witnesses—Mr. Robert Kripowicz, with the U.S. Department of Energy; Dr. Timothy S. Collett, with the U.S. Geological Survey; Dr. Bilal U. Haq, with the National Science Foundation—and I probably didn't say that correctly. I did?

I would like to call on Mr. Robert Kripowicz to begin the testimony.

STATEMENT OF ROBERT S. KRIPOWICZ, PRINCIPAL DEPUTY ASSISTANT SECRETARY FOR FOSSIL ENERGY, U.S. DEPARTMENT OF ENERGY

Mr. KRIPOWICZ. Madam Chairman, members of the Subcommittee, I appreciate the opportunity to present the views of the Department of Energy, and I have submitted a formal statement that I would like to be made a part of the record.

Mrs. CUBIN. Without objection.

Mr. KRIPOWICZ. I have described in my formal statement the chemical and physical makeup of methane hydrates and a little of the history behind their discovery and our renewed interest in them.

Suffice to say, I would hope that from my testimony and from others on the panel, the Subcommittee will recognize the significant potential of this resource. The energy content is not only many times—but many hundreds of times—larger than the world's currently known gas reserves.

This huge potential alone, we believe, warrants a new look at advanced technologies that might one day detect and produce natural gas from hydrates reliably and cost effectively.

I might also mention that aside from the enormous energy potential, we believe a research effort in gas hydrates is important from the perspective of safety. As I have described in my statement, the existence or formation of hydrates in petroleum operations can create safety problems for well operators.

As a result of the new interest in methane hydrates, in Fiscal Year 1998, the Office of Fossil Energy at the Department of Energy revived research into this resource, albeit at a very limited scale. In Fiscal Year 2000, we have proposed a budget of approximately $2 million to begin carrying out initial exploratory efforts.

Our new initiative will build on research conducted by the Department from 1982 to 1992. During that initial effort, we developed a foundation of basic knowledge about the location and thermodynamic properties of hydrates.

Since 1992, work has continued at relatively small scales, primarily through the Ocean Drilling Program, and the U.S. Geological Survey, and in other laboratories, including some work in Japan.

Our new effort in hydrates largely stems from the recommendation of the Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology, or PCAST. Following the PCAST report, the Department hosted two public workshops last year to obtain industry and academic input into developing a coordinated, multi-agency program.

The planning efforts resulted in this document, "A Strategy for Methane Hydrates Research and Development," which we published last August, and we have provided copies for the Committee members and staff. An electronic version of the document can be downloaded from the Fossil Energy Internet website.

I should point out that we are in the final stages of preparing a more detailed program plan that will begin addressing the specific research needs identified in the strategy document.

The research program is intended to answer four specific questions.

Number one, how much? The huge range in estimates of hydrate volume underscores the lack of detailed understanding of the aspects of hydrate deposits. Our efforts in resource characterization will give us much information on the location and nature of methane hydrates.

Second is how to produce the resource. Except in one Russian field, there is no documented commercial gas production associated with hydrates. Much more work is needed in depressurization, thermal processes, and solvent injection to understand how best to produce the resource.

Third is how to assess the impact. Virtually nothing is known about the stability of gas hydrates, especially those along the sea floor, in a period of potential global climate change. For example, we don't know whether warming of the sea water could affect outcrops of methane hydrates at or near the sea floor and lead to significant releases of methane, a gas which is 20 times more potent than carbon dioxide as a greenhouse gas.

And, lastly is how to ensure safety. This is one of the highest priorities at this time for industry. Arctic and marine hydrates are known to cause drilling problems, blowouts, casing collapse, and well-site subsidence in conventional drilling and production. Research is needed to accurately document drilling and production problems caused by gas hydrates and to develop techniques to avoid or mitigate hazards. We also need to study the long-term impacts on sea floor stability.

The two bills, S. 330 and H.R. 1753, provide a solid congressional endorsement of the research effort we proposed in this strategy, and the Department supports the legislation.

We are particularly pleased to see Congress emphasize the need to develop partnerships among the government, industry, and academia in future hydrate R&D. This concept of public/private partnerships, with shared responsibilities and resources, is fundamental to our fossil energy R&D program.

We are also pleased that the Congress has recognized the importance of cooperation among Federal agencies in developing hydrate technologies. As I said earlier, we would not be nearly as well positioned to begin a new, intensified examination of hydrate potential had it not been for the excellent work of the USGS and the Naval Research Laboratory.

The coordinated involvement of these organizations and others, such as the Minerals Management Service and the National Science Foundation, will be essential in carrying out a productive and effectively managed R&D program.

And that concludes my opening statement.

Thank you.

[The prepared statement of Mr. Kripowicz follows:]

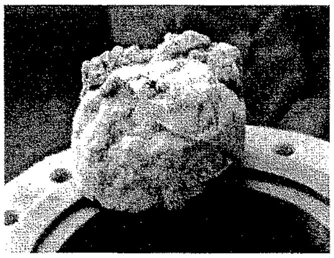
Statement of
Robert S. Kripowicz
Principal Deputy Assistant Secretary
for Fossil Energy
U.S. Department of Energy
Before the
Subcommittee on Energy and Mineral Resources
Committee on Resources
U.S. House of Representatives
May 25, 1999

Mr. Chairman and Members of the Subcommittee:

I am pleased to represent the Department of Energy and to present our views on the potential for methane hydrates as a future source of natural gas and more specifically, to review the progress we are making in preparing a multi-agency coordinated research plan for this potentially vast energy resource. I will also discuss our position on H.R. 1753, the Methane Hydrate Research and Development Act of 1999.

What Are Methane Hydrates?

Simply put, a methane hydrate is a cage-like lattice of ice, inside of which are trapped molecules of methane (the chief constituent of natural gas). In fact, the name for its parent class of compounds, "clathrates," comes from the Latin word meaning "to enclose with bars."


A portion of a methane hydrate core recovered off the coast of Guatemala.

Methane hydrates form in generally two types of geologic settings: (1) on land in permafrost regions where cold temperatures persist in shallow sediments, and (2) beneath the ocean floor at water depths greater than about 500 meters where high pressures dominate. The hydrate deposits themselves may be several hundred meters thick.

Scientists have known about methane hydrates for a century or more. French scientists studied hydrates in 1890. In the 1930s, as natural gas pipelines were extended into colder climates, engineers discovered that hydrates, rather than ice, would form in the lines, often plugging the flow of gas. These crystals, although unmistakably a combination of both water and natural gas, would often form at temperatures well above the freezing point of ordinary ice. Yet, for the next three decades, methane hydrates were considered only a nuisance, or at best, a laboratory oddity.

That viewpoint changed in 1964. In a northern Siberian gas field named Messoyakha, a Russian drilling crew discovered natural gas in the "frozen state," or in other words, methane hydrates occurring naturally. Subsequent reports of potentially vast deposits of "solid" natural gas in the former Soviet Union intensified interest and sent geologists worldwide on a search for how -- and where else -- methane hydrates might occur in nature. In the 1970s, hydrates were found in ocean sediments.

In late 1981, the drilling vessel *Glomar Challenger*, assigned by the National Science Foundation to explore off the coast of Guatemala, unexpectedly bored into a methane hydrate deposit. Unlike previous drilling operations which had encountered evidence of hydrates, researchers onboard the *Challenger* were able to recover a sample intact.

Today, methane hydrates have been detected around most continental margins. Around the United States, large deposits have been identified and studied in Alaska, the west coast from California to Washington, the east coast, including the Blake Ridge offshore of the Carolinas, and in the Gulf of Mexico.

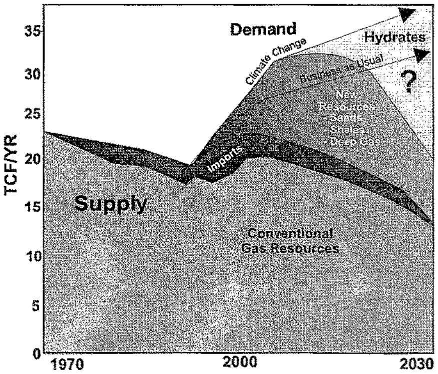
In 1995, the U.S. Geological Survey (USGS) completed its most detailed assessment of U.S. gas hydrate resources. The USGS study estimated the in-place gas resource within the gas hydrates of the United States to range from 112,000 trillion cubic feet to 676,000 trillion cubic feet, with a mean value of 320,000 trillion cubic feet of gas.

Subsequent refinements of the data in 1997 using information from the Ocean Drilling Program have suggested that the mean should be adjusted slightly downward, to around 200,000 trillion cubic feet -- still larger by several orders of magnitude than previously thought and dwarfing the estimated 1,400 trillion cubic feet of conventional recovered gas resources and reserves in the United States.

Worldwide, estimates of the natural gas potential of methane hydrates approach 400 *million* trillion cubic feet -- a staggering figure compared to the 5,000 trillion cubic feet that make up the world's currently known gas reserves.

This huge potential, alone, warrants a new look at advanced technologies that might one day reliably and cost-effectively detect and produce natural gas from methane hydrates.

Why the New Interest in Hydrates?



Beyond 2015, as conventional and new gas resources (shales, tight sands, deep gas, etc.) begin to decline, the U.S. may need to turn increasingly to hydrates to meet rising demand for natural gas.

If only 1 percent of the methane hydrate resource could be made technically and economically recoverable, the United States could more than double its domestic natural gas resource base.

The United States will consume increasing volumes of natural gas well into the 21st century. U.S. gas consumption is expected to increase from almost 22 trillion cubic feet in 1997 to more than 32 trillion cubic feet in 2020 -- a projected increase of 40 percent.

Natural gas is expected to take on a greater role in power generation, largely because of increasing pressure for clean fuels and the relatively low capital costs of building new natural gas-fired power equipment. Also, gas demand is expected to grow because of its expanded use as a transportation fuel and potentially, in the longer-term, as a source of alternative liquid fuels (gas-to-liquids conversion) and hydrogen for fuel cells. Should the nation move to reduce carbon dioxide emissions, as part of our commitment to greenhouse gas reduction, the use natural gas potentially could increase even more.

Given the growing demand for natural gas, the development of new, cost-effective supplies can play a major role in moderating price increases and assuring consumer confidence in the long-term availability of reliable, affordable fuel. Yet, today, the potential to extract commercially-relevant quantities of natural gas from hydrates is speculative at best. With no immediate economic payoff, the private sector is not vigorously pursuing research that could make methane hydrates technically and economically viable. Therefore, federal R&D is the primary way the United States can begin exploring the future viability of a high-risk resource whose long-range possibilities might one day dramatically change the world's energy portfolio.

A Vast New Source of Energy or a Safety and Environmental Hazard?

Methane hydrates represent a tantalizing energy prospect; yet, at the same time, there are significant safety and environmental issues. The hydrate structure encases methane at very high concentrations. A single unit of hydrate, when heated and depressurized, can release 160 times its volume in gas.

Computer simulations indicate that thermal recovery methods, such as the use of hot water or steam flooding, could make hydrates a technically recoverable resource. Alternatively, methods that dissociate the gas by reducing the reservoir pressure may be possible. Chemical injection to decrease the stability of the hydrate lattice could be another approach.

This potential for large volumes of methane to be released due to destabilization of the hydrate formation can also create safety problems, however. Offshore operators are increasingly reporting problems of drilling through hydrates. Normal-speed drilling generates sufficient heat to decompose surrounding hydrates, resulting in high-gas-content mud that can contribute to loss of well control. Hydrates also can form either in the well bore or in connecting lines, plugging the flow. Also, as hydrates decompose, particularly at or near the sea floor, subsidence can occur, potentially causing a loss of foundation support for offshore platforms or possibly damaging underwater cables.

Research into methane hydrates, therefore, could benefit conventional oil and gas operations by developing improved methods to anticipate and diagnose the presence of these formations. As producers move increasingly into regions where hydrates are likely to be found, the federal R&D program could provide important information to mitigate safety and environmental hazards.

DOE's Previous R&D Program

The *Glomar Challenger's* retrieval of a 3-foot long hydrate core in 1981 -- the only one at that time known to exist in the Western Hemisphere -- intensified interest in methane hydrates. The core was shipped to the Colorado School of Mines, which asked several organizations for proposals on how they would study the sample. Six organizations were chosen to carry out the analyses, including the Department of Energy's Morgantown Energy Technology Center, now part of the Federal Energy Technology Center. (The others were the USGS at Menlo Park, CA; the National Bureau of Standards in Boulder, CO; the University of California at Los Angeles; Texas A&M University; and the Sohio Research Center in Cleveland, OH.)

The core studies kicked off a new effort by the DOE Office of Fossil Energy to study the physical and chemical properties of hydrates, the mechanisms for their formation and dissociation, and the geological characteristics of marine and Arctic hydrate formations.

From 1982-1992, DOE's methane hydrate program spent $8 million in developing a foundation of basic knowledge about the location and thermodynamic properties of gas hydrates. The DOE-supported program:

- established the existence of hydrates in the Kuparuk Field on the north slope of Alaska;
- completed studies of 15 offshore hydrate basins;
- developed production models for depressurizing and heating hydrates to release gas,
- developed preliminary estimates of gas-in-place for hydrate deposits, and
- built the *Gas Hydrate and Sediment Test Lab Instrument,* a device that can form hydrates within sediments in a laboratory chamber that simulates deep-sea conditions.

DOE's initial methane hydrate research ended as priorities shifted to more near-term exploration and production R&D. Work continued at relatively small scales at the USGS, universities, other laboratories, and overseas. Studies of the Blake Ridge formation offshore of the Carolinas in 1995 (part of the USGS Ocean Drilling Program Leg 164) contributed significantly to our understanding of hydrates and a refinement of potential resource estimates.

In FY 1997 and FY 1998, DOE provided a small amount of funding from its Natural Gas Supply Program to support activities in preparation for a more definitive program proposed for FY 1999. We participated in the testing and sample analysis of a 1,200-meter deep well in the Mackenzie Delta of Canada drilled by Japan National Oil Company. We also began processing and evaluating seismic data from the hydrate regions of the Gulf of Mexico, and began designing a global database of gas hydrates and related gas deposits. The Department also began participating in the Colorado School of Mines gas hydrate university/industry consortium which is studying the problem of hydrate plugging in conventional wells and handling facilities.

The Development of a New Gas Hydrate R&D Initiative

In its 1997 report, the Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology (PCAST) recommended *"a major initiative for DOE to work with USGS, the Naval Research Lab, Mineral Management Service, and the industry to evaluate the production potential of methane hydrates in U.S. coastal waters and world wide."* PCAST also called attention to the possibility that studies of methane hydrates could lead to possible sequestering of carbon dioxide in CO2 hydrates.

On January 21-22, 1998, DOE hosted a workshop in Denver on the "Future of Methane Hydrate Research and Resource Development." The objective was to take the first step in developing, jointly with the Department of the Interior and the Department of Defense (Naval Research Laboratory), a new R&D program for methane hydrates.

On May 12, 1998, a second workshop was held in Washington, DC, specifically to review a "strawman" Methane Hydrates Program Plan.

From this workshops and other planning activities carried out cooperatively with the U.S. Geological Survey, the Naval Research Laboratory, the National Science Foundation, the Minerals Management Service and industrial and academic experts, the Department of Energy published a *"Strategy for Methane Hydrates Research & Development"* in August 1998.

The strategy outlines a multidisciplinary program that will begin in FY 2000. If successful, this planned 10-year national program will produce the knowledge and products necessary for the private sector to begin the commercial viability of methane production from hydrates by 2015. The program will also address associated environmental and safety issues that could benefit offshore producers operating in suspected hydrate regions.

Our methane hydrates program has four goals:

- **Resource Characterization** - Determine the location, sedimentary relationships, and physical characteristics of methane hydrate resources to assess their potential as a domestic and global fuel resource. Planned RD&D activities include: collection and analysis of geophysical data; oceanographic and arctic sample collection and analysis; geologic and geochemical studies; and database development.

- **Production** - Develop the knowledge and technology necessary for commercial production of methane from oceanic and permafrost hydrate systems by 2015. Planned RD&D activities include: laboratory studies and modeling of hydrate dissociation; and production testing in a well-of-opportunity.

- **Global Carbon Cycle** - Develop an understanding of the dynamics and distribution of oceanic and permafrost methane hydrate systems sufficient to quantify their role in the global carbon cycle and climate change. Planned RD&D activities include: microbiological and chemical studies of the fate of methane in the ocean and atmosphere; and monitoring seafloor hydrate sites.

- **Safety and Seafloor Stability** - Develop an understanding of the hydrates system in nearseafloor sediments and sedimentary processes, including sediment mass movement and methane release, so that safe standardized procedures for hydrocarbon production and ocean engineering can be assured. Planned RD&D activities include: documentation of historic slump and collapse sites; and seismic and well log evaluation of subset hydrate zone structure and strength.

To effectively address this technological complexity, the program will marshal the resources of the petroleum industry, academia, National Laboratories, and a broad base of government programs with concurrent interests in methane hydrates. These groups will comprise a Management Steering Committee that will monitor program progress, assure interagency coordination, and coordinate international exchanges.

Descriptions of several ongoing methane hydrates projects follow:

– DOE is working with the USGS to provide preliminary seismic profile data and necessary laboratory information to assess gas hydrate accumulations in regions of the Gulf of Mexico. The work includes processing and interpretation of Gulf of Mexico seismic profiling data collected in the gas hydrates area of Garden Banks/ Keithley Canyon. Laboratory measurements will be made on the acoustic velocity and resistivity for purposes of improving interpretation of gas hydrate signatures in seismic profiles. USGS has developed instrumentation to evaluate gas hydrate characterization with their GHASTLI system (Gas Hydrate and Sediment Test Laboratory Instrument), which DOE helped develop.

Permafrost Hydrate Samples

In March 1998, the Japan National Oil Company (JNOC), the Geological Survey of Canada (GSC), and the USGS, with support from DOE, drilled a 1,150 foot well to investigate gas hydrates in a permafrost setting. Core samples collected from the Mallik well are the first documented natural gas hydrate samples from beneath permafrost collected in the world. The Geological Survey of Canada will coordinate, with JNOC and other collaborators, an extensive post-field research program that will integrate the field surveys with fundamental studies of hydrate characteristics. Preliminary research results were presented at a special conference in Japan in October 1998

– DOE is supporting research activity at the USGS to assess the availability and potential production of gas hydrates in the Arctic. Recent field studies in Canada are being used to develop gas hydrate computer production models that will enable DOE to assess the production potential of natural gas hydrates in this region. In 1999 and 2000, USGS will work with industry to characterize Arctic sites and conduct production tests to assess the volume of gas, recoverability, and production characteristics of the gas hydrate accumulations in northern Alaska.

– DOE is supporting the Department of Defense Naval Research Laboratory studies of gas hydrate deposits located in deep sea regions. The Naval Research Laboratory is developing a prototype global EMap, which is an electronic relational database for gas hydrate locations and related information. This effort will also include assessment of methods for determining the 3-D distribution and volume of gas hydrates. This data will be applicable to studies of sea floor stability and safety, production, global carbon cycle and the earth-atmosphere system, and environmental benefits of methane from hydrates as a fuel.

- DOE and the DeepStar consortium are building a "flow assurance" test loop at the Rocky Mountain Oilfield Testing Center. Testing will include gas hydrate formation in pipelines and blockage removal techniques.

Because future program activities were still in the formative stage, DOE requested only a minimal level of R&D funding ($500,000) in its fiscal year 1999 budget submission to Congress. In FY 2000, to initiate the multidisciplinary program strategy, the Department has requested an increase in funding to $2.0 million.

The Department's Views on H.R. 1753 , the Methane Hydrate Research and Development Act of 1999

H.R. 1753 and its Senate-passed companion bill, S. 330, would promote the research, identification, assessment, exploration, and development of methane hydrate resources. Both bills provide a clear endorsement from Congress of federal research efforts to better understand the true energy potential of methane hydrates. Both are consistent with the goals we have established for the federal hydrates R&D program; therefore, the Department can support both the House and Senate versions.

We are particularly pleased to see the Congress emphasize the need to facilitate and develop partnerships among government, industry and academia in future hydrate R&D. This concept of a public-private partnership, with shared responsibilities and resources, is fundamental to our fossil energy R&D program. It is particularly important that the private sector, which will ultimately be responsible for converting R&D results into commercially-viable production methods, be part of the project team early in the R&D process. We expect to see substantial industry cost-sharing in those activities that have significance for current drilling practices, such as the studies of hydrate mechanical properties and ocean engineering. As other longer-term technologies mature, we expect the proportion of industry cost-sharing in these areas increase to significant levels. We also will seek a wide range of private sector and academic partners. This will expedite significantly the transfer of technology that evolves from this effort.

We also applaud the Congressional direction to "ensure that data and information developed through the program are accessible and widely disseminated...." Working with the International Centre for Gas Technology Information, we are exploring mechanisms, such as the use of the Internet, that will enhance information dissemination among the world's community of hydrate researchers and technology users, as well as obtain continuing stakeholder input.

We are also pleased that the Congress has recognized the importance of cooperation among Federal agencies in developing potentially promising hydrate technologies. We would not be nearly as well positioned to begin a new, intensified examination of the hydrate potential had it not been for the excellent work of the USGS and the Naval Research Laboratory. The coordinated involvement of these organizations, along with others such as the National Science Foundation, the Minerals Management Service, and the Gas Research Institute, will be essential in carrying out a productive and effectively managed R&D program.

This concludes my prepared statement. I will be pleased to answer any questions you or Members of the Subcommittee may have.

Mrs. CUBIN. Thank you very much.

Next, I would like to recognize Dr. Timothy S. Collett, for his testimony.

STATEMENT OF DR. TIMOTHY S. COLLETT, RESEARCH GEOLOGIST, U.S. GEOLOGICAL SURVEY, U.S. DEPARTMENT OF ENERGY

Dr. COLLETT. Thank you.

Mr. Chairman, and members, I am Timothy S. Collett, research geologist with the U.S. Geological Survey.

In this testimony, I will discuss the USGS assessment of natural gas hydrate resources and examine the technology that would be necessary to safely and economically produce gas hydrates.

The primary objectives of the existing USGS gas hydrate research studies are: one, to document the geological parameters that control the occurrence and stability of gas hydrates; two, to assess the volume of natural gas stored within gas hydrate accumulations; and, three, to identify and predict natural sediment destabilization caused by gas hydrates; and finally, four, to analyze the effects of gas hydrate on drilling safety.

The USGS, in 1995, made the first systematic assessment of the in-place natural gas hydrate resources of the United States. This study shows that the amount of gas in hydrate accumulations in the United States is dramatic.

Even though gas hydrates are known to occur in numerous marine and Arctic settings, little is known about the geologic controls on their distribution. The presence of gas hydrates in offshore continental margins have been inferred mainly from anomalous seismic reflectors that coincide with the base of the gas hydrate stability zone. This reflector, commonly called the “bottom simulator reflector” or “BSR” has been mapped at depths ranging from 0 to 1,100 meters below the sea floor. Gas hydrates have also been recovered by scientific drilling along the Atlantic, Gulf of Mexico, and Pacific coasts of the United States.

Onshore gas hydrates have been found in Arctic regions of permafrost. Gas hydrates associated with the permafrost have been documented on the North Slope of Alaska and Canada, and in northern Russia. Combined information from Arctic gas hydrate studies show that, in permafrost regions, gas hydrates may exist at subsurface depths ranging from 130 to 2,000 meters.

