U.S. DEPARTMENT OF ENERGY

Fiscal Year 2017 Methane Hydrate Program

Report to Congress

August 2019

United States Department of Energy
Washington, DC 20585

Message from the Secretary

The Department of Energy (DOE) is required to submit to Congress an annual report on the actions taken to carry out methane hydrate research and development.[1]

I am pleased to submit the enclosed Report to Congress, *Fiscal Year 2017 Methane Hydrate Program*. The report was prepared by the Department of Energy's Office of Fossil Energy (FE) and summarizes the progress made in this area of research.

This report is being provided to the following Members of Congress:

- **The Honorable Michael R. Pence**
  President of the Senate
- **The Honorable Nancy Pelosi**
  Speaker of the House of Representatives
- **The Honorable Lisa Murkowski**
  Chairman, Senate Committee on Energy and Natural Resources
- **The Honorable Joe Manchin**
  Ranking Member, Senate Committee on Energy and Natural Resources
- **The Honorable Eddie Bernice Johnson**
  Chairwoman, House Committee on Science, Space and Technology
- **The Honorable Frank Lucas**
  Ranking Member, House Committee on Science, Space and Technology
- **The Honorable Frank Pallone, Jr.**
  Chairman, House Committee on Energy and Commerce
- **The Honorable Greg Walden**
  Ranking Member, House Committee on Energy and Commerce
- **The Honorable Richard Shelby**
  Chairman, Senate Committee on Appropriations
- **The Honorable Patrick Leahy**
  Vice Chairman, Senate Committee on Appropriations
- **The Honorable Nita M. Lowey**
  Chairwoman, House Committee on Appropriations

[1] 30 U.S.C. 2003(e)(5).

- **The Honorable Kay Granger**
  Ranking Member, House Committee on Appropriations
- **The Honorable Lamar Alexander**
  Chairman, Senate Subcommittee on Energy and Water Development
  Committee on Appropriations
- **The Honorable Dianne Feinstein**
  Ranking Member, Senate Subcommittee on Energy and Water Development
  Committee on Appropriations
- **The Honorable Marcy Kaptur**
  Chairwoman, House Subcommittee on Energy and Water Development
  Committee on Appropriations
- **The Honorable Mike Simpson**
  Ranking Member, House Subcommittee on Energy and Water Development
  Committee on Appropriations

If you have any questions or need additional information, please contact me or Mr. Christopher Morris, Deputy Assistant Secretary for House Affairs or Mr. Shawn Affolter, Deputy Assistant Secretary for Senate Affairs, Office of Congressional and Intergovernmental Affairs, at (202) 586-5450, or Ms. Jazmin Everett, Office of the Chief Financial Officer, at (202) 586-2499.

Sincerely,

Rick Perry

Rick Perry

Executive Summary

This report describes actions taken in Fiscal Year (FY) 2017 to implement DOE's methane hydrate research and development program (the Program).[2] This report outlines key activities and accomplishments of the Program during FY 2017 and provides a bibliography of 30 peer-reviewed papers that appeared during the year. The Methane Hydrate Research and Development Act of 2000, as amended by Section 968 of the Energy Policy Act of 2005, directs the Secretary of Energy to annually submit a report to Congress on the actions taken to carry out the Program.[3]

The Program is managed within the Department of Energy (DOE) by the Office of Fossil Energy, Office of Oil and Natural Gas and conducted through the National Energy Technology Laboratory (NETL). The fundamental goals and general nature of the Program, similar to prior years – to conduct collaborative research and development (R&D) to deliver science and technology to further understand the nature of gas hydrate deposits, the physical properties and characteristics of gas hydrate-bearing sediments, the energy resource potential of gas hydrates for the United States, and the environmental implications of naturally-occurring methane hydrate.

In FY 2017, DOE allocated $19.8 million to the Program for R&D related to methane hydrates, as per Congressional guidance. With this funding, the Program continued its cooperative efforts with the private sector, DOE's National Laboratories, and international partners to advance the science and technology associated with naturally-occurring methane hydrate. The Program's major efforts continued to focus on the following: 1) preparation for further deepwater characterization and pressure core sampling in the Gulf of Mexico; 2) consideration of potential long-term reservoir response experiment opportunities on the Alaska North Slope in partnership with Japan, private industry, the USGS, and the Alaska Department of Natural Resources; 3) field programs to assess gas hydrate's role in changing natural environments; and 4) opportunities to collaborate with ongoing international programs, most notably India, Japan, and South Korea.

[2] Authorized by the Methane Hydrate Research and Development Act of 2000 (30 U.S.C. 2003); Public Law 106-193), as amended by section 968 of the Energy Policy Act of 2005 (Public Law 109-58).
[3] *Id.*

FISCAL YEAR 2017 METHANE HYDRATE PROGRAM

Table of Contents

I. Legislative Language

This report describes actions taken in Fiscal Year (FY) 2017 to implement the Methane Hydrate Research and Development Act of 2000, as amended by Section 968 of the Energy Policy Act of 2005. The Methane Hydrate Research and Development Act of 2000, as amended by Section 968 of the Energy Policy Act of 2005, also directs the Secretary of Energy to annually submit a report to Congress on the actions taken to carry out the Program.

II. Summary of Accomplishments in FY 2017

In FY 2017, the Program continued advancement of gas hydrate science and technology through various DOE National Laboratory projects, interagency agreements, contracts, and cooperative agreements with the private sector (primarily with universities). Among the most significant events and activities were the following: (1) safe and successful execution of a deepwater gas hydrate drilling and pressure-coring expedition in the Gulf of Mexico (GOM); (2) comprehensive evaluation and planning for potential gas hydrate field opportunities within the greater Prudhoe Bay infrastructure area in collaboration with Japan, the U.S. Geological Survey (USGS), and the State of Alaska; (3) selection by the International Ocean Discovery Program (IODP) for scientific drilling programs in the Gulf of Mexico in FY 2020; (4) completion of the most comprehensive suite of gas hydrate numerical modeling studies yet conducted in collaboration with the USGS, DOE's Lawrence Berkeley National Laboratory (LBNL), and the government of India; and (5) further field evaluations of gas hydrate occurrence and methane dynamics in climate sensitive portions of the U.S. Outer Continental Shelf (OCS).

The following summarizes key activities in FY 2017 in eight topical categories:

1. *Characterization of U.S. Gas Hydrate Resources*

A key goal of the Program in FY 2017 was to continue its efforts to refine knowledge of the scale and nature of occurrence of methane hydrate on the U.S. OCS. From 2001 to 2014, the flagship project in this effort had been the GOM Gas Hydrates Joint Industry Project (JIP). JIP was a cooperative research program between DOE (in coordination with the USGS and the U.S. Department of the Interior's Bureau of Ocean Energy Management [BOEM]), and an international consortium of industry and academic partners under the leadership of Chevron. A primary goal of the project was to test the ability to find and characterize gas hydrate through integrated geology and geophysics analyses, by selecting prospective sites and testing those selections through deepwater drilling and logging programs.

