Technical Detail Report

# The State of the Art in Methane Hydrate Production Technology

## — Checking the Technical Assumptions of a PhD Thesis (2003) Against the Present (2026) —

**Subject thesis: Yuko Kawata, 'Evaluation of Introducing Methane Hydrate into the World Energy System' (PhD thesis, Department of Geosystem Engineering, Graduate School of Engineering, The University of Tokyo; advisor Prof. Kazuo Fujita, 2003)**

**Focus: an update and verification centered on production technology (production methods, production tests, technical challenges, numerical evaluation)**

Date: August 2026 / superscript numbers in the text correspond to the source list at the end

## Executive Summary

This report takes the assumptions, estimates, and technical targets for methane hydrate (hereafter MH) production technology presented in the 2003 PhD thesis as a baseline and checks them against actual technology trends over the subsequent 23 years. The key technical points are as follows.

- **■ Method selection was on target: depressurization, which the thesis rated as 'the most superior,' was subsequently adopted in all of Japan's offshore production tests (2013, 2017) and the US Alaska long-term onshore test (2023–2024), and was demonstrated as the de facto world standard. The thesis's method selection was technically correct.**
- **■ Hot-water injection / new methods: hot-water injection, which the thesis rated as 'inferior,' was not pursued as a primary production method and remains an auxiliary use of waste heat. The $CO_2$-replacement method not covered by the thesis (Ignik Sikumi, 2012)**

was proof-of-concept demonstrated but at low flow rates, and has not reached practical scale.

- ■ Long-term stable production not achieved: long-term stable production, which the thesis flagged as the most important 'future challenge,' remains unestablished after 23 years. Production tests were progressively extended (6 days → 24 days → about 10 months in Alaska), but commercial production on the scale of years of continuous operation and millions of $m^3$/day has not been demonstrated. Controlling sand and water production remains the core barrier.
- ■ Technical targets / cost: most of the technical targets the thesis quantified (about 50% reduction in drilling, subsea production system, and well-workover costs; a 2,000 m horizontal well; improved thermal efficiency) remain unachieved. Costs still greatly exceed LNG import prices, and no breakthrough has overturned the thesis's estimate (70.2–88.8 $/Boe).
- ■ Expansion of scope: shallow-type MH on the Sea of Japan side, which the thesis excluded, has been added as a new development target, requiring production/separation technology different from that for the sandy-layer type. Production-behavior prediction and economic evaluation using a numerical simulator (MH21-HYDRES) have been refined.
- ■ Institutional status: the government's interim evaluation of August 2024 concluded that 'there is no prospect for commercialization.' The commercialization target retreated from the then-planned 2016 to FY2030 or later.

## 1. Scope of the Production Technology Addressed by the Thesis (2003)

As a premise for the comparison, we organize what the thesis addressed technically. Chapters 4 and 7 of the thesis are the core of its production-technology evaluation.

- Target resource  Target resource: offshore MH. Focused on offshore areas on the grounds that they account for over 95% of original reserves (= corresponding to the Pacific-side sandy-layer type).
- Production method  Production concepts: three schemes were set — ① depressurization using a vertical well, ② depressurization using a horizontal well, ③ hot-water injection.

- **Economics  Cost estimation: development and production costs were computed with IHS Energy's QUE$TOR (oil & gas development cost-calculation software).**
- **Environmental  $CO_2$ evaluation: $CO_2$ emissions from production facilities and operating fuel were calculated by method and compared with LNG and oil.**
- **Applied technology  Introduction project: proposes a hybrid combined-cycle power plant fueled by produced MH gas and LNG (with hot-water injection, generation waste heat is used to make hot water).**

In its final chapter, the thesis itself explicitly stated the technical homework: 'an economic evaluation toward commercialization requires the completion of a numerical simulation model based on a detailed geological model' and 'the establishment of drilling and completion technology for long horizontal wells in shallow strata beneath deep water is required.' Below we compare against the degree to which this homework has been accomplished.

