



Methane Hydrate as a Future Energy Source: Framing the Debate

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Abstract

The purpose of this paper is to challenge the industry to think about Methane Hydrate as a future energy resource, examine some of the operational problems, and postulate possible solutions for Methane Hydrate development.

The commercialization of Methane Hydrate as an energy source is an ongoing global research effort conducted by governmental agencies, scientists, academicians and private companies. Extensive coring and research already has taken place and will continue worldwide, along with some limited testing below "permafrost" in Canada¹. Methane Hydrate could be an exceptionally clean, ubiquitous fuel for future generations. The estimated reserves of Methane Hydrate in the Gulf of Mexico are substantial (Figure No. 1).

Industry awareness and participation in this tremendous pioneering opportunity is essential to the successful development of Methane Hydrate. Commercial recovery of Methane Hydrate could become the leading industry challenge of the 21st Century.

Introduction - What Are Methane Hydrates?

Methane Hydrate is a mixture of methane and water that is frozen into an ice. The crystalline structure of the frozen water molecules form a cage-like lattice which traps high concentrations of methane molecules². Methane hydrates generally form in two types of geologic environments: permafrost regions (where cold temperatures dominate) and beneath the sea in sediments off the outer continental margins (where high subsurface pressures dominate).

Methane hydrates can form at temperatures above the freezing point of water. While methane (the chief constituent of natural gas), propane, and other gases are included in the hydrate structure, methane hydrates are the most common. In deepwater environments, the resource exists in a solid frozen state in water depths around 500 meters from the mudline to as deep as 2,500 meters, depending on the geothermal gradient. It is difficult to predict this depth, as Boyle's law controls the occurrence of Methane Hydrates. The solid state form of Methane Hydrate will dissociate, or release free gas upon

a decrease of pressure, increase in temperature, or combinations thereof, depending on water depth, depth of burial and the geothermal gradient.

In the deepwater Industry, Methane Hydrates have been primarily recognized as a nuisance. The fact is, however, that Methane Hydrate could very well become the clean fuel of choice for future generations. If only one (1) percent of the methane hydrate resource could be made technically and economically recoverable, the United States could more than double its domestic natural gas resource base³.

Some Key Participants in Methane Hydrate Development

The Japan Exploration Company has cored Methane Hydrate in deepwater locations off of the southeast coast of Japan⁴, and cored and tested Methane Hydrate in the Mallik gas hydrate field⁵. Anadarko Drilling Corporation, Maurer Technology Inc., and Noble Engineering and Development are conducting a project to address the objectives of the U.S. DOE Methane Hydrates R&D program. The purpose of this project as outlined in their website is "to promote and apply advances in exploration and production to understanding and development of gas hydrates as a resource. This project (Figure No. 2) builds on continuing efforts in the geoscientific, academic and other research communities to identify quantify and predict production potential of hydrates. The goal of this project is to obtain the field data required to verify geological, geophysical and geochemical models of hydrates and to plan, design and implement a program to safely, economically, and environmentally responsibly drill and produce gas from Arctic hydrates⁶". Other notable groups actively involved in the R&D of Methane Hydrates in deepwater environments are the Ocean Drilling Program, JOIDES community⁷ (Figure No. 3), and the JAMESTEC (Japan, et.al.) Ocean Drilling Program in the 21st Century (OD21, Figure No. 4)⁸.

There is an enormous amount of research available in the public domain as to the characterization, composition, and the location of known deposits of Methane Hydrate. *However, the know-how to drill, complete and produce Methane Hydrate in commercial quantities is yet to be*

developed, and has received much less attention. Therefore, this paper will examine some of the HSE and operational aspects of Methane Hydrate recovery rather than dwell on the research aspects of Methane Hydrate.

Environmental Considerations: Recovery of Methane Hydrate

There are two basic environmental schools of thought regarding the recovery of Methane Hydrate, and they are diametrically opposed. First, a negative and very real consideration is that any sudden or catastrophic release of Methane Hydrate could result in a serious problem: the release of large quantities of free Methane to the atmosphere. In deepwater this could pose a hazard to MODU'S and shipping in general. There is also the long-term environmental effect resulting from an unplanned release Methane gas to the atmosphere. A second and more positive environmental consideration is that like natural gas (Methane), the resource is an exceptionally clean burning fuel, which results in low emissions of Greenhouse Gases. The challenge will be to develop safe and efficient means of recovery while ensuring environmental protection.