The USGS 1995 National Assessment of United States’ Oil and Gas Resources focused on assessing the undiscovered conventional and unconventional resources of crude oil and natural gas in the United States. This assessment included, for the first time, a systematic appraisal of the in-place natural gas hydrate resources in the United States in both onshore and offshore environments. That study indicates that the in-place gas hydrate resources of the United States are estimated to range from 113,000 to 676,000 trillion cubic feet of gas. Although this range of values shows a high degree of uncertainty, it does indicate the potential for enormous quantities of gas stored as gas hydrates. However, this assessment does not address the problem of gas hydrate recoverability.

Proposed methods of gas recovery from hydrates usually deal with disassociating or melting gas hydrates by heating the reservoir, or by decreasing the reservoir pressure, or by injecting an inhibitor such as methanol into the formation. Among the various techniques for production of natural gas from gas hydrates, the most economically promising method is considered to be depressurization. The Messoyakha gas field in northern Russia is often used as an example of a hydrocarbon accumulation from which gas has been produced from hydrates by reservoir depressurization.

Seismic-acoustic imaging to identify gas hydrates is an essential component of the USGS marine studies since 1990. USGS has also conducted extensive geochemical surveys and established a specialized laboratory facility to study the formation and disassociation of gas hydrates in nature and also under simulated sea floor conditions. These efforts have also involved core drilling of gas hydrate-bearing samples in cooperation with the Ocean Drilling Program of the National Science Foundation, and, most recently, a cooperative drilling program onshore in northern Canada.

Sea floor stability and safety are two important issues related to gas hydrates. Sea floor stability refers to the susceptibility of the sea floor to collapse and slide as a result of gas hydrate disassociation. Safety issue refers to petroleum drilling and production hazards that may occur in association with gas hydrates.

In regards to sea floor stability, it is possible that both natural and human induced changes contribute to in-situ gas hydrate destabilization which may convert hydrate-bearing sediments to gassy, water-rich fluids, triggering sea floor subsidence and catastrophic landslides. Evidence implicating gas hydrates in triggering sea floor landslides has been found along the Atlantic Ocean margin of the United States. However, the mechanisms controlling gas hydrate induced sea floor subsidence and landslides are not well known or documented.

In regards to safety, oil and gas operators have described numerous drilling and production problems attributed to the presence of gas hydrates, including uncontrolled gas releases during drilling, collapse of wellbore casings, and gas leakages to the surface. Again, the mechanism controlling gas hydrate induced safety problems is not well known.

In conclusion, our knowledge of natural-occurring gas hydrates is limited. Nevertheless, a growing body of evidence suggests that a huge volume of natural gas is stored in gas hydrates; the production of natural gas from gas hydrates may be technically feasible; gas hydrates hold the potential for natural hazards associated with sea floor stability and release of methane to the oceans and the atmosphere; and gas hydrates disturbed during drilling and petroleum production pose a potential safety problem.

The USGS welcomes the opportunity to collaborate with other domestic and international scientific organizations to further our collaborative understanding of these important geologic materials.

I would like to thank the Committee for this opportunity and I would refer the Committee to my written testimony for additional information on natural gas hydrates.

Thank you.

[The prepared statement of Dr. Collett follows:]

STATEMENT OF TIMOTHY S. COLLETT, RESEARCH GEOLOGIST, U.S. GEOLOGICAL SURVEY

Mr. Chairman and Members:

I am Timothy S. Collett, Research Geologist with the U.S. Geological Survey (USGS). In this testimony I will discuss the USGS assessment of natural gas hydrate resources and examine the technology that would be necessary to safely and economically produce gas hydrates.

I. Summary

The primary objectives of USGS gas hydrate research are to document the geologic parameters that control the occurrence and stability of gas hydrates, to assess the volume of natural gas stored within gas hydrate accumulations, to identify and predict natural sediment destabilization caused by gas hydrate, and to analyze the effects of gas hydrate on drilling safety. The USGS in 1995 made the first systematic assessment of the in-place natural gas hydrate resources of the United States. That study shows that the amount of gas in the hydrate accumulations of the United States greatly exceeds the volume of known conventional domestic gas resources. However, gas hydrates represent both a scientific and technologic frontier and much remains to be learned about their characteristics and possible economic recovery.

II. Gas Hydrate Occurrence and Characterization

Gas hydrates are naturally occurring crystalline substances composed of water and gas, in which a solid water-lattice holds gas molecules in a cage-like structure. Gas hydrates are widespread in permafrost regions and beneath the sea in sediments of the outer continental margins. While methane, propane, and other gases are included in the hydrate structure, methane hydrates appear to be the most common. The amount of methane contained in the world's gas hydrate accumulations is enormous, but estimates of the amounts are speculative and range over three orders-of-magnitude from about 100,000 to 270,000,000 trillion cubic feet of gas. Despite the enormous range of these estimates, gas hydrates seem to be a much greater resource of natural gas than conventional accumulations.

Even though gas hydrates are known to occur in numerous marine and Arctic settings, little is known about the geologic controls on their distribution. The presence of gas hydrates in offshore continental margins has been inferred mainly from anomalous seismic reflectors that coincide with the base of the gas-hydrate stability zone. This reflector is commonly called a bottom-simulating reflector or BSR. BSRs have been mapped at depths ranging from about 0 to 1,100 in below the sea floor. Gas hydrates have been recovered by scientific drilling along the Atlantic, Gulf of Mexico, and Pacific coasts of the United States, as well as at many international locations.

To date, onshore gas hydrates have been found in Arctic regions of permafrost and in deep lakes such as Lake Baikal in Russia. Gas hydrates associated with permafrost have been documented on the North Slope of Alaska and Canada and in northern Russia. Direct evidence for gas hydrates on the North Slope of Alaska comes from cores and petroleum industry well logs which suggest the presence of numerous gas hydrate layers in the area of the Prudhoe Bay and Kuparuk River oil fields. Combined information from Arctic gas-hydrate studies shows that, in permafrost regions, gas hydrates may exist at subsurface depths ranging from about 130 to 2,000 meters.

The USGS 1995 National Assessment of United States Oil and Gas Resources focused on assessing the undiscovered conventional and unconventional resources of crude oil and natural gas in the United States. This assessment included for the first time a systematic appraisal of the in-place natural gas hydrate resources of the United States, both onshore and offshore. Eleven gas-hydrate plays were identified within four offshore and one onshore gas hydrate provinces. The offshore provinces lie within the U.S. 200 mile Exclusive Economic Zone adjacent to the lower 48 States and Alaska. The only onshore province assessed was the North Slope of Alaska. In-place gas hydrate resources of the United States are estimated to range from 113,000 to 676,000 trillion cubic feet of gas, at the 0.95 and 0.05 probability levels, respectively. Although this range of values shows a high degree of uncertainty, it does indicate the potential for enormous quantities of gas stored as gas hydrates. The mean (expected value) in-place gas hydrate resource for the entire United States is estimated to be 320,000 trillion cubic feet of gas. This assessment does not address the problem of gas hydrate recoverability.

Seismic-acoustic imaging to identify gas hydrate and its effects on sediment stability has been an important part of USGS marine studies since 1990. USGS has also conducted extensive geochemical surveys and established a specialized laboratory facility to study the formation and disassociation of gas hydrate in nature and also under simulated deep-sea conditions. Gas hydrate distribution in Arctic wells and in the deep sea has been studied intensively using geophysical well logs. These efforts have also involved core drilling of gas-hydrate-bearing sediments in cooperation with the Ocean Drilling Program (ODP) of the National Science Foundation, and, most recently a cooperative drilling program onshore in northern Canada.

III. Gas Hydrate Production

Gas recovery from hydrates is hindered because the gas is in a solid form and because hydrates are usually widely dispersed in hostile Arctic and deep marine environments. Proposed methods of gas recovery from hydrates usually deal with disassociating or "melting" in-situ gas hydrates by (1) heating the reservoir beyond the temperature of hydrate formation, (2) decreasing the reservoir pressure below hydrate equilibrium, or (3) injecting an inhibitor, such as methanol, into the reservoir to decrease hydrate stability conditions. Computer models have been developed to evaluate hydrate gas production from hot water and steam injection, and these models suggest that gas can be produced from hydrates at sufficient rates to make gas hydrates a technically recoverable resource. Similarly, the use of gas hydrate inhibitors in the production of gas from hydrates has been shown to be technically feasible, however, the use of large volumes of chemicals comes with a high economic and potential environmental cost. Among the various techniques for production of natural gas from in-situ gas hydrates, the most economically promising method is considered to be depressurization. The Messoyakha gas field in northern Russia is often used as an example of a hydrocarbon accumulation from which gas has been produced from hydrates by simple reservoir depressurization. Moreover the production history of the Messoyakha field possibly demonstrates that gas hydrates are an immediate producible source of natural gas and that production can be started and maintained by "conventional" methods.

IV. Safety and Seafloor Stability

Seafloor stability and safety are two important issues related to gas hydrates. Seafloor stability refers to the susceptibility of the seafloor to collapse and slide as the result of gas hydrate disassociation. The safety issue refers to petroleum drilling and production hazards that may occur in association with gas hydrates in both offshore and onshore environments.

Seafloor Stability

Along most ocean margins the depth to the base of the gas hydrate stability zone becomes shallower as water depth decreases; the base of the stability zone intersects the seafloor at about 500 m. It is possible that both natural and human induced changes can contribute to in-situ gas hydrate destabilization which may convert a hydrate-bearing sediment to a gassy water-rich fluid, triggering seafloor subsidence and catastrophic landslides. Evidence implicating gas hydrates in triggering seafloor landslides has been found along the Atlantic Ocean margin of the United States. The mechanisms controlling gas hydrate induced seafloor subsidence and landslides are not well known, however these processes may release large volumes of methane to the Earth's oceans and atmosphere.

Safety

Throughout the world, oil and gas drilling is moving into regions where safety problems related to gas hydrates may be anticipated. Oil and gas operators have described numerous drilling and production problems attributed to the presence of gas hydrates, including uncontrolled gas releases during drilling, collapse of wellbore casings, and gas leakage to the surface. In the marine environment, gas leakage to the surface around the outside of the wellbore casing may result in local seafloor subsidence and the loss of support for foundations of drilling platforms. These problems are generally caused by the disassociation of gas hydrate due to heating by either warm drilling fluids or from the production of hot hydrocarbons from depth during conventional oil and gas production. The same problems of destabilized gas hydrates by warming and loss of seafloor support may also affect subsea pipelines.

V. Conclusions

Our knowledge of naturally occurring gas hydrates is limited. Nevertheless, a growing body of evidence suggests that (1) a huge volume of natural gas is stored in gas hydrates, (2) production of natural gas from gas hydrates may be technically feasible, (3) gas hydrates hold the potential for natural hazards associated with seafloor stability and release of methane to the oceans and atmosphere, and (4) gas hydrates disturbed during drilling and petroleum production pose a potential safety problem. The USGS welcomes the opportunity to collaborate with domestic and international scientific organizations to further our collective understanding of these important geologic materials.

Mr. WALDEN. [presiding] Thank you, Dr. Collett.

Dr. Haq.

STATEMENT OF BILAL U. HAQ, DIVISION OF OCEAN SCIENCES, NATIONAL SCIENCE FOUNDATION

Dr. HAQ. Thank you, Mr. Chairman, for giving me the opportunity to present the Subcommittee the outline of the state of our knowledge on natural gas hydrates.

I have submitted a formal statement that I would like to be made a part of the record.

For several decades, we have known gas hydrates exist within the sediments of the continental slope and in the permafrost on land. While it was only during the last decade that the pace of research has picked up, and especially in the last three or four years. Research efforts in several countries had been focused at learning more about the viability of gas hydrate as an energy resource. In addition, their role in slope instability and global climate change is also of considerable interest to the research community and has obvious societal relevance.

In marine sediments, hydrates are commonly detected remotely by the presence of acoustic reflectors known as “bottom simulating reflectors” or “BSR’s.” Now, BSR’s are known from many continental margins of the world, but hydrates have only been rarely sampled through drilling. This lack of direct sampling means that estimating the volumes of methane trapped in the hydrates and the free gas below the hydrate remain largely speculative.

One of the few places in the world where hydrates have been drilled and directly sampled is on the Blake Ridge, a topographic feature off the coast of the Carolinas, Georgia, and Florida. Here it was observed that the BSR is present only where there is a significant amount of free gas below the hydrate zone, whereas hydrate was present even where there was no BSR. Thus, if our estimates are calculated purely on the basis of observed BSR’s, it may lead to underestimation of the lateral extent of the hydrate fields and the total volume of the contained methane.

At present, even the relatively conservative estimates contemplate as much methane in hydrates as double the amount of oil and known fossil fuels. Whether or not these large estimates can be translated into viable energy resource is a crucial question that has been the focus of researchers in many countries in the world.

Scientists theorize that when large slumps that occur when gas hydrates disassociate on the continental slope, they can release large amounts of methane into the atmosphere triggering greenhouse warming over the longer term.

Of more immediate concern, however, is the response of the methane trapped in the permafrost hydrates. If the summer temperatures in the higher latitudes were to rise by even a few degrees, it could lead to increased emission of methane from the permafrost, thereby adding to the greenhouse effect and further raising global temperature. The actual response of both the permafrost and the ice fields on Greenland and Antarctica to the global warming remains largely unknown at the present time due to lack of research in this area.

Although the hydrocarbon industry has had a longstanding interest in the hydrates, but they have been slow to respond to the need of gas hydrate research as an energy resource. This stems from several factors. Many of the industry believe that the widely cited large estimates of methane in gas hydrates on the continental margins may be overstated. Moreover, if this hydrate is thinly dispersed in the sediment, rather than concentrated, it may not be easily recoverable and, thus, not cost effective.

And now, some of our research needs in this area. Much of the uncertainty concerning the value of hydrate as a resource for the future, their role in slope instability and climate change stems from the fact that we know very little about the nature of the gas hydrate reservoir. Understanding the characteristics of the reservoir, finding ways to image and evaluate its contents remotely may be the two most important challenges in gas hydrate R&D for the near future.

We need to know where exactly on land and on the sea floor gas hydrates occur, and how extensive is their distribution. We need to be able to discern how they are distributed. Are they distributed mostly thinly dispersed in sediments or in substantial local concentration? Only then will we be able to come up with a meaningful estimate of their national and global distribution.

We also need a better understanding of how hydrates form and how they get to where they are stabilized. This means learning more about the biological activity and organic matter decay that generates the methane gas for the hydrates, their plumbing system, migration pathways, and hydrate thermodynamics. To understand the role of gas hydrates in slope instability, research will be needed into their physical properties and their response to changes in pressure temperature regimes.

To appreciate their role in global climate change, we need to have a better grasp of how much of the hydrates on the ocean margins and in the permafrost is actually susceptible to oceanic and atmospheric temperature fluctuations. More importantly, we must understand the fate of the methane released from a hydrate source into the water column and the atmosphere.

Once the efficacy of natural gas hydrates as a resource have been ascertained, new technologies will be needed to develop for their meaningful exploitation. This includes new techniques for detection, drilling, and recovery of solid hydrate and free gas below. Such technologies are lacking at the present time.

Mr. Chairman, once again, thank you very much for providing me the opportunity to testify. And I will be happy to answer any questions that I am able.

[The prepared statement of Dr. Haq follows:]

STATEMENT OF BILAL U. HAQ, DIVISION OF OCEAN SCIENCES, NATIONAL SCIENCE FOUNDATION

Thank you, Madam Chairman and members of the Subcommittee for giving me the opportunity to present an outline of the state of our knowledge of natural gas hydrates and the future research needs in this area.

Natural gas hydrates have been known to exist within the continental margin sediments for several decades now, however, it is only during the last decade that the pace of research into their distribution and nature has picked up, and especially in the last three or four years. The research effort in several countries has been focused at learning more about their efficacy as an alternative energy resource. In addition, their role in slope instability and global climate change is also of considerable interest to the research community and has obvious societal relevance.

Gas hydrates consist of a mixture of methane and water and are frozen in place in marine sediments on the continental slope and rise. To be stable the hydrates require high pressure and low bottom temperature and thus they occur mostly at the depths of the continental slope (generally below 1,500 feet depth). Due to the very low temperatures in the Arctic, hydrates also occur on land associated with permafrost, and at shallower submarine depths of about 600 feet. Methane gas that forms the hydrate is mostly derived from the decay of organic material trapped in the sediments.

Methane is a clean burning fuel. Because the methane molecule contains more hydrogen atoms for every carbon atom, its ignition produces less carbon dioxide than other, heavier, hydrocarbons. In addition, the hydrate concentrates 160 times more methane in the same space as free gas at atmospheric pressure at sea level. Thus, natural gas hydrates are considered by many to represent an immense, environmentally friendly, and viable, though as yet unproven resource of methane.

In marine sediments, hydrates are commonly detected by the presence of acoustic reflectors, know as bottom simulating reflectors, or BSRs. However, to produce a boundary that reflects acoustic energy, a significant quantity of free gas needs to be present below the hydrate to induce the contrast that causes the reflector. BSRs are known from many continental margins of the world, but hydrates have only rarely been sampled through drilling. Moreover, the presence or absence of BSR does not always correlate with the presence of hydrate nor provide information about the quantity of hydrate present. The general lack of direct sampling means that estimating the volumes of methane trapped in hydrates, or the associated free gas beneath the hydrate stability zone, remain largely speculative.

One of the few places in the world where hydrates have been drilled and directly sampled is on the Blake Ridge, a topographic feature off the coast of the Carolinas, Georgia and Florida. Here it was observed that the BSR is present only where there is significant amount of free gas below the hydrate, whereas hydrate was present even where there was no BSR recorded on acoustic profiles. Thus, if our estimates are calculated purely on the basis of observed BSRs, it may lead to underestimation of the lateral extent of the hydrate fields and the total volume of the contained methane.

Estimates of how much methane might be trapped in the hydrates in the near-shore sediments therefore remain conjectural at the present, but even the relatively conservative estimates contemplate as much as double the amount of all known fossil fuel sources. Whether or not these large estimates can be translated into a viable energy resource is a crucial question that has been the focus of researchers in many countries. In the past petroleum industry in the U.S. and elsewhere has been less interested in methane hydrates as a resource because of the difficulties in estimating and extracting the gas and distributing it to consumers as a cost-effective resource.

Since gas hydrates in marine sediments largely occur on the continental slope, they may also be implicated in massive slumps and slides when hydrates break down due to increased bottom temperature or reduced hydrostatic pressure. Local earth tremors may also cause hydrates to slump along zones of weakness. When a hydrate dissociates, its bottom layer changes from solid “icy” substance to a “slushy” mixture of sediment, water and gas. This change in the mechanical strength of the hydrate occurs first near the base because the temperature in the sediment increases with depth and thus the bottom part of the hydrate stability zone is most vulnerable to subtle changes in temperature and pressure. This encourages massive slope failure along low-angle detachment faults. Such slumps can be a considerable hazard to petroleum exploration structures such as drilling rigs and to undersea cables. In addition, extensive slope failures can conceivably release large amounts of methane gas into the seawater and atmosphere.

Scientists studying the recent geological past theorize that gas-hydrate dissociation during the last glacial period (some 18,000 years ago) may have been responsible for the rapid termination of the glacial episode. During the glacial period the sea level fell by more than 300 feet, which lowered the hydrostatic pressure, leading to massive slumping that may have liberated significant amount of methane. Methane being a potent greenhouse gas (considered to be ten times as potent as carbon dioxide by weight), a large release from hydrate sources could have triggered greenhouse warming. As the frequency of slumping and methane release increased, a threshold was eventually reached where ice melting began, leading to a rapid deglaciation.

At present, however, the response of the methane trapped in the permafrost as hydrate is of greater concern. If the summer temperatures in the higher latitudes were to rise by even a few degrees, it could lead to increased emission of methane from the permafrost, thereby adding to the greenhouse effect and further raising the global temperatures. These increases in global mean temperature may also lead to further melting of high-latitude ice fields on Greenland and Antarctica. The response of both the permafrost and the ice fields to increased temperature, however, remains largely unknown at the present time.

Direct measurements of methane in hydrated sediments and the free gas below made during drilling on the Blake Ridge by the Ocean Drilling Program, supported largely by the National Science Foundation, show that large quantities of methane may be stored in this gas-hydrate field, and even more as free gas below the hydrate. In the hydrate stability zone the volume of the gas hydrate based on direct measurements was estimated to be between 5 percent and 9 percent of the pore space. Though the hydrate occurs mostly finely disseminated in the sediment, relatively pure hydrate bodies up to 30 cm thick also occur intermittently. Below the hydrate stability pore spaces are saturated with free gas. From the point of view of recoverability, the free gas below the hydrate stability zone, if it occurs in sufficient quantities, could be recovered first. Eventually, the gas hydrate may itself be dissociated artificially and recovered through injection of hot water or through depressurization.

Although the hydrocarbon industry has had a long-standing interest in hydrates (largely because of their nuisance value in clogging up gas pipelines in colder high latitudes and in seafloor instability for rig structures), their slowness in responding to the need for gas-hydrate research as an energy resource stems from several factors. Many in the industry believe that the widely cited large estimates of methane in gas hydrates on the continental margins may be overstated. Moreover, if the hydrate is thinly dispersed in the sediment rather than concentrated, it may not be easily recoverable, and thus not cost-effective to exploit.

One suggested scenario for the exploitation of such a dispersed resource is excavation, which is environmentally a less acceptable option than drilling. And finally, if recovering methane from hydrate becomes feasible, it may have important implications for slope stability. Since most hydrates occur on the continental slope, extracting the hydrate or recovering the free gas below the stability zone could cause slope instabilities of major proportions that may not be acceptable to coastal communities. Producing gas from gas hydrates locked up in the permafrost has so far met with considerable difficulties, as the Russian efforts to do so in Siberia in the 1960s and 70s would imply.

The occurrence and stability of gas hydrates at oceanic depths of the slope and rise has also led to the notion that we may be able dispose off excess green-house gases, especially carbon dioxide, in the deep ocean as artificial hydrates. Although permanent sequestration of carbon dioxide may not be realistic since the hydrate on the seafloor would eventually be dissolved and dispersed in seawater, the isolation of carbon dioxide in the form of solid hydrate that remains stable for relatively long periods of time may be plausible. The long time scales of ocean circulation, the large size of the oceanic reservoir and the buffering effect of carbonate sediments all speak in favor of this potentiality. These notions, however, need considerable measure of research, both in the laboratory and the field, before they can be regarded as practical.

Research Needs

Much of the uncertainty concerning the value of gas hydrates as a resource for the future, their role in slope instability and their potential as agents for future climate change, stems from the fact that we have little knowledge of the nature of the gas-hydrate reservoir. Understanding the characteristics of the reservoir and finding ways to image and evaluate its contents remotely may be the two most important challenges in gas-hydrate R & D for the near future.

We need to know where on land and the continental margins gas hydrates occur and how extensive is their distribution? We need to be able to discern how they are distributed, mostly thinly dispersed in sediments or in substantial local concentrations. Only then will we be able to come up with meaningful estimates of their total volume on the U.S. continental margins and in higher latitudes, as well their global distribution.

We also need a better understanding of how hydrates form and how they get to where they are stabilized. This effort encompasses learning more about the biological activity and organic-matter decay that generates methane for hydrates, their plumbing systems, migration pathways and the hydrate thermodynamics, and it will require laboratory experimentation, field observations and modeling.

To understand the role of gas hydrates in slope instability, research will be needed to learn more about their physical properties and their response to changes in pressure-temperature regimes. Both laboratory experimentation and invitu monitoring will be necessary. Gas hydrates in the Arctic, Gulf of Mexico and off the U.S. East Coast represent extensive natural laboratories for all aspects of gas hydrate research.

