Appendix to Methane Hydrates Advisory Committee (MHAC) Letter of May 21, 2014

1) Estimate of volume of technically recoverable hydrocarbons in hydrates:

We estimate the volume of technically recoverable hydrocarbons from methane hydrate to be ~13,500 trillion cubic feet (TCF) of natural gas. The U.S. consumed approximately 25 TCF of natural gas in 2012 (http://www.eia.gov/tools/faqs/faq.cfm?id=33&t=6). Our estimate of the recoverable volume of methane from methane hydrate is a crude one. However, it underscores the importance of testing this important resource.

The USGS estimated the volume of methane hydrates in-place in sands in the onshore Arctic (Collett et al., 2008). The Bureau of Ocean Energy Management (BOEM) estimated the volume of hydrate in the Gulf of Mexico offshore (Frye, 2008), and the Eastern U.S. offshore (Bureau of Ocean Energy Management, 2012). There are a range of recovery factors for sand reservoirs: Fekete (2010)proposes a range from ~65-75% in sands from the Alaskan North Slope; Kurihara (2009) suggests recovery factors from 35% to 96% in sand reservoirs in the Nankai trough, offshore Japan; and Fekete (2010) suggests recovery rates from 60 to 74% in offshore marine hydrate deposits in the Gulf of Mexico (Fekete Associates Inc., 2010). We use a single recovery factor of 60% in our calculation.

Location	In Place volume in sands(TCF)	Recover Factor (%)	Technically Recoverable Volume (TCF)
North Slope (on land)	not assessed		85
Gulf of Mexico offshore	6,711	60	4,027
Eastern U.S. offshore	15,785	60	9,471
Total			**13,583**

<u>Methane Hydrate Occurrence in the U.S. OCS</u>: The BOEM (Frye, 2008) detailed the methodology of a cell-based, probabilistic assessment of in-place gas hydrate resources in the Gulf of Mexico. The report indicated a mean estimate of 21,444 tcf gas in-place in hydrate form with one-third of that volume (6,711 tcf mean value) occurring as pore-filling gas hydrate in high-saturations in sand-dominated

reservoirs. In 2012, the BOEM (Bureau of Ocean Energy Management, 2012) released the initial findings for gas hydrate gas-in-place volumes throughout the US Lower-48 OCS, including mean estimates for the Atlantic OCS (*15,785* tcf).

Methane Hydrate Occurrence on the Alaska North Slope (ANS) onshore and nearshore only: The USGS estimates that the total risked technically recoverable undiscovered natural gas resources in gas hydrate on the North Slope range between 25.2 and 157.8 trillion cubic feet (TCF; 95-percent and 5-percent probabilities of greater than these amounts, respectively), with a mean estimate of 85.4 TCF (USGS AK Gas Hydrate Assessment Team et al., 2014).

Methane Hydrate Occurrence in the Nankai trough: In 2008, the Japanese MH-21 program released an estimate of 40 tcf gas in-place within a 5,000-sq. mile area of the Nankai trough off the southeastern coast of Japan (Fujii et al., 2008). Of that total, 20 tcf was assessed to occur within 10 high-concentration accumulations within fine-grained turbidite sand reservoirs. Fujii et al. (2008) reported that this area represents only 10% of the total area around Japan that is prospective for gas hydrates.

2) RECENT HYDRATE DRILLING AND PRODUCTION TESTS:

Expedition NGHP-01: Indian Ocean (2006): More than 20 sites in the Bay of Bengal, Andaman Islands, and Arabian Sea were drilled and more natural gas hydrate samples were collected than all previous expeditions combined (Collett et al., 2006; Collett et al., 2008) .

"Mt Elbert" Gas Hydrate Stratigraphic Test Well: Milne Point, Alaska (2007): The U.S. DOE, BP Alaska Exploration, Inc., the USGS, and other organizations performed scientific drilling and data collection at Milne Point Unit (MPU) on the Alaska North Slope (ANS). Analyses of log, core, and downhole pressure response data enabled interpretation of the nature, evolution, petrophysical properties (including in situ permeability in the presence of gas hydrate), and potential production behavior of typical Alaska North Slope gas hydrate reservoirs (see 24 papers compiled in (Boswell et al., 2011)).

Expedition GMGS-01 and GMGS-02: South China Sea (2007 and 2013): During GMGS-01, the Guangzhou Marine Geological Survey (GMGS) of China drilled, logged, cored, and pressure-cored at nine sites in the South China Sea (Zhang et al., 2008). High concentrations of gas hydrate (30% or more) were found at the base of the GHSZ in undeformed and fine-grained sediments. Only limited data are available from GMGS-02. The 102-day expedition evaluated 17 sites through a variety of logging-while-drilling, wireline logging, and coring operations, confirming the presence of a wide range of gas hydrate occurrences (GMGS, 2014).

