Methane Hydrate: An Apocalyptic Panacea

April 23, 2004

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Introduction

The modern industrialized world has demonstrated an insatiable appetite for energy-producing natural resources. Natural gas, coal, and oil have traditionally formed the big three staples of large-scale energy production, however the available worldwide reserves of the three are limited and have been slowly depleted as production has been increased to meet global demand. Crude oil, the precursor to gasoline, and the most versatile of the three, is often used as a metric by which the urgency of "non-conventional" energy source conversion is measured. The closer the worldwide reserves of petroleum come to exhaustion, the more critical it becomes to explore and leverage these new energy sources.

The exhaustion of worldwide petroleum reserves will not be a sudden abrupt occurrence, but rather a gradual transitional period through which costs steadily rise as production decreases. Figure 2 shows that a multitude of estimates exist for the start of this transitional period, ranging from 2003 to 2020, with most current estimates favoring the 2010-2020 range (Magoon). The imminence of this gradual disappearance of a familiar and cheap energy source has sparked significant interest in a replacement non-conventional energy source.

Methane Resources

From a gross estimated recoverable resource standpoint, methane hydrate presents itself as one of the most viable successors to petroleum. Figure 1 illustrates that if only a few domestic sources could be located, the total available methane hydrate resource available, while potentially less than 1% of the global available reserves, would *more than double the nation's current estimated remaining recoverable domestic resource from all discovered and undiscovered natural gas reservoirs* ("Methane Hydrates as a Resource"). Furthermore, the United States Geological Survey has estimated that the organic carbon content of world methane hydrate reserves exceeds the total carbon content of global coal, oil, and natural gas resources combined ("Natural Methane Hydrate").

With such an abundance of methane hydrate, a natural question is why we have not already migrated away from oil. The answer is that extracting and refining methane hydrate presents several unique technical challenges. The gas hydrate form is highly unstable and slight reductions in pressure or increases in temperature can trigger a chain reaction, causing the entire hydrate sample to sublimate into a massive quantity of corresponding gas. Methane has substantially greater heat retention properties than carbon dioxide and thus even small "methane burps" can have drastically greater impacts on environmental warming than a much larger release of carbon dioxide ("Global Warming").

Thus, the exploration and exploitation of methane hydrate reserves promises to inaugurate a revolutionary new energy source, but several technical challenges must first be overcome.

Methane Cycle

The oceanic methane cycle is a complex and intricate process, starting hundreds of yards beneath the ocean seafloor, and eventually impacting the entire biosphere. As Figure 3 illustrates, organic sediments beneath the seafloor form the basis of the cycle, providing the catalyst hydrogen and carbon that are used as an energy source by a primitive lifeform known as archaea that in turn produces methane gas. This methane gas rises into shallower regions and accumulates beneath the seafloor, dropping in temperature as it rises. Much of it remains in gaseous form, but a significant quantity enters into a gas hydrate state as the ambient temperature decreases and pressure increases. This hydrate state is generated when individual methane molecules form a bond with six water molecules and link together with other methane-water formations, crystallizing. This hydrate form is extremely unstable, requiring only slight variations in temperate and pressure to trigger a rapid sublimation (Kunzig, 38).

As fresh sediment is added to the seafloor, the ambient pressure is gradually increased, and at a certain point, the pressure increases to the critical point where the methane hydrate returns to the gaseous state. An extremely small amount of this gaseous methane eventually escapes through fissures in the seafloor known as cold seeps and enters the marine biosphere. The vast majority of this escaped methane is immediately consumed by a second species of archaea that works in tandem with bacteria that reduces sulfate in the surrounding sediment into hydrogen sulfide. This hydrogen sulfide is the primary food source of a number of underwater lifeforms that cluster around these cold seeps much like the animals that receive their sustenance from their thermal counterparts (38).

Methane Hydrate Instability

The underlying problem with this cycle is that it is not sustainable. Although almost 300 million tons of methane is reduced globally each year (Kunzig, 38), a significantly greater amount of methane is created in the sub-seafloor reaction than is consumed by the seafloor cold seep reactions. This causes an extensive buildup of methane in both gaseous and hydrate forms under the seafloor. The gaseous form is relatively stable, but the hydrate form remains intact only as long as the surrounding temperature and pressure remains in a narrow P/T curve. As further sediments accrue, the pressure can increase to a point where a substantial amount of hydrate sublimates at once. This, in turn, cause raise the pressure even more as the required volume increases, causing a local-area chain reaction, releasing even more substantial amounts of methane from hydrate form. When the volume of gas reaches the critical point, it breaches the seafloor barrier in an explosive action known as a “methane burp.”

