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Constructing Shandong's Modern Deep-Sea Industrial System under National Strategic Guidance

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Abstract

After deep-sea science and technology entered the national layout of emerging and future industries, the focus of local marine economic development was no longer merely to expand the scale of nearshore development, but to determine how ports, equipment, research platforms, data resources, and institutional advantages could be organized into an industrial system oriented toward the deep sea. Shandong ranks among China's leading provinces in the scale of its marine economy and has a solid foundation in marine research platforms, shipbuilding and offshore engineering, port logistics, marine fisheries, and marine energy. Nevertheless, its existing strengths are still concentrated mainly in nearshore development and traditional marine industries, and a clear gap remains before it can form a modern industrial system that integrates deep-sea access, exploration, development, and services. Based on the analytical framework of national strategic guidance, regional industrial foundation, transformation of deep-sea scenarios, and institutional ecosystem support, this paper examines the practical foundations, key constraints, and implementation pathways for Shandong to build a modern deep-sea industrial system. The study argues that Shandong should strengthen key core technologies, coordinate the overall planning of major bays, cultivate leading industrial chains, build data and sea-trial platforms, and improve full-life-cycle institutional support, so as to transform its advantages in marine resources, research platforms, and industrial foundations into systemic competitiveness in deep-sea industries.

Keywords

Shandong; deep-sea science and technology; marine industries; blue economy; modern industrial system; marine new quality productive forces

I. Introduction

In recent years, the strategic significance of the marine economy has been undergoing a marked shift. Earlier discussions of marine industries tended to focus on traditional sectors such as port throughput, nearshore fisheries, shipbuilding and repair, marine tourism, and port-adjacent manufacturing. Today, with the accelerated development of deep-sea equipment, seabed observation, offshore and deep-sea aquaculture, offshore new energy, marine data systems, and polar and distant-water services, competition in the ocean has extended from ordinary resource development to a more comprehensive contest of technological capacity, industrial-chain security, and institutional governance. The 2025 Government Work Report included deep-sea science and technology among key emerging industries [1], while the Outline of the Fifteenth Five-Year Plan of the People's Republic of China further called for the strengthening of the overall planning of major bays and for making marine industries stronger, better, and larger [2]. General Secretary Xi Jinping has also stressed the need to promote the high-quality development of the marine economy and to enhance China's capacity to develop and manage the ocean [3]. These policy signals indicate that deep-sea science and technology and the marine economy have moved from sectoral development issues to important components of national strategic capability.

For Shandong, this shift is highly relevant to its development realities. Shandong is one of China's major marine economic provinces. According to the 2026 Shandong Provincial Government Work Report, the province has continued to advance the construction of a modern marine economic development highland, with 211 key marine-related projects completing more than RMB 80 billion in investment and seven new provincial-level modern marine characteristic industrial clusters cultivated [4]. At the same time, Shandong has strong supporting conditions in its coastal port system, shipbuilding and offshore engineering base, marine research platforms, and scale of marine fisheries. However, a large marine economy does not automatically mean strong deep-sea industrial capability. Deep-sea industries require higher standards of equipment reliability, data continuity, maritime testing, ecological risk assessment, and financial and insurance support. Therefore, building a modern deep-sea industrial system is not simply a matter of extending the existing marine economy outward or farther offshore; it is a process of reorganizing Shandong's existing marine strengths in technological, industrial, spatial, and institutional terms.

From the perspective of Shandong's current conditions, the central contradiction is that being "strong in the marine economy" has not yet been fully transformed into being "strong in the deep sea." Shandong does not lack marine resources or an industrial foundation. What it needs to strengthen is the systemic capacity to connect research, manufacturing, ports, application scenarios, and institutions. In other words, the province's next step in building a modern deep-sea industrial system should not remain at the level of adding projects, expanding industrial parks, or applying for platforms. Instead, deep-sea technological breakthroughs, cultivation of leading industries, bay-area spatial coordination, public testing platforms, and financial and talent policies should be integrated into a coherent design.

Against this background, this paper addresses three questions. First, what practical foundations does Shandong possess for developing a modern deep-sea industrial system? Second, what deeper constraints hinder the province's transition from a major marine province to a strong deep-sea industrial province? Third, how can Shandong, under the guidance of national strategy, form a modern deep-sea industrial system with distinct local characteristics and long-term competitiveness? Such an analysis responds to China's strategy of building a strong maritime country and helps clarify the internal logic of deep-sea industrial system construction from the perspective of provincial industrial organization.