To appreciate the role of gas hydrates in global climate change, we need to have a better grasp of how much of the hydrate in the continental margins and the permafrost is actually susceptible to oceanic and atmospheric temperature fluctuations. More importantly, we must understand the fate of the methane released from a hydrate source into the water column and the atmosphere. Studies of the geological records of past hydrate fields can also provide clues to their behavior and role in climate change.

Once the efficacy of natural gas hydrate as a resource has been proven, new technologies will have to be developed for their meaningful exploitation. This includes new methodologies for detection, drilling, and recovery of the solid hydrate and the free gas below. Such technologies are lacking at the present time.

Madam Chairman, once again thank you for giving me the opportunity to testify and I will be happy to answer any questions from the members of the Subcommittee that I am able to.

Mr. WALDEN. Thank you, Mr. Haq; I appreciate your testimony.

I might start with some questions for Mr. Kripowicz. Thank you for outlining the Department of Energy's role as the programmatic lead for a Federal R&D program for methane hydrates.

I realize both the House and the Senate bill put the Secretary of Energy in the driver's seat for steering the appropriated dollars to fulfill the program's goals. Perhaps DOE is the logical home for it. However, I am concerned that while both bills contemplate involvement by the USGS, National Science Foundation, and Office of Naval Research, neither bill requires the Secretary to establish the advisory panel made up of representatives from those agencies and academia. Nor does the Secretary have to listen to them if he does create the panel.

Given the inevitable squeeze under the budget caps agreed to by President Clinton in 1997, it is fair to believe that DOE may try to keep appropriated dollars in-house for the Federal Energy Technology Center or the national labs.

What assurances can you give the Subcommittee that the USGS and the marine minerals research institutions under our jurisdiction will be given a meaningful place at the table?

Mr. KRIPOWICZ. Mr. Chairman, the assurance that I can give you is that we have been working cooperatively with those organizations from the very beginning on this program.

At the outset, before legislation was contemplated, we believed that we needed to get buy-in from all of the other organizations that had an interest in methane hydrates in order to present a rational program.

And the way we have also set up the potential organization is that we will have a management steering committee which includes, not only the Department of Energy, but the USGS and the National Science Foundation, MMS, NRL, the Ocean Drilling Program, and several industrial organizations.

And we have worked through the original strategy document and the beginnings of the program plan in close cooperation with these organizations and have provided a tremendous amount of interplay and public comment on our plans in this area.

Mr. WALDEN. Okay. Given the concerns the panelists have stated about disassociation of gas hydrates on the continental slope, leading to instability of drilling environments, do you believe the Minerals Management Service, which regulates drilling operations on the outer-continental shelf, should be programmatically involved, either directly or via the Center for Marine Research and Environmental Technology at the University of Mississippi, which is one of the centers established by Public Law 104-325, out of this Subcommittee?

Mr. KRIPOWICZ. Yes, sir. MMS is one of the people that is on the Management Steering Committee, and we have a working relationship with MMS and would expect them to be closely involved in this research, including possibly some of their own funding, as well as funding from this money.

Mr. WALDEN. Okay.

And our full Committee chairman is interested in this program, in part, because of the potential to bring gas to remote native villages in the Arctic which are starved for affordable fuels.

Will DOE ensure that gas hydrate studies in permafrost regions be given an equal place at the research table?

Mr. KRIPOWICZ. Yes, sir. As a matter of fact, probably the first experiments—production experiments—would mostly likely be in permafrost areas because there would be cheaper areas in which to drill to establish the characteristics of the resource and get the background information needed to decide whether it can actually be made into a recoverable reserve. So we would expect, you know, a lot of work to go on in the Arctic and permafrost regions.

Mr. WALDEN. Okay.

H.R. 1753 prescribes that the Secretary of Energy create an advisory committee that would solicit proposals for hydrate research which would then undergo a peer review process.

Would the peer review process be enlisted for the review of individual research proposals submitted to the program, or only with respect to the entire gas hydrate program, in general? And could you explain to me how you expect this process to operate?

Mr. KRIPOWICZ. We would assume that there would be more than one way to allocate the funding. For example, research within the government, that portion of it would be determined by the steering committee on it which most of the agencies sit. Then for universities and for industry, there would be an allocation of money which would be available on a competitive peer-reviewed basis.

Mr. WALDEN. Testimony from Dr. Woolsey on the next panel implies the administration is pledging more support to this effort than was outlined in the President's Science Advisors' report several years ago.

Is the Department of Energy satisfied that a viable R&D program for the methane hydrates can be performed under the authorization caps in H.R. 1753?

Mr. KRIPOWICZ. Yes, sir. The cap for Fiscal Year 2000 is $5 million; our budget request is $2 million. And the cap for the succeeding years is $10 million. And what I have testified to previously is that it is clear, that in a long-term program, you need more than $2 million a year. The $2 million is a starting figure to establish the program, but in future years, a program of substantial size would be needed in order to finally get to a decision as to whether this is a producible reserve. And the numbers of $10 million appear to be a reasonable figure, although as you get further into the program, it may or may not be true. But we, at this point, feel we can live with those allocations.

Mr. WALDEN. All right. Thank you.

Turn now to Mr. Underwood.

Mr. UNDERWOOD. Thank you, Mr. Chairman.

This is a question that is related to the length of time that we are imagining, or we are perhaps projecting it would take to actually—and this question is for any one of the panelists. What is the anticipated timeline that actually we would see the technology available, that would actually be able to access and produce gas from these methane hydrates?

Mr. KRIPOWICZ. I would say that that is probably a very fuzzy date, but we would believe that if you financed the program at somewhere near the $10-million range over a considerable period of time, that no sooner than the year 2010, I think you could identify whether this is really an exploitable resource. So it is a long-term program.

Mr. UNDERWOOD. Okay. Would the other two members of the panel agree with that?

Dr. COLLETT. From our perspective, a part of our program is very focused on the Alaska accumulations onshore in the oil and gas areas. Hydrates there are drilled almost on a daily basis in the field areas, and this is an area where we are proceeding with cooperative work with industry to actually develop tests of hydrate accumulations, for the main purpose of engineering reservoir maintenance of conventional reservoirs and, ultimately, to feed maybe a gas-to-liquids program or LNG-type program. So what we perceive is within a five-year timeframe, we will see a very significant test with industry components on the North Slope of Alaska where the interstructure is already present.

I would certainly agree with Mr. Kripowicz, in that for longer-term, large-scale production, we are at least looking 10 to 15 years out. And even in that situation, it will be in isolated areas with very specific motivations to go after the resource.

Mr. UNDERWOOD. Dr. Haq?

Dr. HAQ. I don't have anything to add to that.

Mr. UNDERWOOD. Okay.

In terms of, then, we are really anticipating that the government will invest about $100 million in this enterprise before we see it actually bear fruit.

How much is that going to—well how much do you think private industry is going to be putting into this? Is there a sense of how much private industry will be putting into this during this timeframe?

Mr. KRIPOWICZ. Mr. Underwood, as you get closer toward really showing that this is a producible resource, you will get more and more industrial participation. At the very beginning of this, I would expect that you would get some industrial participation, but not a great deal. You might particularly get participation in areas that affect safety because that effects existing and planned operations on the industrial sites that we would expect to see, you know, more participation by industry there than you would in some of the other areas.

But as a general rule, in our research, when you actually get to the demonstration phases of technology, you talk about at least 50 percent cost-sharing from the industry, but I don't believe you would see that kind of cost-sharing for some time in this area.

Mr. UNDERWOOD. Okay. I understand that the deep seabed mining, that the technology—what is the connection between the technology that would be used to actually begin deep seabed mining and actually access some of the methane hydrates that are on the ocean floor?

I understand that the Japanese are planning to dril somewhere in the Nanki Trough later on this year. What is the ostensible connection between the technology used for this purpose and deep seabed mining? And where are we, as a country, in relationship to that technology, as compared to Japan?

Mr. KRIPOWICZ. I can't speak to that in any detail except to say that we, on very preliminary looks at this, would say that deep seabed methods would probably be among the most expensive way to recover a diverse resource like methane hydrates.

Dr. COLLETT. From our perspective, we come with a cooperative relationship that is five years old now with the Japanese National Oil Company and the Geological Survey of Canada, in which we actually conducted a drilling program with the Geological Survey of Canada in Canada to look at the producibility of Arctic gas hydrates. Just last year, we completed a well in Canada.

Our experience, and I think we have good insight into the Japanese program, we are mainly looking at conventional-style borehole production associated with conventional methods. We would perceive most of the production methodology would probably evolve initially out of conventional oil and gas production technology. But mining is one of the proposed and perceived methods to look at hydrates, mainly for reasons such as the in the Gulf of Mexico, hydrates occur right at the sea floor, so you have this opportunity.

But most certainly, the technology is evolutionary. We are only venturing into those water depths in the last five years, so the type of technology we are discussing now is on the cutting edge.

Mr. UNDERWOOD. I am just, you know, thinking out loud because I am trying to get a sense of how the two intersect. And then, also, in addition, we are not really participants of the law of the sea. And in the meantime, there is a lot of this kind of activity will occur in the ocean floor. And it seems to me that while we are moving ahead in one sense, in terms of developing and encouraging the science which would lead to accessing this source of energy, the policy-end of it, in terms of participation in the law of the sea, and also the technological end of it.

And from what I understand—and I could be mistaken; I could be not fully informed—I have gotten the sense that the Japanese are proceeding with all deliberate speed, in terms of their own technology for deep seabed mining. And that is, obviously, a source of concern for people I represent, and I think people who anticipate that there may be this mineral source as well as this energy source nearby.

Dr. COLLETT. When we look, particularly, at this issue from the U.S. perspective, what our group is largely responsible for in the USGS is the assessment of oil and gas resources and hydrate assessment is limited to the exclusive economic zone of the U.S. That is an EEZ assessment, so our gas hydrate assessment numbers are limited to that. So there is one issue about law and mineral rights that are very clear.

But most certainly, when we look at it, for the lack of a better term, a competitive sense, the Japanese are investing a large sum of money. They have motivations to do that because they import most of their hydrocarbon resources. Ninety five percent of their resources are imported. So their commitment to this has been historically much greater.

And what we are seeing now in the world that the technology may be catching up to the point to start exploiting some of these resources.

Mr. UNDERWOOD. Okay. We will have to deal with the policy issue——

Dr. COLLETT. Yes.

Mr. UNDERWOOD. [continuing] to remaining of whether the EEZ resources belong to the territories or to the Federal Government.

Dr. COLLETT. Yes.

[Laughter.]

Mr. UNDERWOOD. Thank you.

Dr. COLLETT. We will go with it.

Mr. WALDEN. I want to go back to Mr. Kripowicz.

I understand that methane hydrates may occur off the Oregon Coast. Would there be an opportunity for the University of Oregon or OSU, Oregon State University, to be involved in some of the research there and get grants from DOE for the program?

Mr. KRIPOWICZ. Yes, sir. As a matter of fact, Oregon State University has participated in the workshops that we have had in establishing this program, and I believe has done some methane hydrates research, and is doing some right now.

Mr. WALDEN. Okay.

Dr. COLLETT. Excuse me.

Mr. WALDEN. Yes; go ahead.

Dr. COLLETT. They have played a leading role. Particularly, with a cooperative research relationship with the Geological Survey of Germany, a number of research cruises have been led by Oregon State, which dealt with sampling gas hydrates offshore of Oregon. It is one of the more established hydrate sites, and, also, it was the focus of a dedicated leg of the Ocean Drilling Program, under NSF, Leg 146.

So that margin, the Oregon coastal area, is often looked at as one of the critical experimental areas.

And there are also proposals at present in ODP to actually go back to the Oregon coast.

Mr. WALDEN. Okay.

Yes?

Dr. HAQ. I was just going to add to that——

Mr. WALDEN. Dr. Haq?

Dr. HAQ. [continuing] that NSF has—that is, the Division of Ocean Sciences at NSF has just committed to fund a cruise led by

Oregon scientists to the tune of about $600,000 to image the hydrates, as well as to sample the hydrates with a newly-developed sea floor coring system. That is essentially——

Mr. WALDEN. Okay.

Dr. HAQ. [continuing] going to be funded in this fiscal year.

Mr. WALDEN. Okay.

Let me go back to you. What is the status of current geologic models and understanding in predicting the occurrence of hydrate deposits?

Status of the current models in predicting deposits? Either?

Dr. COLLETT. I can reflect back to 1995; in that when we conducted the assessment, the U.S. gas hydrate resource assessment was based on a play model concept where we risked 18 geologic factors that control the occurrence the hydrates—the availability of gas, water, and migration of fluids.

We actually went systematically through all of the continental margins in the U.S. and did a scientific review of the favorability of these factors leading to the accumulation of hydrates. So, basically, that is the model. We assume we understand how hydrates occur.

The problem with our model, however, is the lack of direct information about known accumulations. Other than the Blake Ridge accumulation on the Atlantic margin of the U.S., limited seismic inferred gas hydrates on the Cascadia margin, and on the North Slope of Alaska, we still know very little about any detailed aspects of hydrate accumulations.

So to understand the accumulation of gas hydrate before we can project it into a model for gas formation is a very difficult step, but really the basic research hasn't been done.

Mr. WALDEN. Okay.

Dr. Haq, am I correct to understand the National Science Foundation receives Federal appropriation in its own right for peer-reviewed research grants to academia in many subject matter areas, including methane hydrate research?

Dr. HAQ. Yes. The funding, of course, is extremely competitive, and it is entirely based on the best science, which has to be not only competitive, but also cost effective. And the community has to agree that, yes, this is their high priority. At this time, gas hydrates are being funded because of that reason, because it is a issue that is high priority for the community. And it is also of great scientific value and, therefore, there have been several proposals that have been funded very competitively.

Mr. WALDEN. How would the centralization of the Federal R&D for methane hydrate at the Department of Energy affect the National Science Foundation?

And do you envision that the peer review contemplated in H.R. 1753 will allow NSF's grant proposals process to continue to function as they always have?

Dr. HAQ. NSF will continue to fund proposals in gas hydrates, as long as they are competitive, and as long as the funds are available. But there are no separate earmarked funds for gas-hydrate research at NSF.

One of the effects of DOE funding would be that since we can only fund limited number of projects, the academic community will have another source of funding and, therefore, I think—collaboration between DOE and NSF could actually get you better bang for the bucks, so to speak, if that were to happen.

Mr. WALDEN. Okay.

I just have two other questions for Dr. Collett.

What area of the United States, for example, the coastal waters off the Atlantic coast or the Gulf of Mexico, or onshore in the North Slope of Alaska would be the most profitable—or probable candidate, I should say—for a pilot project to begin producing natural gas from hydrates?

Where do you think are the most probable?

Dr. COLLETT. We feel very strongly about the fact it would be the North Slope of Alaska, particularly the areas in the western part of the Prudhoe Bay oil field region.

The reason for this is that it is, one, an area of the most highly concentrated hydrate accumulations in the world, so it gives you the ability to focus on a sweet spot of hydrate accumulation.

You also have existing industry activity, these are accumulations that are drilled for deeper targets on a regular basis. So you have a catalyst of already in-place resources for the industry to use and to develop the hydrate resources.

And also there is a direct need for gas that is not often spoke about on the North Slope, it is for existing reservoir maintenance of conventional reservoirs and producing of heavy oil; gas is a very important commodity on the North Slope without coming off the slope. So I would see these areas now to pose an immediate demand and synergy of events.

Mr. WALDEN. Okay. I just have one other question for you.

USGS Director Groat testified before this Committee earlier this year during the Budget Oversight hearing. The part of the USGS mission includes helping with the scientific needs of sister-DOI agencies. I believe the programmer initiative was called Integrated Science.

Does the USGS have plans for a cooperative marine science initiatives with the MMS in regard to sub-sea slope stability and other marine geology problems related to methane resources and their exploitation?

Dr. COLLETT. On the formal nature of where these agreements exist, I am not aware of. We can get back to you. But in the practical sense, we are already conducted relationships or joint cruises with the University of Mississippi—what may come up later in the testimony today.

We have also looked at the opportunities of working with MMS. We have been approached by individuals such as Jesse Hunt involved with the Gulf of Mexico safety panels of MMS.

So we see a number of opportunities, but most of them have not been formalized.

Mr. WALDEN. At this point, we are going to go ahead—Mr. Underwood has no further questions nor do I, so we will excuse this panel and then we will recess until we are done voting, which is probably 20 minutes, and then we will resume with panel two.

So the Committee will stand in recess.

[Recess.]

Mr. WALDEN. Okay, if we could come back to—if we could come back to order. And if the staff is ready, I will reconvene the hearing.

And I will just tell the witnesses in advance that we are having a number of amendments on the House floor, which we anticipate will interrupt our business, probably well into the night, every 15 minutes. So, having said that, we will try and proceed as orderly as we can.

And I would like to welcome Dr. Trent, the dean of School of Mineral Engineering, University of Alaska Fairbanks, and I would tell you as a—ahead of your testimony, I am probably the only other one in this room who ever attended the University of Alaska Fairbanks, and I did so my freshman year in college, so—oh, there is somebody else in the back.

[Laughter.]

Two, I know. Three—and another one.

[Laughter.]

Here we are. I can't sing the song, but I lived in Moore Hall.

[Laughter.]

Yes, we got half the student body.

Welcome; good afternoon.

STATEMENT OF ROBERT H. TRENT, P.E., PH.D., DEAN, SCHOOL OF MINERAL ENGINEERING, UNIVERSITY OF ALASKA FAIRBANKS

Dr. TRENT. Thank you, Mr. Chairman.

First of all, I would like to explain my attire. In Alaska we call it "na-nuk," and today it is courtesy of Northwest Airlines giving my luggage extra frequent flier miles somewhere.

[Laughter.]

Mr. WALDEN. Not a problem.

Dr. TRENT. I will keep mine short. I will not speak to the trillions of cubic feet of gas that is out there. I think we all know that.

However, in Prudhoe Bay and Kuparuk River fields, it is pretty well proven that there is approximately 35 to 45 trillion cubic feet of gas in those fields, one of the largest accumulations in the world. Also, our permafrost gas hydrates are in higher concentrations and have excellent quality.

We are working closely with two of the oil companies at this time, developing new cementing methods for bonding casing through permafrost gas hydrates. As noted previously, one of the advantages of the Alaska North Slope is the infrastructure that is available with the oil companies in there. In fact, Japan Oil Corporation, it was there first choice to drill the well that they did eventually put on the McKenzie Delta. It wasn't the fact that we didn't have the infrastructure. It was the fact that it took the attorneys too long to get the job done.

Another advantage to Alaska, particularly—well, all the northern areas, the circum polar northern areas—is that the availability of natural gas from hydrates will be very useful to the Native villages in developing other natural resources throughout the State, Siberia, and northern Canada.

Energy in Alaska villages right now can be as high as 50 cents per kilowatt hour. If we can develop a source of natural gas from hydrates, we could lower that considerably down, hopefully, even to the 5 cents per hour range. In addition, we can use it for home space heat, waste reformation, and, as a I say——

[Laughter.]

[continuing] the warehouse of minerals that we have in the north could be open with a source of natural energy.

Thank you.

[The prepared statement of Dr. Trent follows:]

STATEMENT OF ROBERT H. TRENT P.E., PH.D., DEAN, SCHOOL OF MINERAL ENGINEERING, UNIVERSITY OF ALASKA FAIRBANKS, BROOKS BUILDING, UNIVERSITY OF ALASKA FAIRBANKS, FAIRBANKS, ALASKA

This statement is respectfully submitted in support of H.R. 1753 and S. 330. Recent studies have shown that gas hydrates are widespread along the coastline of the continental United States, onshore areas of Alaska and the possibly in deep marine environments of the Pacific Islands of the United States and other countries. The amount of gas in hydrate reservoirs of the United States greatly exceeds the volume of known conventional gas reserves. The gas hydrate accumulations in the area of the Prudhoe Bay and Kuparuk River oil fields in northern Alaska are best known and documented gas hydrate occurrences in the world. Recently completed domestic gas hydrate assessments suggest that the North Slope of Alaska may contain as much as 590 trillion cubic feet of gas in hydrate form and the offshore areas of Alaska may contain an additional 168 trillion cubic feet of gas in hydrates. The Prudhoe Bay-Kuparuk River gas hydrate accumulation is estimated to contain approximately 35 to 45 trillion cubic feet of gas, which is one of the largest gas accumulations in North America. Unlike most marine gas hydrate accumulations, such as those along the eastern continental margin of the United States or in the Gulf of Mexico, the permafrost associated gas hydrate accumulation in northern Alaska occur in high concentrations and are underlain by large conventional free-gas accumulations.

The occurrence of concentrated gas hydrate accumulations and associated conventional free-gas accumulations are thought to be critical for the successful economic production of gas hydrates. An additional comparison reveals that onshore permafrost associated gas hydrates, relative to marine gas hydrate accumulations, often occur in higher quality reservoir rocks which should also contribute to the economic production of this vast energy resource. It should also be noted that the known gas hydrate accumulations in northern Alaska are found within an area of very active industry exploration and development operations. The existing oil and gas industry infrastructure in northern Alaska will certainly contribute to the eventual economic development of the North Slope gas hydrate resources. This infrastructure and known hydrate reserves were the reason that this area as the first choice for testing by the Japan National Oil Corporation last year. We believe that the cost of developing gas hydrate exploration and production technology will be considerably less on if developed on land rather than at sea.

The first gas hydrate accumulations to be produced may have unique characteristics, such as location, that may make them technically and economically viable. For example, gas associated with conventional oil fields on the North Slope of Alaska is used to generate electricity in support of local field operations, for miscible gas floods, gas lift operations in producing oil wells and re-injected to maintain reservoir pressures in producing fields. In the future, gas may be used to generate steam that may be needed to produce the known vast quantities of heavy oil and more recently the production of a clean diesel fuel by gas to liquid conversion. Existing and emerging operational needs for natural gas on the North Slope are outpacing the discovery of new conventional resources and at least one of the operators in Alaska is looking at gas hydrates as a potential source of gas for field operations. The North Slope of Alaska contains vast, highly concentrated gas hydrate accumulations that may be exploited because of a unique local need for natural gas.

In addition to the above, and even more important is the possibility of utilizing hydrate gas for space heat and the generation of energy in Alaska's Native villages. The current cost of electrical power in the villages in on an average of $0.50 per kilowatt hour. If hydrate gas can be produced it will be possible to utilize fuel cells or other power generating technology to reduce this cost while providing power that can be utilized for home space heat, waste reformation, mineral and other natural resource development. Rural Alaska is a vast warehouse of natural resources just waiting for an economical energy resource to make them viable. By developing natural resources, much needed jobs will be created.

I urge the Committee to support H.R. 1753 and S 330, "Methane Hydrate Research and Development Act of 1999."

Mr. WALDEN. All right.

Dr. Woolsey.

STATEMENT OF DR. J. ROBERT WOOLSEY, DIRECTOR, CENTER FOR MARINE RESOURCES AND ENVIRONMENTAL TECHNOLOGY, CONTINENTAL SHELF DIVISION, UNIVERSITY OF MISSISSIPPI

Dr. WOOLSEY. Thank you, Mr. Chairman.

We certainly appreciate the opportunity to be here, even on a busy and confused day as this. It certainly gives us an opportunity to present testimony on a subject that the three of us are very keen on.

My two colleagues and I are part of the Center for Marine Resources and Environmental Technology. It is a program of applied academic endeavors and serves as an arm of the Minerals Management Service toward this extent. We have, together, worked on our own separate areas of interest, but collectively work as one, and we have enjoyed, you know, some very interesting programs amongst ourselves. We all have particular expertise that we can bring to bear on various problems that various of us have, within in our own areas.