Historical Examples

Methane burps often have wide ranging and potentially catastrophic effects. Evidence suggests that the Paleocene Epoch was ended 55 million years ago by a sudden significant increase in global warming through a large injection of greenhouse gases into the atmosphere. There is also a strong likelihood that many recent ice ages were also brought to a close by methane increases in the atmosphere. Non-climatic impacts of methane bursts have been tentatively linked to several mass extinctions and underwater landslides (Kunzig, 34).

One of the most spectacular landslides in recent history occurred at Storegga, a cliff off the coast of Norway. Evidence suggests that around 8,200 years ago an earthquake struck at a region that had been destabilized by large-scale sublimation of methane hydrate. When the earthquake struck, it created fissures that allowed the trapped gaseous methane to explosively escape, reducing surrounding pressure and triggering a chain reaction as the lower pressure caused other hydrate to abruptly transition back to gas state. This created a tremendous depression in the adjoining region, leaving a huge "hole" for water to rush into. The resulting tsunami may have reached heights of 65 feet and coasts as far away as Scotland. The discovery of methane burst craters off the Eastern coast of the United States in recent years has raised awareness of the possibility of such an event wiping out the Eastern seaboard (39).

Some geologists have linked methane bursts with mass extinction events. University of Oregon geologist Gregory Retallack has proposed that such a burst may have been responsible for the famous extinction at the end of the Permian Period. A chain reaction event releasing epic quantities of methane into the atmosphere could have resulted in global atmospheric oxygen depletion. Northwestern University chemical engineer Gregory Ryskin believes that the modern behavior of the Black Sea, which demonstrates sustained atmospheric methane concentrations, suggests that local concentrations of methane above the large water bodies during the Permian Period may have spontaneously ignited, creating a worldwide blanket of fire (39).

The instability of methane hydrate and the disastrous effects it can have on the environment have been two chief obstacles to its large-scale exploration and exploitation. However, a more important obstacle is the fact that the vast majority of methane deposits are spread across an extremely large surface area, with relatively low concentration. This makes recovery economically unviable. However, there has been some limited amount of success in the few regions in the world with high concentrations of extremely permeable methane hydrate. With a single high concentration source of hydrate, a single well has sufficiently high recoverability rates to sustain itself. High-permeability of the hydrate is equally critical, as the escaping gas from the hydrate must be allowed to escape to the surface where it can be collected. A low-permeability region would instead trap the escaping gas into large pockets that would eventually release in an explosive methane burst (Kerr, 947).

Current Research

Japan has been a large investor in early hydrate research, eagerly searching for a domestic source for the imported energy products that currently comprise 99% of its energy resources. Initial commercial-grade success by a multinational team with a test well in northwest Canada has demonstrated that hydrate-rich high-permeability regions present an economically viable energy source. Timothy Collett, of the United States Geological Survey, and one of the leaders of the Canadian project, points to this as proof of concept that methane hydrate will be an important future energy resource. He points out that the recovery of methane from coal beds, first experimented with over thirty years ago, now accounts for 8% of all United States natural gas production, so we can expect commercial methane hydrate production to follow a similar timeframe (Kerr, 947).

Summary

With all of the risks and current lack of a full understanding of the processes at work in the methane cycle, it is little wonder that large-scale commercial exploration and exploitation has not yet been undertaken. In our never-ending search to quench our thirst for energy-producing resources, we could end up destroying our planet. This remote, but very real possibility is made all the more real by the global impact of methane, both in the explosive bursts it often triggers on its release, and as a greenhouse gas once it has been released into the atmosphere. Unlike petroleum, natural gas, and coal deposits, which form relatively stable and enduring deposits, methane hydrate deposits are highly dynamic resources, constantly in motion. A coal bed, once formed, will not explosively release to the surface. An oil or gas reservoir may suffer blowouts, but these are limited events and can be controlled and stopped. However, the chain reaction nature of hydrate burps, with their corresponding mass sublimations, and the speed at which they operate, make any corrective actions almost impossible. The global effects of an uncontrolled release of methane are also far more catastrophic than a release of oil or gas. Oil and gas releases tend to be far smaller in scale and their environmental impact tends to be more localized. An oil blowout, for example, will often only affect the immediate surrounding region of the blowout. Methane bursts, on the other hand, tend to be on a much larger scale, and the global impact is far more substantial. Methane has twenty-seven times the heat retention properties of carbon dioxide as a green house gas ("Global Warming"). Thus, even a small burst of methane has a much greater impact on the earth as a whole.