JIP's 2009 "Leg II" drilling program was fully successful in this regard, and global gas hydrate exploration and evaluation now rely heavily on its concept of direct detection of gas hydrate through tailored application of established oil and gas prospecting approaches. To maximize the number of sites that could be evaluated, the 2009 expedition relied solely on collecting logging data, and did not acquire cores (a time-consuming and more expensive process).

From 2012 to 2014, JIP worked in collaboration with Japan Oil, Gas and Metals National Corporation (JOGMEC) and the National Institute of Advanced Science and Technology (AIST), the USGS, and Georgia Institute of Technology (Georgia Tech) to further the development and testing of deepwater pressure-coring tools and compatible pressure-core analysis devices. The tools were transferred to DOE in early 2014 as uncertainty related to new GOM regulations were emerging, which in turn prompted JIP to end its effort in gas hydrates.

In the first quarter of FY 2015, NETL awarded a new cooperative agreement to the University of Texas-Austin (UT-A) focused on scientific drilling in the GOM. This project is designed to conduct field operations to assess the nature and origin of gas hydrates in the GOM through two scientific expeditions. In FY 2016, the project completed science planning, ship scheduling, and permitting activities required to conduct the initial expedition – GOM2-Expedition-1 – in May 2017.

In FY 2017, the UT-A team, including DOE, USGS, the Ohio State University (Ohio State), and numerous collaborators, completed extensive scientific planning, permitting, and contracting in order to complete a drilling and coring program from the Helix drillship Q4000 (**Figure 1**). The UT-A team also proposed, finalized, and successfully defended the scientific value and operational safety of plans for additional exploratory drilling and coring in the GOM to occur in FY 2020under the auspices of the Integrated Ocean Discovery Program (IODP).

***Figure 1**: Members of the GOM2-Expedition-1 science team aboard the Q4000 in Green Canyon Block 955 in May 2017.*

The FY 2017 expedition GOM2-Expedition-1 drilled and cored two holes in close vicinity to the 2008 GC955-H discovery well. Each well tested a different configuration of the base pressure-coring device known as the "Pressure Coring Tool with Ballvalve" or PCTB. The PCTB-CS ("cutting shoe" version) was deployed in the first hole (GC995-H002) and had limited success (6%

recovery) in eight attempts at acquiring and maintaining gas-hydrate bearing samples at native pressures. Following a number of critical adjustments to the tool and in various operational parameters, the PCTB-FB ("face bit" version) was deployed in the second well (GC955-H005) with success (75% recovery; more than 28 meters of gas-hydrate-bearing core samples). The team transferred those sample pressure cores to specialized chambers for shipment to temporary shore-based labs at Port Fourchon, Louisiana. There, the samples were scanned, and 21 high-value sections selected and transferred into 1 meter long transport vessels, and transported to the UT-A labs (**Figure 2**).

***Figure 2**: Gas hydrate pressure-core transport vessels at the UT-A.*

The UT-A team had previously solicited sample requests from the broader scientific community, and made preparations to share pressurized samples with labs at Georgia Tech, the USGS, and NETL, as well as other samples and data with more than 40 scientists and 29 students at sixteen other research institutions in the U.S. and in Japan. X-ray scans of the samples (**Figure 3**) show that many samples exhibit outstanding preservation of the fine details of reservoir structure, making the samples ideal for the evaluation of the in situ physical, flow, and geomechanical properties of resource-grade U.S. gas hydrates. All sample recipients have agreed to coordinate scientific reporting on the geochemistry, microbiology, sedimentology, geomechanics, and petrophysics of samples within a single "Scientific Results" volume that will be published in 2019. These samples will support a comprehensive evaluation of the geological processes that lead to the deposit's formation, as well as critical engineering information on the physical strength and flow properties of gas hydrate reservoirs, which are critical to assessing likely responses to energy production activities.

***Figure 3**: X-ray of finely-laminated gas-hydrate bearing sand acquired in Core 5 FB in well GOM2-H005.*

The GOM2-Expedition-1 was conducted on time, under budget, and with no safety or environmental incidents. In addition to outstanding scientific and technology development leadership and a demonstrated commitment to open and collaborative science, the UT-A team surmounted substantial logistical, legal, liability, and regulatory hurdles in enabling this expedition.

Also in FY 2017, the UT-A team successfully defended the scientific merits and the operational safety of a proposed GOM2-Expedition-2 drilling and coring operation at sites in the Terrebonne and Orca/Choctaw mini-basins. This expedition is slated to occur onboard the world-class research vessel *Joides Resolution* in early 2020under the framework of the IODP. This expedition will advance understanding of the geologic conditions that produce and sustain gas hydrate deposits by drilling and coring multiple sites in two basins with contrasting geologic environments.

A project with the University of California at San Diego's Scripps Institution of Oceanography gathered 359 line-kilometers of controlled source electromagnetic (CSEM) data over as well as locations that UT-A and IODP targeted for drilling expeditions in FY 2017 (Green Canyon 955) and in 2020 (Walker Ridge 313 and 100; Green Canyon 781). Analyses of this data, and their ultimate ground-truthing through future drilling, will inform the broader assessment and characterization of gas hydrates in the Gulf of Mexico, and provide insight into the value of CSEM data in the evaluation of gas hydrate energy resource prospects.

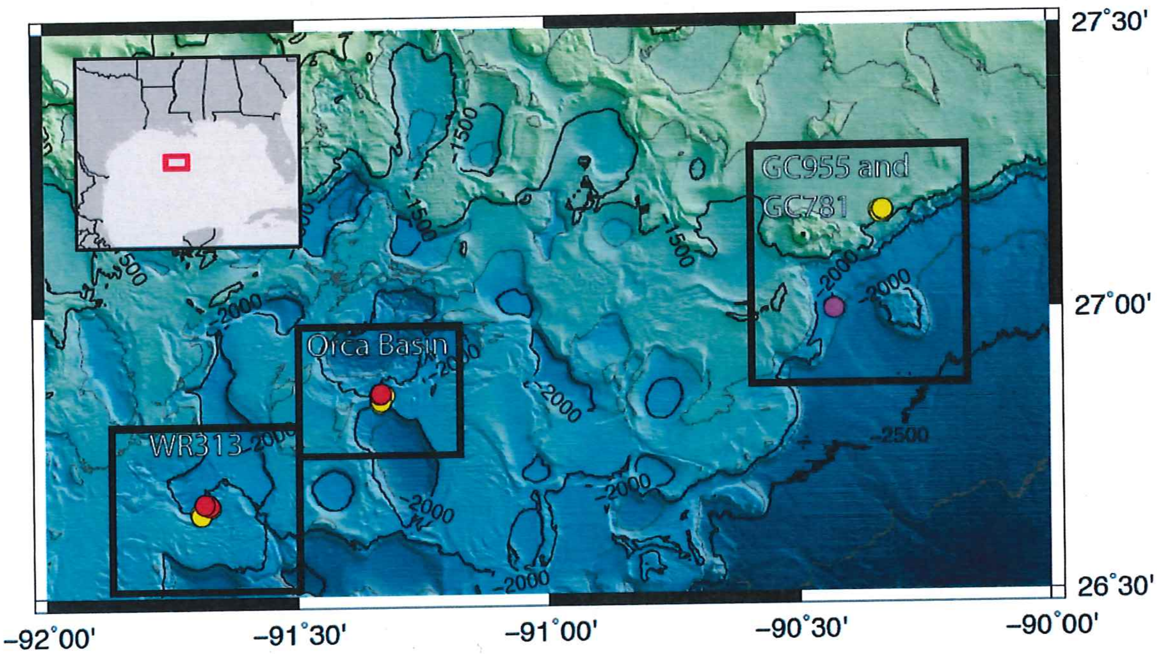


Figure 4: *Locations for collection of CSEM data using the Vulcan device as developed and deployed by U. California Scripps Institute in June and July 2017. The locations are known or are expected sites of gas-hydrate bearing sands that are targets for the DOE-UT-A scientific drilling program.*