On the Gulf Coast now, we have been—in a way of background—we started working with several industries that were experiencing problems that were quite peculiar. At one time, gas hydrates were nothing more than a curiosity, but in the last 10 years plus, as the major oil companies have ventured out beyond 500 meters into the deep, deep water production, they have encountered a series of problems. And when we talk about the hazards that hydrates present, sometimes we take the simplistic use of the term in the occurrence of various amounts of hydrates that occur quite ubiquitously on the sea floor, within the hydrate stability zone, in water depths greater than 500 meters. And these can be readily determined with conventional technology—sidescan-sonar and the like.

But the real problem—or the greater problem—is the more subtle occurrence that hydrates present when they are buried at some depth between what appears—or under what appears to be unstable sediments. And the problem becomes more confused when you understand that industry, in their reporting of any types of problems with sea floor stability, they usually use a terminology that is descriptive. In other words, you will hear things like "shallow flows," referring to the flow of sand under pressure. And this may or may not be related to gas hydrates.

Well, within the last 10 years or so, the impact from let's say accidents that have—related to these shallow flows are more in the terms of billions of dollars—and just in the last year, in the hundreds of millions. This is not to say that all shallow flows are gas hydrates, but the more that we have gotten into this study, the more that we see similarities and ties.

For instance, I had an opportunity to speak with the supervisor for a deep water program of a major producer here a few months back. This was after their latest problem with so-called shallow flows. And I asked him—I said, "On how many occasions have your sensors picked up fresh water in these shallow flow sediments?" And he looked at me straight in the eye and said, "On every occasion."

Well, how are you going to get fresh water in these marine seawater-saturated sediments, unless you had a model, whereby you went with the disassociation of hydrates which exclude salt in their process of formation? And so when they disassociate, they are manifested as fresh water.

So I am just bringing this up to suggest that this hazard problem could be much larger when we get to the bottom of it. And that is one of the things we are doing in our program. And so we are—I see my yellow light is on—but we have got two ongoing programs.

One is a mobile survey, and we are working with a major industry in this regard toward developing high-resolution seismic techniques. And we have had really good luck with this, being able to discern the very fine structural characteristics that can identify these shallow flows and/or hydrates as they occur. And so we are well on the way with this, in a cooperative endeavor, with industry.

Then we have another program that deals with monitoring. And this would be a subsea station. And I am very pleased to announce that Conoco has very graciously provided us access to one of their subsea platforms at their Marquette location, which is very ideally suited for a subsea study. Now they are up on the brink of the slope at about 600 feet, but within 2 miles over the edge is their Juliette platform which is 1,800 feet at only 2 miles distance. And there are a number of hydrate occurrences around there. So we can put our sensors there. It will save us a tremendous amount of money, just through their efforts to help us in this instance.

There was a mention in the—I think in one of the questions to the first panel. Is industry helping in any way? Well, industry is not putting up dollars, but if I were to put a tag on this, it would be worth a half a million, easy, because it provides us with a base, a power source, fiber optic communications, satellite uplink, the whole works, that we can put our sensors out and work from. And this is a collective, cooperative effort with the Navy Research Lab at Stennis, ourselves, a number of universities in our region, particularly in Louisiana, and also some of our friends up at USGS at the Woods Hole facility.

So we have a number of these projects that are ongoing, that are cooperative efforts. And like I say, we all—the three of us—tie together and bank on each other's expertise and assistance in all these endeavors.

Thank you.

[The prepared statement of Dr. Woolsey follows:]

Testimony of
The Center for Marine Resources and Environmental Technology
(formerly The Marine Minerals Technology Center)
Continental Shelf Division
Dr. J. Robert Woolsey, Director
The University of Mississippi

Before the
United States House of Representatives
Committee on Resources
Subcommittee on Energy and Mineral Resources

May 25, 1999

This statement is respectfully submitted in support of H.R. 1753 and S. 330, and of the Center for Marine Resources and Environmental Technology, Continental Shelf Division (CMRET / CSD), formerly the Marine Minerals Technology Center, a research center of the Department of Interior, administered by the Minerals Management Service, Office of International Activities and Marine Minerals. H.R. 1753 and S. 330, both titled the Methane Hydrate Research and Development Act of 1999, call for Congress to promote the research, identification, assessment, exploration, and development of methane hydrate resources. For the past two years, the CMRET has been actively pursuing academic, industry, and government collaborations for the study of methane hydrate resources. **Requested funding for the continuation of projects outlined below is $10 million per year, for each of the next five years.**

Certainly the topic of methane hydrates has been discussed within industry and academic circles for years, but never so much as in the very recent past. Gas hydrate resource estimates range from 100,000 trillion cubic feet (tcf) to well over 7,000,000 tcf under U.S. jurisdiction alone. If you consider that U.S. consumption of natural gas per year is only 25 tcf, gas hydrates represent a tremendous resource for this country. Their production, however, remains very problematical. Perhaps at this point in time, of more importance is the hazard they represent to the oil and gas industry. Prior to 1985, U.S. industry rarely looked for conventional oil and gas prospects beyond the 1,500 foot bathymetric contour in the Gulf of Mexico. Today, leases have been obtained in 11,000 feet of water, more than 400 miles offshore. The complexity and risk of deepwater oil and gas production are very considerable and must be met with an aggressive program of technological research and development based on sound scientific understanding, all of which translate to higher cost. A typical shallow water well might cost between $100 to $500 million; a deepwater development might be in the range of $1 to $3 billion. It is more critical now than ever before that mistakes not be made.

In the way of emphasizing the importance of hydrate research to the understanding and mitigation of related problems with sea floor stability, a number of recent incidences should be mentioned. At an industry forum held in Houston last June, Michael A. Smith of Minerals Management Service, New Orleans, noted that over the previous 14 years shallow water flows (SWF's) have been reported in about 60 lease blocks in the Gulf of Mexico. They typically occur in water depths exceeding 1700 feet and originate in sand deposits located 1,000-2,000 feet below the sea floor. It is not a phenomenon peculiar to the Gulf of Mexico. Members of a panel of experts at a deep water workshop organized by the Society of Exploration Geophysicists in New Orleans last fall unanimously declared that shallow water flows presented the greatest obstacle to deep water drilling worldwide. A number of internationally recognized geologists have stated publically that the flows are very possibly associated with the dissociation of gas hydrates that had formed in the pore spaces of the sand bodies. The only way to detect such sand bodies prior to drilling is through detailed geophysical/geotechnical surveys. More research is critical to the development of reliable systems for the accurate identification of both gas hydrate deposits and buried sand bodies that are potential sources of SWF's.

***Current Activities of the Center for Marine Resources and Environmental Technology*:** During the past two years, the CMRET has been working on two pertinent projects: The first, and highest priority, is the development of high resolution survey technologies capable of detecting buried sand bodies and gas hydrate occurrences in offshore Mississippi/Louisiana. The most significant result to date is the conclusion that it is not possible to obtain sufficient seismic resolution by surveying only from the sea surface. A hybrid system is now being developed by which the seismic receiver (hydrophone) will be towed at depth while the seismic source is towed at the surface. The primary advantages of this arrangement are that 1) the hydrophone is deployed in a very quiet environment, away from the noise typically generated at the surface by wave action and the survey ship; 2) the downward-traveling signal received at the hydrophone constitutes a far-field source signature for each shot; and 3) this signature may be used during processing to enhance the resolution of the reflected (upward-traveling) signal and improve the estimates of sediment properties. Future development includes towing a high-resolution impulsive source at depth also.

The second project began as a collaboration among the CMRET, the U.S. Naval Research Laboratory (NRL) at Stennis Space Center and the U.S. Geological Survey (USGS) at Woods Hole, Massachusetts, and now involves an international team of scientists (see attached list) with the NRL and the USGS acting in an advisory capacity. The object of the project is to install a multisensor monitoring station on the sea floor in the northern Gulf of Mexico. The purpose of the station is to remotely observe physical and chemical changes of the water column and sea floor sediments in the vicinity of a gas hydrate mound. These mounds form along the intersections of faults with the sea floor. They are edifices constructed of water from the sea and hydrocarbon gases that have migrated up the faults from buried reservoirs. In addition to hydrates, they usually incorporate various minerals deposited by bacteria feeding on the hydrocarbons. The mounds are ephemeral, capable of changing greatly within a matter of days. Formation or dissociation of the hydrate constituents are dictated by pressure, temperature, gas chemistry and rate of gas flow. Variations in these can be triggered by water currents and seismic activity. Variations in sediment stability can also occur and be indicated by changes in the speeds at which compressional (P) and shear (S) waves propagate through sediments below the sea floor. The monitoring station would be capable of monitoring all these parameters, as well as some others such as heat flow and electrical conductivity, on a more-or-less continuous basis over an extended period of time. Members of the offshore petroleum industry have expressed interest and are expected to play a supportive role in making the station a reality. Conoco has offered access to their subsea facilities in the Mississippi Canyon area which will greatly reduce our cost, particularly with regard to power supplies and communication links.

Attached with this testimony are three relevant abstracts which have been submitted for publication or have been published.

The Gulf of Mexico Hydrate Research Consortium (GMHRC): In its 1997 report to the President, the Panel on Energy Research and Development of the President's Committee of Advisors on Science and Technology recommended that the Department of Energy (DOE) develop a science-based program with industry, federal agencies, and the U.S. Navy to understand the potential of methane hydrates worldwide, with a recommended funding level of $45 million over a period of 5 years, beginning in FY 1999. It is our understanding that this level has since been substantially expanded upwards to $150-200 million for this period. Senate Bill S. 330 and H.R. 1753 would authorize such a program. In response to this directive, the CMRET formed the Gulf of Mexico Hydrate Research Consortium (GMHRC) in March, 1998. The GMHRC is comprised of a group of researchers from academia, federal research institutions, and the U.S. Navy with varying but compatible interests in gas hydrates research. Under the management of the CMRET, the Consortium was formed for the purpose of promoting communication, coordination, and cooperation among interested researchers. The research mission of the Consortium will be primarily focused on the chemical and physical characterization of gas hydrate deposits, development and improvement of technologies for their recognition and mapping, assessment of sediment mechanics, sea floor instability as related to natural and anthropogenic events/activities of hydrate dissociation, engineering solutions for prevention/avoidance of instability and failure, investigation and monitoring of gas discharges to the water column and atmosphere, and scientific and technical research leading to the eventual production of methane hydrates.

The GMHRC would provide the DOE with a network of established, experienced, qualified researchers who could provide the best and most efficient means through which to approach scientific and engineering problems relating to gas hydrates (specifically those occurring within the Gulf of Mexico region). Maximum cost efficiency for the research dollar would be attained through the pooling of facilities, equipment and expertise. Ideally, the GMHRC will be guided by two Boards, an Industry Review Board and a Scientific Advisory Board, which will collectively be responsible for identifying and prioritizing research interests, and for issuing Requests for Proposals (RFP's), reviewing research proposals, and finally, for recommending funding. The CMRET, as head of the GMHRC, would be responsible for program administration, acting as liaison between the Boards and the consortium members, and for coordinating educational activities, data management and dissemination, and appropriate workshops, seminars, and annual research reviews.

DISCLOSURE OF FEDERAL FUNDS RECEIVED SINCE FY 1997

	FY 1997	FY 1998	FY1999
Marine Minerals Technology Center (now called Center for Marine Resources and Environmental Technology)	- 0 -	400,000	600,000
Nat'l Aeronautics & Space Admin.	- 0 -	- 0 -	100,000
Department of Energy	- 0 -	11,604	18,000

MONITORING STATION DEVELOPMENT ROSTER AS OF 20 MAY 1999

Director: Bob Woolsey, Center for Marine Resources and Environmental Technology (CMRET), The University of Mississippi

Technical Advisor: Paul Higley (Speciality Devices Inc., Plano, Texas)

Site Selection: Tom McGee (CMRET)
Harry Roberts (Coastal Studies Inst., LSU, Baton Rouge)
Pete Simpkin (IKB Technologies Limited, Nova Scotia)
Vaughn Goebel (Lookout Geophysical Co., Dillon, Colorado)
Ian Dinwoodie (Math. Dept., Tulane University, New Orleans)

Acoustics: Ross Chapman (School of Earth and Ocean Sci., U. of Victoria, B.C.)
Ralph Goodman (Applied Research Lab, Pennsylvania State Univ.)
Mary Rowe (High Tech, Inc., Gulfport, Mississippi)

Seismics: Ingo Pecher (Institute for Geophysics, Univ. of Texas, Austin)
Angela Davis (School of Ocean Sci., U.of North Wales, Bangor)

Geoelectrics: Rob Evans (Woods Hole Oceanographic Institute)
Lawrie Law (Consultant, Sidney, B.C.)

Spectroscopy: John Noakes (Center for Applied Isotope Studies, U. of Georgia)
John Pope (Blue Sky Batteries Inc., Laramie, Wyoming)
Valdislov Pustovoit (Cen. Design Bur. for Unique Inst., Moscow)
unnamed postdoc (Detection Limit Inc., Laramie, Wyoming)

Pore Water: Jeff Chanton (Department of Oceanography, Florida State University, Tallahassee, Florida.)

Heat Flow: Earl Davis (Geological Survey of Canada, Sidney, B.C.)

Russian Collab.: Lev Utyakov (P. P. Shirshov Institute of Oceanology, Moscow)

J. Robert Woolsey

220 Old Chemistry Building
University, MS 38677

Phone: 662-232-7320
Fax: 662-232-5625
email: inst@mmri.olemiss.edu

REPRESENTING: The Center for Marine Resources and Environmental Technology

Dr. Woolsey is a graduate of Mississippi State University and received his Ph.D. in Geology at the University of Georgia. He served as a Naval Officer and aviator, working primarily with anti-submarine warfare. Prior to joining the Department of Geology and Geological Engineering, University of Mississippi, in 1980, Woolsey worked for six years with private industry and the United Nations as an exploration and mining geologist, involved with the location and development of alluvial tin, gold, and diamond deposits in coastal and offshore Southeast Asia, Africa, and South America.

Since 1982, Woolsey has served as Director of the Mississippi Mineral Resources Institute (MMRI), devoted to the responsible development of State mineral resources and related environmental technology. In 1988, Woolsey's duties were expanded as Director of the Marine Minerals Technology Center (MMTC), a program established through the U.S. Department of Interior for research in marine mining and environmental technology. Since that time, the program has come under the administration of the Minerals Management Service (MMS) and the name changed to the Center for Marine Resources and Environmental Technology (CMRET). The program goals and functions continue to serve both industry and government agencies in providing scientific and technical council and assistance to various resource and environmental interests within the Exclusive Economic Zone (EEZ) of the United States.

A current major focus of the CMRET under Woolsey's leadership is the establishment and management of the Gulf of Mexico Hydrate Research Consortium (GMHRC). The GMHRC is a cooperative applied research program made up of representatives from industry, pertinent government agencies, and academia. It is unique to the extent that industry has the prerogative to select and prioritize research projects.

The international scope of Woolsey's work has more recently involved cooperative research programs with the P.P. Shirshov Institute of Oceanology (SIO) and the Moscow State Mining University (MSMU), Moscow, Russia, involving appropriate technologies for methane hydrate research. Woolsey recently was awarded an honorary doctorate degree from the MSMU for cooperation in the development of technologies important to marine mining.

OTC 10771

An Installation in the Northern Gulf of Mexico for Monitoring Interactions Between the Water Column and Sea-floor Sediments Containing Gas Hydrates

Thomas M. McGee and J. Robert Woolsey, Center for Marine Resources and Environmental Technology, The University of Mississippi

This paper was prepared for presentation at the 1999 Offshore Technology Conference held in Houston, Texas, 3-6 May 1999.

Abstract

rogram has been initiated to monitor outcrops of gas hydrates on the continental slope of the northern Gulf of Mexico. This will be done by means of a multisensor station deployed on the sea floor for significant periods of time. Sensors will be seismic, acoustic, electromagnetic and spectroscopic. Data will be digitized on site and transmitted by optic fiber cable to an offshore platform from whence they will be relayed to a shore facility via satellite.

Preliminary tests of seismic techniques over gas hydrate outcrops began in June, 1998, as part of a research cruise to areas of Mississippi Canyon where hydrates are known to occur at or near the sea floor. Further preliminary work is being done during fiscal year 1999-2000. It includes very-high-resolution seismic profiling over possible station sites (this time in the Viosca Knoll area), tests of three-component seismic detectors, both seismometers and accelerometers, and deployment of a vertical hydrophone array.

Introduction

The Center for Marine Resources and Environmental Technology (CMRET, formerly the Marine Minerals Technology Center, MMTC) of the University of Mississippi, the U.S. Naval Research Laboratory at Stennis Space Center, Mississippi, and the U. S. Geological Survey (USGS) at Woods Hole, Massachusetts, have initiated a program to install a multisensor monitoring ion on the continental slope of the northern Gulf of Mexico. ne station will monitor physical and chemical parameters of the water column and sea floor for the purpose of remotely observing transient changes to the water column and sea floor in the vicinity of outcrops of gas hydrates. Rationale for the program stems from a growing realization that the stability of the sea floor in the region may be influenced by the presence of gas hydrates and instances of their sporadic disassociation.

The need for such observations was discussed at a meeting of research scientists held at the Stennis Space Center on March 17, 1998. Harry Roberts of the Coastal Studies Institute, Louisiana State University, reported observations from repeated manned submersible visits to hydrate outcrops that "support a pattern of episodic venting. Short-term episodes of venting are probably regulated by fault movement, perhaps controlled by local salt adjustment. Destabilization of gas hydrates by oceanographic processes also causes short-term episodic gas expulsion. These events occur with inter-annual to intra-annual frequencies." Ian MacDonald of the Geochemical and Environmental Group, Texas A&M, also reported physical changes to hydrate outcrops that had been documented by repeatedly diving on the same sites.

Water depth at the outcrops to be monitored is about 1000 meters. It would be difficult and costly to make direct observations of transient events at such depths. It is expected to be more cost effective to design and deploy a remotely operated station that will measure a number of physical and chemical parameters, more-or-less continuously, over an extended period of time.

Studies preliminary to choosing a site for the station began in June, 1998, during a research cruise in the Mississippi Canyon area which was sponsored jointly by CMRET and USGS. Comparison of several techniques of seismic data acquisition were made over areas of known hydrate occurrence. The use of a broadband surface source and a deep-tow receiver seemed to be the most promising. During the 1999-2000 fiscal year, that technique will be applied to obtain very-high-resolution seismic profiling over potential station sites in the Viosca Knoll area.

The first studies leading to the design of the station have been funded for fiscal 1999-2000. They include tests of three-component seismic detectors, both seismometers and accelerometers, and deployment of a vertical hydrophone array.

Submitted to Russian
journal

Long Term Monitoring of Gas Hydrates in the Northern Gulf of Mexico

J. Robert Woolsey and Thomas M. McGee
Marine Minerals Technology Center
The University of Mississippi
220 Old Chemistry Building
University, MS 38677
inst@mmri.olemiss.edu
http://www.olemiss.edu/depts/mmri/

Abstract

A program has been initiated to install a system of acoustic arrays and other sensors on the continental slope of the northern Gulf of Mexico. Both vertical arrays in the water column and horizontal arrays on the sea floor will be deployed. The site environment will be calibrated using known sound sources to establish the distribution of the sound speed in the water and sediment columns. During routine operations the arrays would depend on passing ships as their primary sources of sound. Since the area of interest is subject to frequent ship traffic, a near-constant stream of data is anticipated. Inversion of that data would then provide a more-or-less continuous monitoring of changes of oceanographic and geologic acoustic parameters with time.

Although the system will be of potential use in various types of studies, its first deployment will be in the vicinity of known gas-hydrate outcrops to observe the effect of short-term changes of water temperature on episodes of hydrate disassociation and related sea-floor instability.

I. Introduction

The Marine Minerals Technology Center at the University of Mississippi (an academic research support program of the Department of Interior), the U.S. Naval Research Laboratory, Stennis Space Center, MS, and the U.S. Geological Survey, Woods Hole, MA, have embarked on a program to establish an acoustic/seismic monitoring station on the upper continental slope of the northern Gulf of Mexico with the cooperation of major lease holders in the area.

Although the station potentially would be useful for a variety of studies, its principal purpose will be to provide an in-situ research facility for comprehensive investigation and monitoring of gas hydrates. The need for such research has recently become urgent because serious stability problems are being encountered as the oil and gas industry moves into greater water depths. One of the more serious problems is the destruction of sea-floor installations by sand flowing from shallow depths below the sea floor. The fact that the sand is accompanied by relatively fresh water possibly implies a link with the disassociation, or "thawing", of gas hydrates because chlorine is expelled during hydrate formation.

Since it is difficult and costly to monitor such transient events by means of shipboard observations, the best approach to studying changes in the state of gas hydrate occurrences is considered to be the installation of a remote monitoring station.

II. Rationale

The rationale for deploying such a station developed from the growing realization that the stability of portions of the continental slope in the northern Gulf of Mexico may be influenced by the presence of gas hydrates. The possibility was discussed at a meeting entitled "Monitoring and Investigation of Gas Hydrate Outcrops in the Northern Gulf of Mexico" that was held at the Stennis Space Center on March 17, 1998.

The (unpublished) proceedings of that meeting state that "...direct observations at the sea floor support a pattern of episodic venting. Short-term episodes of venting are probably regulated by fault movement, perhaps controlled by local salt adjustment. Destabilization of gas hydrates by oceanographic processes also causes short-term episodic gas expulsion. These events occur with inter-annual to intra-annual frequencies." (Harry Roberts, Coastal Studies Institute, Louisiana State University)

A likely oceanographic cause is the so-called "counter current" which is an eddy of warm water that separates periodically from the Gulf Stream south of Florida and sweeps westward through the northern Gulf of Mexico. This current can form as often as a couple of times per year and increase water temperatures enough for hydrates at or near the sea floor to disassociate (Harry Roberts, pers.com.).

It is also possible that disassociation is triggered by industrial activities. Activities such as oil well drilling could bring hot fluids into contact with gas hydrates either in the immediate vicinity of the drill hole or along failure planes into which drilling fluids have intruded.

Regardless of the cause, free gas and fresh water are released when gas hydrates disassociate. The observed flows could be produced in cases where the hydrates had formed in sands. Where they had formed in silts and clays, the cohesion of the sediments could be reduced to the point of failure and down-slope movement. Whatever the manifestation, it should be accompanied by a change in the elastic properties of the sediment and that change should be observable acoustically by arrays of hydrophones in the water and/or seismically by arrays of geophones on the sea floor.

Data acquired by such arrays can be analyzed by means of a technique known as "match-field processing". Analysis of data acquired from known sound sources would calibrate the station and determine the structure of its environment. After that is complete, data from "sources of opportunity", i.e. the sound of passing ships, could be used to detect changes in the environment (Ross Chapman, pers.com.).

A single-channel seismic reflection method for quantifying lateral variations in BSR reflectivity

Thomas M. McGee
Marine Minerals Technology Center, University of Mississippi,
220 Old Chemistry Building, University, MS 38677, U. S. A.
tel: 1-601-232-7320, fax: 1-601-232-5625, e-mail: tmm@mmri.olemiss.edu

Abstract

Results of seismic inversion techniques and logs of deep-sea bore holes indicate that bottom simulating reflectors (BSRs) which exhibit high reflection amplitudes are underlain by a thin layer of free gas. Often, however, BSRs exhibit relatively low amplitudes and display significant lateral variability. In these cases the structure is not well understood and remains a topic of research.

