The Methane Accelerator

A Whitepaper by the World Business Academy
(Santa Barbara, CA)

Released for publication on 75th Anniversary of D-Day

June 6, 2019

The Methane Accelerator

World Business Academy (Santa Barbara, CA)

Contents

The Methane Accelerator

World Business Academy (Santa Barbara, CA)

List of Figures

The Methane Accelerator

World Business Academy (Santa Barbara, CA)
June 6, 2019

ABSTRACT

A January 2019 report published in the journal Science reveals that ocean temperatures are warming 40% faster on average than was predicted just five years ago by the United Nations' Intergovernmental Panel on Climate Change (IPCC). This is one of many signs that climate change is accelerating, and already producing considerably graver impacts than has been forecasted by all of the leading scientific consensus bodies analyzing the issue. This consistent failure to accurately assess the severity of climate change impacts cannot be explained by traditional models that focus principally on carbon dioxide (CO_2) levels. Future work must account for all contributory factors to fully appreciate the urgency of requisite actions that far surpass those adopted in the Paris Climate Agreement in order to avoid otherwise catastrophic consequences.

The World Business Academy has for over a decade reviewed the same data as other leading climate researchers but has included in its climate change forecasts a factor the IPCC and most leading climate scientists have until recently discounted, or entirely failed to consider. This additional factor concerns the effects of methane (CH_4) being released from thawing permafrost, glaciers and marine hydrates due to atmospheric warming; and the released methane then independently functioning as a powerful accelerant of greater atmospheric heating, faster ice melt, more severe weather disturbances and ocean acidification.

This paper describes a snowball effect, wherein increased atmospheric warming causes the release of methane from vast worldwide deposits, which in turn produces greater warming that results in the release of even more methane. The World Business Academy refers to this Vicious Circle as the "***Methane Accelerator***". The paper (i) describes why this phenomenon exists; (ii) provides scientific references that support this assessment; and (iii) suggests the imminent catastrophic consequences and existential threat of failing to consider the Methane Accelerator in making future forecasts, planning appropriate remedial actions, and estimating the time available in which to agree upon, fund and implement such actions.

In its most disturbing finding, we conclude that when the cumulative effects from the Methane Accelerator are fully considered, mankind is likely to have already passed the "tipping point" where merely reducing CO_2 emissions, even to zero, will be not be sufficient to curtail the catastrophic effects of climate change. Geologic records from two prior extinction events that respectively resulted in a mass extinction of deep-sea organisms and in killing over 93% of all life forms on Earth, show compelling evidence linking these events to a rapid escape of methane from marine hydrate reservoirs on continental slopes. As ocean temperatures have risen over the past several decades, we have begun to see a marked increase in methane releases seeping into the water column and atmosphere from hydrate reservoirs.

During this period there has been an unexpected, and to this date still unexplained, increase in global atmospheric methane levels. While many scientists have characterized the natural releases of methane from marine and permafrost hydrates as localized incidents whose adverse effects are mitigated by physical, chemical and biological sinks that reduce the amount of methane that reaches the atmosphere, the Academy believes this ignores the broader context provided by the geologic record, thereby failing to account for the extent of the threat.

Given these concerns, we identify several actions that could worsen the situation and conclude by introducing several counter-measures to reverse, rather than merely mitigate, climate change effects that unless abated will outpace mankind's efforts to curtail CO_2 and methane emissions from manmade sources. With its release of this document for publication on the 75th anniversary of D-Day, the Academy is issuing a call for the scientific community to incorporate the accelerating effects of methane in future climate forecasts; and for government, business and the public as a whole to make informed decisions based on these new assumptions, and to mobilize expeditiously and effectively to combat the existential threat this poses to civilization as we know it.

INTRODUCTION

Current forecasts by the Intergovernmental Panel on Climate Change (IPCC),[1] like the group's prior consensus projections, are unduly optimistic. For example, a January 2019 report published in the journal *Science* reveals that ocean temperatures are warming 40% faster on average than was predicted by the IPCC a mere five years ago.[2,3] A February 2019 study reveals "very strong methane growth" between 2014 and 2017, and states that the increase in methane "since 2007 was not expected in future greenhouse gas scenarios compliant with the targets of the Paris Agreement, and [predicts that] if the increase continues at the same rates, it may become very difficult to meet the Paris goals."[4]

---

[1] The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. The IPCC was created in 1988 to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options [https://www.ipcc.ch/].

[2] Lijing Cheng, John Abraham, Zeke Hausfather and Kevin Trenberth, "**How fast are the oceans warming?**", *Science*, January 11, 2019: Vol. 363, Issue 6423, pp. 128-129 [https://doi.org/10.1126/science.aav7619].

[3] Kendra Pierre-Louis, "**Ocean Warming Is Accelerating Faster Than Thought, New Research Finds**," *New York Times*, January 10, 2019 [https://www.nytimes.com/2019/01/10/climate/ocean-warming-climate-change.html].

[4] E. G. Nisbet, M. R. Manning, E. J. Dlugokencky, *et al.*, **"Very strong atmospheric methane growth in the four years 2014-2017: Implications for the Paris Agreement,"** February 5, 2019 [https://doi.org/10.1029/2018GB006009]. The authors write: "the strong methane growth that began in 2007 was so unexpected that it was not considered in pathway models preparatory to the Paris Agreement. The current growth has now lasted over a decade. If growth continues at similar rates through subsequent decades, evidence presented here demonstrates that the extra climate warming impact of the methane can significantly negate or even reverse progress in climate mitigation from reducing CO_2 emissions. This will challenge efforts to meet the target of the 2015 UN Paris Agreement on Climate Change, to limit climate warming to 2 °C."

Twelve years ago, the World Business Academy (the "Academy")[5] became concerned about the influence of methane releases as a catalyst of accelerating global warming trends.[6] Since 2007, the Academy's consideration of the potentially adverse consequences of methane gas held in frozen reservoirs being released by warmer ocean temperatures has enabled the Academy to correctly predict the consistent understatement of IPCC's consensus estimates with regard both to the magnitude and severity of future climate change effects.

Because CO_2 lingers in the atmosphere for significantly longer than methane, the traditional scientific community has been mesmerized by the truly disturbing rise of CO_2 concentrations, which on May 12, 2019 reached 415 ppm (parts per million) for the first time in human history.[7] Until recently, the intense focus on CO_2 has blinded most of the scientific community to the far greater threat to human civilization posed by methane being released from melting permafrost, beneath glaciers and ocean floor sediment, as atmospheric and marine temperatures rise.

Even groups that have expressed concerns about methane traditionally focus on manmade methane emissions rather than natural methane releases triggered by global warming. For example, in 2012, the Environmental Defense Fund (EDF) initiated research to better pinpoint the source of methane leaks. The group explains that curtailing methane emissions is important because "about 25% of manmade global warming we're experiencing is caused by methane emissions [given that during] the first two decades after its release, methane is 84 times more potent than carbon dioxide."[8]

As EDF Chief Scientist, Steven Hamburg, explained in an April 2019 podcast describing the EDF's goal of curtailing methane emissions as one of the group's five primary climate-related initiatives:

---

[5] The World Business Academy is a 501(c)(3) non-profit think tank focusing on the role and responsibility of business in relation to solving critical environmental and social challenges. The Academy's focus on climate change and energy security results from an analysis of the most important threats to human survival and thus the survival of business. Formed in 1987, the organization's 30-year track record of leadership includes the publication of cutting-edge books, articles, podcasts and videos discussing these topics and other issues of primary importance to society and the business community.

[6] As more fully described below, after becoming aware in 2007 of the prospect of methane that has accumulated in frozen reservoirs beginning to be released as gas by warming ocean temperatures, Academy founder and CEO, Rinaldo Brutoco, discussed with Dr. Lorenz Magaard in Hawaii the possibility of a methane effect compounding the adverse consequences of climate change. At the time, Dr. Magaard served as Chairman of the University of Hawaii's Department of Oceanography, Director of the International Center for Climate and Society, and Executive Associate Director of the International Pacific Research Center (IPRC).

[7] Jonathan Shieber, **"CO2 in the atmosphere just exceeded 415 parts per million for the first time in human history,"** TechCrunch, May 12, 2019. [https://techcrunch.com/2019/05/12/co2-in-the-atmosphere-just-exceeded-415-parts-per-million-for-the-first-time-in-human-history/]. Citing to the report by Scripps Institution of Oceanography climate researcher Eric Holthaus [https://twitter.com/Keeling_curve].

[8] Environmental Defense Fund, **"Methane: The other important greenhouse gas"** [https://www.edf.org/climate/methane-other-important-greenhouse-gas].

"[Methane provides] this big lever of action and everyone was still missing it. They acknowledged it, but said the big thing is CO_2."[9] Yet as the podcast indicates, even the EDF's actions are based on the view that the largest portion of methane originates from leakage during oil and gas production, and from old pipes that should be replaced.

The Academy actively supports reducing CO_2 emissions, and agrees with EDF on the importance of reducing methane emissions from oil and gas wells, and pipeline leaks. The Academy also supports policy initiatives such as carbon credits and/or a carbon tax; the development of alternative energy sources; and is optimistic about extracting excessive amounts of CO_2 from the atmosphere using direct carbon capture and sequestration, which are technologically feasible and now appear to be [or are on the verge of becoming] economically viable with projected costs of approximately $100/ton when built at a utility scale. Yet this paper addresses a quite different phenomenon for which these sorts of approaches are woefully inadequate.

As noted above, since 2007, the Academy has focused its work regarding climate change on essentially the same data sets used by other leading climate researchers:

- atmospheric CO_2 increases detected at the Mauna Loa Observatory in Hawaii that are currently higher than at any time in the last 800,000 years;[10]
- increasing ambient global moisture levels that are today about 7% higher than during the 20th century;[11,12]
- shrinking and disappearance of glaciers around the world, particularly in the Himalayan High Plateau that feeds the great rivers of Asia;[13,14]
- increases in ocean temperature;[15]

---

[9] Steven Hamburg and Nathaniel Keohane, Environmental Defense Fund, **"The Great Climate Race (podcast),"** April 17, 2019 [https://www.edf.org/sites/default/files/Climate-Reception-04-17-2019.mp3 at 12:45 to 13:40].

[10] National Oceanic and Atmosphere Administration (NOAA), "**Trends in Atmospheric Carbon Dioxide**" [https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html].

[11] Climate Signals Beta, "**Atmospheric Moisture Increase**," [http://www.climatesignals.org/climate-signals/atmospheric-moisture-increase].

[12] NOAA, "Climate Change: Global Temperature." August 1, 2018 [https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature].

[13] The Hindu Kush Himalaya Assessment, "**Unravelling Climate Change in the Hindu Kush Himalaya: Rapid Warming in the Mountains and Increasing Extremes**," January 5, 2019 [https://link.springer.com/chapter/10.1007/978-3-319-92288-1_3].

[14] "**Climate change is roasting the Himalaya region, threatening millions**," National Geographic, February 4, 2019 [https://www.nationalgeographic.com/environment/2019/02/himalaya-mountain-climate-change-report/].

[15] *See* Footnotes 2 and 3, above.

- loss of ice mass and the accelerating speed of the seaward advance of the Greenland Ice Sheet and the drastic reduction of certain Antarctic glaciers;[16]
- ice core samples that reveal atmospheric greenhouse gases in prior millennia through measurements of mass, height and runoff water volumes;[17,18]
- dramatic winter and summer ice decreases in the Arctic Circle;[19]
- growing instability of the jet stream;[20,21]
- alteration of ocean currents;[22,23,24]
- increasingly extreme weather events due to warmer ocean temperatures[25,26] that feed ever more violent storms (such as 191-mph winds in the middle of the Pacific as measured on Mauna Kea);[27]

---

[16] Douglas Fox, "**The big melt: Earth's ice sheets are under attack**," January 31, 2019 [https://www.sciencenewsforstudents.org/article/big-melt-earths-ice-sheets-are-under-attack].

[17] "**Accelerating changes in ice mass within Greenland, and the ice sheet's sensitivity to atmospheric forcing**," PNAS, February 5, 2019, 116 (6) 1934-1939 [https://doi.org/10.1073/pnas.1806562116].

[18] Live Science, "The Greenland Ice Sheet Is Melting at Astonishing Rate," January 21, 2019 [https://www.livescience.com/64546-greenland-ice-sheet-melting-faster.html].

[19] National Snow and Ice Data Center, "**Arctic Sea Ice News and Analysis**," [http://nsidc.org/arcticseaicenews/].