2. Gas Hydrate Production Technologies

The Program continued its effort to conduct scientific reservoir response experiments on the Alaska North Slope (ANS) in partnership with Japan, the USGS, ANS industry, Petrotechnical

Resources Alaska (PRA) and the State of Alaska. This effort is supported by focused experimental and numerical simulation work conducted at DOE's National Laboratories.

Field programs aiming toward production technology development and testing began in Alaska in FY 2004 with a test well in partnership with Maurer-Anadarko. The result was a test well that failed to encounter gas hydrate. Lessons learned from that well were used to drive a more comprehensive, petroleum systems-based, and interagency approach within a project conducted with BP Exploration-Alaska, Inc. that discovered, drilled, and characterized thick gas hydrate accumulations at the "Mt. Elbert" test well in the Milne Point Unit in FY 2007. That well, which was required to be drilled from a temporary ice pad, as opposed to permanent gravel infrastructure, proved the Program's exploration approach and the ability to conduct research safely and non-disruptively within an area of ongoing industry operations. As a result, from 2008–2010, the focus of the project's discussion was gas hydrate field programs with the broader industry partnership that holds the leases over the most prospective field sites within the Prudhoe Bay Unit (PBU). Plans for a long-term reservoir response experiment from a gravel pad within the PBU were generated in 2010. However, due to site access issues, plans were later modified to a short-duration test focused on chemical exchange in partnership with ConocoPhillips and Japan.

In FY 2014, the Prudhoe Bay partners indicated no continuing interest in collaborative field R&D in Alaska. In an effort to further catalyze gas hydrate science, the Alaska Department of Natural Resources (DNR) and DOE's Office of Fossil Energy signed a Memorandum of Understanding (MOU) in FY 2014 designed to facilitate gas hydrate field programs on the ANS. The Alaska DNR set aside tracts of unleased lands adjacent to the Milne Point and Prudhoe Bay units until such time as DOE could determine if a feasible gas hydrate field experiment could be conducted.

In FY 2015, NETL collaborated with JOGMEC and the USGS to review the available data to assess the presence and nature of methane hydrates within the set-aside acreage. That review concluded that the state-lands sites were not conducive for long-term testing due to high costs and high risks associated with lack of infrastructure (roads, pads, power, gas and liquid gathering lines, etc.) and an uncertain occurrence of gas hydrate.

In FY 2016, NETL, JOGMEC, the USGS, and the Alaska DNR collaborated with the PBU partners to assess specific drill sites within the PBU. A specific location at the site of an unused exploration pad was identified, and a draft plan for operations developed.

In FY 2017, this plan continued to be reviewed and refined through numerical simulation at both JOGMEC and NETL, through consultation with a range of technology providers, and with Alaska engineering firm Petrotechnical Resources Alaska (PRA). The partners are currently reviewing the viability and implications of a test conducted with minimal operator involvement of the PBU Working Interest Owners and with no impact on ongoing PBU operations.

A key initiative related to gas hydrate production evaluation, is the engagement and support by NETL, LBNL, and the USGS for the planning of potential production test wells offshore India. In FY 2017, NETL delivered a final review of simulations of production response for reservoirs discovered during India's 2015 drilling program. A primary aspect of this effort is the integration of geomechanical phenomena (grain movement, reservoir displacement and associated compaction, and seal integrity) and thermal conductivity into representative reservoir models for two alternative potential production test sites. This effort was aided by ongoing collaboration with research institutes in India and Japan, where advanced evaluation of the physical samples acquired offshore India in 2015 were conducted.

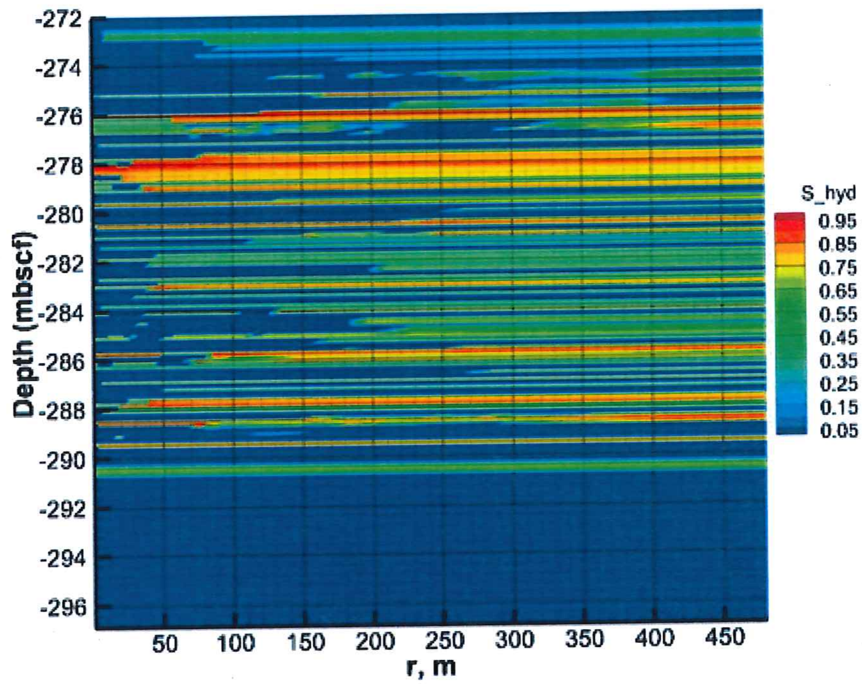


***Figure 5**: Numerical simulation for prospective gas hydrate production test sites in the Bay of Bengal. The modeling captured the full vertical geological heterogeneity of the deposit and integrated both thermodynamic and flow phenomena with geomechanical evolution of the deposit during simulated production.*

3. Fundamental Experimental and Modeling Studies

In FY 2017, the Program continued its support for focused experimental and numerical modeling studies designed to provide foundational science regarding the nature of hydrate-bearing sediments and their potential response to production activities or other changes in their environment.

