The Methane Hydrate Advisory Committee

Advisory Committee to the Secretary of Energy

December 10, 2020

The Honorable Dan Brouillette
Secretary of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585

Dear Mr. Secretary

Enclosed is the Methane Hydrate Science Report, which summarizes critical remaining fundamental science questions that need be addressed to accurately quantify the volume of technically and economically recoverable methane hydrate resource within the United States and internationally. The state-of-the-art in methane hydrates and research recommendations in this report are complementary and go beyond the Long-Range Methane Hydrates Roadmap for 2020-2035. The Methane Hydrate Advisory Committee's (MHAC) key findings and recommendations are the following:

- *Methane hydrates are a massive transitional energy source.*
- *Link methane hydrates to other energy resources.*
- *Assess the environmental impacts of methane hydrate production.*
- *Improve global estimates of methane hydrates.*
- *Advance methane hydrate production testing.*
- *Maintain U.S. leadership in methane hydrates.*

Each of these recommendations are detailed in the executive summary and report and each recommendation is vital to maintaining the U.S.' Global Leadership in methane hydrates. To date, the long-term DOE Methane Hydrate Research Program has significantly advanced the world's understanding of the methane hydrate resource; the MHAC believes it is important to acknowledge the program's successes and substantial contributions and also to provide some key long-term strategic scientific recommendations for the program.

The MHAC would appreciate your willingness to meet with representatives of our committee so that we can convey the key findings and recommendations presented in the Methane Hydrate Scientific Report, which are critical to the long-term production reliability of the massive gas hydrate resources, commercialization of gas hydrates, and important to enhancing long-term national energy security.

Yours truly,

Carolyn A. Koh (Chair) Miriam Kastner (Vice-Chair) Mark Myers (Vice-Chair)

On behalf of the Methane Hydrate Advisory Committee

<u>MHAC Science Report on Methane Hydrates</u>

Reviewed & Approved by the Methane Hydrate Advisory Committee

10th December 2020

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Executive Summary & Introduction

This Methane Hydrate Advisory Committee (MHAC) scientific report to the Secretary of the Department of Energy (DOE) summarizes critical remaining fundamental science and engineering questions that need to be addressed in order to accurately quantify the volume of technically and economically recoverable methane hydrate resource within the United States and internationally. Methane hydrate is an enormous resource of clean natural gas occurring within polar regions and throughout the global oceans, including the U.S. continental margin marine environments. Methane hydrates are formed when water and methane combine at high pressure and low temperature; such conditions are encountered in the polar permafrost, in marine sediments, and on some planetary bodies. The scientific recommendations within this report are vital to maintaining the U.S. global leadership in methane hydrates. To date, the long-term U.S. DOE Methane Hydrate Research Program has significantly advanced global understanding of the methane hydrate resource and it's production potential. The program has also substantially contributed to an improved understanding in other important areas including the role of methane hydrates in global climate change and as a geologic drilling and production hazard. The MHAC believes it is important to acknowledge the program's successes and substantial contributions, and also to provide some key strategic scientific recommendations for the program.

The state-of-the-art in methane hydrate research recommendations in this report are complementary and go beyond the previous scope of the MHAC roadmap [1]. This report is focused primarily on the U.S. DOE flagship field programs in the Alaska North Slope (ANS) and Gulf of Mexico (GoM), including their mid-to-long range research programs. For this report, the MHAC interviewed key stakeholders and academics in methane hydrate research and related communities, ranging from experts in energy economics, methane on Earth and in planetary systems, petroleum systems, and in methane hydrate and conventional production. Recommendations in this report build upon previous MHAC evaluations and external reports over the past decade. While significant advances on key issues have been attained, there are still important uncertainties about the occurrence and distribution of methane hydrate systems and how to achieve commercial production of the resource.

The following are the MHAC's key findings and strategic recommendations for maintaining U.S. leadership:

(I) Methane hydrates are likely to be a massive substantial transitional clean-energy source. Methane hydrates are a significant natural gas resource for the nation and globally, which could be critical to providing long-term and transitional clean-energy fuel for many decades. Sustainable and economic production of methane hydrate reservoirs must be demonstrated, and continued DOE investment is required to continue to advance our understanding of this vast resource and to maintain the U.S. global leadership in methane hydrate production. Better national and global estimates of methane hydrate resources, including in-place, technically recoverable, and ultimately economically viable reserves are needed.