As stated in the Congressional Research Service website: "Sea floor stability refers to the susceptibility of the sea floor to collapse and slide as the result of gas hydrate disassociation. The safety issue refers to petroleum drilling and production hazards that may occur in association with gas hydrates in both offshore and onshore environments. The safety issue affects current oil and gas production as well as being of concern to possible hydrate development in the future" (Ref. 2). Some of the ancillary problems attributable to Methane Hydrate dissociation are also manifested in conventional oil and gas drilling and production operations. Seafloor stability therefore becomes a major hurdle to overcome. In fact, some believe that many current conventional deepwater surface operations could result in seafloor instability, and even seafloor collapse as a result of Methane Hydrate dissociations. Several events could occur and cannot be ignored:

- Uncontrolled gas releases during drilling.
- Collapse of well casings, and gas leakage to the surface.
- Subsidence of general sea floor infrastructures, including pipelines.
- Dissociation of Methane Hydrate while cementing due to exothermic reactions.
- Dissociation of Methane Hydrate while producing due to the higher temperature of produced fluids from deeper horizons.

In the marine environment, gas leakage to the surface around the outside of the well casing may result in local

sea floor subsidence and the loss of support for foundations of drilling platforms. The industry has conducted seminars regarding some of these issues, and considers some of the safety related issues to be crucial to the development of conventional deepwater hydrocarbon resources⁹.

History of Methane Hydrate Production

There is no proof that Methane Hydrate has ever been intentionally produced, although evidence suggests that Methane Hydrate has been removed from existing gas fields in Siberia. Figure No. 5 is a graph of what is believed to be natural gas production as a result of Methane Hydrate dissociation in the Messoyakha Gas Field. If the interpretation of the hydrate contribution to the pressure is true (not proven, but suspected) the gas corresponds to the regions B-C-D, and E-F-G is interpreted as the dissociated gas from hydrates. Since this field is shallow and below permafrost, the suspected Methane Hydrate production is thought to have been dissociated by normal pressure depletion according to the principles of Boyle's Law.

Some Challenges: How Will Methane Hydrate Be Recovered From deepwater Environments?

The challenge will be to provide a well system that might represent a combination of both conventional systems using current or new drilling and completion technologies, possibly coupled with quasi-mining techniques. Fundamental to any development will be solutions to some of the following issues outlined below:

Methane Hydrate Dissociation: The best dissociation methodologies for Methane Hydrate in deepwater environments are yet to be developed. This will be an evolutionary process, and much of the current R&D is directed at solving this problem. Dissociation methodologies will undoubtedly drive the ultimate wellbore design, construction, and producing processes.

Postulated Solutions: The solution to this endeavor could represent a combination of the three basic methodologies: Boyle's Law; Pressure reduction and/or temperature increase, and chemical techniques. The author feels that any methodology could require wellbore systems that facilitate:

- Circulation and/or injection of fluids.
- Dual gradient systems that allow for the application of wellbore pressure reduction at the reservoir.
- Techniques similar to those used for enhanced recovery of heavy oil (Steam Assisted Gravity Drainage, "SAGD")

- Application of heat transfer to the wellbore, for example controlled combustion using oxygen, or electronic heat transfer via umbelicals.

Defined and managed risk will most certainly be critical to the successful development of Methane Hydrates. The current industry coring and test programs underway are assuredly considering and managing risk. However as with any pioneering effort, accepting and mitigating risk is the key to success. In the opinion of the author, if an attempt is made to eliminate all risk then it could become extremely difficult to move forward.

A presumption of a risk-free project denies and defies the potential for real progress. The future test in and of itself should be designed to help define and mitigate, or minimize risks for future Methane Hydrate development. This should be a fundamental goal.

Seafloor Stability: This is possibly the greatest hurdle related to Methane Hydrate development. Reservoir subsidence is already an enormous problem in conventional oil and gas production. In some cases, even very deep reservoir subsidence has been transferred to the surface. Given that Methane Hydrate provides the cementation matrix mechanism for very soft muds and sands, then it follows that recovery of significant amounts of Methane Hydrate could result not only in subsidence, but possibly catastrophic reservoir collapse, eventually manifesting itself at the seabed. In the example of the Mallik cores, it is interesting to note that the Methane Hydrate product was indicated as high as 80% by volume¹⁰.