A major effort in FY 2017 was the solicitation and evaluation of proposals for access to samples collected during GOM2-Expedition-1. These proposals were received from the broad gas hydrates scientific community and comprised requests for both preserved pressure cores and other samples and data. The success of the expedition has provided not only the UT-A team with adequate samples to achieve their project goals, but sufficient samples to enable all external requests to be met. Pressure cores samples will be studied in the labs at the UT-A, and also shared with labs at NETL, the USGS, and Georgia Tech; these are the only known U.S. labs with the capability to receive and evaluate the samples under continuous pressurized conditions. These studies will focus on constraining the continuing uncertainty over the initial permeability and the dynamic petrophysics of gas hydrate-bearing sands under depressurization. Numerous other labs (at present, 49 scientists representing 25 research groups) will receive and evaluate sediment, gas, and water samples. These studies will address fundamental science issues relating to the origin, evolution, and nature of the geologic systems that produce resource-grade gas hydrate deposits. All recipients of samples and/or project data have agreed to share project results within a coordinated special issue in a peer-reviewed publication (slated for publication in late 2019).

Equally notable, DOE has kicked off the 2nd International Gas Hydrate Code Comparison Study (IGHCCS2), which includes participation from all known gas hydrate modeling groups (**Figure 6**). The 1st International Gas Hydrate Code comparison Study (2008-2011) was very successful in aligning and advancing models for the purpose of thermodynamic and flow modeling. The second round of the effort recognizes the current need to integrate flow models with geomechanical processes, which play a key role in determining the response of hydrate reservoirs to depressurization or other means of hydrate destabilization. The IGHCC2 is coordinated by DOE's Pacific Northwest National Laboratory (PNNL) with support from LBNL and NETL.

***Figure 6**: Logo map of participants in the 2nd International Gas Hydrate Code Comparison Study under the guidance of PNNL, LBNL, and NETL.*

During FY 2016, NETL's Research and Innovation Center (R&IC) initiated a collaboration with Stanford University (as well as the USGS and BOEM) to conduct basin-scale petroleum systems modeling using industry standard models. Such modeling has been enabled by recent enhancements to conventional models and its use in gas hydrate applications pioneered in Japan and Germany. The effort is to understand how hydrate systems form and evolve over geologic time. The subject of the initial modeling effort will be the complex but well-characterized Walker Ridge 311 site, which is a target for future planned scientific drilling expeditions (under the ongoing UT-A project previously described).

NETL's R&IC continues to collaborate with USGS and LBNL to advance the art of gas hydrate numerical simulation, including the continuing effort to fully capture the complex geologic nature of hydrate systems. In FY 2017, this effort has focused on the evaluation of potential gas hydrate production testing at two sites in the Bay of Bengal in collaboration with the government of India. The sites, which are in deep water and are composed of complex and thinly-bedded reservoirs, require full integration of flow and geomechanics. Additional modeling at NETL has explored the sensitivity of production predictions on issues such as numerical grid design and the incorporation of geologic heterogeneities over three dimensions. These advances reflect the growing data available to modelers and the ability to progress from simplified to more geologically-robust models.

Several projects selected and funded in prior fiscal years were completed in FY 2017. Georgia Tech's experimental effort addressed fundamental issues associated with the hydraulic and geomechanical behavior of gas hydrate in clay-rich sediments. It confirmed previous views that opportunities to produce hydrates from clay-rich sediments is hindered by an inability to impose pressure or temperature changes at sufficient distances from a wellbore. A second project with Georgia Tech completed successful field tests of a borehole-deployed tool for collection of geomechanical properties of hydrate-bearing sediments. The Colorado School of Mines completed its effort to assess the relationship between gas hydrate content and various acoustic properties of hydrate-bearing sediment. Finally, UT-A continued its theoretical modeling efforts designed to assess the potential methane migration and accumulation mechanisms at a high-saturation, sand-hosted hydrate deposit in the GOM.

New projects added to the portfolio late in FY 2016 included a project with the UT-A which is conducting laboratory evaluation of the dynamic petrophysical attributes of gas hydrate–bearing sands in response to pressure reduction at the macro- and micro-scale. This research will enhance the understanding of hydrate system behavior, improving the ability to simulate hydrate production. A second project with Louisiana State University (LSU) and the USGS is conducting a laboratory evaluation of the nature and implications of fines migration during potential gas production, with specific focus on factors unique to hydrate-bearing sediments such as profound reductions in formation water salinity. A third new project features a collaboration between Texas A&M University and the Korean Institute of Geosciences and Mineral Resources (KIGAM) that is leveraging prior state-of-the-art experimentation using KIGAM's range of large-scale hydrate reactors to advance the integration of geomechanical capabilities into leading numerical models for hydrate system thermodynamic and hydraulic behavior.

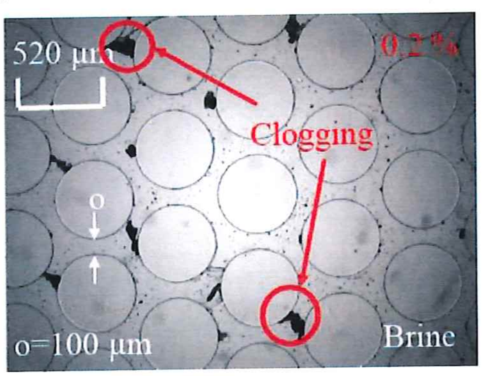


***Figure 7**: Controlled experimental studies at LSU/USGS are investigating the impact of pore fluid chemistry on potential pore-clogging by clay minerals.*

4. Gas Hydrate Environmental and Global Climate Studies

In FY 2017, DOE continued to support a range of studies designed to determine the sources, sinks, and fluxes of methane in gas hydrate-bearing environments that may be sensitive to environmental change. The primary goal is to understand the role gas hydrate might play in natural geohazards, in the global cycling of carbon over long time frames, and in the potential nearer-term feedbacks in response to warming climates. This effort reflects the intent of the

Methane Hydrate Research and Development Act of 2000, which directs DOE to work with our interagency partners to enable research across a broad range of gas hydrate issues, including the impacts of natural degassing from hydrates.

In FY 2017, an emerging consensus was observed within the scientific community that gas hydrate is likely not a major source of methane emissions at the present time, and evidence that those methane emissions observed within gas hydrate-bearing systems are most likely driven by longer-term geologic phenomena and not near-term environmental change. In FY 2017, DOE-funded scientists from Oregon State University, the University of New Hampshire, and the USGS participated in field programs staged by Norwegian and German research institutions along the Svalbard margin in the northern Atlantic Ocean. These expeditions resulted in a number of major findings, including demonstration of:

- The limited impact of short-term warming on gas hydrate dissociation;
- The limited release of methane to the atmosphere over deepwater methane seeps;
- The source of the previously hydrate-linked seeps to longer-term geologic and tectonic processes; and
- The prominent role of carbonate precipitation at the seafloor as a major sink that prevents substantial volumes of rising methane from entering the ocean.