(II) Advance methane hydrates production testing. The Alaska North Slope (ANS) onshore long-term methane hydrate production test (12-24 months) will be the first in the world to address the critical questions related to commercial methane hydrate production and is an international priority. The current Gulf of Mexico (GoM) methane hydrate field program is focused on reservoir characterization, which is expected to lead to U.S. offshore production testing in the future. Therefore, opportunities for improving the design and execution of these onshore and offshore activities should be a continuing focus for the program.

(III) Assess the site-specific impacts of methane hydrate production. Impacts of gas production from methane hydrate accumulations and geomechanical stability of the reservoir during production need further evaluation. Production operations for methane hydrates are expected to be similar in practice to production operations with known conventional gas reservoirs, but the potential impact of their production at each site requires site-specific geologic modeling.

(IV) Maintain U.S. participation in International Field Testing Programs. Continued support for U.S. scientists to participate in international marine methane hydrate research, testing, and future production programs is crucial to maintaining U.S. leadership. These efforts will provide information and insights that can be applied to future U.S. marine methane hydrate production (*e.g.,* in the GoM).

(V) Fundamental research linking methane hydrates to other energy resources. Accurate resource assessment of methane hydrates could reveal other large microbial gas accumulations and their relationships with methane hydrates. This requires the understanding of the processes and rates of microbial methane production, consumption, and loss. Also, understanding these microbial processes will be critical to exploration and assessment of the potentially massive U.S. and international resources of conventional microbial methane and associated methane hydrates. In order to assess these resources, the development of techniques capable of differentiating between primary microbial versus altered thermogenic methane, as well as the possible contribution of abiotic (non-biogenic) methane are essential. Interagency collaboration is recommended to investigate the significance of abiotic methane.

(VI) Improve global estimates of methane hydrates for potential climate change impacts. Current estimates indicate that the impact on global climate of carbon dioxide from methane oxidation to the ocean and atmosphere may be small. However, global methane hydrate distributions and volumes remain uncertain. Improving global estimates of methane hydrate distribution would increase confidence in the understanding of potential climate impacts of rapid methane hydrates dissociation.

(VII) Ensure U.S. Leadership & Program Continuity. DOE funding for the program remains absolutely critical to the success of methane hydrates research. Industry is unlikely to fund basic research in methane hydrate systems until feasibility practicality has been demonstrated, and the expected cost of production falls within regional economic thresholds. To maintain the leadership and continuity of the U.S. methane hydrate program, support of early career scientists is essential.

MHAC Findings, Recommendations & Key Questions

(I) Methane Hydrates as a Future Transitional Clean Energy Supply

Natural gas is the fastest growing energy source in absolute terms and will remain critical as the worldwide energy supply for the future. As global energy sources evolve toward cleaner – and, therefore, more environmentally desirable – sources of energy, natural gas will play a critical role as a transitional clean energy source for decades to come. Methane hydrates have the potential to provide significant volumes of natural gas, particularly to regions or countries that lack adequate resources of conventional or shale gas. From an economic standpoint, gas production from methane hydrates would help augment the long-term supply of natural gas as currently produced resources are depleted or demand grows. From a global security standpoint, methane hydrates have the ability to impact potential energy supply shortages for major growing economies and therefore mitigate the competition and conflict that can often be generated by such shortages.

DOE funding over the past several decades has enabled the U.S. to maintain its leadership position in methane hydrate research. The DOE investment has been critical to advancing the global understanding of this huge potential resource and served as a catalyst for increased international investment and research partnerships. Continued DOE investment in methane hydrate research is essential for this U.S. leadership position to be maintained and key resource questions to be answered. The ability to produce methane hydrates sustainably and economically has yet to be demonstrated. Additionally, high levels of uncertainty remain around the potential volume of economically recoverable resources that might be present within the U.S. Arctic and offshore basins, as well as globally.

