ELMİ İŞ Beynəlxalq Elmi Jurnal. 2025 / Cild: 19 Sayı: 9 /104-107 ISSN: 2663-4619
SCIENTIFIC WORK International Scientific Journal. 2025 / Volume: 19 Issue: 9 / 104-107 e-ISSN: 2708-986X

DOI: https://doi.org/10.36719/2663-4619/121/104-107

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The Exploitation Potential and Economic Efficiency of Gas Reserves

Abstract

Natural gas hydrates (NGH) are increasingly regarded as a strategic unconventional energy resource with reserves estimated to exceed the combined carbon content of all conventional fossil fuels. Their exploitation offers significant potential for addressing future global energy demand, ensuring energy security and supporting the transition to a low-carbon economy. However, the economic viability of NGH remains uncertain, as current production levels are well below the thresholds required for commercial success. Continued technological innovation and cost reduction are expected to narrow this gap, making NGH commercialization a realistic prospect in the coming decades.

Keywords: *natural gas hydrates (NGH), unconventional energy resources, low-carbon transition, economic efficiency, commercialization*

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Qaz ehtiyatlarının istifadə potensialı və iqtisadi səmərəliliyi

Xülasə

Təbii qaz hidratları (NGH) getdikcə, ənənəvi bütün fosil yanacaq ehtiyatlarının ümumi karbon miqdarını üstələyən ehtiyatlara malik strateji qeyri-ənənəvi enerji resursu kimi qiymətləndirilir. Onların istismarı, gələcək qlobal enerji tələbatının ödənilməsi, enerji təhlükəsizliyinin təmin olunması və aşağı karbonlu iqtisadiyyata keçidin dəstəklənməsi baxımından böyük potensiala malikdir. Bununla belə, NGH hasilatının iqtisadi cəhətdən səmərəliliyi hələ də qeyri-müəyyəndir. Çünki mövcud hasilat səviyyələri kommersiya uğuru üçün tələb olunan həddən xeyli aşağıdır. Texnoloji innovasiyaların davamı və xərclərin azaldılması bu fərqi aradan qaldıra bilər və NGH-in kommersiyalaşdırılmasını, qarşıdakı onilliklərdə daha real perspektivə çevirə bilər.

Açar sözlər: *təbii qaz hidratları (NGH), qeyri-ənənəvi enerji resursları, aşağı karbonlu keçid, iqtisadi səmərəlilik, kommersiyalaşdırma*

Introduction

The exploitation potential and economic efficiency of gas reserves depend on a number of factors such as the size of the gas field, its technical and economic indicators, price fluctuations, and the sales market for gas. To assess the potential, geological data, technical studies, and market analyses are carried out. Economic efficiency, on the other hand, is determined by indicators such as production costs, capital investment, technology, energy tariffs, and the geopolitical situation.

Although industrial civilization has achieved significant progress over the past two centuries, it has also led to increasingly severe environmental and climate problems. The low-carbon transformation of energy use is a key pillar in reducing CO_2 emissions toward a carbon-neutral world.

In the future, renewable energy sources such as solar and wind may dominate our energy balance entirely; however, since their current share in energy supply is still very low, it remains uncertain when this will occur (Max & Johnson, 2018).

According to BP's *World Energy Statistical Review*, in 2021 renewable energy accounted for only 18% of total primary energy consumption worldwide (BP, 2022). In the transition to a low-carbon energy future, natural gas is considered a clean and efficient energy source and, as an alternative to coal and oil, is expected to play the role of a transitional fuel during the shift to renewable energy (Anwar, 2016; Chong et al, 2016).

With the acceleration of global industrialization, the demand for natural gas worldwide is projected to increase sharply in the coming decades and reach 4.9 trillion cubic meters by 2040 (Wu et al, 2022). Against the backdrop of the depletion of conventional (traditional) natural gas reserves, the exploration of unconventional gas resources has become increasingly important (Vedachalam et al, 2015; Kong et al, 2018). In this context, natural gas hydrate (NGH) is an ice-like solid formed under conditions of high pressure and low temperature through the combination of gas and water molecules, and it is recognized as an unconventional gas resource (Sloan & Koh, 2007).

Research

NGH contains the largest remaining natural gas reserves on Earth. According to estimates, the total carbon content of NGH is approximately twice the sum of all other fossil energy resources, including oil, coal, and natural gas (Makogon, 1981; Englezos, 1993). NGH reserves have been identified globally, particularly in polar regions—in areas associated with permafrost both on land and offshore—as well as in the sediments of continental slopes. Kvenvolden (1988) notes that 90% of the world's oceans are considered potential sites for NGH deposits. Theoretically, when appropriate expansion coefficients are taken into account, 1 m^3 of NGH can release 164 m^3 of natural gas under standard conditions (Kvenvolden, 1988).