II. Literature Review and Analytical Perspective

A significant change in recent research on the marine economy is the shift from a purely growth-oriented approach to one that emphasizes sustainability and governance. Bennett et al. argue that the blue economy should not be understood merely as output growth in marine industries; it must also take account of ecological carrying capacity, equitable distribution, community participation, institutional governance, and long-term resilience [5]. This view is instructive for local marine economic policy. If local governments emphasize only investment intensity and output contribution when promoting marine industries, they may overlook the carrying capacity of sea areas, the externalities of ecological risk, and the distribution of industrial benefits. For a province such as Shandong, where the marine economy is already large, high-quality development depends not only on "expansion," but also on "restructuring," "improving quality," and "strengthening governance."

The theory of "blue acceleration" reveals trends toward faster marine development, deeper spatial expansion, and more diversified industrial actors. Jouffray et al. suggest that human competition for ocean food, energy, minerals, space, and data is accelerating, while different uses of the ocean may generate new conflicts [6]. This means that deep-sea industries are not a natural extension of traditional marine industries; rather, they constitute a new system shaped jointly by technology, capital, ecology, regulation, and international rules. If Shandong continues to rely on the development logic of nearshore industries and simply relocates nearshore aquaculture, nearshore wind power, and conventional offshore engineering equipment into more distant waters, it will be difficult to form a genuinely deep-sea industrial system.

Research on offshore and deep-sea industries places greater emphasis on scenario-based demand and system integration. Novaglio et al. propose that a sustainable offshore blue economy involves multiple systems, including energy, food, transportation, engineering equipment, data monitoring, and ecological protection, and cannot be understood as the single-point expansion of any one industry [7]. This judgment is highly relevant to Shandong. Its coastal cities have different strengths: Qingdao is relatively strong in research, platforms, and services; Yantai and Weihai have accumulated capacities in offshore engineering equipment and underwater devices; and Dongying, Weifang, Binzhou, and Rizhao have room to expand in marine energy, materials, and port-adjacent industries. How to organize these foundations into industrial chains and clusters is the core question in Shandong's deep-sea industrial development.

Studies on deep-sea resource development also remind local governments to pay attention to uncertainty and prudent governance. In their study of the sustainability of deep-seabed mining, Levin et al. point out that deep-sea ecosystems recover slowly, scientific knowledge remains insufficient, and environmental impact assessment is complex; therefore, any development activity must fully consider long-term risks [8]. Smith et al. further argue that underestimating the ecological vulnerability of the deep sea may lead to a systematic underestimation of development impacts [9]. Although Shandong's modern deep-sea industrial focus is not necessarily deep-sea mining, offshore aquaculture, offshore new energy, seabed observation networks, and deep-sea equipment testing all involve ecological, safety, and long-term governance issues.

At the technological level, existing research shows that the underlying capabilities of deep-sea industries are shifting from single-equipment manufacturing toward the integration of equipment, communications, sensing, data, and intelligent control. Aguzzi et al. emphasize that fixed observation networks, mobile platforms, acoustic and video monitoring, and in situ environmental DNA technologies are becoming important directions in deep-sea ecosystem monitoring [10]. Zhang et al. show, through research on high-speed underwater wireless optical communication in the deep sea, that seabed observation networks require more stable, real-time, and high-capacity information transmission capabilities [11]. These studies indicate that competition in modern deep-sea industries does not occur only in steel-structure platforms or ship manufacturing; it also takes place in underlying technologies such as sensing systems, algorithms, materials, communications, and data networks.

On the basis of the existing literature, this paper adopts an analytical perspective of "national strategic guidance - regional industrial foundation - transformation of deep-sea scenarios - institutional ecosystem support." National strategic guidance determines the direction and policy window of deep-sea industrial development; the regional industrial foundation determines whether local governments can transform existing marine economic strengths into deep-sea industrial advantages; the transformation of deep-sea scenarios determines whether scientific and technological achievements can move beyond the laboratory and enter engineering application; and institutional ecosystem support determines whether deep-sea industries can cross the industrialization threshold characterized by high investment, long cycles, high risks, and difficult validation.