Expedition UBGH-01 and 02: East Sea - Korea (2007 and 2010): The 2007 expedition encountered gas hydrate in three wells, with GH occurring in a variety of forms, including both as pore-fill and as thick sequences dominated by grain-displacing, gas-hydrate-filled fractures (Park, 2008). The 2010 expedition confirmed the wide-scale occurrence of gas-hydrate-bearing "chimney structures" in the East Sea, and also established several minor occurrences of gas hydrate in sand reservoirs, which are presently being further evaluated as potential sites for field production testing operations (Lee et al., 2011).

Mallik production well test program: Northwest Territories, Canada (2007 & 2008): The Japanese MH-21 program (Dallimore and Collett, 2005) conducted gas hydrate drilling and testing programs in the winters of 2007 and 2008. These programs confirmed the technical feasibility of GH production through depressurization (Dallimore et al., 2012). The test suggested that the reservoirs had the potential to exceed the productivity predictions of current numerical models through enhanced permeability related to production-related deformation and natural heterogeneities.

Gulf of Mexico Joint Industry Project Leg II (2009): The DOE-Chevron Gas Hydrates Joint Industry Project (the JIP) conducted logging-while-drilling at three sites in the deepwater Gulf of Mexico. Six of the seven wells drilled confirmed pre-drill predictions, with four discovering gas hydrates at saturations of 50% to 80% in multiple sand horizons (see 14 papers compiled in (Collett and Boswell, 2012)).

"Ignik Sikumi" Field Trial, Prudhoe Bay Unit, Alaska (2011/2012): In 2011, ConocoPhillips, in partnership with DOE, drilled, logged, and conducted wireline pressure tests throughout the gas hydrate sediments below the base of permafrost (Schoderbek et al., 2012). The data obtained in the logging program was used to guide planning for a field trial of gas hydrate reservoir response to gas injection. The program successfully injected a mixture of CO_2 and N_2 gas into a 30-foot thick sand with high gas hydrate saturation. Flowback was accomplished via reservoir depressurization in three phases: 1) at pressure draw-downs above that necessary to initiate dissociation of gas hydrate, in which CH_4, CO_2, and N_2 were recovered, 2) at pressures approximating gas hydrate dissociation conditions, in which CH_4 was recovered, and 3) at pressures sufficient to dissociate native hydrate, in which CH_4 was recovered over a period of 19 days at stable and gradually increasing rates.

MH-21 Nankai Trough Production Test (2012/2013): In 2012, the MH-21 program conducted drilling and coring programs in the Nankai Trough to establish the geologic conditions and to install monitoring wells and equipment, as well as the top hole for the world's first deepwater gas hydrate production test (Yamamoto et al., 2012). In March, 2013, the drill ship *Chikyu* completed the test well, and achieved six days of production at a reported average rate of 700,000 scf/d (JOGMEC, 2013). MH-21 announced plans to proceed with the offshore testing phase of its program, which will feature a longer-duration deepwater flow test, perhaps as early as CY2015.

3) Methane Hydrate Production Technologies

Three primary classes of production methods historically have been considered with respect to subsurface gas hydrates: thermal stimulation, depressurization, and chemical injection. Scientific field experiments conducted at the Mallik site in arctic Canada (1998 and 2002) and subsequent numerical modeling confirmed that thermal stimulation is likely to be ineffective at the commercial scale. However, short duration pressure response tests had indicated that gas hydrate reservoirs likely contain sufficient reservoir permeability and mobile fluids to enable depressurization. Progress toward such as test was achieved with the 2007 BPXA-DOE-USGS "Mt. Elbert" program, which confirmed reservoir geologic and engineering parameters as well as demonstrated the feasibility of staging a scientific field program within an area of ongoing oil and gas production. The following year (2008), a third Japanese-Canadian research program at the Mallik site achieved six days of sustained and stable production through reservoir depressurization. The data from this field program has recently been released to the broader scientific community (Dallimore et al., 2012), *and papers contained within*). In 2011 and 2012, field operations were conducted by ConocoPhillips, DOE, and JOGMEC at a test site within the Prudhoe Bay Unit, Alaska (Schoderbek et al., 2012). These data were provided to the scientific community in early 2013, and, in combination with the 2008 Mallik test data, are expected to enable for a range of scientific learnings that will inform the design of future field tests. In March 2013, following extensive pre-site characterization work and installation of numerous monitoring devices on the seafloor, in the water column, and in neighboring monitoring wells (Nagakubo et al., 2011), Japan's MH-21 program conducted the initial deepwater gas hydrate field production test. The tests achieved ~6 days of depressurization-induced flow from turbiditic sands at a total depth of ~1300 meters in ~1000 meters of water depth, with ~700,000 scf/d of gas production (4.2 mmcf) observed (JOGMEC, 2013).