Waveform inversion has been used to investigate the distribution of propagation speeds in the vicinity of BSRs but the technique is not practical in some situations because it requires multi-channel data sets that include large offset distances between sources and receivers. Such data are not available in many instances, so it has become attractive to consider other methods of achieving the same end.

A method that is applicable to single-channel, short-offset data is discussed here. It was originally developed to help characterize shallow submarine sediments for engineering and environmental purposes. Of course, no single-channel method can provide information concerning speeds of propagation such as is available from multi-channel methods. In this case the single-channel method has an advantage, however, in that it is self-calibrating. That allows it to provide, after correction for wave-front divergence, true reflection amplitudes without considering source characteristics or referencing to a known, or inferred, propagation parameter such as speed or density. These true amplitudes then yield reflection coefficients by correcting for transmission losses.

Use of the method is illustrated with the help of synthetic data. It is demonstrated that the accuracy of results is improved by using a rapid digitizing rate during data acquisition. The method is then applied to a set of real data that previously had been analyzed by full-waveform inversion. The results are noisy, largely due to the data having been digitized at a rather slow rate and the length of recording being too short; average values of reflection coefficients at the sea floor and the BSR compare well with average values obtained by the inversion procedure, however. It is concluded that the single-channel method provides reasonable values for reflection coefficients. This suggests that, with judicious constraints on density variations, single-channel data could provide information on the structure of propagation speed in the vicinity of BSRs. Moreover, it would involve substantially less effort than is required for full-waveform inversion.

Keywords: gas hydrates, bottom simulating reflector, reflection coefficient, deconvolution

Mr. WALDEN. Thank you, Dr. Woolsey.

Dr. Cruickshank.

STATEMENT OF MICHAEL J. CRUICKSHANK, DIRECTOR, OCEAN BASINS DIVISION, UNIVERSITY OF HAWAII

Mr. CRUICKSHANK. Mr. Chairman, I am very glad to be here to have the opportunity to testify in support of these bills.

As you now know, we are part of a three-legged stool, and we in Hawaii, look after the ocean basins, primarily in the Pacific.

We heard a lot about big numbers this morning like thousands of millions or trillions of cubic feet. My “gee, whiz” number or—it is not exactly a number, but a factoid—is that in the Pacific Ocean, the area of seabeds under the jurisdiction of the United States is greater than the area of the terrestrial United States and almost totally unexplored.

If you look at the potential for hydrates in this area, there are many, many thousands of square miles of seabeds which have a potential—anywhere where the sediment is over 1,000 meters thick, and there has been some significant deposition of organic materials. So you are looking at a tremendous potential here right across the Pacific Ocean to Guam and beyond. Hawaii being in the middle of all this, has a prime location to work with all these island areas—not only the U.S. jurisdiction, but others as well—and we certainly feel that is important at this stage because of the global consequences. We not only have the resource, but the potential for the addition of methane to the atmosphere affecting global climate change.

In terms of technology, you have heard already that we really don’t know a lot about characterization of these methane hydrates. To simplify it in our terms, we see a need to target, to go to look for them, characterize them in all ways when we find them, and then work on the recovery method.

I just got back from a technology conference last week. I believe you mentioned manganese nodules. We have worked with those things for 30-40 years now, and there is no question that the United States still takes the lead in the technology for deep seabed mining—not only for nodules, but for crust and for sulfide minerals. There is a lot of activity going on just now, in terms of catch-up by other countries—Japan, Korea, and China and we have close association with these countries and their government research groups.

But at the Offshore Technology Conference, it was very apparent with the deep oil leasing in the Gulf at 3,000 meters, that the oil companies are now developing a lot of the very critical technology that we needed 20 years ago for the mining. It is now possible to put down 50 megawatts of power to the bottom. It is quite possible to put down 50 ton ROVs to roam around the bottom. It is quite possible to put down a 5,000 meter pipeline from a reel, send it down and bring it back up again, at 30 miles an hour. These things are just mindboggling. And this is all through oil development. We are going to be using this technology—and hydrates are a natural for this.

The first thing we have to do, of course, is to find a target and characterize it. And we have a very wide network of connections, not only with the oil companies and through our other centers, but through the international cooperation that we have had over the years.

So we are looking with great interest on the pursuit of the particular efforts proposed in the bill.

And nobody mentioned the idea of natural sublimation of the hydrates. It sometimes happens with explosive force, creating tremendous surges of gas, that has caused at least one, if not more drilling rigs to have been lost. And it has also been suggested—and this is another "gee, whiz" if you like—that the reason the Bermuda Triangle is so dangerous, is because every now and then, the seabed gets a burp as the warm Gulf stream sweeps around and releases gas. It may not be true, but it would certainly be interesting to find that out.

Thank you.

[The prepared statement of Mr. Cruickshank follows:]

TESTIMONY OF

DR. MICHAEL J. CRUICKSHANK, C.Eng.
DIRECTOR, OCEAN BASINS DIVISION
CENTER FOR MARINE RESOURCES AND ENVIRONMENTAL TECHNOLOGY
UNIVERSITY OF HAWAII

Hawaii Natural Energy Institute
2540 Dole Street, Holmes 246
Honolulu, HI 96822
Tel 808-956-6141, Fax 808-956-2335
email mcruick@aol.com

before the

U.S.HOUSE OF REPRESENTATIVES
COMMITTEE ON RESOURCES
SUBCOMMITTEE ON ENERGY AND MINERAL RESOURCES
THE HONORABLE BARBARA CUBIN, CHAIR

at a legislative hearing on

H.R.1753 AND S. 330
MARINE HYDRATE RESEARCH AND DEVELOPMENT ACT OF 1999

on

Tuesday, May 25th, at 2.00 pm
in
Room 1234, Longworth House Office Building
Washington, DC

This testimony is respectfully submitted in support of House and Senate Bills H.R. 1753 and S330, both entitled the "Methane Hydrate Research and Development Act of 1999". Through these Bills the Committee supports a major R&D effort that focuses in three principal regions of the U.S. and its territories, representative of significant methane hydrate occurrences. These regions include the Gulf of Mexico, Alaska, and the Pacific Basin and Rim, each of which fall within the purview of the Center for Marine Resources and Environmental Technology (CMRET). The CMRET serves as an applied academic research arm of the Minerals Management Service authorized by the Marine Mineral Resources Research Act of 1996, (PL 104-325). The CMRET has three divisions representing distinct physiographic environments with unique mineral potential. The divisions are multi-disciplinary and closely networked and include the Continental Shelf Division (CSD) at the University of Mississippi which serves as program manager for the Gulf of Mexico Hydrate Research Consortium; the Arctic Seas Division (ASD) at the University of Alaska in partnership with the Petroleum Development Laboratory; and the Ocean Basins Division (OBD) at the

University of Hawaii, a program within the Hawaii Natural Energy Institute (HNEI). The Committee authorizes the Secretary to provide $50 million to each of the three divisions of the CMRET to undertake this comprehensive program during Fiscal Years 00, 01, 02, 03, and 04.

Background

Natural gas hydrates have been projected to occur ubiquitously in the deep oceans where conditions are appropriate for their formation.These conditions include sediment thickness of at least 1,000 m with a history of significant deposition of organic materials, at least 450 m of overlying seawater, a moderate temperature regime between 0 - 35° C and quite possibly a number of other natural characteristics that have not yet been identified. No one to date has outlined an economic and safe method for sustained recovery of methane from the newly discovered low-grade oceanic hydrate and associated gas deposits. The potential rewards of unlocking the methane hydrate energy bank are potentially very great. The prize is possibly centuries of energy independence for some industrial states including the United States and Japan, and developing countries such as India, which appear to have considerable deposits of methane hydrate immediately adjacent to their landmasses. A number of nations, including the United States, have established, or are establishing, national hydrate research programs but little work on the hydrates has been done beyond the continental shelves. The Exclusive Economic Zone under the jurisdiction of the United States includes the greatest area of seabeds of any nation. Most of this area is in the Pacific Basin and Rim and much of it in deep ocean basins where sediment accumulation has been significant.Tropical Pacific islands under U.S. jurisdiction or affiliation include Hawaii, Northern Mariana Islands, Federated States of Micronesia, Guam, Republic of the Marshall Islands, Palau, American Samoa, Wake, Johnston, Palmyra, Jarvis, Howland, and Baker islands. Litle is yet known about the seabeds around these islands and the potential for hydrate formation needs to be determined. Characterization of hydrate deposits in ocean basins, and the search for targets are a priority in initiating any significant program of research.

Cooperative Activities

The University of Hawaii CMRET/OBD and the HNEI have been closely involved with cooperative research and planning for a number of years and have ongoing programs with the other two divisions of CMRET, and with NRL and Battelle Pacific NW Division. On an international basis the, the OBD has ongoing cooperative minerals research programs with Japan, Korea, China, the South Pacific Geoscience Commission (SOPAC), a consortium of 17 south Pacific countries, and Russia, each of which has a strong interest in the development of marine gas hydrates. The potential for enhanced cooperative work on hydrates at this time is very high in Russia on hazardous emissions in the Sea of Okhotsk off the Kamchatka Peninsula, in Japan as a continuation of ongoing work on deep ocean gas absorption with MITIs Agency for Industrial Science and Technology, and on methods for economic gas recovery with the Geological Survey of Japan and Japan National Oil Corporation.

Joint Research

A White Paper prepared by the NRL (Dr. Richard B. Coffin) for joint research with Batelle and the University of Hawaii describes succinctly some of the problems to be addressed in understanding hydrate formation and stability. "The total amount of methane gas trapped in hydrates is estimated to be at least a factor of two greater than the energy of the total conventional fossil fuel reserves.

Coastal regions in oceans throughout the world are rich in these methane hydrates. This document outlines a proposal for research designed to understand the spatial variation in the percent methane that is contained in hydrates found in different regions of the world ocean floor. This work would be accomplished through a multi-year, broad discipline effort that is organized in collaboration among the Naval Research Laboratory (NRL), Battelle Pacific Northwest Division (Battelle/PND) and the University of Hawaii (UH). To accomplish this goal it is necessary to understand the processes that controls the formation, stability, and fate of methane hydrates in the ocean. The focus of the research is to study how methane hydrates are influenced by biotic and abiotic geochemical cycles in ocean sediments. This research will provide an understanding of the potential for the safe and economical extraction of energy from oceanic methane hydrates. This white paper outlines research focusing on the factors that control the percent methane that is contained in methane hydrates. The following hypotheses address research questions that are required to understand methane hydrate formation and stability.

Hypothesis I Sources of methane in hydrates vary between ecosystems as a function of reduced energy that support the chemosynthetic microbial population and the relative proportion of thermal and biological methane.

Hypothesis II The stability of methane hydrates on the ocean floor is a function of biological and geochemical cycling of organic matter that is trapped with the hydrates and the interstitial spaces between the structures.

Hypothesis III There will be a variation of methane content in hydrates that is controlled by biogenic cycles.

Hypothesis IV There will be a large difference in financial gains between sources of methane hydrates that is related to the formation process.

The proposed research project consists of a team of renowned scientists and engineers and brings together the unique research capabilities resident at Battelle/PND, UH and NRL. Through the proposed field and laboratory experiments, the research will advance our knowledge of an important and yet poorly understood role which complex biological communities and methane hydrates play in ocean carbon cycling. Also, the research will provide the fundamental scientific understanding of hydrate stability needed for applications as varied as carbon dioxide sequestration and the safe and economical extraction of the energy content of methane hydrates."

In addition to the need for resource development, the potential problem of natural release of hydrate gases to the atmosphere resulting in effects on the global climate are of major significance which will require concurrent studies and long term monitoring at appropriate sites. Teaming of experts throughout the Pacific region is a further responsibility which would be assumed by the CMRET, utilizing the wide network of ocean and earth scientists and engineers already involved in these studies.

Justification for Funding

The combination of extended oceanic field operations in deep water involving geophysical, geological, geochemical and biological characterization, including extensive bottom sampling, and subsequent or accompanying laboratory analyses will be limited only by available funding. Other cooperative activities with international programs in Japan and the Pacific will provide valuable data on the technology for hydrate recovery and other problems at greatly reduced costs. Meetings among cooperating personnel will be initiated at an early stage to provide the most economical and effective programs to carry out the goals of sustainable production by 2015 and understanding of the effects of gaseous hydrate release to the atmosphere. The CMRET/OBD is well placed to provide the coordination and management required for this important program.

Amount and source of Federal monies awarded to the CMRET/OBD for Fiscal Years 97/98/99:

	FY 1997	FY 1998	FY 1999
Minerals Management Service	- 0 -	$380,000	- 0 -

The Hawaii Natural Energy Institute (HNEI)

HNEI has been a strong player in the research and development of renewable and unconventional energy sources since its founding after the oil crisis of 1973. It is staffed by a team of engineers and scientists under Dr Patrick K. Takahashi, Director of the Institute and is an independent institute of the School of Ocean and Earth Science (SOEST) at the University of Hawaii. Fourteen professional staff form the nucleus of this institute which two major areas of expertise in Biomass and Fuels, and Ocean Resources. Within the Biomass and Fuels is the Hawaii Integrated Biofuels Research Program, the Renewable Resources Research Laboratory, the Alternative Fuels Program, the Biomass Gasifier Facility, and the Hydrogen Program. Within Ocean Resources is the Center for Marine Resources and Environmental Technology (formerly the Marine Minerals Technology Center) and the Program in Ocean Disposal of Carbon Dioxide, a cooperative program with Japan. Staff members are well known in their fields both in the U.S. and Internationally. The marine minerals program staff bring a wide range of experience experience in mining systems engineering and environmental mitigation in deep seabed environments.

Present Senior Staff in HNEI include:

Michael J. Antal, Jr., *Distinguished Professor of Renewable Energy Resources*; biomass and thermochemical processes
Michael J. Cruickshank, *Director CMRET*; marine mining systems technology
Charles M. Kinoshita, energy conversion, thermoscience
Patrick K. Takahashi, *Director*; renweable energy, ocean resources
Oskar R. Zaborsky, *Williamson-Matsunaga FREE Fellow in Hydrogen Systems;*marine biotechnology, bioenergy, specialty bi products from marine resources, bioremediation
Stepen M. Masutani: thermochemical conversion of biomass, OTEC systems, carbon dioxide mitigation
Charles L. Morgan; marine mineral deposits, envionmental engineering
Richard E. Rocheleau: chemical engineering, thin film processing, hydrogen technology development

OTC 10727

Extraction of Methane from Oceanic Hydrate System Deposits

Michael D. Max, Naval Research Laboratory, Washington DC 20375
Michael J. Cruickshank, Center for Ocean Resources, Univ. of Hawaii at Manoa, 2540 Dole street, Honolulu, HI 96822

This paper was prepared for presentation at the 1999 Offshore Technology Conference held in Houston, Texas, 3–6 May 1999.

Abstract

No one to date has outlined an economic and safe method for sustained recovery of methane from the newly discovered low-grade oceanic hydrate and associated gas deposits. The potential rewards of unlocking the methane hydrate energy bank are potentially very great. The prize is possibly centuries of energy independence for some industrial states including the United States and Japan, and developing countries such as India, which appear to have considerable deposits of methane hydrate immediately adjacent to their landmasses. A number of nations, including the United States, have established, or are considering establishing, national hydrate research programs.

Introduction

Oceanic hydrate system deposits, which include both methane hydrate and associated methane gas, are very large, but relatively low grade when compared with conventional hydrocarbon deposits. They differ in character from conventional hydrocarbon deposits in almost every respect except that they encompass significant concentrations of hydrocarbon. It is now not immediately obvious in detail exactly how the methane from oceanic hydrate and related gas deposits will be recovered. It is not even certain whether hydrate or associated gas, or both, will be the preferred initial and eventual best economic target.

We examine some of the emerging issues likely to govern hydrate recovery and seafloor stability, and suggest geological models for oceanic hydrate system exploitation.

Methane hydrate; its disposition and recognition

Methane hydrates [CH_4 • 6.1 (±0.1%)H_2O] are found in the low temperature- low pressure regimes of permafrost regions and high pressure- moderate temperature (from just below zero degrees C up to about 35 °C max) in ocean sediments. Methane hydrate is stable in seafloors below about 450 meters water depth in open ocean with an average temperate hydrothermal profile that gives hydrate a wide pressure-temperature field of stability[1]. Methane molecules are compressed closely together in the hydrate lattice. 1 m^3 of hydrate yields about 160 m^3 CH_4 at STP and a residue of 0.87 H2O m_3^2.

The hydrate forms in a zone of thermodynamic equilibrium, the Hydrate Stability Zone (HSZ) that extends downward from the seafloor to some depth determined by increasing temperature (Fig. 1). The base of the HSZ is a phase boundary. At constant geothermal gradients the thickness of the hydrate stability zone increases with increasing water depth and increased pressure. Where higher molecular weight thermogenic gases, such as ethane, butane, or propane occur, the hydrate stability field expands considerably. 1% propane in the gas mixture, for instance, can reduce the pressure at which the hydrate forms by nearly 40%[1].

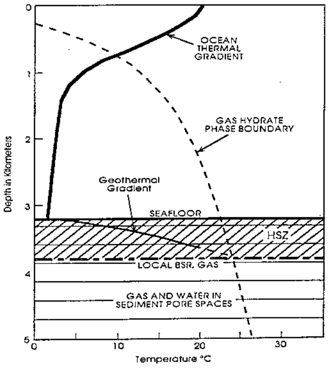


Figure 1. Position of the HSZ with respect to the hydro- and geothermal gradients and the methane hydrate phase boundary.

Hydrate is now widely recognized on continental slopes, where they are well developed, because of their unique appearance on seismic reflection records[3]. Hydrate formation can strengthen sediments through both pore filling and cementation and retard compaction. The presence of significant quantities of hydrate strongly affects the physical properties and seismic response of the sediments in which they occur, but not enough is known yet for commercial quantification. Initial recovery from the less than 30 drill holes from which hydrate has been recovered shows hydrate to vary widely in development, form, concentration, and sediment binding character. Naturally occurring hydrate has been observed in disseminated, nodular, layered and massive forms[4] and shows a strong vertical and lateral variability of the relative amounts of hydrate even on the small scale[5].

On passive margins, production of methane appears to occur in large masses of sediment. Methane migrates toward and into the HSZ largely by its own buoyancy or dissolved in pore fluids. Passive margin oceanic methane is produced mainly from bacteriological decay of organic material in the marine sediment. In contrast, both biogenic and thermogenic methane, produced at deeper levels in subduction complexs, occur in collisional margins, especially those underlain by subduction zones[2].

Hydrate provides a mechanism for concentrating methane both in hydrate itself and in associated trapped gas. Hydrate can often seal the lower part of the HSZ and cause gaseous methane below the HSZ to pond. Where there is a contact between hydrate and gas, a strong impedance contrast termed the bottom simulating reflector (BSR) forms. Presence of BSR is commonly taken as proof of the presence of hydrate, but hydrate is known to extend considerably beyond BSR in large closures in the Blake Ridge off the U.S. SE coast. Hydrate not associated with subjacent BSR occurs in concentrations comparable with those underlain by BSR[6].

Oceanic hydrate deposits are near industrial markets, and accessible

It is remarkable that many of the likely hydrate deposits are located on the continental slopes not far distant from major markets in industrialized countries. Substantial volumes of hydrate system methane has been identified in the Blake Ridge of the U.S. SE coast only about 300 km from the nearest land[7, 8, 9]. This places at least the Blake Ridge hydrate very close to the U.S. east coast gas grid at its probable point of coming ashore. The hydrate deposits that constitute the first economic target of the Japanese hydrate program are within 40 - 60 km of Tokyo Bay, a center of Japanese industry. Hydrate along the northern coast of Alaska, which is not near an industrial center, on the other hand, is close to the terminus of existing hydrocarbon pipelines.

Oceanic hydrate system deposits are also easy of access to relatively shallow drill penetration from the seabed. On the Blake Ridge, for example, the base of the gas hydrate stability zone is at about 400-500 m[7] below the seafloor, in the Lower Pliocene/Miocene. Technologically, the hydrate economic target is also accessable. Much of the engineering required to exploit oceanic hydrate appears to exist currently. The present technological base appears to be adequate for developing exploration, extraction, and subsea transport capabilities. The economic target is spatially predictable in many ways so that innovation should translate to a large number of hydrate localities world-wide.

Methane recovery issues

There needs to be a workable geological model for oceanic hydrate system deposits. Conventional hydrocarbon deposits can be compared with classical high grade mineral deposits in that high values are concentrated in relatively small volumes. Hydrates are fundamentally low grade deposits that will require secondary recovery techniques from inception of recovery. And we don't know what the recovery scenario will consist of yet.

Hydrate and gas deposits associated with hydrate have their individual production issues to surmount. In the case of the gas deposits, concentrations of gas rise to only about 5%[8], which may be too low to allow the gas to flow spontaneously and without some stimulation or intervention. 10% of concentration may be a more likely dependable lower limit for spontaneous gas flow[10]. Sustained forced dissociation of hydrate, on the other hand, will result in strongly overpressured gas and pore fluid[11, 12], whose migration may be difficult to control. Developing dependable techniques to produce gas at specific rates in specific localities, will probably be the key to methane recovery from hydrate deposits.

Like any large but dispersed resource, the locations of greatest concentrations that are coincident with local reservoir and trap attributes favoring recovery must be identified. No one has any real engineering plan for the recovery of hydrate because no good geological model yet exists that would allow for engineering. Like any mineral or conventional hydrocarbon deposit, sweet spots, or those areas that are 'rich' enough in methane to justify recovery, even remain to be identified. Research should be focused on identifying unequivocal physical property relationships from which hydrate percentages and mode of formation (cementation or pore fill, nodular or bedded, etc.) can be inferred. Advanced processing of geophysical information should then yield the same degree of certainty about sweet spot location that 3- and 4-D seismic processing for conventional hydrocarbon deposits has attained. Because of the developments that have taken place within industry in the acquisition and processing of seismic data, and the development of other techniques, principally electrical, a broad technological base exists to be built upon. Because of this, progress could be very rapid. The potential hydrate resource must be quantified before real economic evaluation is practicable.

Comparison with low grade but very large deposits mineral metallic and non-metaliferous ore bodies may be instructive in developing a commercial model for methane recovery from hydrate. Methane hydrates can becompared to the mining industry's low grade porphyry ore bodies like Bingham Canyon, where rock containing copper at about 3 tenths of one percent is mined at the rate of 129,000 tons of ore/day. In the early days, however the mine started out as an underground operation, recovering ore that graded around 5%

copper. It has taken some 80 years of nearly continuous production for the mine to become as efficient as it is now, and progress was a gradual process that depended in many cases on the development of technology elsewhere that could be adapted to the mining efficiency problem. In the same way, there is likely to be initial exploitation of high grade deposits of stable methane hydrate, that develop into more broad recovery operations as technology and experience allow. Many of the currently existing hydrate and related gas deposits are up to several hundreds of meters thick[13], with methane distribution not known with certainty. Although we are not suggesting physical mining, there is an analogy to be made. Methane hydrate system deposits could conveniently be modeled as open pit analogue of conventional mineral deposits.

a. The oceanic hydrate secondary recovery target

From the outset, recovery of methane from hydrate will require application of secondary recovery techniques. Hydrate is a solid that first has to be gasified; left alone it will remain as solid hydrate. Even the associated gas deposits may require intervention to promote controlled flow. Hydrate recovery necessarily will involve forced dissociation. Although hydrate is always either forming or dissociating, depending on local temperature and pressure changes, rates of dissociation necessary to produce methane from oceanic hydrate will be much more rapid than those dissociating as a response to changes in the natural environment. This 'run-away' dissociation necessary for exonomic exploitation introduces a significant demand for heat to keep the system from freezing up with water-ice. Supplying and managing this heat deficit and maintaining an artificial thermodynamic balance that allows the controlled dissociation of hydrate and the save recovery of methane will probably prove the key to commercialization.