The University of Rochester (UR) and the USGS conducted a research expedition from the research vessel (R/V) *Hugh Sharp* from August 24 to September 7, 2017 (**Figure 8**). The expedition was designed to collect water samples at various depths above an array of deepwater methane vents recently observed along the Atlantic Margin. Several new analytical approaches were developed by UR and the USGS and tested against field data from the GOM as well as the Atlantic and Arctic oceans. Over 1,000 water samples collected will be analyzed in FY 2018 with the goal of determining the amount of methane released, its source (and connections to gas hydrate if any), and its fate within the water column. Two primary goals are to assess the potential of methane emitted at the seafloor to reach the atmosphere as well as the impact on ocean chemistry of the methane that is oxidized within the water column. This effort includes a close collaboration with an ongoing project at Texas A&M University that is leveraging prior data collected in the GOM with extensive experimental results obtained at NETL to study the fate of methane in water columns where hydrate shells form around methane bubbles in a process called hydrate bubble armoring.

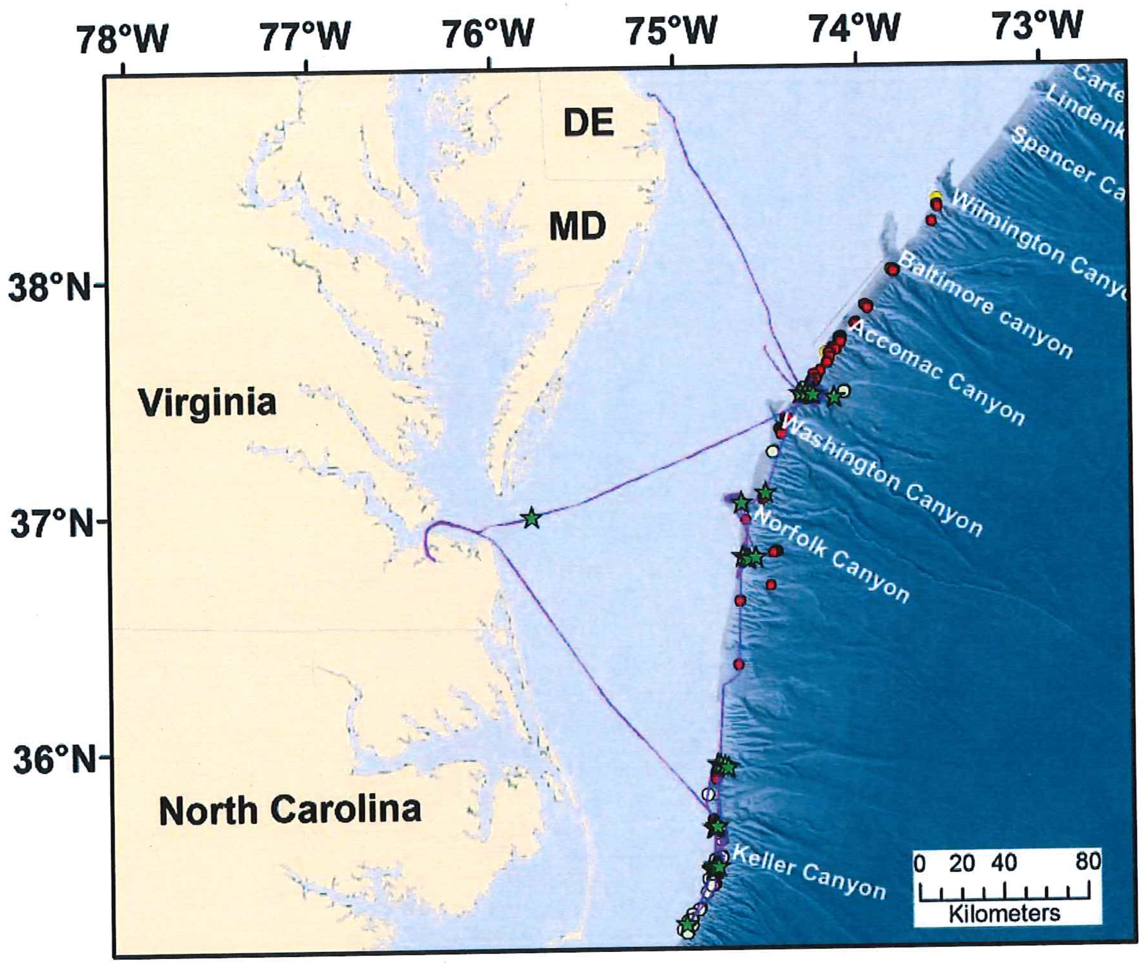
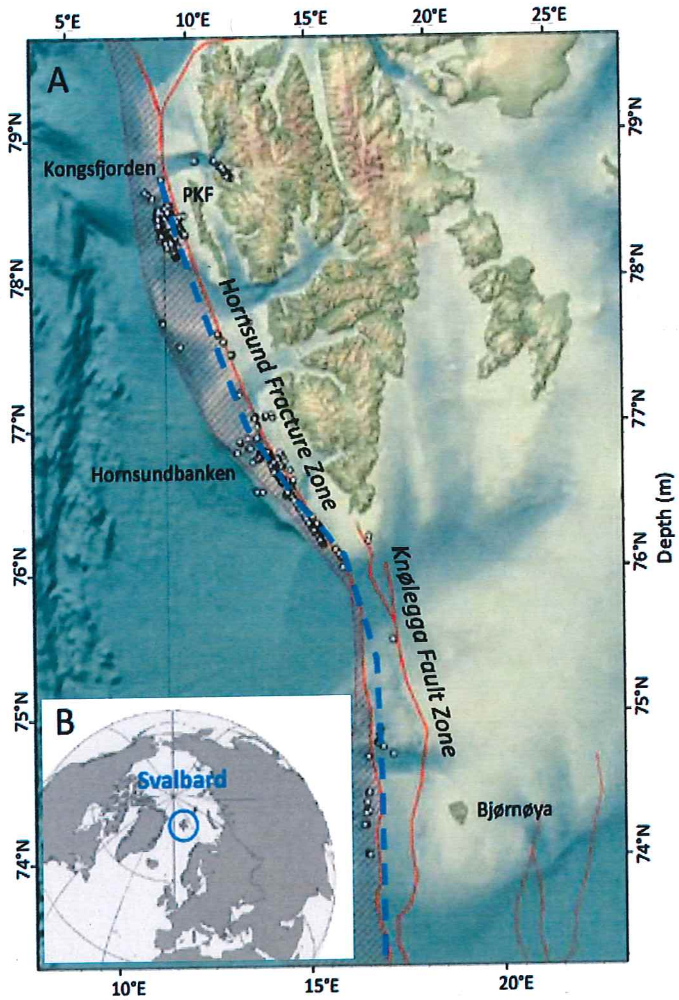


Figure 8*: Cruise track (purple) for the UR/USGS oceanographic expedition conducted aboard the RV Sharp, August and September 2017. Red circles are previously noted methane seeps. Green Stars are locations of water column samples taken during the FY 2017 Expedition.*

Also on the Atlantic margin, the USGS collaborated with members of the British Geological Survey to deploy Oceaneering, Inc.'s Remotely Operated Vehicle (ROV) Global Explorer at deepwater (>10,000 m water depth) methane seep sites in an expedition enabled by the National Oceanic and Atmospheric Administration (NOAA).