Natural gas is an extensively abundant and versatile fuel with a third of the carbon emissions of oil or coal. This makes natural gas a critical transition fuel for both global energy security and climate change mitigation. Natural gas is rapidly displacing coal and oil for power generation and is beginning to be used more as a transportation fuel for vehicles, including locomotives and ships. Although methane hydrates are relatively abundant, they are unlikely to compete with conventional or other unconventional gas accumulations in the short to medium term (*i.e.*, the next 10-20 years), except potentially in regions or countries where other energy resources are not abundant (*e.g.,* Japan and India). In the U.S., except for Alaska, shale gas production will need to significantly decline before methane hydrate production will likely occur. Nevertheless, it will be prudent to start seriously addressing the issue of methane hydrate-originating gas production until such a time. Thus, continued and planned efforts, including an ANS production test and an ongoing GoM assessment, are essential to establishing the potential and economic feasibility of methane hydrate production. These studies would provide estimates of possible recovery costs, an understanding of which geographic areas with methane hydrate accumulations would be most likely to be exploited, and a better grasp of the potential impact on local/regional/global energy supplies.

Why does this need to be a government (DOE) funded program?
Private industry is unlikely to fund basic research in methane hydrate recovery until sustained methane hydrate recovery has been demonstrated to be technically viable at commercial rates of production. As such, it is in the public interest to conduct research into cost-effective ways to safely develop methane hydrates as an expansive potential future energy source until this can be demonstrated and viable public-private partnerships can be formed. The current status of methane hydrate recovery is analogous to the successful approach used for the research that led to development of the resource assessment of and the technologies to produce coalbed methane, shale gas and tight gas, which now account for the majority of the U.S. gas production.

(II) Field Experimentation

Alaska North Slope (ANS)
Put simply, the lack of a long-term methane hydrate production experiment anywhere in the world, leaves key questions unanswered about production over the many years during which a commercial methane hydrate well would be expected to flow. Brief tests, onshore in Alaska, Canada, and offshore Japan and China, provided encouraging results, but these tests also demonstrated the need for long-term reservoir response experiments. Reservoir response modeling suggests that, in marked contrast with quickly depleting resources such as those associated with shale gas, gas production from methane hydrates grows during the first several years of exploitation before production begins to decline as the resource is exhausted. To verify these reservoir production prediction models, which is crucial for economic analyses, a field experiment lasting one to three years or more is required.

The North Slope long-term test infrastructure is envisioned to include two monitoring and two production test wells located on an established gravel pad. The first monitoring well was successfully installed in 2018 and confirmed the presence of two significant high-quality sandstone methane hydrate reservoirs. The test is being designed to:

- Demonstrate sustained, safe, and stable production, including sand control, reservoir and well geomechanical integrity, as well as safe well shut-in and startup.
- Gather sufficient high-quality downhole, production, and seismic data to enable high confidence in (a) geophysical-based estimates of the resource, (b) thermal behavior of methane hydrate-bearing media, (c) geomechanical response to hydrate dissociation, (d) multiphase flow behavior of methane hydrate deposits under production, and (e) reservoir simulations of commercial-scale production.
- Provide data needed to build better models for estimation of technical and economic resources for methane hydrates in sand reservoirs.

The first long-term test will provide key insights about how to sustainably produce methane hydrates and is likely to lead to many additional questions. Assuming the production test produces favorable results, additional tests may be carried out at the same production test site in Alaska. These additional tests could include a high-rate production test at the end of the first test-sequence, and additional production tests in untested methane hydrate zones penetrated by wells at the test location. Such tests may include additional well-constrained production to further explore the long-time production behavior of methane hydrates (including their geomechanical response) and include additional experience gathering on well design and well start-up and shut-in production operations. This work would strongly leverage the previous investments, experience, and infrastructure of the site. Ultimately, an industry-managed multi-year commerciality pilot is envisioned in the 2029-2034 timeframe [1] to directly demonstrate commerciality of methane hydrate gas production. It is recommended that, in the long-term, DOE work towards transitioning this test site from government to an industry-funded production pilot.

<u>Gulf of Mexico (GoM)</u>

Since marine methane hydrates are estimated to be as much as 99% of the total global methane hydrate resource, future methane hydrates production from the GoM should be investigated. Due to the high cost of offshore drilling and testing, the current DOE-supported GoM program is focused on identifying, drilling, coring, and characterization of coarse-grained methane hydrate reservoirs in preparation for production testing. DOE funding is required to pave the way to private-public partnerships for advancing methane hydrates production. Research site assessment in the GoM, however, must precede future potential industry involvement. Otherwise, the only alternative for U.S. involvement in marine production of methane hydrates is participation in international tests (*e.g.*, India, South Korea, Japan).