Although hydrate is widely dispersed, its natural disposition favors the recovery of methane. Hydrate is most stable in the upper part of the HSZ and least stable near the HSZ base. Coincidentally, the lower zone is where hydrate is most concentrated. The closer the pressure-temperature position of the hydrate body is to the stabile phase boundary, the less thermal energy needs to be introduced or the less chemical inhibitor is required to cause dissociation. Depressurization is feasible anywhere in the HSZ, but the least stable hydrate at the base of the HSZ may be the best place to begin. Thus, potentially the most economic application of any form of intervention will have an immediate effect. As intervention continues and dissociation moves to more stable regions within the HSZ, the economics of hydrate recovery may be affected.

Both hydrate and the associated gas deposits of methane may prove to be recoverable economic resources. Although it would appear that the gas deposits might be more familiar to energy production companies in their geological and engineering characteristics, they are significantly different in a number of respects from conventional gas deposits. Hydrate system deposits are found in relatively shallow seafloor sediments that are younger than most of the conventional hydrocarbon fields, especially when the usually uncompated nature of the sediments is taken into consideration. Most conventional hydrocarbon traps are geologically strong, with the reservoir composed of a matrix of grain-supported sediment detritus in which flow can be well modeled hydraulically. Hydrate system deposits, in contrast, are composed of fine grained, high porosity materials whose internal flow characteristics are not well known. Bound water in conventional deposits is relatively unimportant while it would appear to constitute a large percentage of available porosity in hydrate system deposits.

Secondary recovery inhibitor and thermal injection are well understood by industry and will be effective in dissociating hydrate. However, both are potentially expensive. Depressurization, in theory, is the most elegant solution[11, 14] but no tests have ever been carried out in oceanic hydrate. The usual case cited for successful production by the depressurization method is the Messoyakha field in Siberia. A reexamination of the evidence suggests that methane production from hydrates there has not been as great as was previously thought[15]. Dissociation by pressure reduction requires the same heat of fusion as dissociation by thermal stimulation, and places a theoretically enormous demand for thermal energy in the system. Although a large enough interface between gas and hydrate at the base of hydrate phase boundary could allow depressurization to operate alone[11], this would require substantially open equilibration conditions within the gas reservoir. It would seem that unless an external source of even low-grade heat is supplied, dissociation may shift the local thermal environment into a water-ice+gas field. With even a small amount of ice in reservoir pores, there would be a reduction of permeability and a continued heat demand to melt the water-ice that could substantially inhibit methane production.

b. Permeability and gas flow

A primary concern for methane recovery from hydrate is permeability. Suitable primary porosity in grain-supported sediment reservoirs is usually the key to the recovery of conventional hydrocarbon deposits. Flow modeling of the gas and the response of fluids can be taken into consideration for different recovery scenarios of drill hole receptor placement and draw-down rates, using well tested engineering concepts. Many of the potential hydrate deposits, however, are in sedimentary materials that have no easy analog with conventional hydrocarbon deposits and much of the existing reservoir engineering expertise may not be directly applicable to recovery of methane from hydrate. Briefly, the potential oceanic hydrate reservoirs, such as in the Blake Ridge off the U.S. SE coast, are much more fine grained and higher porosity than conventional reservoirs that have undergone considerable compaction, diagenesis, and lithification.

In addition to primary porosity, however, extensive secondary porosity, in the form of faults, fractures, solution veinworks, and volume changes owing to crystallization, produce pathways for fluid and gas migration in rocks that are otherwise too tight to allow significant internal flow. Extensive faulting has been observed in gas hydrate bearing strata in many areas, and the faults show evidence of fluid flow[5, 9]. The little high resolution reflection seismics available show that a strongly fractured concentrated hydrate zone at the base of the HSZ may prove to be more common than unfaulted hydrate. Oil industry technology of fracking conventional hydrocarbon reservoirs is very well developed. Fracking may not be necessary, however, where high sediment permeability allows gas flow without redistribution of sediment that blocks permeability in hydrate deposits residual sediment following dissociation. Where sediment does not collapse, however, minor redistribution of the fine grained sediment fraction could close porosity.

Controlled formation and management of secondary porosity may be key to recovery of methane. Fracking in sediments with concentrated hydrate should be a relatively straight-forward problem for industry to resolve if necessary. Sediment-hydrate mixtures world-wide will have a relatively consistent range of ambient pressure depths, with the deposits in shallower water probably more likely to be the initial economic targets[12]. Temperatures will vary in the reservoir by no more that 10 °C - 20 °C. Mechanical properties of the material will likely be much less than in conventional hydrocarbon reservoirs and will also vary within a narrow range depending on the nature of the marine sediment and the amount and mode of formation of the hydrate.

c. Drilling and recovery options

Forced dissociation of hydrate concentrations may produce, "a muddy soup of methane and water"[16]. This situation would be unwelcome as it would create many problems within a conventional hydrocarbon recovery scenario. Drilling and maintaining the position of collector pipes, particularly those which are placed horizontally[11], will be difficult as they are very likely to fail structurally. The pipes might either rise or fall in the fluidized sediment, depending on their buoyancy. Maintaining the integrity of sub-surface drill pipe might be very difficult where subjacent sediment mass movement or strongly overpressured flow horizons would be created as these may affect the seafloor. Flexable, rather than rigid metal pipe might be called for or some method of piling the pipes to allow them to hold position may have to be developed. Blocking of collector pipe screens is also likely to be a problem in this fluidized environment. If the very fine sediment grains and authigenic clays flow toward the collector pipe with the gas, the collector may become packed in a fine grained, low porosity clay very quickly.

A number of options for recovery of methane from the main economic target in the lower part of methane hydrate deposits have been proposed[11, 13, 17]. These include drilling into the free gas layer to penetrate the deposits from the side and below to avoid disturbing the more unstable uppermost layers of the HSZ. In this scenario the removal of the underlying gas reduces the pressure on the formation, causing a continuous renewal of the gas by pressure-induced dissociation from from near the base of the hydrate. This method would appear to be most suited to those deposits where widespread gas occurs in a closure below hydrate, such as in the Blake Ridge[12]. The method is less likely to work where hydrate deposits are not underlain by considerable gas.

Other methods for recovering methane from the oceanic methane flux are even less conventional. These include the capping of gas seeps emanating from more deeply seated deposits, fracturing of the hydrates to produce a situation similar to that used in coal bed methane-type production, and controlled in-situ oxidation for a local heat source.

The actual mining of solid hydrate in the manner of an open pit is unlikely. It is more likely to concieve of dissociating the hydrate and transporting gas, after separation because the problem of maintaining the gas hydrate as a transportable solid along with its very large volumes of sediment matrix would probably introduce intolerable environmental and logistical effects. Seafloor hydrate, however, could be pelletized in situ and transported to shallow water where they would slowly decompose to yield fuel and water. But large volumes of seafloor hydrate are not known to occur. Alternatively, chemical engineers could perhaps design additives to make hydrate more stable at lower pressures and higher temperatures, which would facilitate its transport as a solid.

It is likely that more intensive investigation will confirm that the hydrate deposits have a variety of naturally occurring characteristics and that many of these may be used to advantage in developing unconventional methods for the commercial recovery of methane. Until we reach that time, there is an immediate need to characterize and quantify the deposits in an economical way will be paramount. Improved exploration tools being developed for conventional deep water oil and gas will provide the technological springboard for methane recovery from oceanic hydrate. The wide range of options currently proposed for methane recovery from the oceanic hydrate system illustrate the present lack of a coherent strategy.

d. Potential energy benefit of methane transport

For hydrate to be of commercial interest, the methane has to be extracted and transported to markets. Although ships could be used to transport the gas from marine moorings, it is more likely that pipelines would be more economically and environmentally satisfactory. Fixed installation is much more likely to survive accidents or weather disruption than ship transport. In addition, pipelines can be engineered to minimize the environmental impact of accidents.

Deep sourced gas brought to shore by pipelines offers other interesting possibilities for energy recovery. For instance, it would be possible to use the gas flow to generate electricity. The pressure drop from the field to shore in a pipeline from the Blake Outer Ridge area, for instance, would be over 40 mPa (megaPascals where 1 mPa = about 10 atmospheres total pressure). Although the primary energy resource is the gas itself, a pipeline to a land based terminal will have a large pressure gradient that could conveniently be dealt with by stage decompression. The pipe-line transported gas and fluids, used in driving electricity generating turbines, would accomplish the dual goal of reducing flow velocity through the transfer of kinetic energy while yielding electrical current.

e. Indirect economic effect of hydrate cycle activity?

Oceanic hydrate appears by its widespread presence in continental slope sediments to be very persistent. One of the questions that can be asked is, has hydrate also been persistent temporily. That is, is there some indication in the geological record of the one-time activity of the oceanic hydrate system that might have economic significance beyond the current possibility that methane might be recovered economically from oceanic hydrate.

The superabundance of methane in pore fluids and veins can alter local geochemical conditions. This has the potential to affect solubility and precipitation of a number of mineral species. Authigenic siderite (Fe carbonate) in the Blake Ridge area, for instance, formed in a methane fermentation zone in equilibrium with anomalously heavy oxygen water from decomposed hydrate[18]. Deposition of other carbonates may also mark stratigraphic horizons associated with either the one-time base of hydrate stability or methane gas-fluid interfaces or other chemical zones related to hydrate formation or dissociation. To our knowledge, no examination of economic mineral paragenesis, however, has yet considered the diagenetic interaction of metals transported in groundwater with the methane hydrate cycle of repeated formation and dissociation.

Vein-hosted gold deposits in low- to medium-grade metamorphic terrains, for instqance, are commonly associated with low-salinity hydothermal fluids rich in CO_2 and/or CH_4[19]. Groundmass sediments are commonly fine- to medium-grained, carbon-rich, and many may well have a continental slope affinity. In this situation they would have been passed through the pressure-temperature range of hydrate stability. The association of low salinity groundwater with high CO_2 and/or CH_4 values is strongly reminiscent of the overpressured fluids produced by the hydrate dissociation reaction[11]. The veinworks themselves may have been formed by the forceful passage of methane rich fluids[9] that provided vents for mobilized sediment and the strongly pumped fluids. We suggest that reevaluation of existing sedimentary or stratigraphically controlled gold (and possibly other deposits) should be carried out with a view to assessing the likelihood that strong variations in the presence of methane during diagenesis could have been a critical factor in the concentration and deposition of economic mineral deposits. This could offer a new perspective to identification of mineral deposits in mineraliferous terranes.

National responses to hydrate research

Why have methane hydrate system deposits not been exploited? Firstly, energy prices have been falling as awareness of the hydrate potential has grown. Secondly, all energy research has suffered from an overall diminishment of research resources. US Federal energy R&D budgets have decreased 5-fold since the late 1970s. Private sector R&D spending by the 112 largest US electric utilities fell 38% between 1993 and 1996 alone, Government funding for energy R&D has also been falling in most other industrialized countries, with the particularly notable exception of Japan. President's Committee of Advisors on Science and Technology[20] argued that this downward trend must be reversed to meet national and global economic development, environmental, and security challenges.

Until recently, consideration of hydrate system deposits as a new energy source was retarded simply because not enough was known. And very little is known now. Enough is now known, however, that they are presently being considered very seriously as potential energy sources. If even what we know now about the extent of methane hydrates was known at the time of the oil crises of 1973 and subsequently, it is likely that considerable attention to the recovery of methane would have been rendered then by the major energy companies, probably with government support. The current low prices of petroleum is presently retarding commercial consideration of hydrate as a major energy resource. But low energy prices may continue to be a feature of the industrial world, especially if methane from hydrate can be recovered economically.

Economics, of course, is the present reason why little active consideration is being given to development of hydrate. Hydrocarbon supplies are abundant and at historically near-low costs, a situation that could persist for a number of years. With no major distortions to world trade, gas and oil prices are likely to continue to remain low well into the next century. A short-term economic paradigm, however, may be a bad basis for longer-term policy, on the order of hundreds of years, upon which may rest economic and political stability.

Methane hydrate is often referred to as a potential energy source that will be exploited only when the price of petroleum oil and conventional gas would rise substantially owing, to the natural exhaustion of other hydrocarbons. But no one knows what the cost of methane recovery from hydrate recovery would be. Deep water drilling for conventional deposits has become so technologically advanced that deposits once conceived of as prohibitively expensive to recover, are now being exploited at production costs comparable to or even less than, shallow water or land conventional hydrocarbon resources. Hydrate deposits might prove to be commercial even in a low cost energy environment.

Large world hydrocarbon resources do not necessarily mean that favorable projections based on their gradual consumption alone will push development of methane hydrate well into the next century or beyond. It is possible that there could be sudden and unpredicted demands for gas hydrate development to replace other gas and oil supplies. The present apparent abundance of conventional hydrocarbon deposits and their relatively low prices are dependent on a veneer of world political stability. Ultimately, we will need other unconventional sources of energy, and the creativity and funding sources will be brought to bear. The energy question will be resolved by the market and political considerations. There may be enough energy in the various available sources: - oil shales, tar sands, solar, wind, coal conversion, oceanic system and permafrost hydrates, etc. to maintain an objective of indefinite inexpensive energy supply.

Oceanic hydrate is a very new topic in ocean science and as a potential candidate for energy resources. It has been only a little over two short decades since hydrates were recognized in the natural environment. It is thus not surprising that little quantitative information about hydrate exists. As recently as the earliest 1960s, not only had hydrate not been recognized in the oceans, but respected opinion was that no significant amounts of hydrate could occur naturally. In 1964., however, hydrate was discovered associated with permafrost in Siberia. Shortly afterwards, the presence of oceanic hydrate was serendipitously identified on seismic records in the late 1960's in the course of seismic reflection surveys.

Hydrate in the natural environment has only been recognized recently[21, 22]. In 1969, the U.S. Geological Survey assessed and mapped the global potential for deep water petroleum[23]. A primary criterion for the presence of hydrocarbons was the presence of at least 1 km of unmetamorphosed marine sediments. Other criteria, such as the presence of nearby known hydrocarbon fields or recorded seeps, were used in assessing the likelihood of petroleum occurrence. With the paucity of data available at that time the assessments were highly speculative. No mention was made of gas hydrates and all projected occurrences were confined to shallow water in the continental margins. Deep water targets of any sort were not then thought to be accessible commercially.

Recognition of hydrate in permafrost regions followed shortly. In 1972, ARCO/EXXON first recovered a pressurized specimen of naturally occurring gas hydrate from a depth of about 650m from a Prudhoe Bay, Alaska exploration well[24]. By 1996, 27 sites of gas hydrate sampling had been catalogued[25]. In 1997 the ODP Blake Ridge drilling of hydrate, which was the first drilling campaign specifically designed for hydrate and related issues such as methane generation and flux, immensely increased the corporate knowledge of hydrate. Recognition of hydrate as a potential major resource has only very recently spurred focused programs.

The government of Japan was first to establish a national hydrate research program. An exploratory five year plan for hydrate research program was established in 1995 and in 1998 the Japan National Oil Corporation (JNOC) sponsored drilling tests of known hydrate deposits in McKenzie Delta of Canada in consort with the Geological Survey of Canada, the U.S. Geological Survey (partly funded by the U.S. Department of Energy Federal Energy Technology Center, Morgantown, WV) and contract university and research institutes. The Japanese National Oil Corporation (JNOC) is conducting extensive research of a potential hydrate resource off Hokkaido Island and is on target to drill test wells in two locations in 1999. Commercial production is targeted for 2010, barely 10 years away. It is estimated that recovery of only one tenth of Japan's estimated reserve would provide Japan with methane for 100 years. The Japanese government has authorized a second five year plan, headed by NEDO (New Energy and Industrial Technology Development Organization, <http://www.nedo.go.jp>), which is intended to develop methane recovery engineering.

India, in 1996, was the second nation to establish a gas hydrate research program. The Indian approach is somewhat different from that of Japan, which can call on large foreign currency reserves and already possesses a large, high-technology industrial base. The Oil Industry Development Board of India, as part of its plan to boost natural gas resources, earmarked $56 million for a program of methane hydrates research. The main early research has been carried out under the auspices of the Gas Authority of India, Ltd. (GAIL). India is aiming at defining their national hydrate resource, and encouraging industry to develop hydrate leases through advantageous tax structure and other economic enticements. Whereas the approach of Japan can be maintained in the face of low world energy prices, the present low energy price structure is retarding Indian activities.

Other nations are also conducting assessment of deep water hydrocarbons, including hydrate. Canada, which closed its offshore minerals program some years ago, is revitalizing its program. The European Union has allocated funds for development of methane sensors, specialized hydrate coring apparatus, and marine research to identify hydrate and quantify methane in European North Atlantic waters.

In the United States, the first National U.S. Gas Hydrate Workshop[4] brought together government, industry, and academic research interests and proposed that research into hydrate should take place as a broad, integrated research program. At that time, industrial representatives noted that the major costs associated with development of the deep water drilling capability envisaged as a requirement for exploiting hydrate methane resources would not be carried out solely for the problematical hydrate target. Now, however, industry is exploring extensively in the deep water regions where hydrate deposits occur, and drilling capability to the base of the potential economic hydrate zone of about 3.5-4 m[12], is already being built for conventional hydrocarbon drilling. More than deep 300 wells were planned for 1998 in depths of 1,000 to 2,000 m and deeper, exactly the depth range to explore for hydrate deposits. Spin-off of this conventional operational technology into hydrate recovery is inevitable now.

The President's Committee of Advisors on Science and Technology[20] recommended a major initiative by the Department of Energy, the U.S. Geological Survey, the Naval Research Laboratory[17], and industry to evaluate the production potential of methane hydrates in U.S. coastal waters. In 1997, Senators Akaka (D.HI)[26], Craig (R. ID) and Landrieu, (D. LA) introduced a bill (S1418) to promote the research, identification, assessment, exploration, and development of methane hydrate resources and for other purposes[27]. Senator Lott subsequently associated himself as a sponsor of the bill. At hearings on the bill it was pointed out that other nations including Japan, India and Canada were aggressively pursuing methane hydrate development. The PCAST proposal was incorporated in the bill for the Methane Hydrate Research and Development Act of 1997 with a planned budget over the next five years, (FY99 - FY03) of 5, 5, 11, 11, and 12 million dollars respectivly[28]. In carrying out the Act the Secretary of Energy would, (1) Facilitate and develop partnerships among government, industry, and academia to research, identify, assess and explore methane hydrate resources; (2) undertake programs to develop basic information necessary for promoting long-term interest in methane hydrate resources as an energy source; (3) ensure that the data and information developed through the program are accessible and widely disseminated as needed and appropriate; and promote cooperation among agencies that are developing technologies that may hold promise for methane hydrate resource development. A subsequent amendment incorporated methane hydrates as a defined marine mineral resource within the Marine Mineral Resources Research Act (PL 104-325), giving research authority to the national Marine Mineral Research Centers to work with the hydrates program[29]. This inclusion was limited to research and did not have any implication for federal mineral policy or mineral leasing. Passage of the Hydrate Act and funding for both hydrates and mineral research is being sought for FY2000 and beyond.

Managing the resource, the MMS approach

Most of industry's contact with gas hydrates to date has been in the field of flow assurance. Hydrate creates an economic nuisance in pipelines where it can spontaneously form and constrict the internal diameter of the pipe, and thus reduce flow. This can be a problem even at surface ambient pressures and temperatures in the presence of higher density hydrocarbons, but in the Gulf of Mexico and around the world, as exploration moves into increasing water depths, constriction of pipes by hydrate will be a general problem even if only methane is present.

Some initial concern was expressed following the amendment of the Marine Mineral Resources Research Act, that jurisdiction under the Department of Interior's oil and gas regulations might not be directly applicable to hydrate. MMS was quick to assure the companies that there would be no change, and that existing regulations would apply. It might be, however, that special circumstances in recovery of hydrates will call for special regulations in the future. DOE in testimony before the Senate[30] recognized that intensive research is required.

In addition to the energy issue, very little is known about the history of stability of gas hydrates, especially those dispersed along the sea floor, in a period of global climate change. The fate of methane in seawater is also not well established yet. A better understanding of the dynamics and distribution of the oceanic methane hydrate system is needed to quantify their role in the global carbon cycle and climate change[31].

There also appears to be the danger to persons and equipment from destabilization of hydrate-bearing seabeds that are disturbed by exploration and production activities of conventional deep water oil and gas deposits. Marine hydrates may be potential causes of drilling problems, blowouts, casing collapse, and well site subsidence in conventional drilling and production[33]. Such problems need to be accurately modeled and documented and techniques developed to avoid or mitigate hazards[32]. Because forced dissociation of hydrate is primarily a matter of managing thermal regimes in the vicinity of exploration and production equipment, these problems almost certainly have relatively straight-forward solutions. Long term impacts of sea floor stability and safety owing to methane production, including the likelihood of subsidence, must be investigated so that safe, standardized procedures for hydrocarbon production and sea floor engineering can be assured. There is probably a need for MMS to develop appropriate regulations beyond those for conventional oil and gas.

In addition, recent knowledge of the permafrost hydrate resource potential suggests that these may be exploited first[34]. These deposits occur on land, however, and are part of a wider problem associated with the combined water-ice and hydrate permafrost zone.

Future Research

Background information to the Methane Hydrate Research and Development Act of 1997 indicate a proposed U.S. commercial demonstration well in operation by 2015. Well before this time, other countries may have achieved methane recovery from oceanic hydrate. If the countries presently involved in, or planning to commence, research and development at the level of intensity claimed, there will be a very good opportunity for technology transfer on an international basis, which would speed up the hydrate research process and save considerable resources of individual countries.

An opportunity exists for international cooperation to develop and exploit the potential hydrate resource. Such an effort could also be well justified from the point of view of global environmental security. There is a strong implied potential for marine methane hydrate, as an important part of the global carbon flux, to affect the amount of methane in the atmosphere and thus influence global warming.

Conclusions

Oceanic hydrate may be compared with low grade mineral deposits, such as some strata-bound sulfides and porphyry copper deposits that have to be mined in very large volumes.

Conceptually, the recovery of methane from the oceanic hydrate system may be an analog for large scale open pit mining, or other methods of high volume-low concentration 'mining', in contrast to conventional hydrocarbon deposits whose exploitiation mirrors more concentrated mineral deposits.

Recovery of oceanic hydrate system deposits will be achieved most likely using the dissociation reaction to produce high pore volume, overpressured gas deposits and controlling the development of secondary porosity to manage gas migration.

Development of methane hydrate resources adjacent to major industrial countries would return a measure of energy independence to these countries and help stabilize the world economy, which is now significantly integrated. Development of hydrates thus may be construed as a security, as well as a purely energy issue.

A fully developed economic geological model for oceanic hydrate deposits has not yet been established. Thus, application of engineering and seismic interpretive methods may not yield accurate numerical results.

Some new method is required to recover methane from the as yet not well known geological environment in which they occur in marine sediments on continental slopes.

Acknowledgments. This work was supported by the Federal Energy Technology Center (FETC), Morgantown WV (U.S.