Given the relative paucity of field test data and the limited duration of the tests completed to date, very little is conclusively known about the potential commerciality of production (Moridis et al., 2009). Recent simulations that incorporate full geologic complexity have reported promising maximum production rates (Gaddipati and Anderson, 2012). However, numerous technical challenges exist (Boswell, 2011; Hancock et al., 2010), including potential production hazards associated with the relatively shallow occurrence of producing horizons, and the lack of consolidation of both the reservoirs and the overburden, particularly in deepwater settings. Consideration of these geohazards are expected to focus initial gas hydrate exploration and production to the most geomechanically-stable settings, which include the more technically-viable, deeply buried, sand-rich, accumulations (Boswell and Collett, 2011).

4) Methane Hydrates and Operational Geohazards

Current "operational" gas hydrate-related geohazards relate primarily to oil and gas production activities and can be categorized as 1) shallow foundational issues related to the installation of infrastructure in areas of shallow sub-seafloor gas hydrates, 2) shallow drilling and well-installation hazards that are encountered by wells targeting deeper horizons ("*drilling through*" (see (McConnell et al., 2012) for a review), and 3) long-term hazards associated with producing warm hydrocarbons from deeper zones through shallow gas hydrate-bearing intervals ("*producing through*") (Stevens et al., 2008).

5) Methane Hydrates and Natural Geohazards

A primary naturally-occurring geohazard associated with gas hydrate is seafloor instability related to gas hydrate dissociation. Natural phenomena such as pressure decline due to sea-level drop or temperature rise due to changes in climate or oceanic conditions can create intervals of potential sediment weakness at the BGHS. The association of large-scale slide events and dissociation of gas hydrates has been investigated over the past decade through field investigations at the Storegga (offshore Norway: (Kvalstad et al., 2005)) and at Cape Fear (U.S. Atlantic Coast: (Hornbach et al., 2007)); however, to date, these studies have not confirmed a significant role for gas-hydrate dissociation. While the case for major past episodes of globally-synchronized gas-hydrate-related sea-floor failures remain poorly supported with available data, gas hydrate likely does play a role in certain local seafloor failures. Gas venting may also be a geohazard, and can occur in many marine settings - perhaps the most compelling evidence reported in the recent literature are the "pingo-like features" observed on the shallow

Beaufort Shelf, arctic Canada, that have been interpreted to reflect gas and sediment expulsion associated with ongoing destabilization of permafrost-associated gas hydrate related to post ice-age shelf inundation (Paull et al., 2007). Many chimney-type structures are found to have a central core of gas hydrate (Ryu et al., 2013) suggesting that gas hydrate formation may have a role in mediating the flow of gas through such features, although the processes are not well understood.

6) Methane Hydrate and Global Climate

The study of the linkages between gas hydrate, long-term global carbon cycling and short-term response to global climate change has escalated rapidly in recent years (Ruppel, 2011). Given the findings of (Sowers, 2006) and others, primary attention on the issue of gas hydrate linkages to past climate events has shifted away from Ice Age terminations (Kennett et al., 2003) to the Paleocene-Eocence thermal maximum (PETM). The PETM has been postulated to have been driven by massive carbon release from marine gas hydrates over geologically-short timeframes in response to ongoing global warming (Dickens, 2011); although alternative explanations exist (DeConto et al., 2012; Wright and Schaller, 2013). With respect to present conditions, observation of numerous methane vents in both arctic deepwater (Westbrook et al., 2009) and shallow shelf settings (Shakhova et al., 2010), as well as on lower-latitude continental shelves (Phrampus and Hornbach, 2012) have indicated that prior views of the contribution of the global oceans to methane flux may be underestimated and accelerating in response to ongoing climate warming. However, evidence linking those releases to gas hydrate or even to recent anthropogenic warming has been limited (Berndt et al., 2014). Numerical studies (*exs.* (Archer et al., 2009; Biastoch et al., 2011; Reagan and Moridis, 2008) depend greatly on a number of input parameters, many of which remain poorly understood. At present, these studies largely confirmed prevailing views (Kvenvolden, 1988) that low-latitude marine systems are likely too well buffered to respond to potential climate change scenarios in a substantive way in the near-term, but that high-latitude systems deserved further study. At present, there appears to be minimal risk of significant exacerbation of near-term climate change through gas hydrate dissociation (Ruppel, 2011), although this determination requires further confirmation.

7) References

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