[20] Michael Mann, Stefan Rahmstorf, Kai Kornhuber, Byron Steinman, Sonya Miller and Dim Coumou, "**Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events**," March 27, 2017 [https://www.nature.com/articles/srep45242].

[21] Bob Berwyn, Inside Climate News, "**Polar Vortex: How the Jet Stream and Climate Change Bring on Cold Snaps**," February 2, 2018, [https://insideclimatenews.org/news/02022018/cold-weather-polar-vortex-jet-stream-explained-global-warming-arctic-ice-climate-change].

[22] Wikipedia, "**Effects of Global Warming on Oceans-Ocean Currents**," [https://en.m.wikipedia.org/wiki/Effects_of_global_warming_on_oceans].

[23] Bob Berwyn, Inside Climate News, "**Scientists Say Ocean Circulation Is Slowing. Here's Why You Should Care**," May 7, 2018, [https://insideclimatenews.org/news/07052018/atlantic-ocean-circulation-slowing-climate-change-heat-temperature-rainfall-fish-why-you-should-care].

[24] Science News, **"Climate change might not slow ocean circulation as much as thought**," January 31, 2019 [https://www.sciencenews.org/article/climate-change-might-not-slow-ocean-circulation-much-thought].

[25] International Union for Conservation of Nature (IUCN), "**Issues Brief-Ocean Warming**," [https://www.iucn.org/resources/issues-briefs/ocean-warming].

[26] Conservation in a Changing Climate, "**Extreme Temperature Change: Water Temperatures**," [http://climatechange.lta.org/climate-impacts/water-temperatures/].

[27] USA Today, "**Potent storm slams Hawaii with 191-mph winds, 60-foot waves and rare snow on Maui**," February 10, 2019, [https://www.usatoday.com/story/news/2019/02/10/hawaii-storm-brings-60-foot-waves-power-outages/2832866002].

- rising sea levels;[28,29] and
- various trends in alternative energy developments and technologies that seek to reduce the adverse effects of climate change.

The principal difference between the Academy's analyses of these factors and the perspectives on this data by traditional climate researchers, is that for over a decade the Academy has incorporated into its review and consideration of these data classes a concern that (i) the rise in ambient air and ocean temperatures may be triggering the release of methane from natural deposits; and (ii) even if diffused so as not to be locally significant, the derivative increase in methane as this gas is released is in turn accelerating all of the foregoing negative climate change indices.

The Academy refers to this effect as the "***Methane Accelerator***".

Based on the Academy's research, it appears these unforeseen and unintended methane releases (both into the atmosphere and absorbed into the ocean before methane reaches the water surface) are now the most critical factor leading to what is increasingly becoming a global tragedy. The failure to fully understand this phenomenon and account for its effects when modelling future trends and devising actions to reverse climate change, obscures the prospects for destruction of all human civilization *as we know it* well before the end of the current century unless appropriate counter-measures are undertaken.

"The renewed strong methane growth that began in 2007 was so unexpected," writes one research group, "that it was not considered in pathway models preparatory to the Paris Agreement. The current growth has now lasted over a decade."[30] The failure to account for the Methane Accelerator appears to be a significant reason that predictions made by the IPCC have historically been understated. From the Academy's perspective, even more important than what the IPCC has missed in its past estimates is concern that the IPCC's forthcoming climate predictions for the next 50 years – with or without targeted CO_2 emission reductions – will grossly understate climate impacts due to the uncontrolled (and uncontrollable) release of increasing volumes of methane into the atmosphere due to the combination of melting permafrost, receding ice sheets and rising ocean temperatures.

Beginning in 2007, with the detection of large quantities of methane bubbling from the seafloor to the ocean's surface in the Santa Barbara channel,[31] the existence of a Methane Accelerator is

---

[28] National Oceanic and Atmosphere Administration (NOAA), "**Is sea level rising?**", [https://oceanservice.noaa.gov/facts/sealevel.html].

[29] National Geographic, **"Sea level rise, explained,"** February 19, 2019 [https://www.nationalgeographic.com/environment/global-warming/sea-level-rise/].

[30] *Id*., Nisbet, Manning, Dlugokencky, *et al*. (citing references).

[31] Susan Mau, *et al.*, "**Dissolved Methane Distributions and Air-Sea Flux in the Plume of a Massive Seep Field, Coal Oil Point, California**" Geophysical Research Letters, November 2007 [http://doi.org/10.1029/2007GL031344]. ("Most seep bubbles are composed of ~90% methane at the seafloor and ~60–70% methane at the sea-surface")

a phenomenon about which World Business Academy founder, Rinaldo S. Brutoco, has both conjectured and periodically questioned oceanic and climatology experts. Despite subsequent methane releases from the Arctic seabed, the Atlantic shelf, and a growing number of other locations around the globe, the failure by climate authorities to seriously consider the Methane Accelerator effect resulted in the Academy deciding that publication of this paper is important as a call for further research into a phenomenon that most mainstream climatologists have previously discounted or entirely failed to consider.

A number of authors have conclusively shown that melting permafrost is releasing methane from thawing ruminant animal remains and other organic materials (*e.g.*, grasses, trees and shrubs) that have been trapped and frozen solid for millennia.[32,33,34] A number of other references affirm that increases in ocean temperature are causing massive reserves of ice-like solid structures known as methane hydrates, located on or just beneath the ocean floor, to undergo a phase change into gas, which is then released into the ocean and then the atmosphere.[35,36]

Based on its review of these studies and related data, the Academy surmises that a snowball effect often referred to as a "Vicious Circle" (in contrast to a "Virtuous Cycle") has been, and is being accelerated as rising ambient air and ocean temperatures trigger the release of methane that has been "locked" in solid hydrate structures on the ocean floor.[37] As noted by the EDF, for the first few decades following its release, methane emissions are considerably more potent than CO_2.[38]

---

[32] Boris Biskaborn, *et al.*, "**Permafrost is Warming at a Global Scale**," Nature Communications, January 2019 [https://www.nature.com/articles/s41467-018-08240-4.pdf]. It is generally understood that methane deposits in permafrost were created from frozen plants and animal carcasses encased during the Ice Age. So long as these remains stayed frozen, they didn't decompose and leach methane. However, as the permafrost melts, methane is increasingly being released into the atmosphere.

[33] Kevin Schaefer, **"Methane and Frozen Ground**," National Snow and Ice Center [https://nsidc.org/cryosphere/frozenground/methane.html].

[34] "**Unexpected Boost of Methane, Permafrost is Warming at a Global Scale**" YouTube video [https://youtube.com/watch?v=cBSjLD01rXo]

[35] Carolyn Ruppel and John Kessler, "**The interaction of climate change and methane hydrates**," Reviews of Geophysics, 55: 126-168, March 2017 [https://doi.org/10.1002/2016RG000534].

[36] Carolyn Graves, "Marine Methane," AWE International, December 14, 2015 [https://www.aweimagazine.com/article/marine-methane-1198].

[37] The methane trapped on, or in, the sea floor is maintained in solid form by two forces: the high pressure from the weight of water and ice, and the low temperature of the water. Thus, decreases in pressure as the ice caps melt and/or increases in the water temperature permit some of the solid methane to return to its natural gaseous state and "off gas." Depending on the volume of gas released and depth of the deposit, some portion of the CH_4 may be absorbed by the water column, resulting in acidifying the water, and any portion that is not absorbed will be released into the atmosphere when the bubbles break the surface of the water.

[38] See Footnote 8, *supra*. Also see V. Ramaswamy, *et al.*, "**Radiative Forcing of Climate Change**," Climate Change 2001: The Scientific Basis, Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by J. T. Houghton, et al., p. 388, Cambridge Univ. Press. [https://www.ipcc.ch/site/assets/uploads/2018/03/TAR-

Consequently, these releases in turn further heat the atmosphere, which in turn further heats the ocean, thereby causing additional solid hydrate structures to revert to gaseous methane that bubbles to the surface and enters the atmosphere. These atmospheric and ocean temperature increases then provoke further detrimental effects – ergo, our basis for selecting the *"Methane Accelerator"* term to describe the phenomenon.

The Academy is concerned that the *status quo* – if not abated – will lead to an unceasing acceleration of global atmospheric warming irrespective of additional CO_2 emissions reductions. Thus, by having raised temperatures to the point that vast natural reserves of methane that have been held as hydrates for millennia are now being released at an accelerating pace, it will be these uncontrolled (and uncontrollable) methane releases that accelerate further climate damage from increasing amounts of moisture evaporated into the air (the proximate cause of massive global flooding); melting of the Earth's glaciers, the Greenland Ice Sheet and Antarctic Ice Sheet (the proximate cause for increases in sea level);[39,40] desertification caused by persistent drought (the proximate cause of agricultural failure, starvation and mass migration);[41,42] and accelerating increases in global temperatures (compounding the risk of extreme weather events, humanitarian disasters, conflict, price shocks and power outages).[43,44]

06.pdf] (see Table 6.7. Direct Global Warming Potentials. Showing that per unit mass, methane (CH_4) warms the Earth 62 times more than CO_2 when averaged over 20 years).

[39] Al Gore, An Inconvenient Truth: The crisis of global warming, Viking Press (2007), pages 104-5, 109. Vice President Gore predicted 18 - 20 feet of sea rise would occur with the melting of Greenland's ice dome, and approximately 20 feet if the Western Antarctic ice shelf melted or broke up into the sea.

[40] NASA, "New study finds sea level rise accelerating," February 13, 2018 [https://climate.nasa.gov/news/2680/ new-study-finds-sea-level-rise-accelerating/], quoted in Christina Nunez, "**Sea level rise, explained**," National Geographic, February 19, 2019 [https://www.nationalgeographic.com/environment/global-warming/sea-level-rise/]. NASA and European data currently predict a rise of 26 inches (65 centimeters) by the end of this century if the current trajectory continues. If all the ice that currently exists on Earth in glaciers and sheets melted it would raise sea level by 216 feet.

[41] United Nations Convention to Combat Desertification (UNCCD), "**Fact Sheet Series No. 3: Desertification and Migration,**" 2011 [http://catalogue.unccd.int/22_loose_leaf_Desertification_migration.pdf]. "[G]lobal environmental change could drive anywhere from 50 to almost 700 million people to migrate by 2050."

[42] Carolyn Beeler, "**UN compact recognizes climate change as driver of migration for first time**," Public Radio International, December 11, 2018 [https://www.pri.org/stories/2018-12-11/un-compact-recognizes-climate-change-driver-migration-first-time].

[43] Holly Shafftel (editor), Earth Science Communications Team at NASA's Jet Propulsion Laboratory, "**2018 fourth warmest year in continuing warming trend, according to NASA, NOAA**," February 6, 2019 [https://climate.nasa.gov/news/2841/2018-fourth-warmest-year-in-continued-warming-trend-according-to-nasa-noaa/]. "Earth's global surface temperature in 2018 was the fourth warmest since 1880, according to independent analyses by NASA and the National Oceanic and Atmospheric Administration (NOAA). […] Globally, 2018's temperatures rank behind those of 2016, 2017 and 2015. The past five years are, collectively, the warmest years in the modern record."

[44] Daniel R. Coats (DNI), "**Worldwide Threat Assessment of the US Intelligence Community**," February 13, 2018, pages 16-17 [https://www.dni.gov/files/documents/Newsroom/Testimonies/2018-ATA---Unclassified-SSCI.pdf]. "The past 115 years have been the warmest period in the history of modern civilization, and the past few years have been the warmest years on record. Extreme weather in a warmer world have the potential for greater impacts and can

Most concerning of all, the Academy believes that this catastrophic tipping point could also ultimately trigger an abrupt seafloor gas hydrate dissociation (or so-called "*methane burp*").[45] Scientists have linked abrupt massive methane emissions from seafloor gas hydrate dissociation as a proximate cause of at least two mass extinction events in the geologic past, including the Paleocene-Eocene Thermal Maximum (PETM) approximately 55.5 million year ago, which resulted in the largest deep-sea mass extinction event in the last 93 million years;[46,47] and the Permian Extinction approximately 250 million years ago that killed over 93% of all life forms on earth.[48,49] Because analysis of these events relies on interpretations from the geologic record, there is considerable room for debate regarding how far changes must progress before the runaway effects became lethal.[50]

Little is known about whether, and for how long, localized gas hydrate dissociation incidents such as those that are already taking place around the globe today preceded worldwide methane releases that extinguished life of all but a few species during these earlier mass extinction events. Without this knowledge, it is impossible to know whether the methane releases that have been

---

compound with other drivers to raise the risk of humanitarian disasters, conflict, water and food shortages, population migration, labor shortfalls, price shocks, and power outages."