According to preliminary estimates, the total global reserves of NGH amount to approximately 1.5×10^4 trillion cubic meters (Makogon et al., 2005). This volume of reserves is sufficiently large to compensate for the depletion of conventional oil and gas resources. Consequently, NGH is regarded at the international level as a strategically and commercially promising resource in the 21st century. Its industrial development plays an important role in optimizing the global energy balance, promoting green growth, and achieving carbon neutrality by peaking carbon emissions.

The extraction of natural gas from NGH (natural gas hydrate) deposits can theoretically be carried out using one of three main methods, or a combination of them (Moridis & Sloan, 2007; Walsh et al, 2009; Max & Johnson, 2018):

1. Depressurization: In this method, the pressure of the system is reduced below the equilibrium pressure at the existing temperature, which destabilizes the hydrate structure and releases natural gas. This method is considered the most preferred technical approach in gas production.

2. Thermal stimulation: In this method, the temperature of the system is increased under existing pressure conditions to a level above the equilibrium temperature. As a result, the hydrate loses its stability and releases natural gas.

3. Injection of inhibitors: In this technology, inhibitors such as salts or alcohols are used to alter the stability zone of the hydrate. These substances shift the equilibrium curve toward lower temperatures and higher pressures, leading to hydrate dissociation and gas release.

Among these methods, depressurization is considered the most efficient. It offers both technical and economic advantages and is regarded as the most feasible option for industrial-scale application.

The industrialization of NGH proceeds through five main stages: theoretical research and simulation, exploratory production testing, experimental production testing, pilot-scale production testing, and finally, commercial production (Hao, 2022). In 2017, China carried out the world's first successful offshore production test from clay–silt type NGH reservoirs. This process continued uninterrupted for 60 days and resulted in the production of 30.9×10^4 cubic meters of gas (Li et al, 2018). Three years later, in 2020, the next test set a world record in NGH production. During 30 days of continuous operation, total gas output reached 86.14×10^4 cubic meters (Ye et al, 2020).

Due to these significant results, China has already entered the pilot-scale testing stage of NGH production. At present, the country is accelerating efforts to achieve commercial-scale NGH production by 2030. This development holds major importance not only for China's strategic energy security but also for the green and sustainable future of global energy.

As with other conventional and unconventional energy resources, before starting industrial-scale production of natural gas hydrates (NGH), the economic efficiency of the process must be evaluated (Chen et al, 2022). Numerous factors must be considered to determine whether an NGH project is economically viable. Among these, the economic production indicator is of particular importance (Wu et al, 2021). However, to date, only a limited number of quantitative analyses have been conducted regarding the economic outcomes of NGH production. Based on previous NGH industrialization studies (Yamamoto et al, 2014; Yang et al, 2014; Li et al, 2018; Ye et al, 2020). Wu et al. (2021) concluded that the economic production indicator should be 30×10^4 cubic meters per well per day for onshore deposits, and at least 50×10^4 cubic meters per well per day for offshore reservoirs.

Yet, these indicators are two to three times higher than the results of current pilot production tests. Nevertheless, the production level required for economic feasibility in NGH exploitation is not a fixed value. With the advancement of low-cost extraction technologies, this threshold is likely to decrease over time. This would enhance the economic viability of NGH production, making its commercialization more realistic and attainable.

Since the technology for commercial-scale NGH production has not yet been fully developed, investigating the threshold of economic production is of particular importance for understanding the gap between pilot test results and commercial production. It should be noted that due to the lack of sufficient field data, very few studies have been conducted on the evaluation of the economic indicators of NGH industrial production in the South China Sea. This remains one of the main gaps in the development of commercial production in the region.

Conclusion

The exploitation potential and economic efficiency of natural gas reserves are shaped by a wide range of technical, economic, and geopolitical factors. In the context of a global transition toward low-carbon energy, natural gas is increasingly recognized as a strategic bridge fuel, while unconventional resources such as natural gas hydrates (NGH) represent a long-term solution to energy security and sustainability challenges. With reserves estimated to be larger than all conventional fossil fuels combined, NGH holds enormous promise as a 21st-century energy resource.

The industrialization of NGH, however, remains in its early stages. Successful pilot-scale production tests in China have demonstrated technical feasibility and marked significant milestones, yet large-scale commercialization has not been achieved. Economic efficiency remains the central challenge: current pilot production levels fall well short of the economic production indicators deemed necessary for viability. Nevertheless, advances in extraction technologies and cost reduction strategies suggest that these thresholds may decline over time, improving the prospects for commercialization.

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Received: 17.05.2025
Accepted: 21.08.2025