(III) Environmental Impacts of Methane Hydrate Dissociation

There are two general areas that can be associated with a possible environmental impact of methane hydrate dissociation: **(I)** gas production of methane hydrate deposits as part of hydrocarbon recovery operations, and **(II)** dissociation of methane hydrate accumulations in response to natural factors unrelated to production.

<u>Environmental Impact of Gas Production from Methane Hydrate Deposits (I)</u>

Understanding the environmental impacts of methane hydrate production is an area of scientific research that must be better understood and quantified prior to large-scale commercial production. There are specific environmental questions that remain because methane hydrate reservoirs (specifically the gas storage and transport mechanisms) are remarkedly different from conventional gas reservoirs. Current evidence suggests, however, that a production well for methane hydrates will not be significantly different from that of a conventional gas production well. With this understanding, it is still reasonable to expect that gas losses from wells installed in methane hydrate deposits would be at a similar level as those encountered in conventional gas reservoirs, recasting the problem into an issue of competence and effectiveness of well design and construction. Additionally, there is no possibility of uncontrolled methane hydrate dissociation (and related gas releases) after cessation of production because research on the subject has shown dissociation to be a self-limiting reaction, that is followed by methane hydrate reformation as the pressure in the methane hydrate reservoir rises rapidly in the vicinity of the production well. Issues related to geomechanical stability during production will be discussed in the ANS long-term production test section of this report.

With the conclusion that gas production from methane hydrates does not pose any additional environmental detriment, is the expectation of the existence of a competent boundary to flow overlying the methane hydrate deposit. This means that a very low permeability layer that limits upward flow/migration of the released gas (a gas cap) is universally present in conventional gas reservoirs and is the reason for the existence of such reservoirs. In the case of methane hydrates, there is a possibility that the gas cap is the methane hydrate-bearing porous medium itself, as the presence of methane hydrates at high saturations could reduce the intrinsic permeability of porous media to extremely low levels. Such a scenario would be expected to be associated mainly with marine methane hydrate deposits.

Depressurization-based production under these conditions is associated with a significant problem. The problem is that methane hydrate dissociation occurs both at the base and at the top of the methane hydrate-bearing layer. The top boundary is caused by the reversal in the geothermal gradient caused by the endothermic reaction of methane hydrate dissociation, with the potential of environmental health and safety hazards, if there is no low-permeability layer impeding the rise of the escaping gas through the subsurface profile. Subsequently, the problem that needs to be addressed is the availability of a reliable geologic model and the high-confidence establishment of the existence of a competent geologic gas cap (*i.e.,* non-hydrate associated), prior to the installation of the well. There is currently insufficient information on the frequency of occurrence and reliability of methane hydrate-based gas caps.

Environmental Impact of Naturally Dissociating Methane Hydrates (II)

Understanding natural methane hydrate formation and dissociation provides valuable insights into the behavior of methane hydrates in geological reservoirs. Naturally dissociating methane hydrate occurs at or near the ocean floor, near the upper limit of the methane hydrate stability zone. Here, methane hydrate may be subject to dissociation in response to warming of the ocean bottom waters.

There is sufficient evidence to indicate that the vast majority of methane (CH_4) released from marine methane hydrate deposits cannot reach the stratosphere because of rapid oxidation to carbon dioxide (CO_2) both in the water column and if released to the atmosphere. This recasts the question of the impact of dissociation of methane hydrates from one concerning the net methane flux to one of the net contributions of the dissociating methane hydrates to oceanic and atmospheric CO_2. Current estimates have been based on assessments of the known or expected methane hydrate occurrences in the northern hemisphere, and they indicate that the impact on the CO_2 released to the ocean and atmosphere would be small. Hence, the associated potential CH_4 releases are expected to represent a minor addition to the global CO_2 load. This estimate/realization holds true even for Arctic regions, where the largest oceanic temperature increases are expected to take place.