[45] John P. Rafferty [Editor], "**Methane burp hypothesis**," Encyclopædia Britannica, April 30, 2010 [https://www.britannica.com/science/methane-burp-hypothesis].

[46] Gerald R. Dickens, "**The blast in the past**," Nature (1999), 401, 752-755 [https://www.nature.com/articles/44486]. The Paleocene-Eocene Thermal Maximum (PETM) was formerly known as the "Initial Eocene" or "Late Paleocene Thermal Maximum (LPTM)". Some geologists consider the PETM to be the best analog for current global warming.

[47] Hongyue Dang and Jia Li, "**Climate Tipping-Point Potential and Paradoxical Production of Methane in a Changing Ocean**," Science China Earth Sciences, December 2018, pp. 1714-27 [https://link.springer.com/article/10.1007/s11430-017-9265-y] ("The massive CH_4 emissions putatively caused by abrupt sea floor gas hydrate dissociation are considered to be a very important factor contributing to global warming during certain historical events in the Earth's history, including the PETM [*i.e.*, the Paleocene–Eocene Thermal Maximum period] and the termination of the Marinoan "Snowball" ice age (Dickens *et al.*, 1995, 1997; Kennett *et al.*, 2003; Maslin *et al.*, 2004; Svensen *et al.*, 2004; Kennedy *et al.*, 2008; Dickens, 2011). Catastrophic CH_4 emissions associated with massive and abrupt marine gas hydrate dissociation are also hypothesized to have been involved in mass extinctions (Katz *et al.*, 1999; Norris and Röhl, 1999; Hesselbo *et al.*, 2000.").

[48] Uwe Brand, Nigel Blamey, Claudio Garbelli, *et al.*, "**Methane Hydrate: Killer cause of Earth's greatest mass extinction**," Paleoworld, Vol 25, Issue 4, December 2016, pages 496-507 [https://doi.org/10.1016/j.palwor.2016.06.002].

[49] Ian Johnston, "**Earth's worst-ever mass extinction of life holds 'apocalyptic' warning about climate change, say scientists**," Independent Minds, March 24, 2017 [https://www.independent.co.uk/environment/earth-permian-mass-extinction-apocalypse-warning-climate-change-frozen-methane-a7648006.html], citing to above article.

[50] *Id.*, Ruppel and Kessler (citing references). A number of reviews of contemporary methane emissions from marine hydrate structures describe physical, chemical, and biological sinks including anaerobic oxidation of methane (AOM), rapid dispersion by ocean currents, dissolution and aerobic microbial oxidation (MOx), and tropospheric oxidation as factors that mitigate the adverse impact that hydrate-derived methane has on the ocean and atmosphere. While the Academy agrees that such factors mitigate adverse effects, the geologic record is clear that at some point such mitigating factors are overwhelmed. The question becomes not if, but for how long such processes slow the adverse effects before the continued releases result in global warming levels that are lethal to most life on land and in the oceans.

observed at various locations around the planet since at least 2007 are merely early warning signs, or themselves a sequential part of an uncontrollable worldwide release of methane that will end human existence unless significant remedial measures are taken. One certainly wishes to remain optimistic, but prudence also dictates that business and government leaders consider the possibility that a methane burp could occur at any time, as it did hundreds of millions of years ago, and undertake requisite action to eliminate this existential threat to humanity.

On May 6, 2019, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) formed by the United Nations issued a comprehensive report based on over three years of research by 145 experts from 50 countries. The IPBES report states that due to the impact of climate change and other human factors over the past 50 years, the Earth's biodiversity has already declined at a rate that is "faster than at any time in human history."[51] During testimony to Congress on May 22, 2019, IPBES representatives reiterated the report's dire conclusions that "around 1 million species already face extinction, many within decades, unless action is taken to reduce the intensity of drivers of biodiversity loss," adding that "[w]ithout such action, there will be a further acceleration in the global rate of species extinction, which is already at least tens to hundreds of times higher than it has averaged over the past 10 million years."[52]

These are sobering estimates that affect 1 out of 8 species on Earth. The Academy's concern is that absent immediate action to stop the release of methane hydrates by reversing the continued heating of the planet through proactive counter-measures, the IPBES estimates – like those of the IPCC – seriously understate the severity of the threat, and mask the fact that it is humanity's own existence that now rests in the balance. Our objective in this whitepaper is to draw attention to the certainty that unless the Methane Accelerator effect is reversed, human civilization as we know it will cease to exist as nation states disintegrate due to mass migrations to ever higher altitudes to escape rising sea levels and crop failure,[53] together with the ever greater risk that a methane burp could occur at any time, as it did millions of years ago.[54,55]

---

[51] Sandra Díaz, Josef Settele, Eduardo Brondízio, *et al.*, "**Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services**," IPBES, May 6, 2019, page 1 [https://www.ipbes.net/news/Media-Release-Global-Assessment].

[52] Testimony of Sir Robert Watson, "**Oversight Hearing: Responding to the Global Assessment Report of the Inter-governmental Science-Policy Platform on Biodiversity and Ecosystem Services**," US House of Representatives, Subcommittee on Water, Oceans, and Wildlife, May 22, 2019 [http://naturalresources.house.gov/download/watson-testimony-wow-ov-hrg-052219].

[53] Approximately 40% of all humans reside within 100 kilometers of a coastline and even populations in areas which have arable land at that new sea level would find the temperatures too hot for agriculture and potentially too hot for normal human living.

[54] Thom Hartman, "**Methane: The Ticking Time Bomb**," Before the Flood, October 21, 2016 [https://www.beforetheflood.com/explore/the-crisis/methane-the-ticking-time-bomb/]. See the full movie at https://www.filmsforaction.org/watch/before-the-flood-2016/.

[55] Channel 4 Equinox, "**The Day the Oceans Boiled (Part 3)**," June 17, 2001 [https://youtu.be/iDBt07skLbQ].

UNDER-ESTIMATING CLIMATE CHANGE TRENDS

In 2012, one thoughtful observer wrote: "Across two decades and thousands of pages of reports, the world's most authoritative voice on climate science has consistently understated the rate and intensity of climate change and the danger those impacts represent."[56] A recent publication[57] describes some of the reasons why:

> "The IPCC has done critical, indispensable work of the highest standard in pulling together a periodic consensus of what must be the most exhaustive scientific investigation in world history. It does not carry out its own research, but reviews and collates peer-reviewed material from across the spectrum of this incredibly complex area, identifying key issues and trends for policymaker consideration. However, the IPCC process suffers from all the dangers of consensus-building in such a wide-ranging and complex arena. For example, IPCC reports, of necessity, do not always contain the latest available information. Consensus-building can lead to 'least drama', lowest-common-denominator outcomes, which overlook critical issues. This is particularly the case with the 'fat-tails' of probability distributions, that is, the high-impact but lower-probability events where scientific knowledge is more limited.
>
> "Vested-interest pressure is acute in all directions; climate denialists accuse the IPCC of alarmism, whereas many climate action proponents consider the IPCC to be far too conservative. To cap it all, the IPCC conclusions are subject to intense political oversight before being released, which historically has had the effect of substantially watering-down sound scientific findings."

From the Academy's perspective, these challenges associated with the consensus process employed by the IPCC do not fully explain why forecasts made by the world's most astute group of climatologists and experts consistently underestimate future warming, sea rise, ice melt extent and atmospheric methane concentration levels by increasingly wide margins. The IPCC's failure to adequately account for the effects of methane acceleration within its trend analyses adds an earth sciences-based explanation for the differences.[58] Accordingly, it is essential that we understand

---

[56] Glenn Scherer, "**Report: IPCC Underestimates Climate Risks**," Climate Central, December 10, 2012 [https:www.climatecentral.org/news/report-ipcc-underestimate-assessing-climate-risks-15338] "A comparison of past IPCC predictions against 22 years of weather data and the latest climate science find that the IPCC has consistently underplayed the intensity of global warming in each of its four major reports released since 1990." *Also* "**How the IPCC Underestimated Climate Change**," Scientific American, December 6, 2012 [https://www.scientificamerican.com/article/how-the-ipcc-underestimated-climate-change/].

[57] David Spratt and Ian Dunlop, "**What Lies Beneath: The Understatement of Existential Climate Risk**," National Centre for Climate Restoration. Melbourne, Australia. August 2018, page 5 [http://climateextremes.org.au/wp-content/uploads/2018/08/What-Lies-Beneath-V3-LR-Blank5b15d.pdf].

[58] In 2018, the **IPCC Summary for Policymakers on Global Warming of 1.5 °C**, pages 14-15 [https://www.ipcc.ch/site/assets/uploads/2018/10/SR15_SPM_version_stand_alone_LR.pdf] acknowledged a major role that can be played by reducing methane emissions from agriculture and manmade sources, but has yet to incorporate hydrates into its trend forecasts.

and begin to address methane as a primary cause of accelerating warming trends. A number of examples can be cited where the IPCC forecasts underestimate the actual extent and severity of climate change effects.

Figure 1.
Sea level rise: IPCC projections and actual observations

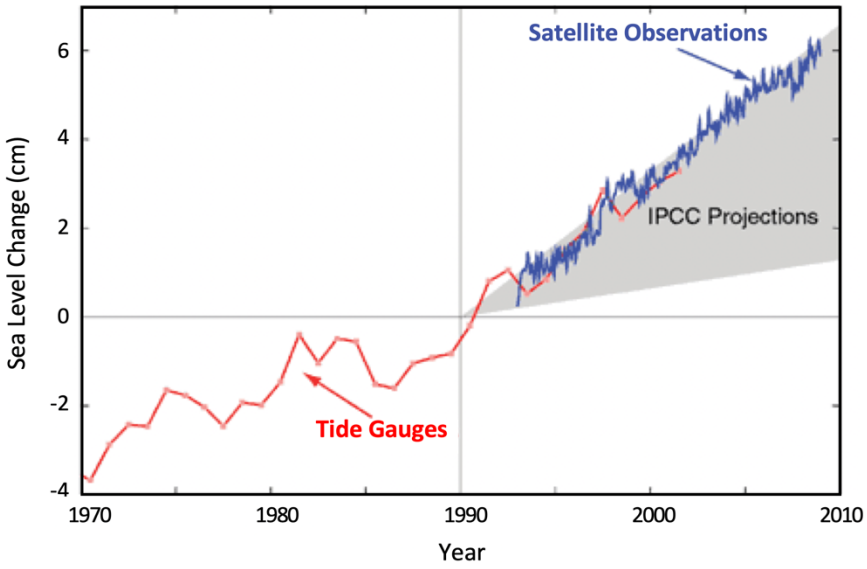
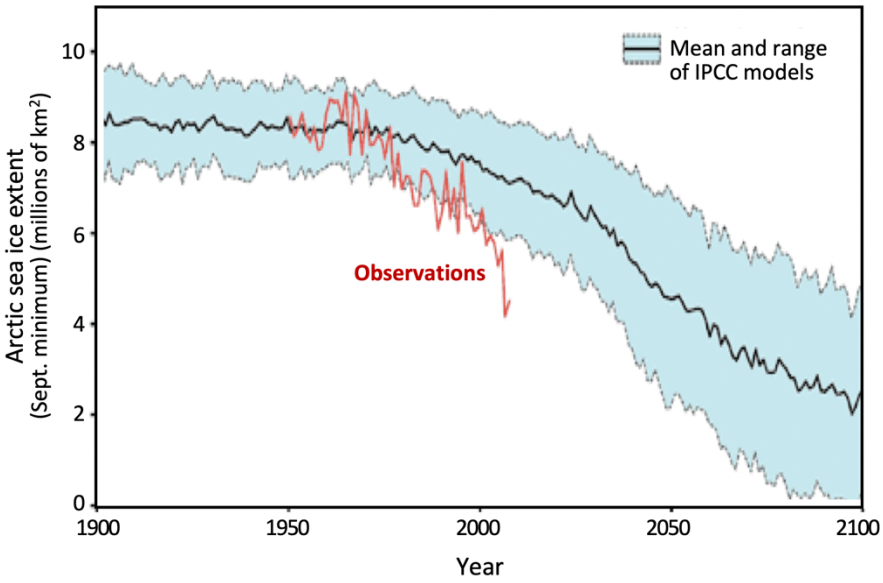


Figure 1 compares observed sea level rise since 1970 from tide gauge data (in red) and satellite observations (in blue) to model projections for 1990-2010 from the IPCC Third Assessment Report (shaded area).[59] As shown, actual observations of sea level rise have consistently mirrored most aggressive forecasts, rather than IPCC consensus averages.