## 2. Technical Evaluation of Production Methods — the Thesis's Predictions and the Present

### 2.1 Depressurization: the thesis's 'most superior' rating was demonstrated

The thesis concluded that depressurization using a horizontal well is the most superior in both economics and $CO_2$ emissions (unit cost of 70.2 $/Boe at 10% IRR, $CO_2$ intensity of 58.4 g-C/Mcal — both superior among gas options). Depressurization lowers the pressure in the well to dissociate hydrate into water and gas; because no artificial heat input is needed, its energy efficiency is high.

**Present: Japan's first (2013) and second (2017) offshore production tests and the US Alaska long-term onshore test (2023–2024) all adopted depressurization[1][2][6][7]. Depressurization is established as the de facto standard method for MH production, so the thesis's technical evaluation can be said to have hit the mark.**

### 2.2 Hot-Water Injection: non-mainstream, just as the thesis's 'inferior' rating held

The thesis evaluated hot-water injection as inferior to depressurization in both economics and $CO_2$, because it consumes produced gas to make hot water (88.8 $/Boe, $CO_2$ intensity 79.6 g-C/Mcal, comparable to conventional oil). Even now, there is no case in which hot-water injection alone was adopted as the production method in a production test, and heating (hot water, electromagnetic, etc.) that complements depressurization remains auxiliary. The thesis's relative evaluation is consistent with the subsequent direction of technology development.

### 2.3 A New Method the Thesis Did Not Address: $CO_2$ Replacement ($CO_2$-$CH_4$ Exchange)

A new scheme field-verified after the thesis is the $CO_2$-replacement method. It recovers methane by exchanging it for $CO_2$ in the hydrate structure, with the feature of simultaneously targeting methane production and geological $CO_2$ storage. In 2012, the world's first field demonstration was conducted in the Ignik Sikumi #1 test at Prudhoe Bay, Alaska (ConocoPhillips, DOE, JOGMEC, USGS)[3][4].

- A $CO_2$+$N_2$ mixed gas was injected for 12 days, then recovered by 21 days of depressurization flowback. Total gas production over 37 days was about 24,410 $m^3$.
- Methane replacement does occur, but the replacement rate (reaction kinetics) and flow rate are low, so it has not scaled as a stand-alone commercial method. Currently, research continues from the perspective of combining it with depressurization and with CCS.

= The thesis's three-method framework was later supplemented by a fourth option, '$CO_2$ replacement,' but the structure in which depressurization is the mainstay has not changed.

#### State of the Art in Production Methods (Summary)

| Production method | The thesis's evaluation (2003) | State of the art (2026) |
|---|---|---|
| Horizontal well depressurization | Most superior (70.2 $/Boe, low $CO_2$) | Adopted in all production tests = the standard method. However, long horizontal wells remain unestablished |
| Vertical well depressurization | Low output, high cost (1,084 $/Boe) | Tests centered on vertical/deviated wells. Low productivity as the thesis noted |
| Hot-water injection | Inferior (88.8 $/Boe, high $CO_2$) | Not adopted as a primary production method. Heating remains an auxiliary use |
| $CO_2$-replacement method | (not covered) | Field-demonstrated in 2012. Low flow rate, below commercial scale. Research continues with CCS |

## 3. Track Record of Production Tests — the Thesis's Homework of 'Long-Term Stable Production'

The thesis cited long-term stable production as the greatest technical challenge for commercialization. As of 2003 no offshore production test had been conducted, but the subsequent set of tests has progressively verified this homework. The number of continuous production days has steadily extended: '6 days → 24 days → about 10 months.'