On the Pacific Margin, the University of Washington concluded its effort to asses, gather, and evaluate data on methane sources, sinks, and fluxes offshore of Washington. This project gathered extensive data on heat and fluid flow in the region, and reached a conclusion similar to that found off Svalbard - that despite apparent observed recent warming, hydrate dissociation is not widespread and is only a minor source of methane seepage to the seafloor.

In FY 2017, Southern Methodist University (SMU), Oregon State, and the USGS concluded their project to assess deepwater gas hydrate on the Alaska Beaufort shelf through reference to seismic and heat flow data. They conclude that the area of gas hydrate stability throughout the shelf is continuing to shrink, and that it will continue to shrink for the next 3,000 to 5,000 years.



The Norwegian island of Svalbard (**Figure 9**) is perhaps the best-characterized setting in which gas hydrate dissociation and methane release has been attributed to ongoing warming of bottom water. DOE has supported major funding for a series of expeditions staged by University of Tromsø (Norway) and University of Bremen (Germany) in the area around the Svalbard margin in FY 2016 and FY 2017 to verify methane seepage and assess linkages to gas hydrate. DOE funded participation by scientists from Oregon State University and the University of New Hampshire in 5 cruises; supported deployment of integrated cavity output spectroscopy (ICOS) instrumentation for methane measurement; and funded ongoing shore-based chemical and microbiological analyses. Preliminary results (mostly published in FY 2017) indicate that observed methane release occurs with spatial distribution that shows no strong link to hydrate occurrence, at timescales inconsistent with any recent anthropogenic forcing, and instead likely represent longstanding geologic processes.

Figure 9: *Location of observed gas seeps off the Svalbard margin, northern Atlantic Ocean. The area has been a premier international research site for the investigation of the potential links between the occurrence of such seeps and the potential climate-driven destabilization of gas hydrates. DOE-funded scientists contributed to a number of collaborative expeditions led by research institutions in Norway and Germany that have revealed that the seeps have little direct connection to gas hydrates.*

5. *International Collaboration*

DOE maintained active engagement and discussion with the world's leading international gas hydrate R&D programs in FY 2017. These collaborations provide the Department access to critical data and insights on the performance of gas hydrate exploration and sampling technologies.

Additionally, formal departmental-level agreements continued with the governments of Japan (Ministry of Economy, Trade, and Industry), India (Ministry of Petroleum and Natural Gas; Directorate General of Hydrocarbons), and South Korea (Ministry of Knowledge Economy).

As reviewed above, the primary focus of collaboration with Japan continues to be the pursuit of field testing programs on the ANS. Interaction during FY 2017 was extensive, including bi-weekly web-based conferences.

Collaboration with India is focused on joint evaluation of drilling sites and operational plans for a proposed third Indian National Gas Hydrate Program, to be focused on gas hydrate production testing at one or more sites discovered in the FY 2015 expedition. NETL, the USGS, and LBNL continue to support planning primarily through the development of geologic models for the prospective sites and a series of integrated numerical simulation studies intended to support detailed field test design. The ongoing modeling effort is supported by collaboration between the USGS and AIST (Japan) scientists in the advanced evaluation of pressure cores collected during the Indian government's FY 2015 expedition in the Bay of Bengal.

Research efforts at PNNL and LBNL in FY 2017 continued collaborative numerical modeling efforts with KIGAM as enabled by the Korean National Gas Hydrate Development Organization (GHDO).

Lastly, NETL maintains informal contacts with researchers in many other nations (Mexico, Brazil, New Zealand, China, and others) and will continue to monitor opportunities to expand international collaboration.

6. Support for Education and Training

NETL, through its cooperative agreements with academia, are currently supporting dozens of students obtaining advanced degrees across a wide range of scientific disciplines. In addition, in cooperation with the National Academies of Science, Engineering, and Medicine, NETL established the National Gas Hydrate R&D Program Fellowship in 2007. No new fellows were selected in FY 2017.

7. Program Management and Oversight

Throughout FY 2017, DOE continued to manage a broad portfolio of R&D projects. No new project solicitations were conducted. DOE continued to engage its Methane Hydrate Advisory Committee in the evaluation of gas hydrate R&D priorities and progress, conducting a thorough review of program activities at meetings in Washington, DC in October 2016 and April 2017.

8. Technology Transfer

DOE and its research partners continued to disseminate research results to the scientific community during FY 2017. Appendix A provides a press release related to the completion of GOM2-Expedition-1. Appendix B lists 30 peer-reviewed publications that were released during FY 2017 that resulted in, whole or substantial part, from DOE support. Appendix C lists 33 papers derived from the DOE program that were presented at the triennial International Conference on Gas Hydrates that was held in Denver, Colorado in June 2017.

In addition, the DOE/NETL Gas Hydrate Newsletter, *Fire in the Ice*, continued to report on global developments in gas hydrate R&D. This periodic publication is distributed to approximately 1,500 subscribers in more than 35 countries. FY 2017 highlights included an early report on the UT-A/DOE gas hydrate drilling and coring expedition, as well as the first published report on the finding of massive gas hydrate deposits off the western coast of Japan. DOE/NETL and the UT-A provided regular public updates on the progression of GOM2-Expedition-1 over the internet.

III. Conclusion

This report describes the activities and accomplishments of DOE's Methane Hydrate R&D Program in FY 2017. DOE effectively managed its international collaborations, its work with DOE's National Laboratories, its collaboration with other Federal agencies, and its portfolio of ongoing work with the private sector to further advance the science and technology needed to improve our understanding of the occurrence, nature, resource potential, and environmental implications of naturally-occurring gas hydrate.

FY 2017 was highlighted by the successful acquisition of pressure cores from the Green Canyon 955 site in the northern GOM – the first from U.S. waters. The expedition – led by the UT-A and in collaboration with NETL, the Ohio State University, the USGS, and other institutitons – overcame tremendous logistical and regulatory issues, as well as real-time operational challenges, to aquire a substantial volume of high-quality samples of resource-grade gas hydrate. These samples will enable high-impact science at numerous laboratories in the U.S. for years to come. This fiscal year also saw the UT-A led GOM effort successfully propose further scientific drilling as part of future activities within the IODP.

The Program's international activities were also highlighted by ongoing and extensive collaborations with Japan and India. Collaborative work with Japan included an ongoing effort to develop long-term gas hydrate field testing programs on the ANS, an effort that NETL continues to coordinate with the State of Alaska and the USGS. Collaboration with India featured the completion of the most complex numerical simulations conducted to date as part of an effort to support India's evaluation of future gas hydrate production testing operations in the Bay of Bengal. That effort helped spawn a new international effort to compare and evaluate the current state of numerical simulation, in particular the effort to integrate thermodynamics and flow modeling with the geomechanical response of the reservoir system.

Finally, DOE and its research partners continued to disseminate research results to the scientific community during FY 2017 through an extensive technology transfer program, including a widely-read newsletter. The Program's funded research efforts produced more than 60 peer-reviewed publications including contributions to the triennial International Conference on Gas Hydrates in FY 2017.