Postulated Solutions: Some industry experts¹¹ (along with the author) feel that a combination of conventional drilling and completion techniques, coupled with mining technology could be the part of the solution. The industry is also familiar with techniques such as solution mining in salt caverns. The precept of salt cavern development is that the structure of the cavern actually provides vertical support by shaping the top of cavern as an "arch" to promote cavern stability and prevent collapse (Figure No. 6¹²). The process would be to drill a conventional wellbore designed to enable typical salt cavern "leaching" techniques, the leaching process essentially becomes removal of Methane Hydrate utilizing pressure reduction, zonal heating, chemical removal, or a combination thereof.

Reservoir Stability: Reservoir stability while drilling through and completing Methane Hydrate intervals will be difficult. As mentioned earlier, Methane Hydrate provides the

matrix or the muds and very fine sands existing in shallow intervals below the mudline. Key considerations will be Methane Hydrate stabilization while drilling, solids control and mitigation, and maintaining hole integrity, especially in events such as tripping in and out of the hole.

Postulated Solutions: The industry has already experienced these problems in drilling for conventional resources. Fluids programs provide Methane Hydrate stability while drilling; casing, liner and coiled tubing drilling techniques could prove ideal for ensuring wellbore stability. Screen technology and expandable tubulars could also prove successful blended solutions for drilling and completion operations.

Multibore Systems: As a result of the generally accepted position that Methane Hydrate dissociation will most likely be a slow process¹³, especially if a "critical mass" release is to be avoided, then it follows that Methane Hydrate dissociation must be controlled, and that the resultant pseudo-PI will require exceptional amounts of reservoir exposure to enable commercial production of Methane Hydrate.

Postulated Solutions: The industry has developed the ability to construct multibore, multilateral systems. "Motherbore" configurations could also be required to provide the necessary reservoir exposure. Many of the previously mentioned technologies could facilitate this. Designer well technology will more than likely be fundamental to the solution of this problem.

Well Control: Even though conventional well control techniques could be applicable (at least partially), it will be necessary to develop techniques to mitigate uncontrolled dissociated release of Methane Hydrate. A major problem is that kick tolerances in these shallow Methane Hydrate-bearing, soft reservoir media will exhibit very narrow margins necessary to ensure casing seat integrity. This could be further complicated by the loss of cement bonding as a result of the exothermic reaction of cement dehydration.

Postulated Solutions: The solution to this problem will more than likely require a combination of industry technologies. This could include the ability to exchange heat or cooling to the wellhead (depending on the state of Methane Hydrate in the tubulars), insulated tubulars, composite insulated risers, and top-mounted BOP systems to enable direct BOP surface control. Dual gradient drilling techniques could also help improve margin tolerances. Equipment providing subsea external real time monitoring for free Methane could also be required. Development of cementing techniques, and cement (or other bonding

agents) that provides bonding without associated exothermic reactions could be essential.

Wellheads and Tubulars: It will be important to control the state of the Methane Hydrate product in drilling, completion, and producing phases of operations. Hydration post-Methane Hydrate dissociation in the drill or production strings could prove necessary to promote well control and general safety; however, untimely hydration could also be detrimental. Another factor to consider is related to the dissociation methodology in that Motherbore systems and Multibores could be required, and it is therefore conceivable that well systems could have dual-purpose requirements. Imagining this is akin to Enhanced Oil Recovery, except that injection and recovery of fluids could be simultaneous within the same wellbore systems.

Postulated Solutions: The transfer of heat to wellhead and well control components will be necessary. Insulated wellhead and well control systems, along with insulated tubulars should support these requirements.

Kickoff, Directional Techniques: The fact that the Methane Hydrate reservoir occurs at shallow depths, in fine, unconsolidated and very soft media renders conventional directional techniques difficult, not to mention issues such as establishing kick-offs with enough dynamic integrity to enable horizontal drilling and Geosteering techniques.

Postulated Solutions: Issues such as directional techniques with casing and coiled tubing require improvement, especially with large bore systems. Structural systems, SPARS or trusses that provide built-in directional techniques (directional guide capabilities) could also prove useful. A system such as this could also be instrumental in providing Multibores via smaller risers. Many of the previously discussed solutions could blend with assisting the development of directional techniques applicable to Methane Hydrate recovery.

There are many other challenges to be considered, and certainly more will evolve as Methane Hydrate R&D progresses. For example, many of the deepwater basins containing Methane Hydrate are located in harsh Metocean environments. Extraordinary time will be required to drill and complete Motherbore/Multibore configurations. Current development of improved top-mounted BOP systems will help facilitate this in that this will improve the utilization of the older generation MODUS's, reducing the horsepower, stationing requirements, and ancillary cost of operations.