Department of Energy), funding element DE-AT26-97FT34344, and the Office of Naval Research, Program Element No. 0601153N

References

1. Sloan, E.D., Jr. 1997. Clathrate Hydrates of Natural Gases. Marcel Dekker, Inc., New York and Basel, 730pp.
2. Kvenvolden, K.A.. 1993. A primer on gas hydrate. In: Howell, D.G. et al. (eds). The Future of Energy Gases. U.S. Geological Survey Professional Paper 1570, 279-291.
3. Singh, S.C., Minshull, T.A. and Spence, G.D. 1993. Velocity structure of a gas hydrate layer. Science 260, 204-207.
4. Max, M.D., Dillon, W.P. & Malone, R.D., 1991. National Workshop on Gas Hydrates 23-24 April, 1991, US Geological Survey, Reston, VA. US Department of Energy DOE/METC - 91/6/24, DE91016654, 38pp.
5. Rowe, M.M. & Gettrust, J.F. 1993. Faulted structure of the bottom simulating reflector on the Blake Ridge, western North Atlantic. Geology 21, 833-836.
6. Paull, C.K. 1997. Drilling for gas hydrates: Ocean Drilling Program Leg 164. In: Proceedings of the Offshore Technology Conference, Houston, Texas, 5-8 May, 1997, Paper OTC 8294, 1-8.
7. Dillon, W.P. and Paull, C.K., 1983. Marine gas hydrates - II: Geophysical Evidence. In: Cox, J.L. (Ed). Natural Gas Hydrates: Properties, Occurrences, and Recovery. Butterworth Publishers, Boston, 73-90.
8. Dickens G.R., Paull C.K., & Wallace, P. 1997. Direct measurement of in situ methane quantities in a large gas-hydrate reservoir. Nature 385, 426 428.
9. Dillon, W.P., Danforth, W.W., Huthchinson, D.R., Drury, R.M., Taylor, M.H., & Booth, J.S. 1998. Evidence for faulting related to dissociation of gas hydrate and release of methane off the southeastern Untied States. In: Henrtiet, J-P, & Mienert, J, (eds). Gas Hydrates: Relevance to World Margin Stability and Climate Change. Geological Society London, Special Publication 137, 293-302.
10. Shell International Hydrate Research Team, pers. com. 2 November, 1998, Rijswijk, The Netherlands.
11. Max, M.D. & K. Chandra, K., 1998. The dynamic oceanic hydrate system: Production constraints and strategies. In: Proceedings of the Offshore Technology Conference, 4-7 May 1998, Houston Texas, 217-226.
12. Max, M.D. & Dillon, W.P. 1998. Oceanic methane hydrate: Character of the Blake Ridge stability zone and potential for methane extraction. Journal of Petroleum Geology 21, 343-358.
13. Lowrie, A., 1991, Massive gas deposits in the deep sea: US Offshore Technology Conference, OTC 6534, Houston, 6-9 May, pp. 309-316.
14. Max, M.D. & Lowrie, A., 1997. Oceanic methane hydrate development: Reservoir character and extraction. Offshore Technology Conference 5-8 May, Houston Texas, Procedings, 235-240.
15. Collett, T. S., & Ginsburg, G. D., 1998. Gas Hydrates in the Messoyakha Gas Field of the West Siberian Basin - A Re-examination of the geologic evidence: Int. Journal Offshore and Polar Engineering, 8, 22-29.
16. Kvenvolden, K.A.. 1998. Personal communication.
17. Max, M.D., Pellenbarg, R.E. & Rath, B.B. 1997. Oceanic gas hydrate: guidance for research and development at the Naval Research Laboratory: U.S. Naval Research Laboratory, Washington, DC, Workshop Report NRL/MR/6100-97-8124, 51pp.
18. Matsumoto, R. 1989. Isotopically heavy oxygen-containing siderite dervied from the decomposition of methane hydrate. Geology 17, 707-710.
19. Naden, J. & Shepherd, T.J. 1989. Role of methane and carbon dioxide in gold deposition. Nature 342, 793-795.
20. PCAST. 1997. Report to the President on federal energy research and development for the challenges of the twenty first century: U.S., President's Committee of Advisors on Science and Technology, Panel on Energy Research and Development, November.
21. Bryan, G.M. & Markl, R.G. 1966. Microtopography of the Blake-Bahama Region. Columbia University, Lamont Geological Observatory Technical Report No. 8 (CU-8-66-NOpBSR-85077), 26pp, 16 figs.
22. Stoll, R.D., Ewing, J. & Bryan, G.M. 1971. Anomalous wave velocities in sediments containing gas hydrates, Journal Geophysical Research 76, 2090-2094.
23. McKelvey, V.E., Wang, F.F.H., Quinterno, P. & Martin, Jr., R.G. 1969, World subsea mineral resources, preliminary map of potential petroleum resources: U.S. Geological Survey, Miscellaneous Geologic Investigations, Map I-632, Sheet 3 of 4.
24. Collett, T.S. 1983. Detection and evaluation of natural gas hydrates from well logs, Prudhoe Bay, Alaska. In: Proceedings of the Fourth International Permafrost Conference, Fairbanks Alaska, (1983) July 17 22, 169-174.
25. Booth, J.S., O'Leary, D.W., Popenoe, P., Robb, J.M. & McGregor, B.A. 1988. Map and tabulation of Quaternary mas movements along the United States Canadian Atlantic continental slope from 3200' to 4700' N latitude. U.S. Geological Survey Miscellaneous Field Studies Map, 2 sheets.
26. Akaka, D.K., 1998, Methane hydrate: fuel for the future: Unpublished presentation to Congress in support of Senate Bill S.1418.
27. Record. 1997. Congressional record - Senate: US Congress, November 7, S12004-12006.
28. US Senate, 1997, S. 1418, to promote the research, identification, assessment, exploration and development of methane hydrate resources, and for other purposes: U.S. 165th Congress, Ist Session, a bill introduced by Senators Akaka (D.HI), Craig (R.ID), and Landrieu (D.LA), November 7.
29. Record. 1998. Congressional record - Senate: US Congress, July 17, S8537.
30. Kripowicz, R.S., 1998, Testimony before the Subcommittee on Energy, Research, Development Production and Regulation: US Senate Committee on Energy and Natural Resources, May 21.
31. Haq, B.U. 1998. Gas hydrates; greenhouse nightmare, energy panacea, or pipe dream? November GSA Today 8/11, 1-6.
32. Oebius, H.U. 1997. Deepsea mining and its environmental consequences, three contributions to deep sea mining: Technical University of Berlin, 166pp.
33. Borowski, W.S. & Paull, C.K. 1997. The gas hydrate detection problem: Recognition of shallow-subbottom gas hazards in deep-water areas. Proceedings, Offshore Technology Conference OTC97. OTC Pater 8297, 1-6.
34. Collett, T.S. & Dallimore, S.R. 1998. Quantitative assessment of gas hydrates in the Mallik L-38 Well, Mackenzie Delta, N.W.T. Procedings of the 7th International Conference on Permafrost, Yellowknife, Canada, June 1998, 1-8.

Mr. WALDEN. Thank you, sir. I appreciated your comments.

How will the research center which you run participate in hydrate research? Is there an opportunity for Guam-based operations or from any other U.S. possessions to study the deep ocean trench environment for hydrates?

Mr. CRUICKSHANK. Well, I believe so. It is obviously a ship mining operation, and we do have a research fleet of our own in Hawaii. And we also work with other agencies to acquire ship time.

Guam is certainly the far-end of the regime. I think it would be very appropriate to have some kind of presence there. We have talked about it in previous times. We never had the capital to do that, but it certainly makes a lot of sense——

Mr. WALDEN. Okay.

Mr. CRUICKSHANK. [continuing] because that means that you have got the whole coverage in between, the east and west Pacific.

We are working, also, very closely with Battelle and the Naval Research Laboratory, with Dr. Coffin who is here now and has prepared a white paper on the research to look at the characterization of these hydrates and many of the scientific issues that are involved in hydrate recovery.

Mr. WALDEN. Okay.

Do you believe, as with remote native villages in the Arctic, that methane hydrates represent a potentially viable source of energy for remote Pacific island communities?

Mr. CRUICKSHANK. That is possible; yes.

Mr. WALDEN. Possible?

Mr. CRUICKSHANK. The cost of deep water work is coming down, as the oil companies take it, in their stride. These depths used to be considered totally out of sight. Now, they are looking to be not quite yet conventional, but cutting edge. In 10 years time, that will be conventional.

Yes, a very strong possibility of these deposits putting a completely new face on the Pacific island resources.

Mr. WALDEN. Okay.

Dr. Woolsey, how soon do you estimate that we could have an operational pilot project for gas production from hydrates in the Gulf of Mexico, OCS?

Dr. WOOLSEY. I think that, as was brought out earlier by my colleague, Dr. Trent, that Alaska probably takes the lead, as far as having the opportunity to produce the first resource derived from gas hydrates. It is more of a natural there and we certainly understand that logic.

We also know that a lot of the—working closely with the industries that are operating in the Gulf, their prime interest now is to pursue the conventional resources. But they have apparently let you know that they have the infrastructure to produce these hydrates. They want to know all there is to know about producing hydrates. So at an appropriate time, they can switch over. They have—you know, they have all the big gathering facilities in the Gulf that lead into the big pipelines that run up to the big user areas of the Northeast. And so they look at production—eventual production—of gas hydrates in the Gulf as a major industry. But they are quick to remind you that they have got a lot of conventional production for years to come.

Their biggest concerns now are these hazards that represent a tremendous risk, and that is why they are backing some of these projects that we are involved with them in, to be able to identify and really identify and assess the occurrence of these hazards before they go in and set up unknowingly and have the whole thing turn to quicksand under their feet—and I think it was brought out in the first session—that there are two areas of concern here.

One is the natural triggering of these hydrates, just by natural phenomena—be it seismic, the water temperature changes, gas chemistry, whatever. And then there is the anthropogenic, or man-induced activities, when you actually go in there and try to drill or establish a site that might trigger these, because one thing we do know that these hydrates occur right on the phase boundary. If you put up the phase diagram that we try to present to our students, we are right on the edge there, and it doesn't take much to kick these things over into either a gaseous state if they are in the hydrate or vice versa. And so that is where this monitoring station is going to come in, to better identify just what causes these changers so we will have a better understanding and establish safer procedures in their assessment.

But when the time comes, the majors in the Gulf are very keen on letting you know that they want to be in the number one seat to produce hydrates and to use the facilities that they have established there.

Mr. WALDEN. Tell us more about the so-called hydrate mounds offshore. Do they have exceptional potential for commercial methane production because of hydrate——

Dr. WOOLSEY. The mounds are more of curiosities. They, more or less, are the tip of the iceberg, let's say. They are, in most cases, you find these in the vicinity of a source of methane, which is typically associated with a salt dome. And in the case of salt domes, there is a myriad of fractures that tend to characterize this—the area around the salt domes. And gas, then—these fractures provide conduits for the natural gas to migrate up to the surface. And then when this gas that is probably in a rather warm state, moves into this colder zones near the sea floor, with the pressures in the range of 150 psi at about 500 meters and temperatures in the range of about 4 degrees centigrade, they freeze up.

And so these are typically in the upper reaches, and so—also, when they freeze, they become lighter than anything around them, so they will actually work their way up toward the surface. And they will actually breach the sea floor, very often on a submersible or an undersea video, you can see an escarpment on the sides of these mounds. And it will be just blue ice there, right there on the surface.

And then maybe you will come back a week later and it is gone. And where this large area was inhabited by this big mound of blue ice, now you have got a big slump, a big subsidence. And very often it is breached, and you will see an avalanche that had formed. If you look and just do a survey of these types of occurrences, you will see some mega occurrences that are measured in many tens of miles.

Mr. WALDEN. Really?

Dr. WOOLSEY. There is one off the coast of Norway, I think, where the avalanche is measured some 160 miles in extent. So some of these can be quite large.

And in our area, we have this almost catastrophic disassociation along our slope off the Gulf Coast. And one of the peculiarities that we have in the region are what we refer to as “loop currents.” When you get real strong trades blowing into the Caribbean, and we get a real strong jet of water coming up through the strait of Yucatan, and a little push of loop current up close to our shore. And these loop currents will maybe occupy the bottom area there for maybe as much as six weeks or so. And so there is an opportunity for a warming of these sediments. And we will go from maybe 4 degrees C up to 11 degrees C. And then all of a sudden, we might see these various mounds dissociate rapidly. And these mounds might be just all associated with a more common substratum of hydrates. And the whole thing could—and very often does—give way. And if you are downstream of that, it can be quite hazardous.

Mr. WALDEN. How high are those mounds from the sea floor?

Dr. WOOLSEY. Usually a pretty good—an average height would be maybe 5 meters, something like that.

Mr. WALDEN. Oh.

Dr. WOOLSEY. Say 3 to 5 meters. And maybe they would be measured laterally by as much as 100 meters or so. And then you see the smaller ones, but usually the ones that are more often studied are more in that realm.

And what you find with the larger or more typical type mounds, the biologists often refer to them, from their perspective of interest, as a chemosynthetic community, because you have such an abundance of life—that profusion of life around them.

One problem that we have had in studying the shallower occurrences is that the deep troll shrimpers, after the imperial red shrimp will go out as deep as 700 meters sometimes trying to pick these things up. And so we have learned a lot from the shrimpers—where not to put our expensive equipment. Now they are not supposed to go in these regions. These areas are supposed to be protected by the Minerals Management Service, but they are quite ubiquitous out on the slope below 500 meters.

Mr. WALDEN. Okay. Thank you, Dr. Woolsey.

Dr. Tent, based on your testimony, are you suggesting that Alaska would be the best location for a pilot development of hydrate resource because the on-land permafrost deposits could probably be extracted with the least potential for catastrophic impact?

Dr. TRENT. Potential for what now?

Mr. WALDEN. That doing the development in the permafrost, you could extract it there with the least potential for catastrophic impacts. Is that better than out in the ocean?

Dr. TRENT. Well, I believe we know far more about it, with all the wells that have been drilled in Prudhoe Bay area.

There is still some problems that exist in having good bonding between the casing and the permafrost as we go through it, but not a serious problem.

The other thing, of course, we have the infrastructure, the roads. There has been—with Dr. Collett and the Japanese, we have identified at least two existing pads that we can put a new winter ice road to and drive a rig right to them, and that would save a considerable amount of money when it comes to doing basic research.

Mr. WALDEN. Okay. So from your experience, what are the relative drilling costs for, say, a 1,500 feet well in the Arctic permafrost region versus, say, a well at the same depth offshore in, say, 2,000 feet of water.

Dr. TRENT. I am going to look across my shoulder at Dr. Collett, but I think we would probably be looking in the neighborhood of $3 to $4 million.

Mr. WALDEN. For onshore?

Is that right, Dr. Collett?

Could you speak into the microphone?

Dr. COLLETT. It depends a great deal on the——

Mr. WALDEN. Right.

Dr. COLLETT. This is Tim Collett, I am with the U.S. Geological Survey.

It depends a great deal on the configuration of the well. But in an industry development mode, you are probably looking at around $2 million to $4 million, depending on what you are actually going to do in the well.

In a marine environment, we would estimate about two to three times more.

Mr. WALDEN. Dr. Woolsey, would you agree with that—in a marine environment?

Dr. WOOLSEY. Yes. I think that would—and that would probably be a little cheaper than we could do this in the Gulf.

They do have—another thing that Dr. Collett mentioned earlier was that there has been a tremendous amount of expertise developed by the Russians. Here a few weeks ago, we had a workshop down on the Gulf Coast, and we had a contingent of eight Russian researchers that were experts in gas hydrates. And they are working very cooperatively with us and have for some time. We have had a cooperative program with this group for about 10 years now, and so they have been very open to share with us information on a lot of their work in some of the Siberian fields. And so I think that it would be very appropriate to utilize some of this expertise in Alaska as well.

Now, the Russians are no better off than we are when it comes to subsea production of hydrates. We have learned a lot from them on using various technologies to identify and assess these resources, but they are back to square one, just as we are, in——

Mr. WALDEN. Yes.

Dr. WOOLSEY. [continuing] through the process of doing a subsea——

Mr. WALDEN. Yes.

Dr. WOOLSEY. [continuing] completion.

Mr. WALDEN. As long as you are not sharing nuclear secrets, we will probably be okay.

[Laughter.]

Mr. WALDEN. So, the research dollar for actual field studies, Dr. Trent, rather than laboratory studies, you would say goes much farther onshore as opposed to off?

Dr. TRENT. Yes, and I think another thing that onshore, you can go year to year to year, where offshore, you would have to maintain your platform. Onshore, your costs of maintenance would be much less.

Mr. WALDEN. And one final question for each of you to answer briefly if you would.

Do you believe the program could provide discernible benefits at the $42.5-million level over 5 years that is sought after in the bill?

Dr. Trent, do you want to start?

Dr. TRENT. I believe that that would be adequate, especially with industry support.

Mr. WALDEN. Okay.

Dr. TRENT. Cost sharing in a lot of cases.

Mr. WALDEN. All right.

Dr. Woolsey?

Dr. WOOLSEY. In the Gulf, I would certainly like to see this elevated. I think you referred earlier to something in my written statement where I have been hearing—and very pleased to hear that—from a number of experts in government and industry suggesting that a figure somewhere between $150 and $200 million over a 10-year period would be much more appropriate. And we need to look at a 10-year, more than we do a 5-year. And also—then, this was two different groups that had arrived at these figures separately, but from their own perspectives. And so I was very heartened to see this.

Just in my own area, just talking about working offshore with this subsea monitoring program, one of the tools that we would be using would be an autonomous vehicle. Well, those don't come cheap in themselves, but we would have this docked remotely, and when we would see one of these warm currents coming in through satellite imagery, we could launch this remotely to go out to these pre-located sites, where it could make these readings remotely, and then come back and dock and download. But we are talking about a vehicle that, for openers, is going to run around $1.5 million.

So, when you start talking about these types of technologies and tools—but when you look at that against a background of just this last year, several $100 million lost because of our lack of knowledge of hydrates and associated problems—not even talking about, you know, the eventual payoff in production and the problems with greenhouse gases—just looking at the hazards, alone, then that puts it all in perspective.

And I think there is a certain urgency there, in trying to address these problems that are represented by the hazards.

Mr. WALDEN. Okay.

Dr. Cruickshank?

Mr. CRUICKSHANK. I am inclined to agree with Dr. Woolsey, that long term is more appropriate. And also, as you get into the deep water, costs go up commensurately.

There is no question that the oil companies are now looking at deep water wells. They are very expensive. The latest drilling vessels to be built may cost about $230,000 a day, which relates to what has been stated previously. Nevertheless, over the long-term, these costs are going to be unavoidable. It will be in the later part of the program that these very high costs will occur, when it is necessary to drill and even put down systems for hydrate production—I don't think you should start off big and stay flat. It should progress appropriately, as new knowledge is attained.

Thus what you were mentioning before, about $10 million a year, at the beginning, would be adequate. But the anticipation, it would definitely go up, as we learn more.

Mr. WALDEN. Okay, that is it for questions from the Committee.

[Laughter.]

I appreciate all your testimony; it has been very enlightening for myself, and I know for the staff, and for having it in the record as well.

We will keep the record open for two weeks for additional testimony and comments from the public.

And, unless there is anything else, to come before the Committee, I will——

Yes, Mr. Cruickshank?

Mr. CRUICKSHANK. I just have a couple of things I would like to have for the record——

Mr. WALDEN. Okay.

Mr. CRUICKSHANK. [continuing] for the Committee.

Mr. WALDEN. Yes; just submit those to the staff. We will be happy to include those as part of the public record.

[The information follows:]

Mr. CRUICKSHANK. Thank you, Mr. Chairman.

Mr. WALDEN. Thank you, gentlemen, for your testimony.

The Committee stands adjourned.

[Whereupon, at 4:20 p.m., the Subcommittee was adjourned.]

[Additional material submitted for the record follows.]

LETTER TO MRS. CUBIN FROM DR. HAQ

NATIONAL SCIENCE FOUNDATION,
4201 WILSON BOULEVARD,
ARLINGTON, VIRGINIA 22230.
June 8, 1999

Hon. BARBARA CUBIN,
Chairman, Subcommittee on Energy
and Mineral Resources,
U.S. House of Representatives,
Washington, DC 20515

Dear Ms. Cubin:

I am responding to your request of May 28, 1999, for additional information on methane hydrates as follow-up to my testimony before the House Resources Subcommittee on Energy and Natural Resources.

1. *What is the chemical purity of methane hydrates?*

   Gas hydrates in nature are relatively pure, composed of methane and water. Rarely, heavier hydrocarbons (e.g., propane, butane) may also occur in trace quantities (<1%).

2. *Are there any contaminants contained within, such as heavy metals, organic chemicals, or other waste products such that refining or separation would be necessary, and waste products would then have to be disposed of in order for hydrates to be utilized as an energy resource?*

   During the formation of the hydrate under high pressure and low temperature conditions, the methane molecule is captured inside a cage of water molecules and chilled to form a solid, while at the same time expelling salts that occur dissolved in pore waters where the hydrate is forming. Since the hydrates occur more commonly dispersed in the sediment, the sediment itself can be considered as "waste product" if the hydrate is to be exploited. In fact, sediment may be a "co-product" of production from hydrates, which the industry is well equipped to handle. If the hydrate occurs more concentrated locally, it may still contain smaller amounts of sediments associated with it. Sediments generally contain particles of sand, silt and/or clay, as well as organic materials and trace elements.

Please contact me should you need additional information.

Sincerely,

BILAL U. HAQ,
Program Director,
Marine Geology and Geophysics

Hawaii Natural Energy Institute

http://www.soest.hawaii.edu/HNEI/hnei.html

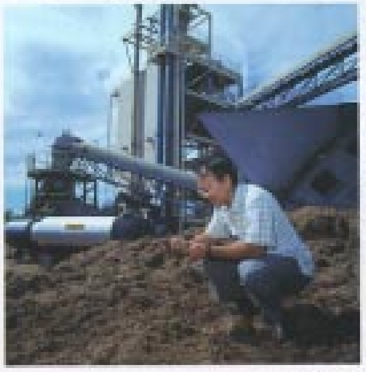
THE "T" IN SOEST stands for technology, and the Hawaii Natural Energy Institute's research and development emphasis has been on the technology to harness the islands' renewable energy and ocean resources. Work is in several major areas: finding ways to use island-grown biomass for energy, fuels, and other products; developing the means to produce and store hydrogen efficiently and economically; and tapping the marine resources potential of the Pacific Ocean.

BIOMASS AND BIOFUELS

Biomass is the most versatile non-petroleum energy resource available, and Hawaii is a leader in the development, production, and utilization of biomass energy.

Hawaii Integrated Biofuels Research Program

The Hawaii Integrated Biofuels Research Program completed its seventh phase of funding by the U.S. Department of Energy (USDOE) through the National Renewable Energy Laboratory. The program features basic and applied research on the production of biomass and its conversion into gaseous and liquid fuels and into electricity to support the production of biofuels. The goal is to create the necessary infrastructure to aid in the development of sustainable biomass-based energy systems. It is being met by activities organized along three broad thrusts: (1) biomass production, (2) thermochemical conversion, and (3) biochemical conversion.


Researcher Charles Kinoshita examines the bagasse that will serve as feedstock for the biogasifier in the background. (Photo by Bob Chinn, University Relations)

Biomass production The objectives of the biomass production component are the identification of the fastest-growing, highest-yielding biomass species and the improvement of their yields through genetic characterization and plant breeding, greenhouse and field-testing, and large-scale demonstrations. Current research tasks have included assessing the genetics of acacia through crop tests on Maui; comparing results of wood yields from mixed polyculture and monoculture of tropical hardwood tree species; and harvesting a 4.5-acre bannagrass crop on Molokai to validate crop production simulations and develop the information needed to determine the feasibility of producing bannagrass as a commercial energy source.