Another example is found regarding the extent of Arctic sea ice, shown in **Figure 2**, which compares actual observations of September minimum Arctic sea ice extent through 2008 (red line) with IPCC AR4 model projections. [60]

Figure 2.
Arctic sea ice extent: IPCC projections and actual observations



As reflected in the graph, Arctic sea ice is melting much faster than predicted by IPCC climate models. The solid black line shows

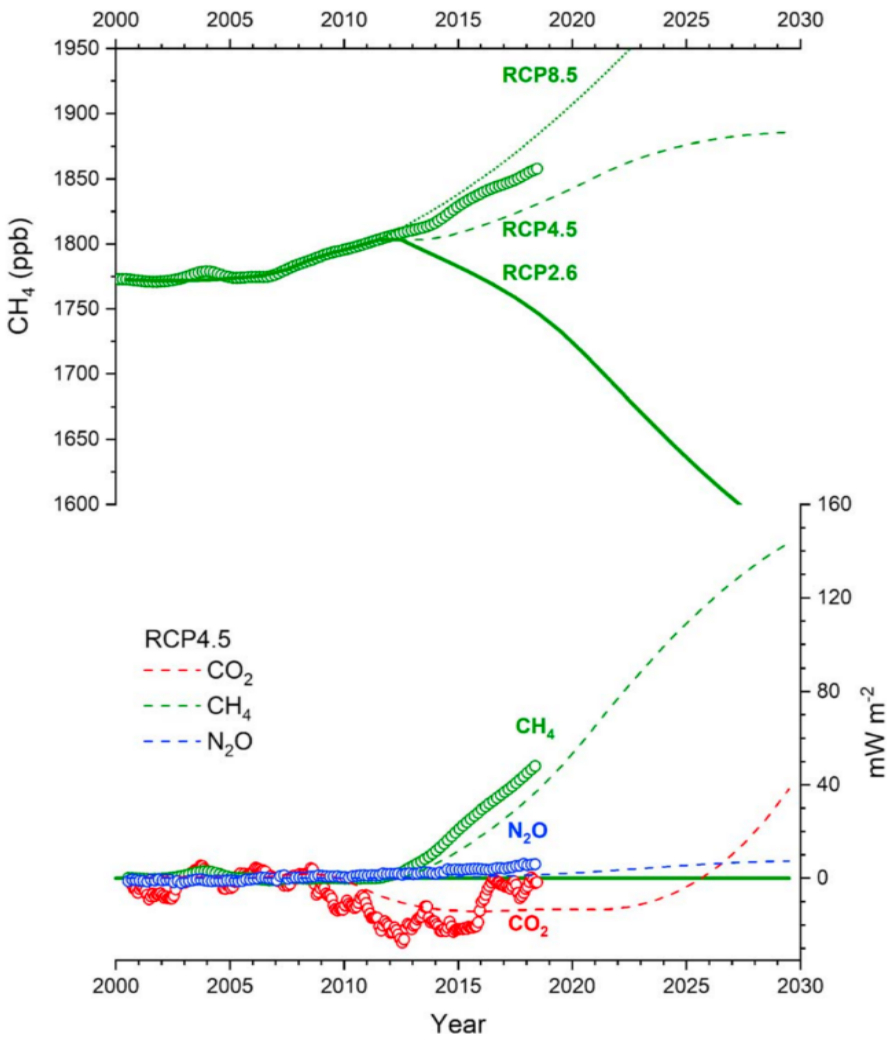
[59] Skeptical Science, "**How Reliable are Climate Models?**" citing to graphs from I. Allison, N. Bindoff, *et al.*, The Copenhagen Diagnosis, 2009: Updating the world on the Latest Climate Science. The University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia (2009) [https://skepticalscience.com/climate-models.htm].

[60] Penn State College of Earth and Mineral Sciences, "**From Meteorology to Mitigation: Understanding Global Warming: Sea Ice, Glaciers, Ice Sheets**" also citing to graphs from I. Allison, N. Bindoff, *et al.*, The Copenhagen Diagnosis, 2009 [https://www.e-education.psu.edu/meteo469/node/156].

the mean of the 13 models and dashed black lines on either side of the shaded band show the range of the model results.

Figure 3 compares the actual observed concentration of methane in the atmosphere as measured by NOAA at 3-month intervals (indicated by green circles) with concentration levels of methane projected in the Representative Concentration Pathway (RCP) scenarios adopted by the IPCC in its fifth assessment report (AR5) in 2014.

Figure 3.
Methane concentration: IPCC projections and actual observations



As shown, methane levels (CH_4) continue to climb despite the view held by most scientists that levels had peaked at around 1,775 ppb (parts per billion) at the end of the 1990's and accordingly, that efforts to cut such emissions could reverse the historical trend.[61]

As defined by the IPCC, "radiative forcing" is a measure of how strongly a given climatic factor has on the amount of radiant energy that affects the Earth, with "positive forcing" being exerted by factors such as CO_2 and methane that contribute to the warming of the surface, and "negative forcing" by factors that contribute to cooling it.

In this regard, the lower half of Figure 3 indicates the differences in radiative forcing since 2000 between the actual

[61] Julia Rosen, "**Methane in the atmosphere is surging, and that's got scientists worried**," Los Angeles Times, March 2, 2019 [https://www.latimes.com/science/sciencenow/la-sci-sn-methane-atmosphere-accelerating-20190301-story.html], citing Nisbet, Manning, Dlugokencky, *et al.* (*supra* at FN 4), Figure 6, p. 335..

evolution of methane (green open circles), carbon dioxide (red circles), and nitrous oxide (blue circles) compared to the RCP2.6 pathway (solid line) and the RCP4.5 pathway (dashed lines). "At this growth rate, […] even if anthropogenic CO_2 emissions are successfully constrained to a RCP2.6-like pathway, the unexpected and sustained current rise in methane may so greatly overwhelm all progress from other reduction efforts that the Paris Agreement will fail."[62]

As referenced in the Introduction, a more recent and dramatic example where the IPCC forecasts have under-estimated actual change is the 40% faster rate that the world's oceans are warming compared to the IPCC's projections in its 2013 report.[63] Antarctic sea ice is melting 300% faster than predicted;[64,65,66] and Arctic sea ice is similarly melting faster than projected due to air temperatures increasing faster than forecasted.[67,68]

For the reasons described in the following sections, the Academy is convinced that the problem suggested by these tables dictate considerably more aggressive counter-measures, including reversing the warming of the Earth's surface and thereby cooling the ocean temperature to stop further releases from hydrate deposits.

---

[62] *Id*., Nisbet, Manning, Dlugokencky, *et al*., p. 335.

[63] See articles in New York Times and Science (Footnotes 1 and 2, *supra*). These increases are particularly important because ocean temperatures are the best way to measure the impact of climate change on a global basis, inasmuch as the ocean is where most of the additional heat ends up.

[64] Eric Rignot, Jérémie Mouginot, *et al.*, "**Four decades of Antarctic Ice Sheet mass balance from 1979–2017**," PNAS, January 22, 2019, 116 (4) 1095-1103 [https://doi.org/10.1073/pnas.1812883116].

[65] Nicolas Rivero, "**Antarctica's ice sheets may melt faster than we thought, accelerating sea level rise**," Quartz, January 15, 2019. [https://qz.com/1524901/]. The IPCC's most recent report [IPCC report (PDF)] predicts that sea levels will rise as much as a meter by the end of the 21st century. But Eric Rignot, lead author of the study cited in the previous footnote, told *Quartz* in an email, "IPCC projections are very conservative and ignore potential contribution from East Antarctica."

[66] Brandon Miller, "**Antarctica ice melt has accelerated by 280% in the last 4 decades**," CNN, January 14, 2019. [https://www.cnn.com/2019/01/14/world/climate-change-antarctica-ice-melt-twin-studies/index.html].

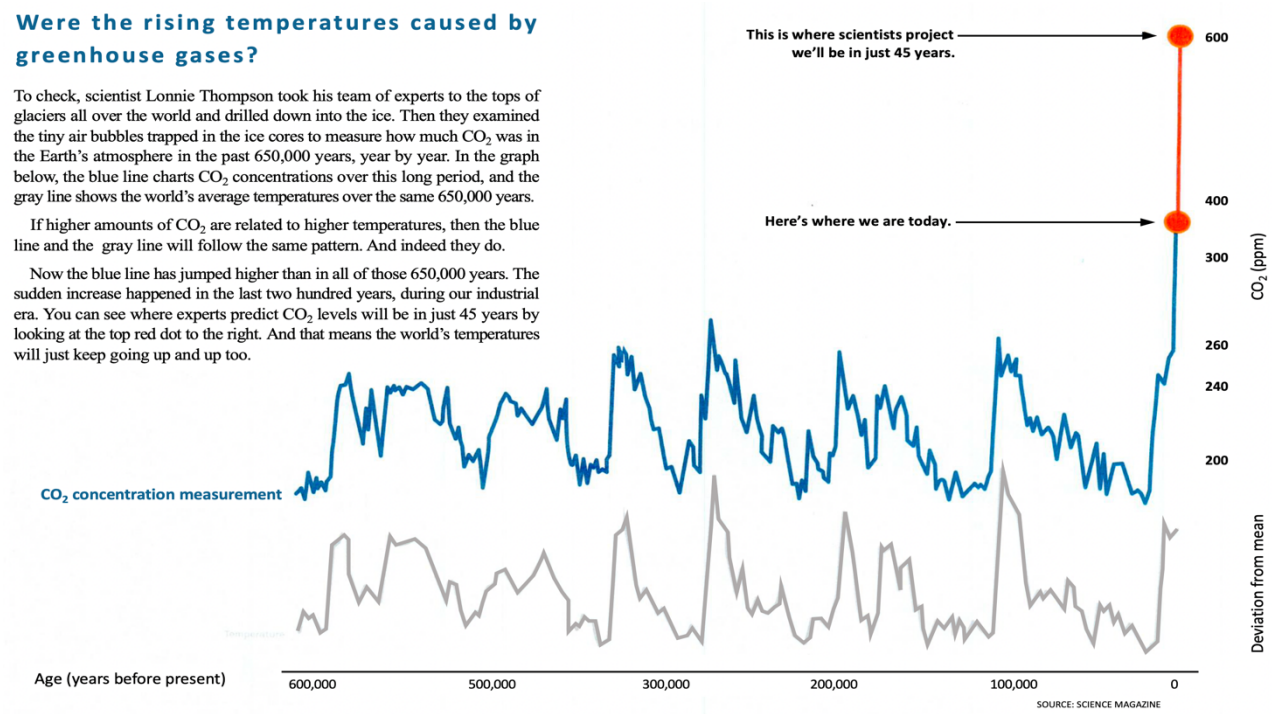
[67] CBC News, "**Arctic sea ice melting faster than most scientists project: study**," May 1, 2007 [https://cbc.ca/news/technology/arctic-sea-ice-melting-faster-than-most-scientists-project-study-1.672051]. Scientists at the National Center for Atmospheric Research and the University of Colorado in Boulder, using actual measurements, concluded Arctic sea ice has declined at an average rate of about 7.8% a decade between 1953 and 2006. By contrast, 18 computer models used by the IPCC estimated an average rate of decline of 2.5% per decade over the same period.

[68] NOAA, "**Arctic Report Card: Update for 2018**" [https://arctic.noaa.gov/Report-Card/Report-Card-2018]. Surface air temperatures in the Arctic continue to warm at twice the rate relative to the rest of the globe. Arctic air temperatures for the past five years (2014-18) have exceeded all previous records since 1900.

CLIMATE-INDUCED RELEASES OF METHANE FROM NATURAL DEPOSITS

During its research leading up to the 2007 publication of its book, *Freedom from Mideast Oil*, the Academy began to consider the effect methane might have as a heat accelerant[69] and potential that its release could heat the atmosphere beyond what CO_2 emissions alone were doing.[70] Based on this research, the Academy concluded that the famous hockey stick chart (see Figure 4) reproduced in Al Gore's book and movie, "An Inconvenient Truth," [71,72] is incomplete because it

Figure 4.
650,000 Years of CO_2 levels (from Antarctic ice cores, in red) and temperature (in blue)



---

[69] V. Ramaswamy, *et al.*, "**Radiative Forcing of Climate Change**," in Climate Change 2001: The Scientific Basis, Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by J. T. Houghton, et al., p. 388, Cambridge Univ. Press [https://www.ipcc.ch/site/assets/uploads/2018/03/TAR-06.pdf]. (see Table 6.7. Direct Global Warming Potentials, showing that per unit mass, methane warms the Earth 62 times more than CO_2 when averaged over 20 years.) Other sources report that methane is so good at trapping heat that one ton of the gas causes 32 times as much warming as one ton of CO_2 over the course of 100 years.