Information on the DOE Methane Hydrate Program, including detailed summaries of all active and completed projects and reports and publications resulting from DOE-funded investigations, are regularly updated and can be found at http://www.netl.doe.gov/research/oil-and-gas/methane-hydrates.

Further information on the Program, including reports and activities of the Methane Hydrate Advisory Committee, are available at http://energy.gov/fe/science-innovation/oil-gas-research/methane-hydrate.

Appendix A: News Release

Frozen Heat: Exploring the Potential of Natural Gas Hydrates

May 10, 2017

Washington, DC -- Everyone hears about the vastness of our more traditional fossil fuel resources. But one potential source of fossil energy could exceed the energy content of all other known fossil fuels combined—and that's natural gas hydrate.

Natural gas hydrates – natural gas trapped in ice-like cages of water molecules – can be found trapped under arctic permafrost, as well as beneath the ocean floor. They can also form during drilling and production operations. When gas hydrate is warmed or depressurized, it reverts back to natural gas and water.

When brought back to the earth's surface, one cubic foot of methane hydrate releases 164 cubic feet of natural gas. Estimates of potential energy resources in global gas hydrates are on the order of tens of thousands trillion cubic feet (Tcf) of natural gas, while all other proven global natural gas resources are estimated to be nearly 7,000 Tcf. That's a lot of untapped potential energy.

So methane hydrates represent a massive natural storehouse of energy that hold significant potential as a future energy source. But first we need to better understand the locations and scale of this resource and the nature of hydrate-bearing geological formations. The Office of Fossil Energy's National Energy Technology Laboratory is currently managing a broad suite of fundamental research into gas hydrates, including six new research projects that aim to develop the science and technology to assess gas hydrates occurrence in nature, and reveal their potential as a future energy resource.

This month, FE is partnering with a research consortium led by the University of Texas-Austin to conduct a three-week drilling and coring expedition to a site where prior DOE-funded drilling discovered resource-quality gas hydrates in the deepwater Gulf of Mexico. This expedition will gather samples from the hydrates deposit in specialized equipment that will maintain those samples in their natural state throughout recovery and transfer into laboratory devices for analyses. You can follow the progress of that expedition here.

Appendix B: FY 2017 Peer-Reviewed Publications

Behseresht, J., Bryant, S., 2017. Physical mechanisms for multiphase flow associated with hydrate formation. *Journal of Geophysical Research-Solid Earth* **122** (5), 3585-3623.

Boswell, R., 2017. Naturally occurring gas hydrates. *McGraw-Hill AccessScience*. https://doi.org/10.1036/1097-8542.281250

Gai, X., Sanchez, M., 2017. A geomechanical model for gas hydrate-bearing sediments. *Environmental Geotechnics*

Haines, S., Hart, P., Collett, T., Shedd, W., Frye, M, Weimer, P., Boswell, R., 2017. High-resolution seismic characterization of the gas and gas hydrate system at Green Canyon 955, Gulf of Mexico, USA. *J. Mar. Pet. Geol.*

Handwerger, A., Remple, A., Skarbek, R., 2017. Submarine landslides triggered by destabilization of high-saturation hydrate anomalies. *Geochemistry, Geophysics, Geosystems* **18** (7), 2429-2445.

Hillman, J., Cook, A., Daigle, H., Nole, M., Malinverno, A., Meazell, K., Flemings, P., 2017. Gas hydrate reservoirs and gas migration mechanisms in the Terrebonne basin, Gulf of Mexico. *J. Marine and Petroleum Geology* **86**, 1357-1373.

Hillman, J., Cook, A., Sawyer, D., Kucuk, H., Goldberg, D., 2017. The character and amplitude of bottom simulating reflections in marine seismic data. *Earth and Planetary Science Letter* **459**, 157-169.

Hong, W-L., Torres, M., Carroll, J., Cremiere, A., Panieri, G., Yao, H., Serov, P., 2017. Seepage from an arctic shallow marine gas hydrate reservoir is insensitive to momentary ocean warming. *Nature Communications* **8**, 15745.

Johnson, H.P., Gomberg, J., Hautala, S., Salmi, M., 2017. Sediment gravity flows triggered by remotely generated earthquake waves, J. Geophys. Res. Solid Earth, 122, 4584-4600.

Kim, B., Akkutlu, I., 2017. A new laboratory setup for phase equilibriua studies of methane hydrate in porous media. *Adv. In Laboratory Testing and Modeling of Soils and Shales*, Springer, 223-230.

Leonte, M., Kessler, J., Kellerman, M., Arrington, E., Valentine, D., Sylva, S., 2017. Rapid rates of aerobic methane oxidation at the feather edge of gas hydrate stability in the waters of Hudson Canyon, US Atlantic Margin. *Geochimica et Cosmochimica Acta*, **204**, 375-387.

Lin, J-S., Seol, Y., Choi, J-H., 2017. Geomechanical modeling of hydrate-bearing sediments during dissociation under shear. *Numerical and Analytical Methods in Geomechanics* **41** (14), 1523-1538.

Lorenson, T., Collett, T., 2017. National Gas Hydrate Program Expedition 01 offshore India; gas hydrate systems as revealed by hydrocarbon geochemistry. *J. Mar. Pet. Geol.,*

Majumdar, U., Cook, A., Scharenberg, M., 2017. Semi-quantitative gas hydrate assessment from petroleum industry well logs in the northern Gulf of Mexico. *J. Marine and Petroleum Geology* **85**, 233-241.

Mau, S., Romer, M., Torres, M., Bussman, I., Pape, T., Damm, E., Geprags, P., Wintersteller, P., Hsu, C-W., Loher, M., Bohrmann, G., 2017. Widespread methane seepage along the continental margin off Svalbard – from Bjornoya to Kongsfjorden, *Scientific Reports* **7**, 42997.

Nole, M., Daigle, H., Cook, A., Hillman, J., Malinverno, A., 2017. Linking basin-scale and pore-scale gas hydrate distribution patterns in diffusion-dominated marine hydrate systems. *Geochemistry, Geophysics, Geosystems* **18** (2), 653-675.

Panieri, G., Bunz, S., Fornari, D., Escartin, J., Serov, P., Jansson, P., Torres, M., Johnson, J., Hong, W-L., Sauer, S., Garcia, R., Gracias, N., An integrated view of the methane system in the pockmarks at Vestnesa Ridge, 79°N, *Marine Geology* **390** (1), 282-300.

Phrampus, B., Harris, R., Trehu, A., 2017. Heat flow bounds over the Cascadia margin derived from bottom simulating reflectors and implications for thermal models of subduction. *Geochemistry, Geophysics, Geosystems* (9), 3309-3326.

Pohl, M., Prasad, M., Batzle, M., 2017. Ultrasonic attenuation of Pure THF-Hydrate. *Geophysical Prospecting*

Pohlman, J., Greinert, J. Ruppel, C., Silyakova, A., Vielstadte, L., Casso, M., Mienert, J., Bunz, S., 2017. Enhanced CO_2 uptake at a shallow Arctic Ocean seep field overwhelms the positive warming potential of emitted methane. *PNAS* **114** (21), 5355-5360.