Thermochemical conversion The thrust of the thermochemical conversion component is to identify, analytically and experimentally, efficient thermochemical means of converting biomass into fuel gases, methanol, and electricity to support biofuels production. Current research activities include refining a gasification technology using a bench-scale unit; developing a predictive model of nitrogenous-species evolution in gasification and downstream combustion; testing a wide array of no- or low-cost feedstocks and several forms of whole biomass using supercritical-water gasification; and determining the extent to which alkali compounds can be removed from biomass to reduce corrosion and unwanted deposits in energy conversion facilities.

Biochemical conversion The objective of the biochemical conversion component is to identify optimal means of pretreating biomass feedstocks prior to biological conversion of biomass into ethanol. Research activities have focused on autohydrolysis, i.e., the use of hot, compressed liquid water to dissolve lignocellulosic material without the addition of acids, bases, or solvents, and the use of steam-explosion to evaluate mass recovery, sugar recovery, degradation products, carbon loss in the vented gas stream, and efficacy of hydrolysis in biomass.

Renewable Resources Research Laboratory

The Renewable Resources Research Laboratory (RRL) has produced some of Hawaii's most innovative and novel developments in the field of biomass conversion. The laboratory is supported by HNEI and the UH College of Engineering.

Aquasolv Researchers continued work on a process, Aquasolv, which is a simple method of fractionating biomass using only hot, compressed, liquid water. Aquasolv splits biomass, such as bagasse and wood, into two products: a solid residue and a liquid extract that contains solubilized material. These products have several potential applications that are being investigated in collaboration with other universities and private companies. Researchers are constructing a pilot plant to demonstrate the Aquasolv process, using two research subcontracts from Dartmouth University.

Hydrogen production from high-moisture-content biomass Researchers have successfully developed a system that efficiently produces hydrogen gas from "wet" biomass (biomass with very high moisture content). This gasification process uses water at high temperature and pressure—600° C and 345 atm, respectively—and a catalyst that is extremely effective in the gasification of biomass. Complete conversion of glucose to gas has been achieved using very concentrated feed solutions. The researchers have completely gasified various biomass feedstocks, including water hyacinth, sewage, paper sludge, and liquid extract from depithed bagasse, and are now studying the gasification of wood pastes to produce hydrogen. The university is seeking a patent for the catalyst. This research is being supported by HNEI's Hydrogen from Renewable Resources Research program (described below).

Charcoal Reactor A charcoal reactor was designed, constructed, and used to produce charcoal, activated carbon, and gas from biomass. Charcoal has been produced from a variety of biomass feedstocks, such as small leucaena and eucalyptus logs and macadamia and kukui nut shells. Yields of the charcoal have been very high, nearly double that of conventional processes. High production is a benefit of the short reaction time, which averages between 1 and 2 hours compared to the 8 to 12 days of existing methods. With support from the UH Office of Technology Transfer and Economic Development, the charcoal reactor was refurbished and is now producing hundreds of pounds of high-yield charcoal from macadamia nut shells for local distribution to test the market for this novel product. Two patents have been awarded and a third on activated carbon production is being sought.

Alternative fuels

The Hawaii Alternative Fuels Utilization Program originated as a five-year grant from the U.S. Department of Energy. The objective of the program was to stimulate the use of alternative ground transportation fuels in Hawaii, most recently by demonstrating alternative fuel vehicles and educating the public on alternative fuels.

Demonstration activities centered on the use of methanol-based fuels in methanol flexible fuel vehicles (FFVs). Efforts to engage the general public and businesses in the purchase of methanol vehicles or the establishment of a public methanol fueling station have been unsuccessful. Although interest was expressed by various individuals and companies to participate in such activities, the newness of the technology and the uncertainty of economic viability were significant deterrents.

Despite failure to achieve some of the stated objectives of the program, a number of successes can be reported in promoting alternative transportation fuels and vehicles in Hawaii, including the installation of an underground methanol-fuel storage tank and dispensing station at J.K.K. Look Laboratory; purchase and demonstration of a small fleet of FFVs and dedicated methanol vehicles on Oahu and Maui; stimulation of importation to Hawaii of a fleet of FFVs by the U.S. General Services Administration; and participation in a wide variety of public events featuring vehicle demonstrations to educate the public on alternative transportation fuels and vehicles.

Biomass Gasifier Facility

HNEI researchers are members of a team, headed by the Pacific International Center for High Technology Research, which is scaling up pressurized biomass gasification technology for use in converting biomass feedstocks into electricity and transportation fuels. This project is being funded by the USDOE and National Renewable Energy Laboratory, State of Hawaii, and UH. The project team also includes Hawaiian Commercial and Sugar Company, Institute of Gas Technology and The Ralph M. Parsons Company. The facility is located in Paia, Maui, adjacent to a sugar factory owned by the sugar company.

Shakedown testing of the facility utilizing bagasse as the feedstock took place in October 1995 and again in December, with the objective of gaining operational experience. More extensive trials, at higher pressures and feed-rates, are planned for the remainder of the current first phase of a planned three-phase program. In the second phase, plans call for the expansion of the gasifier unit to commercial scale to process more than 200 tonnes per day of bagasse and wood wastes and generate electricity in a combined-cycle power plant. Slip-stream testing of methanol fuel production is planned for the third phase. The successful conclusion of long-term trials in Hawaii should yield sufficient experience and confidence in this technology to allow the industrial sector to proceed with commercialization.

Hydrogen

Hydrogen has long been considered the ultimate energy carrier, a versatile fuel that converts easily and efficiently to other energy forms without the release of harmful emissions. Hydrogen can be used for all the major energy needs: transportation, electricity generation, and cooking and heating. Best of all, this abundant element can be produced from renewable resources, such as the splitting of water into hydrogen and oxygen using solar energy, or the conversion of biomass into H_2 and other gases. The two major barriers to the everyday use of hydrogen are the cost of production and availability of a compact, cost-effective means of storage.

The HNEI Hydrogen from Renewable Resources Program, now in its sixth phase of funding with the USDOE, is addressing both obstacles by developing critical technologies for the renewable production of hydrogen and the compact storage of this potentially unlimited resource. HNEI's 1994-96 program, the largest university-led effort in the nation, included photoelectrochemical production, gasification of high-moisture-content biomass in supercritical water, photobiological production, and storage using mechanical polyhydride metal complexes.

Photoelectrochemistry Researchers at HNEI are studying low-cost ways to electrolyze water into hydrogen and oxygen, using only sunlight for energy. Analysis conducted at the UH has shown that multijunction solar devices could alleviate the critical materials problems which have limited the efficiency and lifetime of conventional photoelectrochemical cells. HNEI's applied research is focused on development of systems based on multijunction amorphous-silicon (a-Si:H) alloy solar cells, which because of the very thin semiconductor layers and compatibility with high-throughput manufacturing techniques have the potential of also meeting USDOE's cost goals. Utilizing high-efficiency triple junction a-Si:H solar cells and thin film sputter-deposited catalysts developed at UH, prototype structures with solar to chemical conversion efficiencies greater than 8 percent (higher heating value of H_2 produced/incident sunlight) and extended operating lifetimes have been demonstrated. Current efforts involve fabricating new devices which operate at even higher efficiencies while also developing larger area systems.

Richard Rocheleau adjusts a thin-film sputtering device that is an important tool in his efforts to design low-cost electrodes that efficiently electrolyze water into hydrogen and oxygen. (Photo by Bob Chinn, University Relations)

Gasification As described in the section on the Renewable Resources Research Laboratory, researchers are testing the use of supercritical water to gasify wet biomass into various gases, including hydrogen. Early work showed that a broad class of carbonaceous solids, including macadamia shell charcoal and coconut shell activated carbon, can effectively catalyze the gasification of high concentrations (greater than 20 weight percent) of organic feeds in supercritical water. Carbon gasification efficiencies approach 100 percent and the product gas contains significant concentrations of only hydrogen, carbon dioxide, methane, and carbon monoxide. The goals of the current work are to demonstrate complete gasification of waste and biomass slurry feedstocks in supercritical water using a continuous flow reactor, continue the development of effective catalysts for the steam-reforming process, identify a commercially available pump that can feed sewage sludge into the pressurized reactor system, initiate studies of the rheology of biomass-oil slurries being fed to the reactor, and assist Air Products Corporation and NREL with an economic evaluation of the process.

Photobiology The goal of the Hawaii BioHydrogen Program is to generate hydrogen gas from water with solar energy using marine microbes under sustainable conditions. HNEI researchers have two major objectives: (1) establish the premier culture collection of microbes (algae, cyanobacteria, and bacteria) suitable for effective hydrogen production and (2) conduct engineering-relevant research on bioreactor systems that utilize the best microbes.

A major first step was taken with the transfer of microbes to the UH from the late Professor Akira Mitsui's laboratory at the University of Miami. The Mitsui collection, consisting of 3,000 marine algal and photosynthetic bacteria, represents a lifetime of work by the scientist. Mitsui had gathered them in Florida and the Caribbean over a 20-year span, in his quest to find species that could serve as a source of clean, renewable hydrogen to supplant fossil fuels.

This culture collection, along with other strains obtained independently, has been named the International Marine Biotechnology Culture Collection (IMBCC).

The collection is being housed in HNEI's Marine Biotechnology Center, located at the University of Hawaii's J.K.K. Look Laboratory on the Honolulu waterfront. It is a Biosafety Level 2 facility, as certified by the Centers for Disease Control and National Institutes of Health.

HNEI has formed the Marine Biotechnology Center to further explore many scientific and technological aspects of the tropical marine microbe collection and engage more actively in cutting-edge research and development in renewable energy resources, new bioactive compounds, and specialty chemicals and materials derived from marine bioresources. The initial focus of research is on the characterization of hydrogen-generating marine microbes, particularly cultures found in the IMBCC, along with bioprocess engineering.

Oskar R. Zaborsky was appointed director of the newly formed center. He is also the Williamson-Matsunaga FREE Fellow in Hydrogen Systems. The FREE (Fellows in Renewable Energy Engineering) program was created to advance the development of renewable energy and ocean resources and is named in honor of the late U.S. Senator Spark M. Matsunaga, who championed renewable and hydrogen energy in Congress. Zaborsky's position has been named the Williamson-Matsunaga Fellow in recognition of the contributions of Harwood "Bud" Williamson, the former president and chief executive officer of Hawaiian Electric Company. Hawaiian Electric helped endow the position.

The Hawaii BioHydrogen Program is being supported by the USDOE. Additional support is being provided by Japan's Ministry of International Trade and Industry through the Marine Biotechnology Institute and the Research Institute of Innovative Technology for the Earth.

Storage Hydrogen is normally stored as a gas in high-pressure tanks or a liquid at very low (cryogenic) temperatures. Hydrogen can also be stored as a solid by reacting it with a variety of metals, such as magnesium or titanium-iron. These materials provide safe, low-pressure storage, but conventional metal hydrides store hydrogen at levels too low to be practical or with too strong a bond, requiring large energy inputs for its release.

This part of the hydrogen program has been geared toward developing "non-classical" polyhydrides—transition metal complexes—as a storage medium. This new class of materials can be tailored to store and discharge hydrogen at very favorable rates in the solution and solid state with more favorable energetics than conventional hydride materials. While attempting to develop complexes of improved available hydrogen densities, it was discovered that iridium dihydride complexes containing PCP pincer ligands act as catalysts for the low temperature, reversible dehydrogenation of cycloalkanes to aromatic hydrocarbons.

A fundamental constraint of hydrogen storage systems based upon the reversible dehydrogenation of cycloalkanes to aromatic hydrocarbons is that equilibrium favors the release of free hydrogen only at temperatures above 200°C. New complexes with improved high temperature stability are being synthesized and characterized. In order to engineer a hydrogen storage system based on this catalytic process, the thermodynamic limitations and physico-chemical rate-limiting processes must be identified and characterized. In a separate subtask, a prototype reactor system will be built to study the rate limiting steps in the reversible dehydrogenation of cycloalkane and demonstrate efficient and continuous hydrogen retrieval at favorable rates and operating conditions.

OCEAN RESOURCES

Marine Minerals Technology Center

The University of Hawaii's Marine Minerals Technology Center joins its counterpart at the University of Mississippi as two such centers supported by the U.S. Department of the Interior's Mineral Institutes Program. Hawaii's multidisciplinary program of research, technology development, and education is directed at the ocean basins, while Mississippi's targets the continental shelf.

Research focuses on the characterization and development of minerals, other than oil and gas, within the seabeds of the continental shelf and the ocean basins. Both centers (1) promote research and development by industry; (2) promote, initiate, and assist in the development of improved systems for geological, geophysical, geotechnical, and geochemical surveying and sampling to characterize mineral deposits, and where appropriate, systems and sub-systems for mining, transporting, and processing; (3) conduct characterization and assessment studies of deposits; (4) train scientists and engineers and provide students with educational opportunities, work, and financial support; and (5) facilitate technology transfer through cooperative research projects, conferences, and reference center development with an emphasis on interchange between government, academic, and industrial institutions. Current MMTC projects are described below.

Characterization of shallow seabed hydrothermal crust deposits Economic and scientific studies of shallow-water hydrothermal gold systems have expanded significantly in recent years. In the past, research on sea-floor hydrothermal activity focused primarily on deep-sea, polymetallic sulfides found along active portions of the mid-ocean ridges or in deep back-arc basins. These deposits occur in depths ranging from 5,000 meters in the mid-Atlantic to about 2,000 meters on the Juan de Fuca Ridge in the northeastern Pacific. Hydrothermal systems at much shallower depths (e.g., above 1,500 meters) have been virtually unexplored. The deep-sea hydrothermal deposits closely resemble ancient massive sulfides mined on land today, whereas hydrothermal systems at much shallower water depths may resemble terrestrial epithermal systems.

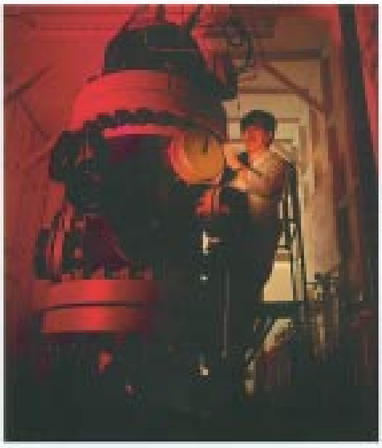
White Island, in the Bay of Plenty off the northeastern coast of North Island, New Zealand, is an emerging andesitic composite volcano that reaches several hundred meters above sea level. White Island has provided an excellent location for researchers to study the transition from a subaerial to submarine hydrothermal system.

MMTC conducted a side-scan survey and sampling expedition to White Island in November and December 1995. During 15 days of field activity, extensive data and samples were collected; analyses of the results are continuing. Preliminary findings have revealed that significant submarine gold precipitation does not occur in the hydrothermal system of White Island but may be occurring in the deeper, entirely submerged volcanoes farther offshore.

Underwater Mining Institute The 25th Annual Underwater Mining Institute was held in Washington, D.C., at the National Research Council. This gathering of marine mining experts was coordinated in large part by the UH's MMTC and included meetings with congressional leaders with interests in marine minerals and marine technology.

Manganese tailings management With strong support from BHP (Broken Hill Proprietary), Inc., the international mining giant, work has continued on developing useful by-products from marine mineral tailings. BHP provided several tons of tailings, technical advice, and matching funding support. Several small businesses in Hawaii have also joined the project, mitigating an environmental problem for marine minerals processing as they are developing useful recycled building products.

Researchers at MMTC have used tailings for several different potential products. Some of the most encouraging responses have come from the resin casting industry and from ceramic glaze marketers. Ceramics Hawaii has already requested one ton of tailings to be used as a glaze. Material has been sent to several mainland casting houses and resin suppliers; initial feedback has been very positive. The tailings mix well with resin, cast to a hard surface, offer a color not easily obtained, and will not fade in sunlight. If research proves successful, the tailings could have major applications in building products.



This chamber, which simulates ocean depths of 600 meters, is being used by Stephen Masutani (pictured here) to test the feasibility of disposing of carbon dioxide in the ocean. (Photo by Bob Chinn, University Relations)

Multimedia retrieval system for marine minerals and environmental data The MMTC is developing a user-friendly automated research information retrieval system compatible with the center's multimedia collection of marine mineral and environmental data, information, and materials. The system will also complete the cataloging of key sections of the collection.

Ocean disposal of carbon dioxide

Greenhouse gas emissions and their potential impact on the climate have been the focus of intensifying interest and debate. Carbon dioxide (CO_2) currently is the most important of these gas species because of the large quantities being released into the atmosphere—largely through the combustion of fossil fuels. A number of studies have been initiated to evaluate the feasibility of techniques to recover, reuse, and/or dispose of CO_2 generated through the combustion of fossil fuels. One technique that has emerged as a primary candidate for the control of emissions involves extraction of CO_2 from flue gases, followed by liquefaction and sequestration in the deep ocean.

An accurate assessment of the viability of CO_2 flue gas separation/ocean sequestration has been hampered primarily by insufficient information related to the ocean disposal component of the process. An HNEI laboratory study, funded by a three-year USDOE grant, has been devised to address this deficiency.

Data obtained in these tests will be applied to the development and validation of predictive models which can estimate the term of CO_2 sequestration, perform (ocean) environmental hazard assessments, and be employed to devise injection methods and to identify candidate nozzle designs that ensure rapid dissolution and, hence, long-term containment of the discharged CO_2 from the atmosphere.

The study employs a unique laboratory facility comprising a fully instrumented pressure vessel that is partially filled with chilled sea water and pressurized to simulate conditions in the ocean at depths to approximately 600 m. Liquid CO_2 is released into the water as a continuous discharge (jet) or as single droplets through a removable injector. Two categories of tests are being performed to investigate the phenomena of (1) CO_2 jet break-up and the formation of a dispersed droplet phase, and (2) dissolution of single droplets of liquid CO_2. The break-up tests will attempt to elucidate the dependence of initial droplet size distribution, coalescence, and lateral dispersion on simulated discharge depth, jet velocity, nozzle orifice size and geometry, liquid CO_2 temperature, and the formation of a hydrate phase.

[illegible]

James P. Szyper
Aquatic ecosystem dynamics

JUNIOR RESEARCHERS

Evelyn F. Cox
Coral reef ecology/biology

Nurney H. Richman III
Fish endocrinology

RESEARCH AFFILIATES

Whitlow Au
Chief Scientist, Marine Mammal Research Program
Marine mammal sensory and acoustic capabilities

Joseph DiStefano
Professor, University of California at Los Angeles
Fish endocrinology

David Greenfield
Professor, Dept. of Zoology
Systematics and ecology of fish

Kevin D. Hopkins
Associate Professor,
University of Hawaii at Hilo
Aquaculture

David Itano
Pelagic fisheries research, reproductive biology

Robert Kinzie
Associate Professor,
Dept. of Zoology
Coral reef biology and reproduction

David Krupp
Instructor, Biological Science
Coral biology

Chhorn Lim
USDA/ARS, Fish Disease and Parasites Research Laboratory
Aquaculture

Piamsak Menasveta
Professor, Chulalongkorn University
Aquaculture

Paul Nachtigall
Director, Marine Mammal Research Program
Marine mammal sensory and acoustic capabilities

Peter K. T. Pang
Professor, University of Alberta

John Randall
Ichthyologist, Bishop Museum
Hawaiian reef fishes

Ernst Reese
Professor, Dept. of Zoology
Fish behavior, ecology, conservation biology

Robert H. Richmond
Professor, University of Guam

Richard Shomura
Fisheries biology

John Stimson
Associate Professor, Dept. of Zoology
Marine ecology

EMERITUS FACULTY

Philip Helfrich
Director Emeritus
Aquaculture, fisheries management

POST-DOCTORAL FELLOWS

Miko Iwasa
Marine mammal physiology

Christopher Kelley
Fish reproduction, hormones, aquaculture

POST-DOCTORAL RESEARCHERS

Jianguang Qin
Aquatic ecology and aquaculture

VISITING FACULTY

Clifford Hearn
SPECIES model for research, education, and community awareness

Hawaii Natural Energy Institute

PROFESSORS, RESEARCHERS, AND SPECIALISTS

Michael J. Antal, Jr.
Distinguished Professor of Renewable Energy Resources (Coral Industries Chair)
Biomass and thermochemical processes

Michael J. Cruickshank
Marine minerals technology

Charles M. Kinoshita
Energy conversion, thermoscience

Patrick K. Takahashi
Director
Renewable energy, ocean resources

Oskar R. Zaborsky
Williamson-Matsunaga FREE Fellow in Hydrogen Systems
Marine biotechnology: bioenergy, specialty bioproducts from marine resources, bioremediation

ASSOCIATE RESEARCHERS

Stephen M. Masutani
Thermochemical conversion of biomass, OTEC systems, carbon dioxide mitigation

Charles L. Morgan
Marine mineral deposits, environmental engineering

Richard E. Rocheleau
Chemical engineering, thin film processing, hydrogen technology development

ASSISTANT RESEARCHERS

Kathleen K. Baker
Marine biotechnology

Bor Yann Liaw
Materials science, energy conversion devices

Anupam K. Misra
Hydrogen production, photoelectric chemistry, thin films, novel sensors, high Tc superconductors

Scott Q. Turn
Biomass energy systems: resource assessment, fuel processing, conversion technologies, environmental aspects

Ragaiy Zidan

JUNIOR RESEARCHER

Stephen G. Allen
Biomass energy, renewable resources, wood chemistry

Yukihiko Matsumura
Biomass and thermochemical processes

Hawaii Undersea Research Laboratory

PROFESSORS AND SPECIALISTS

Alexander Malahoff $^{\mathrm{OCE}}$
Director

Keith A.W. Crook
Science Program Director
Sedimentology and tectonics of convergent plate margins

ASSOCIATE SPECIALISTS AND RESEARCHERS

Edith H. Chave
Marine biology, ichthyology

Thomas Loudat
Marine minerals development economics, mine tailings management, agriforestry

John C. Wiltshire
Associate Director
Geochemistry of marine minerals

JUNIOR SPECIALIST

Kevin M. Kelly
Remotely operated vehicles

Joint Institute for Marine and Atmospheric Research

PROFESSORS, RESEARCHERS, AND SPECIALISTS

Roger Lukas $^{\mathrm{OCE}}$

Douglas Luther $^{\mathrm{OCE}}$

Dennis W. Moore $^{\mathrm{OCE}}$
Director, JIMAR

John Sibert $^{\mathrm{SOEST}}$

Bin Wang $^{\mathrm{MET}}$

ASSOCIATE PROFESSORS

Richard Brill $^{\mathrm{SOEST}}$

Steven Businger $^{\mathrm{MET}}$

Eric Firing $^{\mathrm{OCE}}$

Thomas A. Schroeder $^{\mathrm{MET}}$
Acting Director, JIMAR

ASSISTANT RESEARCHER

Sabine Stocker
Pelagic fisheries modeling

JUNIOR RESEARCHER

June Firing
General circulation, circulation in the Hawaiian waters

EMERITII FACULTY

Takio Murakami $^{\mathrm{MET}}$

Colin Ramage $^{\mathrm{MET}}$

Klaus Wyrtki $^{\mathrm{OCE}}$

AFFILIATE AND VISITING FACULTY

Rudolf Kloosterziel $^{\mathrm{SOEST}}$
Visiting Scientist

Michael Laurs
Director, NMFS
Fishery, oceanography, satellite oceanography, tuna ecology

Jeffrey Polovina
Chief, Insular Investigations, NMFS
Larval recruitment, population dynamics, statistics