Another challenge will be developing corporate Organizations that promote communications and cooperation between R&D Technologists, Research

Groups, Service Providers, and Operational personnel. The continuous alignment of goals and objectives between these parties will be essential to the successful development of Methane Hydrate as a major energy resource.

Some Additional R&D Questions

Before we can design a system that has HSE, maintenance of reservoir integrity, and seafloor stability as fundamental goals, characterization of effluents and volumes of solids in post-Methane Hydrate dissociation must be developed. There are fundamental questions that must be answered:

- What, if any fluids will displace the dissociated Methane Hydrate product?
- If the produced Methane is replaced by water, will the water freeze? If so, when will this event most likely occur?
- What will the drive mechanisms be?
 - Depletion Drive?
 - Water Drive?
 - Other?
 - None?
- After dissociation, what will be the anticipated volume of solids, and will there be any in-situ granular cementation mechanisms to aid in maintaining reservoir integrity?
- Is slow seafloor subsidence acceptable from an environmental perspective? In other words, absent catastrophic collapse, is any rate of subsidence acceptable?

Without a better knowledge of some of the above issues, it will be difficult to determine fit-for-purpose drilling and completion technologies. It will also be essential to determine a pseudo-Productivity Index¹⁴ which projects reservoir exposure required for a successful wellbore system. *The ultimate design configuration will be driven by methodologies of dissociation and the desired Methane Hydrate producing rates.*

Conclusions

There has been an extensive global research effort to understand the complexities of Methane Hydrates. The R&D has produced a substantial amount of knowledge, and efforts in this regard will continue. The deepwater drilling industry and services industry as a whole will play a crucial role in developing Methane Hydrate as a commercial energy source. Most definitely, this is an emerging technology that demands industry participation, particularly by the outstanding service sector for which the producing sector of the industry is so privileged to have as a resource. There will be many hurdles to overcome to

successfully produce commercial Methane Hydrates, the most substantial of which will be reservoir and seafloor stability. The Best Practice methodologies to dissociate Methane Hydrate are yet to be defined. The wellbore systems to enable the dissociation, or mining are also yet to be defined, and will be driven by the resultant pseudo-Productivity Index of Methane Hydrate derived from the dissociation techniques.

The industry has several technologies already developed, or under development which will facilitate this effort. Refinements of existing technologies, as well as new technologies will also be required.

Furthering our industry's understating and involvement in the development of Methane Hydrate could well be the future for our industry, and crucial to future generations and their environment.

Acknowledgments

The author used many public domain websites with appropriate references denoted herein. The list of references by no means represents the totality of those involved in the development of Methane Hydrate. The author also recognizes that there are a myriad of nations, organizations, and others who have participated in this tremendous pioneering effort. The Global community of participants therefore deserves much credit for substantial information already developed, and the ongoing research. This is a tribute to all of those *pioneers* involved.

Special thanks to John W. Wilson, Wilson and Associates Publishing Company for his industry editing expertise.

References

1. <http://www.gashydrate.com/mallik2002/home.asp>.

.... "An international consortium has been formed to establish a world research site for the study of continental natural gas hydrates in the Mackenzie Delta of northwestern Canadian Arctic. This site, the Mallik gas hydrate field, was discovered through an exploration well drilled by Imperial Oil Ltd. in 1971-1972. In 1998, several of the host organizations of the proponents of the Mallik 2002 proposal collaborated to complete a 1150 m deep scientific research well at the site where the first terrestrial gas hydrate core samples in the world were collected".... from the Canadian Geological Survey Website.

2. <http://www.gtionline.org/ref/member/library/3/030103/199a0001.htm>

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Source: James E. Mielke, Congressional Research Service, United States, February 8, 1999

3. http://www.fe.doe.gov/oil_gas/methanehydrates/

Fossil Energy.gov, a US DOE website

4. http://www.japex.co.jp/e/13_methane/index.html

From 1999 to 2000, JAPEX was successful in drilling and coring a methane hydrate layer for the first time at the Nankai-Trough offshore Japan, at a water depth of 945 meters. In Nankai Trough, quantitative well log determinations and core studies revealed at least 10 discrete gas hydrate layers, exceeding 110 m in total thickness, from 890m to 1106 m depth.