| Test | Date / location | Method | Main results | Technical achievements / challenges |
|---|---|---|---|---|
| 1st offshore production test | March 2013 / eastern Nankai Trough, Daini-Atsumi Knoll (water depth ~1,000 m) | Depressurization | Produced about 120,000 $m^3$ over 6 days (average ~20,000 $m^3$/day) | World's first offshore production. Interrupted on day 6 by sand production blocking the production line. Gas/water separation, well-pressure control, and sand control emerged as challenges |
| 2nd offshore production test | April–June 2017 / same area (2 wells) | Depressurization | AT1-P3: 12 days, 41,000 $m^3$ (intermittent sanding) / AT1-P2: 24 days, 222,500 $m^3$ (no sanding; heavy water production limited depressurization range) | Extended continuous production days. Sand control improved somewhat but was still unstable; greater-than-expected water production constrained the depressurization range |

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|---|---|---|---|---|
| Alaska long-term onshore test (Hydrate-01) | September 2023 – July 2024 / North Slope, Alaska, USA | Depressurization (long-term) | Conducted a long-term depressurization test over about 10 months (started 2023/9/19, completed 2024/7/30) | Obtained the world's first month-scale long-term production-behavior data. Aimed at establishing a methodology toward commercial production in Japan |

**Sources: 1st test[1], 2nd test[2], Alaska[6][7].**

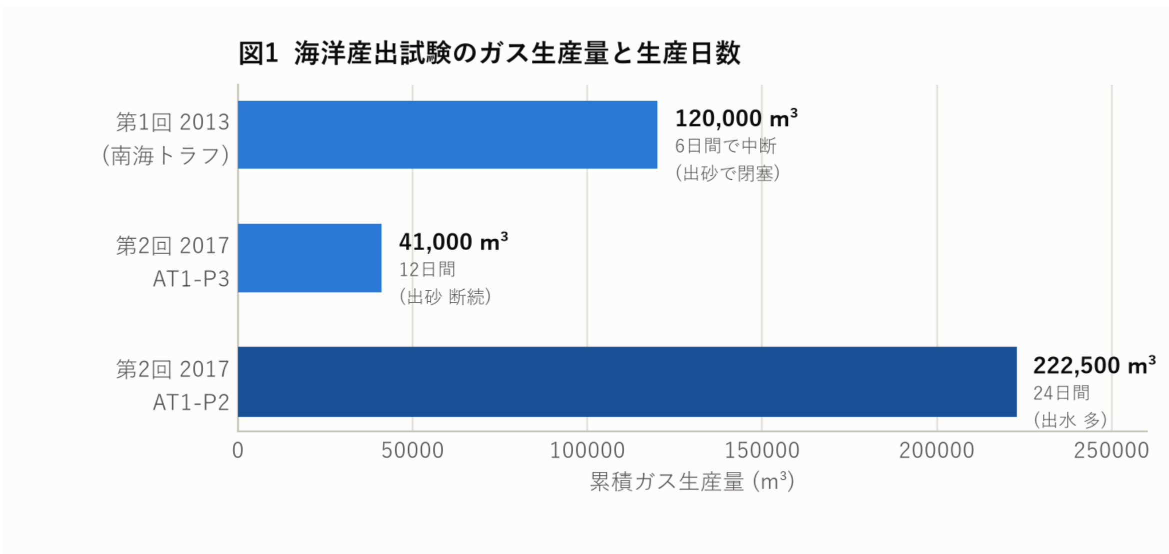


Figure 1 Gas production volume and number of production days in offshore production tests. Depressurization. Continuous production days extended from 6 to 24, but sand and water production prevented long-term stable production. The Alaska long-term onshore test (2023–24, ~10 months) is not included here because its production volume is undisclosed.

Regarding the thesis's point that 'the completion of a numerical simulation model based on a detailed geological model is required,' the production-behavior prediction simulator MH21-HYDRES was developed and is used for history matching against production-test data and for development economic evaluation and concept design[8]. The foundation for numerical evaluation has advanced greatly since the thesis.

## 4. Remaining Technical Challenges — the Degree to Which the Thesis's Technical Targets Were Met

Through the production tests, many of the challenges the thesis raised remain as 'challenges backed by real data.'