However, there is a caveat to this evidence; the related studies have been based on limited quantitative data on the abundance and distribution of methane hydrate occurrences in marine systems. Knowledge on the global marine methane hydrate inventory (which represents 99% of the total, the remaining 1% being permafrost-associated methane hydrates) is highly limited, and most relevant information is based on data and studies in the northern hemisphere. Information on methane hydrate occurrences and abundance in the southern hemisphere, especially in the vicinity of Antarctica, is scant. Therefore, investigating the methane hydrate inventory and distribution in the southern hemisphere, together with emphasis on the Arctic and Antarctica, are of great importance for understanding both, the geologic controls on the distribution of the methane hydrates and on global resource assessment. For this reason, investing in research there is strongly recommended to the U.S. DOE. Such an effort should respect international treaties and involve collaboration/coordination with other research-supporting organizations (*e.g.*, USGS, NOAA, NSF).

It is important not only to look at the global effects of methane hydrate dissociation, but also in areas where localized effects may be more pronounced. Of particular importance to research appears to be the issue of the impact of natural and/or methane hydrate-originating CH_4 releases in closed to semi-closed seas, (*e.g.,* the Ohkotsk and possibly the Mediterranean seas). The rise and fall of the relative sea level as controlled by local and regional tectonics, glaciation changes and the opening/closure of basins all have a significant impact on methane hydrate stability through time in many isolated marine basins. In addition, the warming of the ocean will impact the oxidation rate of seep CH_4 in the water column, thus oxygen consumption, and gas solubilities, which may lead to the creation of anoxic conditions that will impact bottom-dwelling and water-column biota.

(IV) International Programs & U.S. Leadership

International Activities To-Date

Current and future involvements in international marine methane hydrates programs both inform and advance the U.S. DOE's methane hydrate field programs in the GoM and ANS. International methane hydrate programs focused on gas production from marine methane hydrate reservoirs have been strongly supported by individual countries, notably in Japan, China, India, and South Korea. Discovery of reservoirs containing high methane hydrate concentrations in sediments with significant intrinsic permeability has helped drive the active pursuit and investment in the research and development of methane hydrate production technologies that are largely akin to conventional production methods.

These international programs followed the initial demonstrations of gas production by depressurization from a methane hydrate reservoir in the Japanese-Canadian Mallik program and the U.S.-led Mount Elbert project, as well as the use of a novel CO_2/N_2 injection production method, followed by 19 days of production via depressurization in the ANS led by the U.S. DOE in 2012. Japan conducted the first marine depressurization-induced production test in the eastern Nankai Trough in 2013 that was terminated after 6-days of production, largely because of problems caused by excessive sand production. Returning to the Nankai Trough in 2017, sand control caused cessation of production of one well after 12 days, while production in the second well continued with effective sand control for 24 days. China followed in 2017 with a 60-day production test in the Shenhu region of the South China Sea, using depressurization and mechanical stimulation, producing 309,000 m^3 of gas, including free gas [2].

Key Challenges to be Addressed in International Field Tests

The above onshore and marine production tests have helped reveal key challenges that need to be addressed for technically and economically viable methane hydrate production, including operational hazards of gas flow and borehole stability while drilling through, or during production from, methane hydrates. Such mechanical stability issues may arise because of methane hydrate destabilization. To develop the methane hydrate production technologies required to circumvent/mitigate operational hazards, long-term onshore and marine production tests will be critical. Onshore methane hydrate production tests will be U.S.-led in the ANS, while new marine production tests are being planned through significant investments in international methane hydrate programs (*e.g.*, the Japanese, Chinese, and Indian national methane hydrate programs). Therefore, it is critical that the U.S. DOE continue to support/facilitate the participation and technical leadership that U.S. scientists are uniquely qualified to provide to international marine methane hydrate programs through current agreements. Such participation will be invaluable to the future U.S. marine production in the GoM.

Maintaining Global U.S. Leadership

The planned long-term ANS production test led by the U.S. DOE is a global priority, and largely in partnership with U.S. scientists, will advance the strategies for future marine production test programs around the world. It is expected that in Japan "*further characterization of the well-established Nankai Trough testing site will be planned, and/or to possibly explore for additional candidate test sites";* in India "*an initial geoscience drilling leg) is expected to confirm the geologic conditions at two proposed test sites";* in China "*additional large scale drilling and testing projects in the South China Sea (SCS)" are expected in the near future, likely including horizonal and/or multiple cross-well testing";* in South Korea "*a new cooperative gas hydrate drilling (possible testing) program is being considered, with U.S. technical participation being sought, for the Ulleung Basin off the eastern margin of South Korea."* [3]