5. <http://www.gashydrate.com/mallik2002/home.asp>

... "High gas hydrate saturation values, which in some cases exceeded 80% of the pore volume, establish the Mallik gas hydrate field as one of the most concentrated gas hydrates reservoirs in the world."

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From Maurer Technology website, a Noble company.

7. <http://www.oceandrilling.org/Default.html>

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9. <http://www.netl.doe.gov/publications/proceedings/00/hydrates/appendix.pdf>

Gulf of Mexico Hydrates R&D Workshop Proceedings, August 2002.

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11. Tom Williams, Maurer Technology

12. <http://www.pbenergy.com/>

PB Energy Storage, Inc. is a developer, constructor and operator of subterranean storage caverns worldwide.

13. **Authors' note:** This is an unknown at this time; the Productivity Index ("PI") (described below) and the best practices employed for Methane Hydrate dissociation will ultimately determine the rate of dissociation required for commercial production.

14. Authors' note: The definition of Productivity Index will more than likely be very different than the classic conventional oil and gas $PI = \frac{Q}{P}$, however the principle will be the same in that the objective is to define the amount of product delivered for given dissociating rates and methodologies. In any event, a goal of ongoing research should be to define "Productivity" derived from energy material balances, and/or other typical reservoir techniques.

Figures

Figure 1: Estimated US Methane Hydrate Reserves

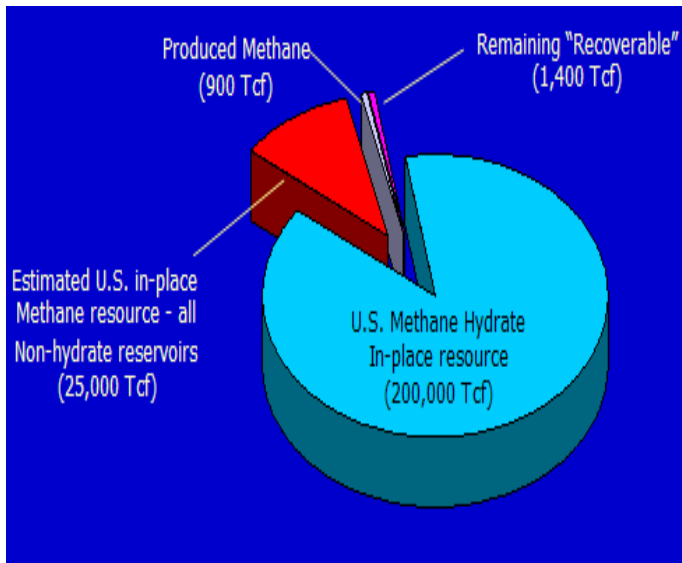


Figure 2: Anadarko et. al. Methane Hydrate Testing Time Line:

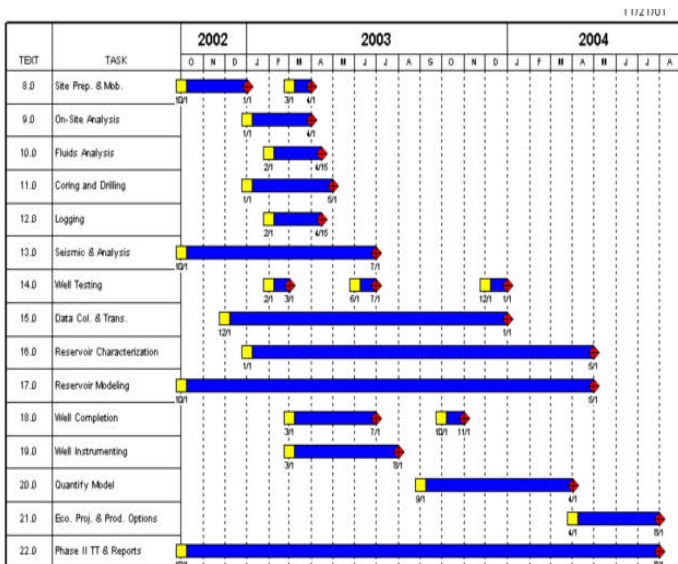


Figure 3: The ODP JOIDES Community

LEG 204
PRELIMINARY REPORT

8

increased considerably in the past several years because of increasing recognition that the large volumes of gas stored in these structures represent a significant fraction of the global methane budget (see review by Kvenvolden and Lorenson, 2001) and may, therefore, be a potential energy resource for the future (e.g., Milovoy and Sassen, 2002). Several authors have also suggested that sudden widespread dissociation of subsurface gas hydrates in response to changing environmental conditions may have had a significant effect on past climate (e.g., Revelle, 1983; Nisbet, 1990; Paull et al., 1991; Katz et al., 1999; Dickens, 2001). These effects remain speculative, as the volume of gas stored in the gas hydrate reservoir and its behavior during changing environmental conditions are currently poorly constrained.