[70] Jerry Brown, Rinaldo Brutoco and James Cusumano, **Freedom from Mideast Oil**, World Business Academy, 2007 [https://archive.org/details/freedomfrommidea0000brow], pages 113-8 and 393-4.

[71] *Id*., Al Gore, pages 46-47.

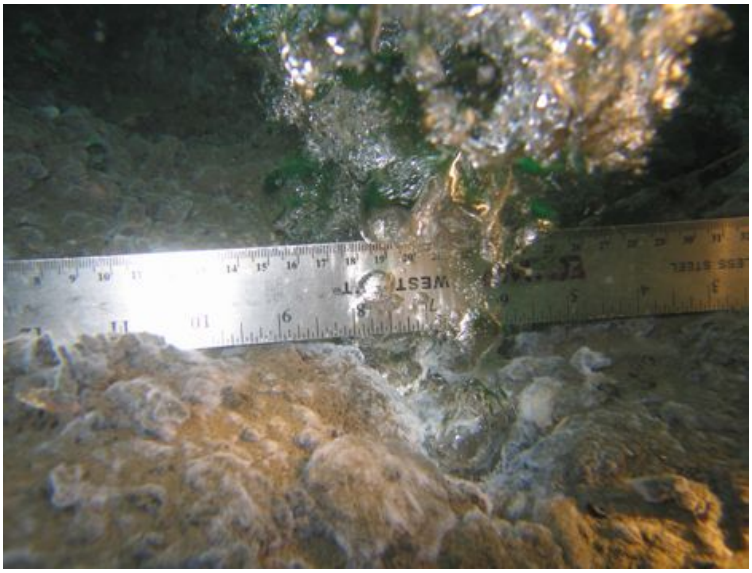
[72] D. Guggenheim (Director). (2006). **An inconvenient truth: A global warning.** To see a clip from the movie featuring Al Gore's description of this chart, see https://youtu.be/-JIuKjaY3r4?t=127.

only deals with CO_2 and its relationship to atmospheric heating, without incorporating the accelerating effects of methane emissions.[73]

Although the Academy hadn't yet named the phenomenon, our concern was (and is) that the truth could be far worse by 2050 if methane emissions are also taken into account.

Accordingly, when World Business Academy founder, Rinaldo Brutoco, first learned of the characterization that natural occurrences of methane gas bubbling to the ocean surface off the coast of Santa Barbara (see **Figure 5**) were "not such a big deal" from an environmental perspective,[74] he asked Academy Vice President, Madeline Austin, to arrange a meeting to discuss this with Dr. Lorenz Magaard, the former Chairman of the University of Hawaii's Department of Oceanography, Director of the International Center for Climate and Society, and Executive Associate Director of the International Pacific Research Center (IPRC). His question to Dr. Magaard was simple.

Figure 5. Methane bubbles seeping from the seafloor



"Is it possible," Brutoco inquired, "that the release of methane from hydrates could be related to rising ocean temperatures?" When Magaard responded that this was a possible explanation, Brutoco posed another question to the prominent oceanographer. "How would we know," Brutoco asked, "and still have time to potentially undertake effective remedial action?" Dr. Magaard responded that the only way to know would be if ocean temperatures continued to rise and "you begin to see similar methane releases taking place in other areas of the ocean with different topographic structures."[75]

---

[73] Joe Romm, "**Earth's thawing permafrost threatens to unleash a dangerous climate feedback loop**," ThinkProgress, April 11, 2017 [https://thinkprogress.org/global-warming-permafrost-thaw-97436404e353/]. There's little question that atmospheric heating is causing massive water pattern destabilizations. It's not the purpose of this paper to quantify or predict the severity of those activities. Rather, the purpose of this document is to point out the implications of methane releases – which are accelerating the overall calculation. Incorporating this added factor, the hockey stick becomes almost straight up.

[74] Jeremy Elton Jacquot, "**Methane Leaks from the Ocean Floor: Not Such a Big Deal**," Treehugger, December 23, 2007 [https://www.treehugger.com/clean-technology/methane-leaks-from-the-ocean-floor-not-such-a-big-deal.html] citing to S. Mau, D. Valentine, J. Clark, *et al.* (2007), "**Dissolved methane distributions and air-sea flux in the plume of a massive seep field**," Geophysical Research Letters, Vol. 34, Letter 22603 [https://doi.org/10.1029/2007GL031344].

[75] Rinaldo Brutoco, Madeline Austin and Dr. Lorenz Magaard, Honolulu, Hawaii, 2007.

The fact that one of the largest and best studied regions of marine seepage was situated in the Santa Barbara Channel made scientific investigations conducted by researchers at UCSB and other prominent institutions seem like hometown news. Already concerned that Gore's climate predictions failed to take methane into account, the fact that literally tons of methane emissions per day from the seafloor were being characterized as not a big deal environmentally, caused the Academy to intently watch for reports that similar releases were taking place elsewhere and thereby positively correlated with the rise in ocean temperature.

It didn't take long to conclude that what was happening near Santa Barbara was not an isolated incident. In 2008, more than 250 plumes of methane bubbles were discovered issuing from the seafloor offshore western Svalbard, close to the depth (400 meters) at which the hydrate stability zone outcrops at the seafloor.[76] Numerous subsequent observations of methane releases all over the globe have been made since 2008, including an unexpected seepage for hundreds of miles along the U.S. Atlantic margin from Cape Hatteras, N.C. to Cape Cod, MA.[77] This release apparently has the greatest intensity in those areas of the ocean experiencing the most dramatic temperature increases, including in the Arctic Sea, where water temperatures are forecast to warm by 2 – 8° C.[78]

Due to the effects of rising air temperatures associated with the increase in greenhouse gases (GHGs), in 2008, the Academy observed that permafrost was no longer staying permanently frozen. Approximately one-quarter of the Northern Hemisphere and an estimated 17% of the Earth's exposed land surface is underlain by permafrost.[79] The Academy hypothesized that because "the thermal state of permafrost is sensitive to changing climatic conditions and in particular to rising air temperatures and changing snow regimes,"[80] as increasing amounts of permafrost melted, larger volumes of methane would be released into the atmosphere; and

---

[76] Rachael James, *et al.*, "**Effects of Climate Change on Methane Emissions from Seafloor Sediments in the Arctic Ocean: A Review**," Association for the Sciences of Limnology and Oceanography (ASLO), Volume 61, 2016, pp. S283-S299 [https://aslopubs.onlinelibrary.wiley.com/doi/pdf/10.1002/lno.10307], citing to Westbrook, *et al.*, 2009. The methane emissions have been attributed, at least in part, to hydrate dissociation as a result of seasonal fluctuations in bottom water temperatures (Berndt, *et al.*, 2014), and warming of bottom waters in this area over the last 30 years (Westbrook, *et al.*, 2009; Thatcher, *et al.*, 2013).

[77] A. Skarke, C. Ruppel, M. Kodis, D. Brothers and E. Lobecker, "**Widespread methane leakage from the sea floor on the northern U.S. Atlantic margin**," Nature Geoscience, Volume 7, Pages 657-661 (2014) [https://www.nature.com/articles/ngeo2232].

[78] Antoine Berchet, Philippe Bousquet, Isabelle Pison, et al., "**Atmospheric constraints on the methane emissions from the Eastern Siberian Shelf**," Atmospheric Chemistry and Physics, 16: 4147 (2016) [http://doi.org/10.5194/ acp-16-4147-2016].

[79] Stephan Gruber, "**Derivation and Analysis of a High-Resolution Estimate of Global Permafrost Zonation**," The Cryosphere, February 2012 [https://www.the-cryosphere.net/6/221/2012/tc-6-221-2012.pdf].

[80] *Id.*, Biskaborn, *et al*. (citing multiple references).

together with methane produced by ruminants,[81] would further increase atmospheric heating.

In 2010, Dr. Magaard described the paradoxical risk and opportunity presented by methane hydrates and permafrost melt at the 2010 Pacific Congress on Marine Science and Technology:[82]

> Methane hydrates are the world's most abundant form of natural gas. Worldwide, the resource is twice the total of all other fossil fuels and found in sea-floor sediments and areas of arctic permafrost....
>
> So, methane hydrates may well be a significant contributor to solving the world's energy crises, and as such, it would be a blessing. Now it has to be determined how to extract methane hydrates safely from the ground without polluting the atmosphere. Methane is a greenhouse gas about twenty-five times more powerful (sic) than CO_2. Due to global warming there is already some outgassing from permafrost areas. Such outgassing will lead to more outgassing and to more global warming and so on. This unstable process is called runaway methane global warming and as such, it is a curse.

In 2014, some of the first pictures of permafrost taken in Siberia showed where the snow looked like it had been hit by an artillery shell due to sub-surface methane explosions.[83] Partial thawing of permafrost on the shallow (average depth of 45 meters) East Siberian Arctic Shelf (ESAS) is considered to be responsible for very high dissolved methane concentrations in the water column (> 500 nM) and elevated methane concentrations in the atmosphere, by 5–10% up to 1800 meters in height above the sea surface.[84]

According to a 2017 study,[85] as permafrost melts, a depressurization occurs that also accelerates a phase change from organic material into methane gas. In an analogy to the way a champagne cork is held in a bottle by a thin metal lid, the study likens subsea permafrost in the ESAS to the lid that holds the champagne cork in place, and observes that when the lid is removed or loses its integrity, champagne bubbles will push the cork out of the bottle just as substantial increases

---

[81] Thin Lei Win, "**Fighting Global Warming, One Cow Belch at a Time**," Reuters, July 19, 2018 [https://www.reuters.com/article/us-global-livestock-emissions/fighting-global-warming-one-cow-belch-at-a-time-idUSKBN1K91CU]. "Ruminants such as cattle, buffalo, sheep and goats produce nitrous oxide, carbon dioxide and methane, which is the most emitted gas and is released through belching. […] Livestock are responsible for about 14.5% of global greenhouse gas emissions according to the United Nations' Food and Agricultural Organization (FAO)."]

[82] Lorenz Magaard, "**Methane Hydrates – Blessing or Curse?**" Pacific Conference on Marine Technology, June 2010, p.72 [http://blog.hawaii.edu/pacon/files/2009/10/5.25.2010_PACON-Final-Program-File.pdf]..

[83] Jeremy Plester, "**All hell breaks loose as the tundra thaws**," The Guardian, July 20, 2017 [https://www.theguardian./environment/2017/jul/20/hell-breaks-loose-tundra-thaws-weatherwatch].

[84] *Id.*, Rachael James, *et al.*, citing to Shakhova, *et al.*, 2014.

[85] Natalia Shakhova, Igor Semiletov, *et al.*, "**Current rates and mechanisms of subsea permafrost degradation in the East Siberian Arctic Shelf**," June 22, 2017, Nature Communications, 8: 15872 [http://doi.org/10.1038/ncomms15872].

in methane emissions will be released as rising ocean temperatures destabilize massive solid methane hydrate structures on the seafloor. The study concludes that "there are more intricate mechanisms of permafrost disintegration, above ground and below the sea, not known before, that allow gas migration pathways to form well before the whole permafrost body is thawed through."[86]

Scientists estimate that of the 2,000,000 square kilometers that comprise the ESAS, 200,000 square kilometers (approximately 10%) are what they would call contemporary "*hotspots,*" areas where methane emissions presently occur far more often than in the lower background area. The difference between emissions in background areas and hotspots is several orders of magnitude, and should the hotspot areas double in size, there would be huge difference in the scale of emissions.[87] Finally, the study states that hydrates are just one form of possible methane reservoirs, in which pre-formed methane could be preserved in the seabed with proper pressure and water temperature conditions. The layer of hydrates only comprises a few hundred meters – a very small fraction when compared to thousands of meters of underlying gas-charged sediments in the ESAS.