(V) Fundamental Research

Methane Hydrate Systems

Constraining the amount, distribution, and economically viable accumulations of methane in methane hydrate requires a fundamental understanding of the methane hydrate system. In the marine environment, deep-water petroleum systems are globally well studied, described, explored, and have successfully produced hydrocarbons at a commercial-scale. Marine gas hydrate systems, however, are less understood and differ from petroleum systems in that they represent predominantly methane carbon reservoirs that can be ephemeral to long-lived. The methane in gas hydrate systems can (1) form from in-situ microbial, deeper thermogenic, altered thermogenic, or abiotic methanogenesis processes, and many of the methane hydrate systems may turn out to be of these mixed sources, (2) dissolve, dissociate, and remain stable on short timescales (100 to 10,000 years) to long timescales (10,000 to millions of years), (3) be lost through anaerobic oxidation at the seafloor, or simply via dissolution enabled by advective flow through the methane hydrate stability zone, and (4) be recycled at the base of the methane hydrate stability zone due to continuous burial.

In some settings, methane hydrate systems overlie deeper petroleum systems (*e.g.*, the GoM), while in others, they exist as the sole hydrocarbon reservoir (*e.g.,* the Cascadia margin). The ultimate formation, distribution, and preservation of methane hydrate in marine sediments through time is a function of all of these variables. Studies that utilize in-situ sampling to establish the reservoir characteristics, constrain processes and the timescales at which they operate, and validate models of methane hydrate systems, should be a significant part of the DOE-funded research portfolio.

Constraining Gas Sources, Transformations, and Losses

While it is known that marine methane hydrates are dominated by microbial methane, the source of the methane and the associated accumulation processes remain poorly constrained. *There is a need for the development of techniques and approaches that can differentiate primary microbial vs. altered thermogenic methane* and that can assess the possible contribution of abiotic gases from magmatic or serpentinization processes to methane hydrate systems. Continued research efforts to understand methane hydrate systems may also reveal the origin of other large microbial gas accumulations and any relationship they might have with methane hydrate systems. Mixing of methane sources may, however, mask the true origin of the large microbial methane accumulations. Fundamentally, exploration for methane hydrates requires a systems-level understanding of the gas sources.

At present, there are no good constraints on the methane budget and its residence times in many parts of methane hydrate systems. Therefore, research that addresses the mechanisms and monitors rates of methane production, methane consumption via the anaerobic oxidation of methane (AOM) or other microbial carbon transformations, and methane losses from the seafloor (diffusively or focused at methane seeps) is crucial. Critical remaining research aspects include measurements of the flux of methane to seafloor bottom waters and its fate in the marine carbon cycle.

U.S. Leadership in Methane Hydrate Research on Earth and Beyond

The U.S. is a global leader in both the science and production technology for methane hydrate systems and helps guide the development of the international methane hydrate research effort. Just to maintain this leadership position, the rather low funding for methane hydrate research in the U.S. (relative to various international efforts) will have to be substantially increased. With continued (and hopefully enhanced) U.S. DOE funding and leadership, as well as with interagency collaboration involving the U.S. DOE, the U.S. Dept. of the Interior (e.g., USGS, BOEM), NSF, NOAA and NASA, the U.S. research contributions and leadership would be further advanced. The NASA research efforts have revealed the existence of extraterrestrial methane hydrate systems on several planetary bodies, including Mars, where they may represent potential fuel sources for interplanetary travel. Specific interagency collaboration between the U.S. DOE and NASA could advance our understanding of methane hydrate systems on Earth and throughout the solar system. Investigating the role of abiotic methane production on Earth and other planetary systems could have profound implications for the origin of life in our solar system.

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https://www.aapg.org/about/aapg/overview/committees/emd/articleid/26345/committee-emd-gas-hydrates

APPENDIX 1 - Task Force Members, Study Participants, and Process

Task Force Members:

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Study Process:

The MHAC science report planning group held ~ 16 meetings (between June to October 2020) with the above study participants/guest speakers and within the committee to gather new knowledge and insights into the key gas hydrate and related areas, discussing the critical questions required to advance U.S. science leadership in:

(I) Hydrates as a Future Transitional Energy Supply.

(II) Field Experimentation.

(III) Environmental Impact due to Hydrate Dissociation.

(IV) International Programs & Leadership.

(V) Fundamental Research.

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