In order to evaluate the economic potential of hydrates, their role as a natural hazard, and their impact on climate, we need to know the following:

- How are hydrates and underlying free gas distributed vertically and horizontally in the sediment?
- What is the gas hydrate inventory on Hydrate Ridge?
- What controls their distribution (i.e., lithologic controls on fluid migration and on hydrate nucleation and growth)?
- What are the effects of this distribution on the mechanical properties of the seafloor?
- How can hydrate and gas distribution be regionally mapped using remote sensing geophysical techniques?
- How does hydrate respond to changes in pressure and temperature resulting from tectonic and oceanographic perturbation?
- How can we use the isotopic record as a proxy for past tectonic and climate changes?
- Does the hydrate system harbor a rich biosphere? This question is of broad interest, particularly given the recent recognition that the biosphere extends deeper into the earth and that it has a larger impact on the geologic record than previously thought.

These questions were the focus of Ocean Drilling Program (ODP) Leg 204, which was dedicated to understanding the biogeochemical factors controlling the distribution and concentration of gas hydrates in an accretionary margin setting. Coring was guided by a three-dimensional (3-D) seismic site survey (Trehu and Bangs, 2001; Trehu et al., 2002) and by logging-while-drilling (LWD) data acquired at the beginning of the leg. These two data sets provided a "road map" to guide coring and sampling, enabling us to anticipate the depths at which gas hydrates should be expected and better focus special sampling tools. Accurate quantification of in situ hydrate and gas concentrations is difficult because of hydrate dissociation and gas loss during core retrieval (Paull and Ussler, 2001). A major focus of Leg 204 was, therefore, to acquire samples under pressure using the ODP pressure core sampler (PCS) system and the recently developed Hydrate Autoclave Coring Equipment (HYACE) system, which includes a laboratory transfer chamber for maintaining pressure while making physical property measurements. Extensive use was made of infrared (IR) cameras on the catwalk to rapidly identify potential hydrate-bearing samples and preserve them for careful study. Extra attention was also given to making high-resolution measurements of the chemistry of interstitial waters, resulting in a large number of interstitial water samples from this cruise. We also had frequent deployments of tools to measure in situ temperature and pressure, especially in zones where LWD data indicated rapid changes in the physical properties of the sediments, and conducted an extensive suite of downhole and two-ship seismic experiments.

Full Members

- Australia/Canada/Korea/Chinese Taipei Consortium for Ocean Drilling
- European Science Foundation Consortium for Ocean Drilling (Belgium, Denmark, Finland, Iceland, Ireland, Italy, Norway, Portugal, Spain, Sweden, Switzerland, and the Netherlands)
- Germany
- Japan
- The United Kingdom
- United States of America

Associate Members

- France (Level 3)
- People's Republic of China (Level 1)



Figure 5: Production history of the Messoyakha Gas Field.

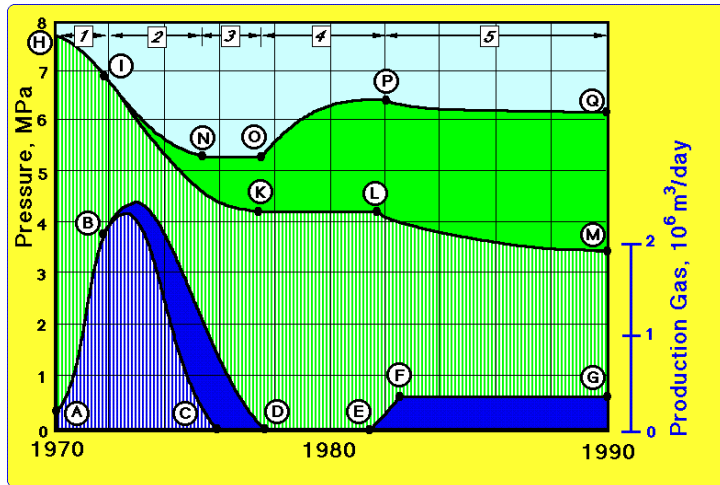


Figure 6: PB Energy Storage Solution Mining