- **① Sand control  Sand-production control: sand influx from unconsolidated shallow sand layers is the biggest factor interrupting production. It was the cause of interruption in 2013 and occurred intermittently in 2017. Sand-control and well completion able to withstand long-term production remain unestablished.**
- **② Water management  Water management: large amounts of associated water accompany dissociation. In the 2017 AT1-P2 well, greater-than-expected water production limited the depressurization range to 5 MPa, suppressing productivity. Water treatment and pumping design are the keys to long-term production.**
- **③ Well technology  Well completion technology: the drilling and completion technology for the '2,000 m-class horizontal well in shallow strata beneath deep water' that the thesis explicitly identified has not yet been established. Production tests have centered on vertical and deviated wells.**
- **④ Flow assurance  Flow assurance: the risk of hydrate re-formation (blockage) within production lines. In the second test, the re-formation behavior in the produced-water line was also an object of analysis.**
- **⑤ Formation stability  Formation stability: the effect of dissociation on ground subsidence and well integrity. A geomechanical challenge that could become apparent with longer-term, larger-scale operation.**
- **⑥ Environmental technology  Methane leakage: leakage of dissociated methane to the seabed and atmosphere (methane has 20–80× the greenhouse effect of $CO_2$). An environmental-technology challenge the thesis did not emphasize, now taken seriously.**

### The Thesis's Quantitative Technical Targets vs. the Degree Achieved

| Technical targets set by the thesis (2003) | Aim | Degree achieved (2026) |
|---|---|---|
| Reduce drilling, subsea production system, and well- | About 40% total cost | Unachieved. No fundamental improvement in cost structure |

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|---|---|---|
| workover costs by about 50% | reduction | has been demonstrated |
| Depressurization using a 2,000 m horizontal well | Estimated reducible to 38.4 $/Boe | Unachieved. Drilling/completion technology for long horizontal wells not established |
| Improve the thermal efficiency of hot-water injection (use of other heat sources) | Improve the economics of hot-water injection | Limited. Hot-water injection itself dropped out as a primary production method |
| Long-term stable production (years of continuous operation, millions of $m^3$/day) | Prerequisite for commercial production | Unachieved. At most the ~10-month Alaska test stage |

## 5. Expansion of Resource Types — Shallow-Type MH the Thesis Did Not Address

The thesis mainly targeted the offshore sandy-layer type (Pacific side, Nankai Trough). Subsequently, shallow-type methane hydrate, common on the Sea of Japan side, was added as a new development target[9][10]. The two differ in occurrence form and require different production technologies.

| Category | Sandy-layer type (the thesis's main target) | Shallow type (targeted after the thesis) |
|---|---|---|
| Distribution | Pacific side (eastern Nankai Trough, etc.) | Sea of Japan side (off Joetsu, around Oki, etc.) |
| Occurrence form | Mixed with sand in the pores of sandy layers | Present as massive blocks at the seabed surface and in shallow mud layers |
| Production technology | Dissociated/produced by depressurization (production tests conducted) | Depressurization is hard to apply because it is massive. Recovery and methane-separation technology at the research stage |

| | | |
|---|---|---|
| Development stage | Development of long-term production technology; production-test preparation | Compilation of drilling-test results; experimental/analytical stage of separation technology |

The addition of the shallow type means that the thesis's technical framework (sandy layer + depressurization) alone cannot cover all of Japan's MH resources, giving rise to new development challenges in production and separation technology.