Today, it is clear that methane releases are occurring all over the world, with the most extreme taking place in the shallow arctic waters due to higher temperature fluctuations relative to the rest of the oceans in the northern latitudes.[88,89] What has fueled the Academy's interest in the phenomenon is its concern about the potential implications of methane releases to accelerate the adverse effects of climate change – conceivably to an extent that reducing man-made CO_2 to zero (even if possible) would be insufficient to reverse the existential threat. Seeing what has transpired thus far, the concerns today go well beyond this.

TWO PRIOR MASS EXTINCTION EVENTS PROVIDE A CONTEXT

There is compelling evidence from geologic records that rapid and massive methane releases from marine hydrates accompanied two previous mass extinction events in the Earth's history.

The most recent of the two events took place approximately 55.8 million years ago during the Latest Paleocene Thermal Maximum (LPTM), also referred to by scientists as the "Initial Eocene"

---

[86] *Ibid*.

[87] Nick Breeze, "Subsea permafrost on East Siberian Arctic Shelf in accelerated decline," June 24, 2017 [https://envisionation.co.uk/index.php/blogs/nick-breeze-blogs/203-subsea-permafrost-on-east-siberian-arctic-shelf-now-in-accelerated-decline].

[88] Radboud University Nijmegen. "Worldwide Increase in Methane Bubbles Due to Climate Change," ScienceDaily, November 2017, Available online at https://www.sciencedaily.com/releases/2017/11/171122093100.htm

[89] Ralf Aben, *et al.*, "Cross Continental Increase in Methane Ebullition Under Climate Change," Nature Communications, November 2017. Available online at https://www.nature.com/articles/s41467-017-01535-y

(IE) or the "Paleocene-Eocene Thermal Maximum (PETM)" period. This period, which is marked by the largest mass extinction among deep-sea organisms in the past 93 million years,[90] is widely considered to be the best analog we have for contemporary global warming even though the rate of carbon being released into the atmosphere today is nearly 10 times ***faster*** than during the PETM.[91]

Oceanographers are able to use the composition of sediments and the fossil shells of marine organisms, which take up chemical substances from seawater as they grow, to estimate the ambient temperatures under which these organisms formed. Based on this technique, scientists estimate that approximately 2,000 gigatonnes of carbon entered the atmosphere and oceans at the same time as the PETM, causing sea surface temperatures to increase by 4-6°C, and deep-water temperatures to increase by 6-8°C, over a period of approximately 6,000 years.

Although geologic records provide a good picture of how climate changed during the period, "the origins of the greenhouse gases that apparently caused this event are less clear. The most likely explanation is the mass release of methane from sediments on the sea floor, where the gas was sequestered, as it is now, in a solid form as methane hydrate."[92] The PETM or "LPTM hydrate dissociation hypothesis," – as confirmed by analysis can be summarized as follows: [93]

> "Similar to the present day, vast quantities of [methane] … were stored as gas hydrate in the upper few hundred meters of continental slope sediments before the LPTM. Long-term global warming during the late Paleocene pushed the ocean-atmosphere system past a critical threshold, causing warm surface waters to sink and intermediate to deep ocean temperatures to rise by 4° to 8° C. This warming propagated into the sediments, converting once solid [methane] hydrates into free gas bubbles. This dissociation resulted in an increase in pore pressure at depth, leading to sediment failure and the release of massive quantities of [methane] into the ocean."

Analysis of carbon-isotope excursion (CIE) in a core sample with a continuous expanded LPTM section from the sub-tropical western North Atlantic Ocean provides critical evidence that rapid hydrate dissociation and massive methane input as the proximate cause for the mass LPTM

---

[90] Lee Kump, Timothy Bralower and Andy Ridgwell, "**Ocean Acidification in Deep Time**," Oceanography, Volume 22, No. 4 (Special Issue on the Future of Ocean Biogeochemistry in a High-CO2 World), December 2009, page 101 [https://www.jstor.org/stable/24861027].

[91] Penn State, "**Carbon release to atmosphere 10 times faster than in the past, geologists find**," ScienceDaily, June 2011 [www.sciencedaily.com/releases/2011/06/110605132433.htm].

[92] Phil Jardine, "**Patterns in Palaeontology: The Paleocene-Eocene Thermal Maximum**," Paleontology / Online, 2011, Vol. 1, Article 5 [https://www.palaeontologyonline.com/articles/2011/the-paleocene-eocene-thermal-maximum/].

[93] Miriam Katz, Dorothy Pak, Gerald Dickens and Kenneth Miller, "**The Source and Fate of Massive Carbon Input During the Latest Paleocene Thermal Maximum**," Science, Vol. 286, November 19, 1999, p. 1531 [https://science.sciencemag.org/content/sci/286/5444/1531.full.pdf].

extinction.[94] A high-resolution carbon isotope record of terrestrial organic material from the Fushun Basin in Northern China revealed "significant linear correlation with the marine carbonate CIE, implying that these events are likely attributable to recurring injections of ^{13}C-depleted carbon from submarine methane hydrates and/or permafrost,"[95] and reinforcing the global nature of these events.

The second mass extinction event for which scientists have found compelling evidence of a rapid release of methane from marine hydrate reservoirs is the Permo-Triassic, or end-Permian, which is also colloquially known as the Great Dying or the Great Permian Extinction. This extinction event took place between 252 and 251 million years ago; and is estimated to have killed approximately 90% of marine species, 70% of terrestrial vertebrate species, 30% of insect orders and an indeterminate percentage of terrestrial and marine plants, making it the greatest natural catastrophe ever experienced by life on Earth. Although the cause of the end-Permian mass extinction is hotly debated among scientists, the geologic record suggests that "***the emission of carbon dioxide from volcanic deposits may have started the world onto the road of mass extinction, but it was the release of methane from shelf sediments and permafrost hydrates that was the ultimate cause for the catastrophic biotic event***."[96] (*Emphasis added*)

This massive release of methane from marine hydrates has been referred to as a "methane burp;" and based on the geologic record, is described as follows:[97]

> "[Carbon isotopes] show a massive shift towards the light isotope, carbon-12, exactly at the time of the big extinction. Pulses of carbon-12 in the geological record are usually indicative of a volcanic eruption or a large die-off. Both certainly happened at the end of the Permian. But the carbon-12 pulse is far too big to be explained by these mechanisms alone. Calculations of global carbon budgets have suggested that, even if every plant, animal, and microbe died and was buried, altogether they would only account for about one-fifth of the observed carbon shift. The Siberian Traps [volcanic CO_2 emissions] would have added another fifth. Where did the remaining three-fifths come from?
>
> "The extra carbon-12 was probably buried, frozen deep under the oceans in the form of gas hydrates. These are extraordinary accumulations of carbon-12-rich methane locked up in cages of ice at very high pressure. If the atmosphere and

---

[94] *Ibid*., pp. 1531-2.

[95] Z. Chen, Z. Ding, Z. Tang, X. Wang and S. Yang, "**Early Eocene carbon isotope excursions: Evidence from the terrestrial coal seam in the Fushun Basin, Northeast China**," Geophysical Research Letters, 41, p. 3559 [https://doi.org/10.1002/2014GL059808]. ^{13}C-depleted carbon is a marine carbonate derived from organic carbon reservoirs on the Earth's surface such as submarine methane hydrates and/or permafrost (citing references).

[96] *Id*., Uwe Brand, Nigel Blamey, Claudio Garbelli, *et al.*

[97] University of Bristol, Earth Sciences, "**Wipeout**," New Scientist, Vol. 178, Issue 2392, April 26, 2003, p. 8 [http://palaeo.gly.bris.ac.uk/Essays/wipeout/default.html].

oceans warm up sufficiently, these gas reserves can suddenly melt and release their contents in a catastrophic way. The explosion of gas through the surface of the oceans has been termed a "methane burp". A very large methane burp at the end of the Permian could have produced enough carbon-12 to make up the deficit.

"The cause of the burp was probably global warming triggered by huge releases of CO_2 from the Siberian Traps. Methane is a greenhouse gas too, so a big burp raises global temperatures even further. Normally, long-term global processes act to bring greenhouse gas levels down. This kind of negative feedback keeps the Earth in equilibrium.

"But what happens if the release of methane is so huge and fast that normal feedback processes are overwhelmed?

"Then you have a 'runaway greenhouse'. This is a positive feedback system: excess carbon in the atmosphere causes warming, the warming triggers the release of more methane from gas hydrates, this in turn causes yet more warming, which leads to the release of more methane and so on. As temperatures rise, species start to go extinct. Plants and plankton die off and oxygen levels plummet. This is what seems to have happened 251 million years ago."

THE RISK OF UNINTENDED CONSEQUENCES

As Dr. Magaard observed in June 2010, the worldwide energy potential locked in methane hydrates represents approximately twice the total reserves of all other fossil fuels combined, making the commercial exploitation of these resources a very appealing prospect for oil and gas companies and governments wishing to locate new energy sources.[98] The Office of Fossil Energy estimates that "when brought to the earth's surface, one cubic foot of gas hydrate releases up to 180 cubic feet of natural gas, making it a potentially massive new energy source."[99]

"The USGS estimates that 106,000 and 876,000 trillion cubic feet (TCF) of resources exist globally; [and given this] huge potential, scientists have been drilling and studying gas hydrates all over the world, from the Gulf of Mexico to the northwestern United States, Canada, India, Japan, South Korea, China, Norway, and New Zealand."[100] The Department of Energy serves as the lead federal agency in the U.S. National Gas Hydrate R&D Program, which is an interagency effort

---

[98] *Id.*, Lorenz Magaard, June 2010.

[99] Office of Fossil Energy, "Frozen Heat: Exploring the Potential of Natural Gast Hydrates," May 10, 2017 [https://www.energy.gov/fe/articles/frozen-heat-exploring-potential-natural-gas-hydrates].

[100] EarthDate, "Fire in Ice," Bureau of Economic Geology at The University of Texas at Austin, Episode ED-068, [http://earthdate.org/fire-in-ice].

including representatives from the USGS, the Bureau of Ocean Energy Management (BOEM), Bureau of Land Management (BLM), Department of Defense Naval Research Laboratory (NRL), NOAA, and the National Science Foundation (NSF) that is "designed to maintain the US as a global leader in the science of natural gas hydrate."[101,102]

Internationally, there is even more robust development interest. "Japan conducted its second production test of these deposits [in May 2017]. China soon followed with its first attempt to do the same. The news caught natural resource experts off guard because most of them thought it would still be years before nations tried to turn these icy gases into commercial products. Production might still be a decade or more away in the U.S., which has been a quiet partner with Japan and China, although the Department of Energy has begun discussions with Alaska and Japanese interests about performing an extended production test in Alaska's North Slope."[103]

As Dr. Magaard also observed in 2010, the apparent blessing associated with commercializing this vast new source of carbon-based fuel could rapidly turn into a curse if efforts to extract these massive reserves end up contributing to runaway global warming.[104] The previously described artillery-sized craters that can be seen in the Siberian tundra from the natural release of gas as the permafrost melts,[105] illustrate one of many challenges associated with seeking to commercialize this hydrocarbon resource. A 2017 review article in *Scientific American* summarizes a number of others:

> Drilling into hydrates to mine energy could change [methane emissions seeping from seabed and permafrost hydrates]. Drilling and piping methane to the ocean surface could release the gas into the atmosphere. So could transporting it through pipelines. These kinds of leaks from production and transportation of natural gas resources have been well documented. Countries exploring methane hydrate production are still trying to properly design wells. Methane hydrates, after all, were largely responsible for corrupting the containment dome intended to stop the 2010 Deepwater Horizon oil spill rising from the ocean bottom; the viscous mixture clogged the dome and a redirection pipe intended to take leaking oil to a tanker waiting above. Tapping into thawing permafrost for methane -

---

[101] Interagency Technical Coordination Team of the National Methane Hydrate R&D Program, "**An Interagency Roadmap for Methane Hydrate Research and Development: 2015-2030**," May 24, 2013 [https://www.energy.gov/sites/prod/files/2013/06/f1/Roadmap%202013%20FAC%20Draft%205-28-13.pdf].

[102] U.S. Department of Energy, "**Gas Hydrates Research and Development**," Quadrennial Technology Review 2015, [https://www.energy.gov/sites/prod/files/2016/10/f33/Gas%20Hydrates%20Research%20and%20Development.pdf]. Providing descriptions of ongoing research and extensive citations references.

[103] Zack Colman, "**Should the World Tap Undersea Methane Hydrates for Energy?**," Scientific American, August 1, 2017 [https://www.scientificamerican.com/article/should-the-world-tap-undersea-methane-hydrates-for-energy/].

[104] *Id.*, Lorenz Magaard, June 2010.