Ruppel, C., Kessler, J., 2017. The interaction of climate change and methane hydrates. *Reviews of Geophysics* **55** doi:10.1002/2016RG000534.

Reagan, M., Moridis, G., Seim, S., 2017. Fast parametric relationships for the large-scale reservoir simulation of mixed CH4-CO2 gas systems. *Computers & Geosciences* **103**, 191-203.

Salmi, M. S., Johnson, H.P., Harris, R., 2017. Thermal environment of the southern Washington region of the Cascadia Subduction Zone, *J. Geophys. Res. Solid Earth*, 122, 5852-5870.

Sanchez, M., Gai, X., Santamarina, C., 2017. A constitutive mechanical model for gas hydrate bearing sediments incorporating inelastic mechanism. *Computers and Geotechnics* **84**, 28-46.

Schindler, M., Batzle, M., Prasad, M., 2017. Micro X-Ray computed tomography imaging and ultrasonic velocity measurements in tetrahydrofuran-hydrate-bearing sediments. *Geophysical Prospecting* **65** (4), 1025-1036

Sherman, D., Kannberg, P., Constable, S., 2017. Surface-towed electromagnetic system for mapping subsea Arctic permafrost. *Earth and Planetary Science Letters* **460**, 97-104.

Sparrow, K., Kessler, J., 2017. Efficient collection and preparation of methane from low concentration waters for natural abundance of radiocarbon analysis. *Limnology and Oceanography Methods*, **15** (7), 601-617.

Wang, J., Wu, S., Geng, J., Jaiswal, P., 2017. Acoustic wave attenuation in the gas hydrate bearing sediments of well GC955H, Gulf of Mexico. *Marine Geophysical Research*, 1-14.

Weitermeyer, K., Constable, S., Shelander, D., Haines, S., 2017. Mapping the resistivity structure of Walker Ridge 313 in the Gulf of Mexico using the marine CSEM method. *Mar. Pet. Geol.* **88**, 1013-1031.

You, K., Flemings, P., 2017. Methane hydrate formation in thick sand reservoirs: 1. Short-range methane diffusion. *J. Mar. Pet. Geol.* **89**, 428-442.

Appendix C: Papers presented at the 9th International Conference on Gas Hydrates

The International Conference on Gas Hydrates (ICGH) is the world's only international research conference dedicated to gas hydrate science. The meeting is held once every three years. In 2017, it was held in the U.S. for the first time since 1999. The following are papers presented at the conference related to work funded by DOE's gas hydrate program.

Boswell, R., et al., The increasingly complex challenge of gas hydrate reservoir simulation. *(NETL)*

Cook, A., et al., Phase reversals in sand-rich gas hydrate systems. *(Ohio State U.)*

Dafov, L., et al., Basin and petroleum systems modeling of gas hydrate deposits in the Walker Ridge area, northern Gulf of Mexico. *(Stanford U.)*

Dai, S., et al., What has been learned from pressure cores. *(Georgia Tech)*

Daigle, H., et al., Methane transport and accumulation in coarse-grained reservoirs in the Terrebonne basin, northern Gulf of Mexico. *(U. Texas-Austin)*

Flemings, P., et al., GOM2: prospecting, drilling, and sampling coarse-grained hydrate reservoirs in the deepwater Gulf of Mexico. *(U. Texas-Austin)*

Graw, M., et al., Microbial communities in the methane seep sediments along the US Atlantic margin. *(Oregon State U.)*

Haines, S., et al., High-resolution seismic imaging of depositional characteristics at gas hydrate research sites in the Gulf of Mexico. *(USGS)*

Jang, J., et al., Pore-fluid sensitivity of clays and its impacts on gas production from hydrate-bearing sediments. *(Louisiana State U.)*

Jun, I., et al., Effect of hydrate on rising hydrocarbon bubbles released from natural gas seeps in the deep ocean *(Texas A&M U.)*

Kneafsey, T., et al., Behavior of methane hydrate in layered media- experimental and numerical investigation. *(LBNL)*

Lewis, K., et al., Brookian sequence well log correlation and the occurrence of gas hydrates north-central North Slope of Alaska. *(USGS)*

Leung, R., et al., Investigation of fracture generation due to capillary pressure effects in a three-phase hydrate stability zone. *(U. Texas-Austin)*

Lin, J-S., et al., Geomechanical analysis of initial stage of gas production from interbedded hydrate-bearing sediment. *(U. Pittsburgh/NETL)*

Malinverno, A., et al., Modeling discreet intervals of methane hydrate-filled veins in fine-grained continental margin settings. *(Columbia U.)*

Majumdar, U., et al., Gas hydrate volume and distribution in the northern Gulf of Mexico. *(Ohio State U.)*

McConnell, D., et al., Gas hydrate characterization from a 3D seismic dataset in the deepwater eastern Gulf of Mexico. *(Fugro)*

McConnell, D., et al., Planning and execution of marine methane hydrate pressure coring programs. *(Fugro)*

Moridis, G., et al., Long-term system behavior following cessation of gas production from hydrate deposits. *(LBNL)*

Myshakin, E., et al., Numerical studies of depressurization-induced gas production from an interbedded marine turbidite gas hydrate reservoir model. *(NETL)*

Nole, M., et al., The impact of heterogeneous lithology on gas hydrate accumulations in marine sediments. *(U. Texas-Austin)*

Phrampus, B., et al., Along-strike variation in gas hydrate formation/re-equilibration in response to tectonic/oceanographic forcing: Cascadia. *(Oregon State U.)*

Quieruga, A., et al., the T+H+M code for the analysis of coupled processes during hydrate dissociation. *(LBNL)*

Sawyer, D., et al., Hydrate-bearing submarine landslides in the Orca Basin, Walker Ridge, Gulf of Mexico continental slope. *(Ohio State U.)*

Solomon, E., et al., Chronic downward flow of seawater in bacterial mats at hydrate ridge. *(U. Washington)*

Teymouri, M., et al., Analysis of key factors affecting gas production from hydrate-bearing sediments. *(Texas A&M University)*

Uchida, S., et al., Numerical simulations of sand production in interbedded hydrate-bearing sediments during depressurization. *(Rensellear Polytechnic Inst/NETL)*

Vanderbeek, B., et al., On the importance of advective versus diffusive transport in controlling the distribution of methane hydrate in marine sediments. *(U. Oregon)*

Waite, W., et al., Physical properties of sediment from the Krishna-Godovari basin during Indias NGHP-02 expedition. *(USGS)*

Wei, L., et al., Methane migration and gas hydrate occurrence in a 2.5 m sand in the Terrebonne basin, Gulf of Mexico. *(Ohio State U.)*

Whorley, T., et al., Investigating the response of methane hydrate to bottom water warming along the Cascadia margin. *(U. Washington)*

You, K., et al., Methane hydrate formation in thick sand reservoirs: long-range gas transport of short-range methane diffusion? *(U. Texas-Austin)*

Zyrianova, M., et al., Characterization of the structural-stratigraphic and reservoir controls on gas hydrate in the Eileen Trend. *(USGS)*