## 6. The Present State of Economics and Development Organization (Insofar as It Affects Technology)

- **Cost  Production cost: even in current estimates, MH gas production cost is said to greatly exceed the LNG import price, and no cost breakthrough has overturned the thesis's 70.2–88.8 $/Boe (about 3× LNG CIF). Commercialization requires cost reduction through technical progress and economies of scale, and demonstration of stable production.**

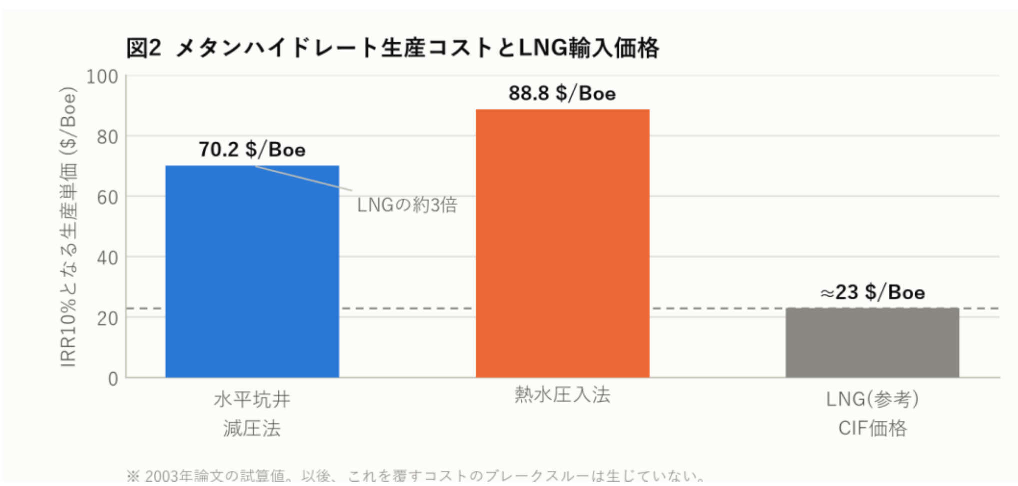


Figure 2  Methane hydrate production cost and LNG import price (estimated values from the 2003 thesis). No cost breakthrough has since overturned this.

- **Evaluation technology  Numerical evaluation: production-behavior prediction and economic evaluation / development-concept design using MH21-HYDRES have become established. The numerical-simulation foundation the thesis called for has been put in place.**

**Development organization: research moved from MH21 to the MH21-S R&D consortium. The R&D period for the sandy-layer-type Phase 4 was extended from the initial end of FY2022 to the end of FY2025[5][11]. The government's interim evaluation of August 2024 concluded that 'there is no prospect for commercialization'[5], and the commercialization target retreated from**

**the 2016 planned at the time of the thesis to FY2030 or later (with a private-led project to start in FY2023–2027).**

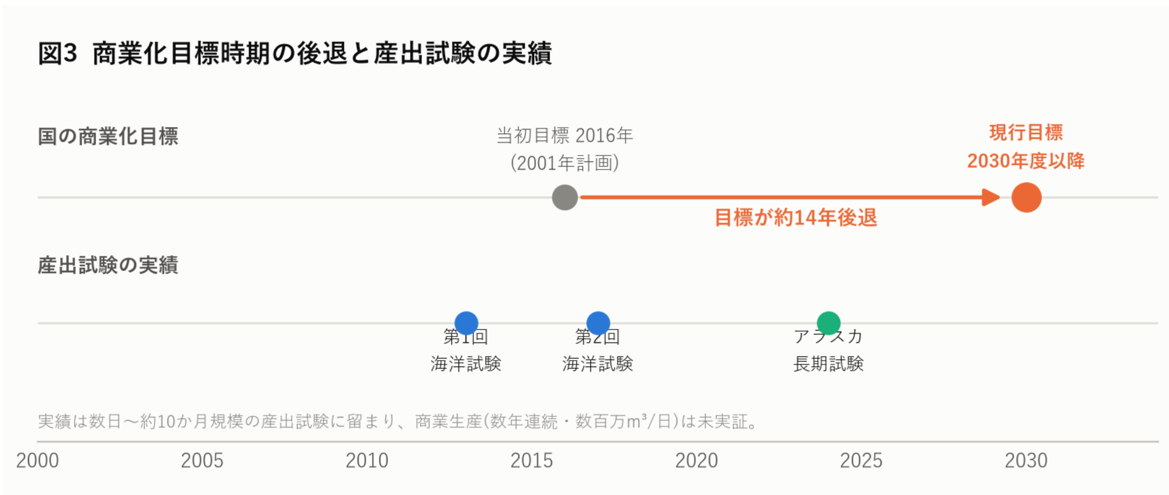


Figure 3 Retreat of the commercialization target date and the track record of production tests. The record is limited to production tests on the scale of a few days to about 10 months; commercial production (years of continuous operation, millions of $m^3$/day) is undemonstrated.