[105] *Id.*, Jeremy Plester, 2017.

which does not necessarily mean methane hydrates - would also present similar risks in producing conventional natural gas.[106]

The Academy would be remiss not to identify the risk that unintended anthropogenic (manmade) consequences of commercialization could exacerbate the climate-change based risks associated with increasingly warmer ambient air and sea water temperatures, and reduced pressure due to receding ice sheets. The Academy has for nearly two decades advocated a roadmap for simultaneously replacing dependence on burning hydrocarbons with embracing new sources of energy that are technologically feasible, financially sustainable and eco-friendly.[107] For all the foregoing reasons, the Academy strenuously objects to the mining of hydrates for their natural gas potential as moving in the wrong direction.

MONITORING METHANE EMISSIONS FROM SPACE

Environmental Defense Fund (EDF) President, Fred Krupp, announced plans in April 2018 to develop and launch MethaneSAT, "a new satellite purpose-built to identify and measure methane emissions from human-made sources worldwide, starting with the oil and gas industry. [As Krupp explained in the TED Talk in which he announced the proposal], data from MethaneSAT is intended to give both countries and companies robust data to spot problem areas, identify savings opportunities, and measure their progress over time."[108]

MethaneSAT is currently scheduled to launch in 2021. Under the leadership of Jet Propulsion Lab (JPL) scientist and architect of NASA's Mars Exploration Program, Dan McCleese, a team of scientists from EDF, NASA, JPL and Harvard, seek to equip the satellite with sufficiently accurate data analysis and sensor technology to reveal methane's unique fingerprint and calculate as little as a 0.1% increase in methane emissions at ground level in order to track even minor methane emissions from fracked wells, landfills, and other terrestrial sources, and to "spot previously unidentified sources of methane pollution with each pass across a 125-mile wide swath of the planet as it flies over regions of the world that produce 80% of the world's oil and gas."[109]

As noted in the Introduction, methane is today estimated to be responsible for 25% or more of contemporary global warming. Figure 3, *supra*., shows that this contribution continues to climb well beyond the levels previously forecast by the IPCC and most climate scientists. "EDF has set

---

[106] *Id.*, Zack Coleman.

[107] *Id*., Jerry Brown, Rinaldo Brutoco and James Cusumano.

[108] Environmental Defense Fund, "EDF Announces Satellite Mission to Locate and Measure Methane Emissions," April 11, 2018 [https://www.edf.org/media/edf-announces-satellite-mission-locate-and-measure-methane-emissions].

[109] Environmental Defense Fund, "This scientist wants climate action, and is developing the satellite to make it happen," Medium, April 18, 2019 [https://medium.com/the-fourth-wave/this-scientist-wants-climate-action-and-is-developing-the-satellite-to-make-it-happen-aae35ce27f18].

a goal of reducing methane pollution from the oil and gas industry worldwide 45% by 2025."[110] The Academy strongly supports this work.

In 2022, an U.S. Interagency program researching gas hydrates seeks to "document the potential for ongoing climate change to affect the stability of coastal gas hydrates, and to evaluate the impact of gas hydrate degassing on atmospheric greenhouse gas concentrations."[111] It is the Academy's hope that the MethaneSAT technology can supply reliable data for such an assessment and the risk posed by methane releases occurring as a byproduct of global warming.

METHANE ACCELERATION

MethaneSAT was conceived and financed due to a growing awareness of methane's role in the climate crisis we are facing. The Academy's concern is that monitoring and regulating anthropogenic point source emissions simply cannot keep up with the natural release of methane resulting from the amount of atmospheric warming of air and oceans that has already taken place. The Methane Accelerator captures the idea that increasing levels of methane are being released as a result of rising CO_2 levels that have accumulated over the past 20 years and are continuing to increase atmospheric and oceanic temperatures every day; and that the release of this methane increases the warming and in turn further accelerates more methane to be released, and so on and so forth in a Vicious Circle, as described above.

The Academy believes there exists the very real possibility that we've reached a point where even achieving the CO_2 emission reduction levels contemplated by the Paris Agreement tomorrow morning would be too late, since the natural feedback actions are now increasing atmospheric heating at a faster rate than anthropogenic actions can relieve. Thus, if CO_2 is characterized as the kindling that starts a fire, then the methane hydrates locked in permafrost and seafloor sediment can be seen as giant logs that will create a massive thermal bonfire.

Scientists are working on improved methods for modeling methane hydrates,[112] and the advent of technologies such as MethaneSAT will hopefully increase the precision of future projections. In the meantime, it is certain an acceleration is occurring in the number of methane releases from hydrates all over the globe as atmospheric warming continues, and this increase in methane being released from marine hydrates and permafrost melt is taking place at the same time as a "surprising"

---

[110] *Id*., Environmental Defense Fund, April 2019.

[111] *Id*., Interagency Technical Coordination Team of the National Methane Hydrate R&D Program, page 31.

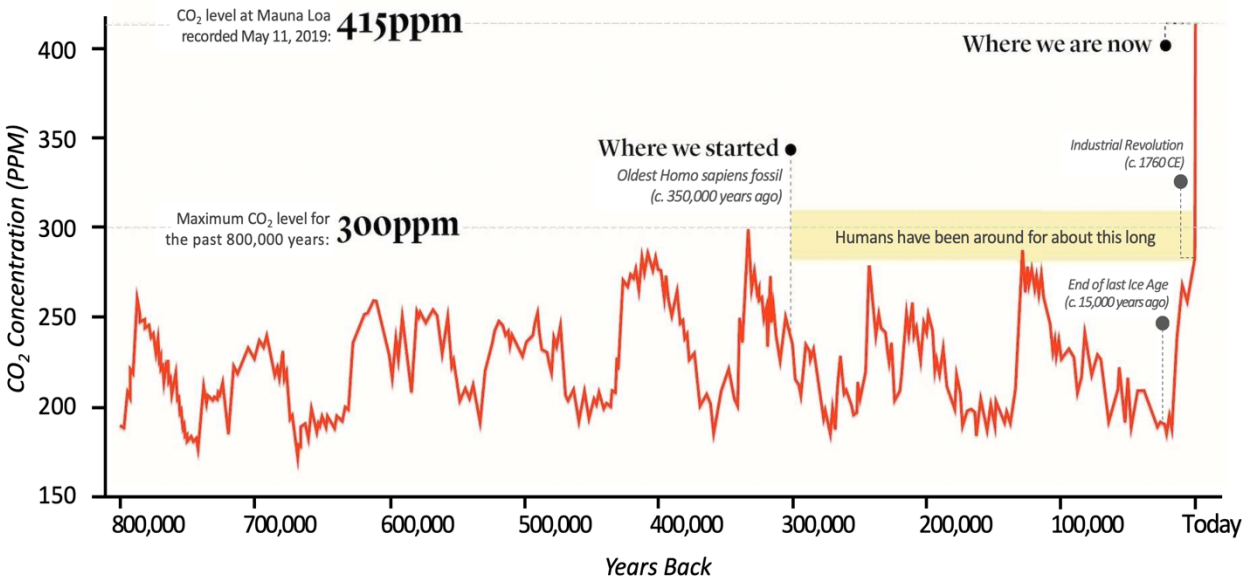
[112] David Archer, Bruce Buffett and Victor Brovkin, "**Ocean methane hydrates as a slow tipping point in the global carbon cycle**," PNAS December 8, 2009 106 (49) 20596-20601;[https://doi.org/10.1073/pnas.0800885105], presenting two global models of methane hydrate in the world ocean, one to simulate the detailed spatial distribution of methane and the other to assess its sensitivity to changing climate and simulating the vertical profiles of methane concentration in its three phases (dissolved, gas and hydrate). Such models are in their infancy.

multi-year increase in methane is identified (see Figure 3, *supra*) that scientists cannot explain using traditional models.[113]

We have documented at least two prior extinction events in which an abrupt, massive release of methane from marine hydrates is strongly suggested by the geologic record. The Academy recognizes that terms such as "abrupt" and "rapid" have considerably different meanings when expressed with respect to geologic time, and that in the context of events lasting tens of thousands of years, the release of methane over a period of just 500 years can be relatively abrupt and quite rapid. We are also aware of the limitations of ascertaining granular answers from core samples and fossil records, and thereby the challenges of knowing for how many years, decades or centuries, methane bubbled up from the seafloor in relatively small quantities akin to what we've experienced over the last few decades before the cumulative effects of these releases makes a mass extinction event unavoidable by any means.

"In *The Sixth Extinction*, journalist Elizabeth Kolbert documents the dizzying pace of modern ecological destruction. 'Just in the past century, CO_2 levels in the atmosphere have changed by as much -- a hundred parts per million -- as they normally do in a hundred-thousand-year glacial cycle,' she writes. 'Meanwhile, the drop in ocean pH levels that has occurred over the past fifty years may

Figure 6. Carbon dioxide levels haven't been this high in human history



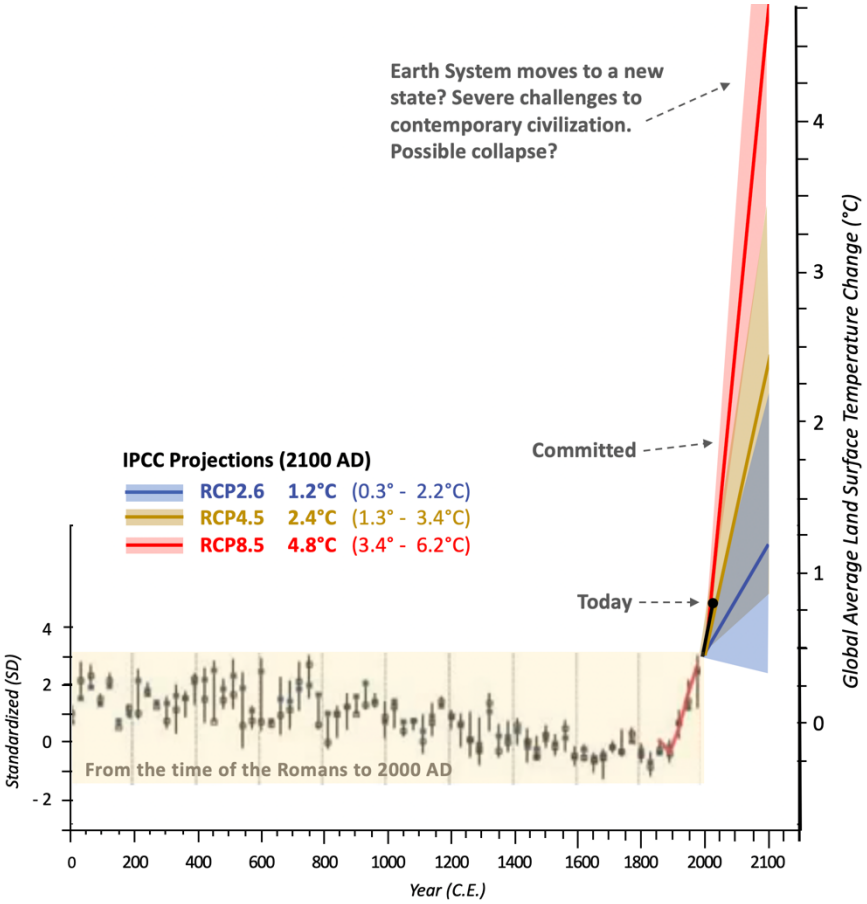
Data from the Scripps Institute of Oceanography at UC San Diego

[113] *Id*., Nisbet, Manning, Dlugokencky, *et al*., page 322. ("During the 4-year period 2014–2017, methane growth was sustained, each year bringing a major increment upon the remarkable growth of the previous year. […] In the late 20th and early 21st century pattern, single years of strong regional methane growth were typically followed by declines to the global background…. In marked contrast, recent year-to-year growth has been so strong that growth has been recorded everywhere. Thus, in the post-2000 context, 2014–2017 is very unusual, with few pronounced short-lived zonally averaged declines.")

well exceed anything that happened in the seas during the previous fifty million.' [On May 11, 2019], air temperatures around parts of the Arctic Ocean reached 84 degrees Fahrenheit, while the concentration of CO_2 eclipsed 415 parts per million for the first time in human history"[114] and, as shown in **Figure 6**, above, are now higher than at any point in the last 800,000 years.[115]

The May 6, 2019 publication of the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) report provides a number of additional sobering facts that reinforce the Academy's view that we are already well advanced in an existential crisis. Over the past 50 years, the IPBES report states, the Earth's biodiversity declined at a rate that is "faster than at any time in human history"[116] and the "global rate of species extinction [is] already at least tens to hundreds of times higher than it has averaged over the past 10 million years."[117]

Figure 7.
Comparing global average surface temperature since the time of the Romans with the IPCC's projections for 2100



Source: *Will Steffen, "The Anthropocene: Where on Earth are we going?" Big History Anthropocene Conference (2015). Yellow shaded area redrawn from PAGES 2K Consortium, 2013, which gives further information on the methodology used.*

Figure 7 shows a comparison of the estimated global average land surface temperatures over the last 2000 years with today, and then

[114] Casey Williams, "**The 'Great Dying' Has Begun. Only Transforming the Economy Can Stop It,**" OneZero, May 16, 2019 [https://onezero.medium.com/the-great-dying-has-begun-only-transforming-the-economy-can-stop-it-4eadd8f7ccf8]. Citing to Elizabeth Kolbert, **The Sixth Extinction: An Unnatural History**. Henry Holt and Company, New York (2014) and Jason Samenow, "**It was 84 degrees near the Arctic Ocean this weekend as carbon dioxide hit its highest level in human history**," The Washington Post, May 14, 2019.