Conclusion

The environmental impacts of methane hydrate, combined with the lack of high-yield sources and technical difficulties in exploitation present a unique set of challenges for the future. While available reserves of the big three energy sources remain sufficient to keep prices low, the amount of research devoted to finding new methods of developing this resource will remain small. However, as we continue to deplete our familiar energy sources at a steadily growing rate, the day will soon come when we must turn to methane hydrate as a primary energy source. Hopefully by that day we will have a far greater understanding of the methane cycle that will allow us to turn this resource into an energy panacea, rather than an apocalyptic ending to life as we know it.

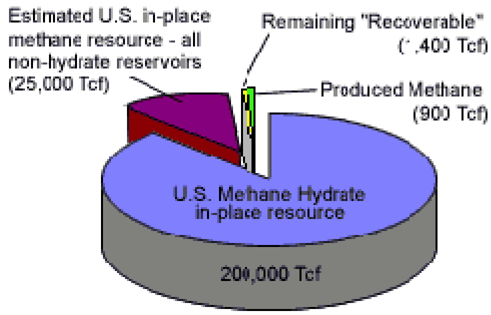

Figure 1

Table 2

Year of THE BIG ROLLOVER	FORECASTER
2003	Campbell, 1998
2004	Bartlett, 2000
2007	Duncan and Youngquist, 1999
2019	Bartlett, 2000
2020	Edwards, 1997
2010-2020	International Energy Agency, 1998

Figure 2

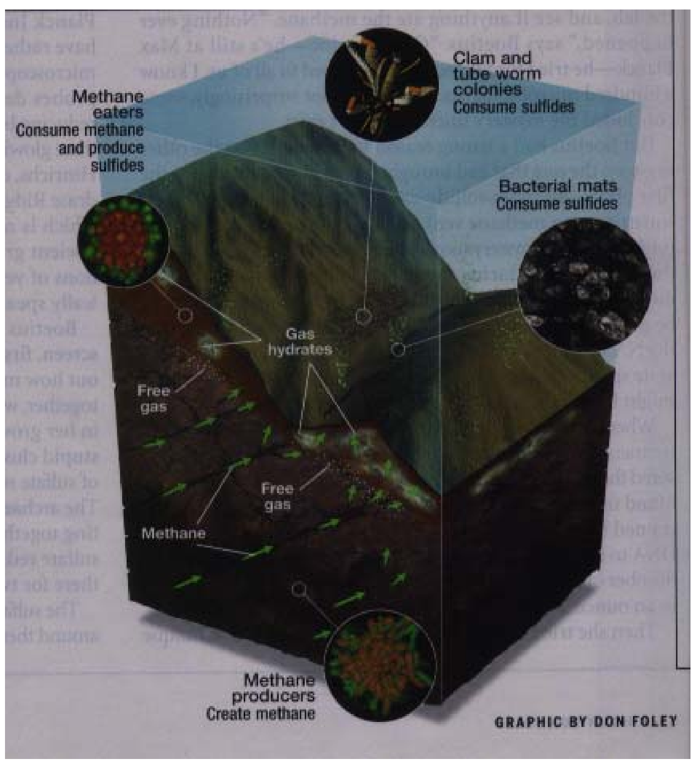

Figure 3

References

"EPA : Global Warming : Emissions." 15 August 2003. United States Environmental Protection Agency. 16 April 2004 <http://yosemite.epa.gov/OAR/globalwarming.nsf/content/Emissions.html>

Kerr, Richard A. "Gas Hydrate Resource: Smaller But Sooner." *Science*. 303 (2004): 946-947

Kunzig, Robert. "20,000 Microbes Under the Sea. Discover." *Discover*. March. 2004: 32-41.

Magoon, L.B. "ARE WE RUNNING OUT OF OIL?" United States Geological Survey. 16 April 2004 <http://geopubs.wr.usgs.gov/open-file/of00-320/of00-320.pdf >

"Methane Hydrates: All About Hydrates: Methane Hydrates as a Resource." 26 January 2004. National Energy Technology Laboratory. 16 April 2004 <http://www.netl.doe.gov/scng/hydrate/about-hydrates/resource.htm>

"Methane Hydrates: Methane Hydrates: All About Hydrates: Natural Methane Hydrate." 26 January 2004. National Energy Technology Laboratory. 16 April 2004 <http://www.netl.doe.gov/scng/hydrate/about-hydrates/about_hydrates.htm>