## 7. Technical Overview

| The thesis's technical propositions (2003) | Verification result | Assessment |
|---|---|---|
| Depressurization (especially horizontal wells) is the most superior | Depressurization adopted and demonstrated in all production tests | Hit |
| Hot-water injection is inferior | Not adopted as a primary production method | Hit |
| Vertical wells have low productivity | Low productivity confirmed in tests as well | Hit |
| Long-term stable production is the greatest challenge | Still unestablished after 23 years (at most a ~10-month test) | Unachieved (challenge ongoing) |
| Drilling/completion of long horizontal wells is needed | Not established | Unachieved |

| | | |
|---|---|---|
| About 50% cost reduction is needed | Fundamental reduction undemonstrated | Unachieved |
| Detailed numerical simulation is needed | Put in place with MH21-HYDRES | Achieved / advanced |
| (Unforeseen) $CO_2$-replacement method | Field-demonstrated in 2012 | Unforeseen development |
| (Unforeseen) Shallow-type MH | Newly targeted for development on the Sea of Japan side | Unforeseen development |
| (Unforeseen) Greenhouse effect of methane leakage | Taken seriously as an environmental-technology challenge | Unforeseen development |

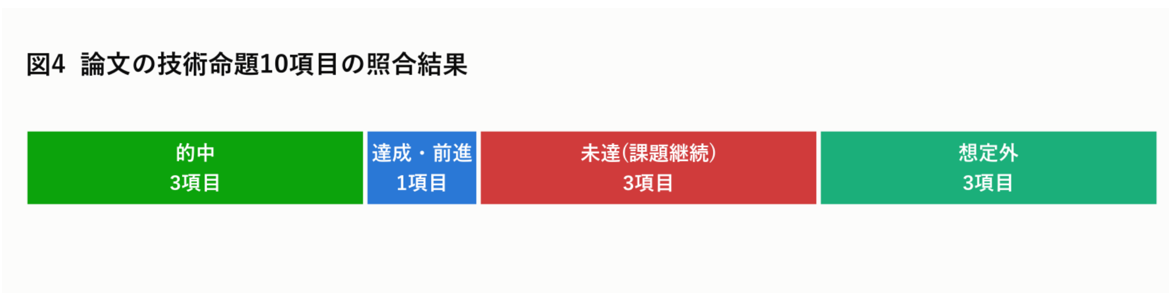


Figure 4 Verification results for the thesis's 10 technical propositions. Hits = superiority of depressurization, inferiority of hot-water injection, low productivity of vertical wells / Achieved-advanced = numerical-simulation development / Unachieved = long-term stable production, long horizontal wells, major cost reduction / Unforeseen = $CO_2$-replacement method, shallow-type MH, methane leakage.

In conclusion, the thesis's technical evaluation of production methods (superiority of depressurization, inferiority of hot-water injection, low productivity of vertical wells) has been borne out by subsequent demonstration. On the other hand, the technical targets the thesis quantified as 'future challenges'—long-term stable production, long horizontal wells, and major cost reduction—remain mostly unachieved after 23 years. In addition, elements unforeseen by the thesis—the $CO_2$-replacement method, shallow-type MH, and methane leakage—have joined the current points of technical debate.

## Sources


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※ This report is an interim deliverable that, starting from the technical descriptions in the 2003 PhD thesis (production methods, estimated values, technical targets), checks the current state of the art against public information. Quantitative values are as of the time of each source.