[115] Alex Schwartz, "'**Record-setting' doesn't do our CO_2 levels justice. This chart does.**" Popular Science, May 14, 2019 [https://www.popsci.com/record-breaking-co2-graph-climate].

[116] *Id*., Sandra Díaz, Josef Settele, Eduardo Brondízio, *et al.*

[117] *Id*., Testimony of Sir Robert Watson.

shows how land temperatures experienced over this period during which modern civilization developed compare with the IPCC's latest projections for 2100.[118,119]

Even setting aside concerns that IPCC projections have consistently understated the rate and intensity of climate changes, as noted with regard to Exhibit 7, "from an Earth System perspective, you would get really worried about what this means for sustainability because compared to the 2,000-year period we've developed our contemporary civilization, compared to the natural variability our eco-systems, our agriculture systems, and so on, are designed to cope with, this is an enormous shock – this is like a meteorite strike on planet earth. […] The argument from a sustainability point of view is that if the system gets out of control [and follows the upper range of the IPCC forecasts], it is really a collapse scenario. It's hard for me to imagine even a modern, highly technical civilization coping with the changes of that rapidity and that magnitude."[120]

From the Academy's perspective, this is precisely the point. When the Methane Accelerator and the manifold ways that climate change of this magnitude are properly taken into account, we are already beyond the tipping point. Unless we proactively find ways to cool the Earth's surface, we face the end of human civilization as we know it during the lifetime of our grandchildren, if not our own children.

We do not make the foregoing declaration lightly, or without selecting our words carefully. By "end of human civilization as we know it," we mean that by 2050, climate-change induced destabilization and extreme weather events will have become so severe and so common that normal systems of government which maintain a modicum of order will devolve into a dystopian state where violence and raw force becomes the ultimate determinate of civilian behavior.

Now here's the good news. The Academy also firmly believes that we possess the technology necessary to reverse these trends, and thus the challenge we face – the defining challenge of our time – is whether we're able to muster the determination to agree upon, fund and apply these technologies before it's too late.

---

[118] Will Steffen, Wendy Broadgate, Lisa Deutsch, *et al.*, "The trajectory of the Anthropocene: The Great Acceleration," (2015). The Anthropocene Review, Vol. 2(1), pages 81–98. [https://doi.org/10.1177/2053019614564785] and the associated video presentation at https://www.youtube.com/watch?v=PJlEK6HJBk8]. Figure 7 is recreated based on Steffen's presentation and slides beginning at 22:30 into the video, citing to data from PAGES 2K Consortium.

[119] M. Collins, R. Knutti, J. Arblaster, *et al.*, "2013: Long-term Climate Change: Projections, Commitments and Irreversibility," In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY [https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf], Table 12.2, pages 1054-5.

[120] Will Steffen, "The Anthropocene: Where on Earth are we going?" Big History Anthropocene Conference, Sydney, Australia (2015) [https://www.youtube.com/watch?v=PJlEK6HJBk8] at minutes 30:10 – 34:00.

THE NEED FOR URGENT ACTION

The Academy has discussed this topic with other scientific groups, many of which have been reticent to openly discuss the implications of methane acceleration because it could create widespread panic if fully understood. Yet they privately agree that merely curtailing CO_2 emissions at this point is "too little, too late;" and to reverse the trends requires:

(1) CO_2 removal on a global scale, using both natural reforestation, ecosystem restoration, and direct air capture and sequestration technologies; and

(2) reducing ocean temperatures worldwide so that marine hydrates will stay in solid form rather than continuing to release methane in increasing quantities.

Because CO_2 is ambient at low altitudes in air and in seawater, its removal anywhere lowers CO_2 concentrations everywhere. The problem is the scale required to create a meaningful positive climate impact. The Academy believes that a carbon tax represents the best capital markets mechanism to make those parties who emit carbon bear the responsibility for its adverse effect, as well as a catalyst for adoption of alternative technologies with a reduced carbon footprint.

Consider the following analogy. If an individual opens a small restaurant, he or she is expected to operate with sanitary conditions and to responsibly dispose of the business' waste, or else risk its food license being revoked. The fossil fuel industry is the only industrial sector that is allowed to spew their waste into the air and water of the collective commons without paying a price. For everyone else, society expects the owner to manage their own waste, and to incorporate the cost of responsible waste removal in the price of the product or service they sell. This is precisely the function of a carbon tax – to account for the damage done by burning fossil fuels so that the damage of the waste being left in the air can be properly remediated.

In a promising breakthrough, developers of Direct Air Capture ("DAC") technology confidently project that with economies of scale, the cost per ton of CO_2 extraction from the air will be as low as $100/ton.[121,122] Three DAC plants are currently in operation and thousands more will be needed globally, which we anticipate will result in a manufacturing efficiency effect similar to Swanson's Law[123] and, in turn, bring DAC costs per ton down substantially more over time.

The Academy supports the imposition of a carbon tax of at least $100/ton in order to incentivize capital investment in DAC technology. At this price, fossil fuel companies who emit CO_2 would

---

[121] David W. Keith, Geoffrey Holmes, David St. Angelo, Kenton Heidel, "**A Process for Capturing CO_2 from the Atmosphere**," Joule, Volume 2, Issue 8, pp. 1573-1594, August 15, 2018 [https://doi.org/10.1016/j.joule.2018.05.006].

[122] Steve Hanley, "**Carbon Engineering Claims Direct Air Capture Of Carbon Costs Less Than $100 Per Ton**," CleanTechnica, October 5, 2018 [https://cleantechnica.com/2018/10/05/carbon-engineering-claims-direct-air-capture-of-carbon-costs-less-than-100-per-ton/].

[123] Wikipedia, "**Swanson's Law**," [https://en.wikipedia.org/wiki/Swanson%27s_law]. Named after SunPower founder, Ricard Swanson, holds that solar modules will drop 20% in price with every doubling in cumulative shipped volume.

pay at least as much as it costs society to recapture the CO_2 gas (and preferably a bit more to account for transaction costs) and either sequester or utilize it in a carbon-neutral or carbon-free manner.

With a respect to methane, the Academy believes we must reduce the amount of radiant energy in order to cool the Earth's surface and lower ocean temperatures, and thereby to slow the rate of ice melt and methane releases from permafrost and marine hydrates. We have reviewed a number of proposals that have been made for albedo[124] modification through direct climate interventions and/or geoengineering strategies such as stratospheric aerosols and marine cloud brightening as a means to cool the Earth's surface.[125,126] The Academy believes such proposals present unacceptably high risks and introduce the potential for numerous unforeseen and unmanageable adverse consequences.

As an alternative, the Academy has researched a strategy of locating a number of lightweight shade structures in low earth orbit above the equator in order to gradually reduce global temperatures while at all times retaining the ability to accelerate, slow or entirely discontinue the amount of shading in small or large increments. This approach, which the Academy refers to as its "*Earth Shades*" initiative, can be commenced incrementally using existing technologies and avoids the prospect of regrettable consequences since global temperatures will be able to be regulated by commands sent to the individual shades.[127]

For the reasons we have discussed, the Academy believes that unless substantial remedial action such as this is taken on a global scale, the beginning of the end of human civilization *as we know it* will occur by 2050, with the early indications becoming evident to everyone between 2025 and 2035 as a result of climate changes continuing to outpace the IPCC and other experts' consensus targets, increasingly extreme weather events, species extinctions, mass migrations to escape rising sea levels and crop failure, increases in violence between various groups fighting over diminishing resources, civil unrest and the increasing breakdown / distrust in traditional institutions.[128]

---

[124] "Albedo" is the proportion of sunlight that is reflected back to space.

[125] National Research Council. 2015. ***Climate Intervention: Reflecting Sunlight to Cool Earth***. Washington, DC: The National Academies Press [https://doi.org/10.17226/18988].

[126] Eli Kintisch, "**U.S. should pursue controversial geoengineering research, federal scientists say for first time**," Science, January 9, 2017 [https://www.sciencemag.org/news/2017/01/us-should-pursue-controversial-geoengineering-research-federal-scientists-say-first].

[127] World Business Academy, "**Earth Shades,**" Internal Workpaper due for release later in 2019. The Academy views Earth Shades as analogous to Liberty Ships, thousands of which were built during WWII. Such ships were simultaneously critical to the war effort and were powerful catalysts to strengthening the industrial capacity of America. (For additional information about Earth Shades, please contact us at (805) 892-4600 or by email at rinaldo@worldbusiness.org).

[128] Recognition of these unavoidable problems is already beginning. See, for example, Julia Hollingsworth, "**Climate change could pose 'existential threat' by 2050: Report**," CNN, June 5, 2019 [https://edition.cnn.com/2019/06/04/health/climate-change-existential-threat-report-intl/index.html?no-st=1559963958], citing to David Spratt and Ian Dunlop, "**Existential climate-related security risk: A scenario approach**," May 2019 [https://docs.wixstatic.com/ugo/148cb0_a1406e0143ac4 c469196d3003bc1e687.pdf].

Until we reverse the Vicious Circle in which we are now caught, such events will continue to increase as higher atmospheric and ocean temperature levels create these sorts of extreme weather events with increasing regularity and produce extreme heat and drought in between. Like the accelerating wave pattern of an oscilloscope, unless effective counter-measures are undertaken, increasingly severe weather events that occur with increasingly greater frequency are the foreseeable results of the Methane Accelerator.

Accordingly, there is a need for immediate action. The brief amount of time we have left in which to reverse global warming, protect humanity and the natural world from climate catastrophe requires dramatic remedial action on a WWII-scale of mobilization, as called for by The Climate Mobilization group.[129] The Academy shares this belief that a comparable "mighty endeavor" is required of this generation; and is the reason we have chosen to release this paper for publication on the 75th anniversary of D-Day, which historians and military strategists consider was a major turning point that ultimately led to Allied victory in the war.

CONCLUSION

In confronting climate change, we face a much different adversary, and a much more powerful one. At this time, only global solutions that can push the climate back into a state that we know is sustainable are of any utility. Nothing else will enable humanity to avoid hitting the brick wall towards which we are racing.

It is no longer a question of whether geoengineering should be considered, but rather a consideration of which strategies for cooling the planet are technologically feasible, present the fewest adverse consequences, have the best chance of success, and assure the least risk of unintended consequences. One thing is for certain: As Franklin Roosevelt said on this date exactly 75 years ago, we must "set upon a mighty endeavor, a struggle to preserve our Republic, our religion and our civilization, and to set free a suffering humanity."[130]

It is the Academy's sincere hope that the thought exercise underlying this paper will attract additions, refinements, re-publications, expansions and a sustained commitment to this mighty endeavor. Our time to reverse the Vicious Circle is limited; and our hope is that this analysis will help attract serious consideration, and in turn help preserve human civilization *as we know it*.

Rinaldo S. Brutoco, Chief Executive Officer
World Business Academy[131]
June 6, 2019

[129] The Climate Mobilization, [https://www.theclimatemobilization.org/].

[130] Franklin D. Roosevelt, "Prayer on D-Day, June 6, 1944," Franklin D. Roosevelt Presidential Library and Museum [https://www.fdrlibrary.org/d-day].

[131] Please direct all correspondence and inquiries to the World Business Academy at 2020 Alameda Padre Serra, Suite 135, Santa Barbara, CA 93101, (805) 892-4800 or by email to rinaldo@worldbusinss.org.