III. Practical Foundations for Building a Modern Deep-Sea Industrial System in Shandong

Shandong's construction of a modern deep-sea industrial system is first supported by the considerable scale of its marine economy. According to the provincial government work report, Shandong's gross ocean product reached RMB 1,900.15 billion in 2025, exceeding RMB 1.9 trillion for the first time, ranking second nationwide, accounting for 18.4 percent of the province's gross regional product, and growing at an average annual rate of 7.9 percent since the beginning of the Fourteenth Five-Year Plan period [4]. These figures show that the marine economy is no longer a supplementary sector in Shandong's industrial system, but an important force supporting high-quality provincial development. A large industrial scale provides market space and application scenarios for deep-sea equipment, marine new energy, offshore and deep-sea aquaculture, marine biomanufacturing, and marine services.

Second, Shandong has strong marine research and platform support. The province has gathered a group of national-level marine research institutions and innovation platforms, and high-level platforms such as Laoshan Laboratory have continued to advance. These platforms provide important conditions for deep-sea technological breakthroughs, pilot testing, sea trials, and achievement transformation. Deep-sea industries differ from ordinary manufacturing in that many technologies must be validated in complex marine environments before they can move from prototypes to engineering applications. If Shandong can further connect its research platform base with enterprise demand and maritime testing scenarios, this foundation will become an important support point for a modern deep-sea industrial system.

Third, Shandong has a relatively complete marine industrial foundation. Qingdao has agglomeration advantages in marine research, marine information, high-end marine services, and international cooperation. Yantai and Weihai have built certain foundations in shipbuilding and offshore engineering, marine ranching, underwater equipment, and green ship and offshore manufacturing. Dongying, Weifang, Binzhou, and Rizhao have room for expansion in marine energy, petrochemical materials, salt chemicals, port and shipping services, and port-adjacent manufacturing. Compared with single-port cities, Shandong's advantage lies not only in the strength of individual cities, but also in the multi-node foundation formed by its coastal urban agglomeration.

In addition, Shandong has continued in recent years to build a modern marine economic development highland, with steady progress in key marine-related projects, modern marine characteristic industrial clusters, and industrial platforms. This indicates that the province already possesses certain policy-organizing and project-bearing capacities. It should be noted, however, that deep-sea industrial development cannot simply repeat the promotion model of traditional marine projects. Existing projects and platforms should be further guided toward deep-sea equipment, deep-sea data, offshore applications, and public validation services.

In terms of development potential, Shandong may form a spatial pattern of "one core, two belts, and multiple supporting nodes." Qingdao can serve as the core for deep-sea scientific and technological innovation, standard setting, and platform origination. Yantai and Weihai can form a demonstration belt for deep-sea equipment manufacturing, underwater robotics, offshore and deep-sea aquaculture, and green ship and offshore applications. Dongying, Weifang, Binzhou, and Rizhao can develop an expansion belt focused on marine energy, marine materials, port-adjacent manufacturing, and port and shipping support. If this pattern can be effectively implemented, it will help Shandong move beyond competition among isolated projects and toward chain-cluster coordination across the province.

IV. Main Constraints on the Construction of Shandong's Modern Deep-Sea Industrial System

First, the overall industrial level remains relatively shallow, and resource advantages have not been sufficiently transformed into deep-sea industrial advantages. Although Shandong has a large marine economy, its existing strengths are concentrated mainly in port shipping, nearshore fisheries, traditional offshore engineering manufacturing, and marine tourism. Industrial chains related to deep-sea access, exploration, development, and services have not yet been fully developed, while new growth areas such as offshore and deep-sea aquaculture, marine new energy, marine biomanufacturing, and marine information services remain in the cultivation stage. The deeper issue is not that Shandong lacks marine industries, but that a capability threshold exists between traditional marine industries and deep-sea industries. Deep-sea industries require higher-level equipment, more complex system integration, and more continuous data support. Without these capabilities, it is difficult for resource and scale advantages to generate high-end industrial competitiveness.

Second, the connection between the innovation chain and the industrial chain remains insufficiently smooth. Shandong has numerous marine research platforms, but mechanisms for enterprise-led application transformation still need to be strengthened. Key links such as deep-sea equipment, sensors, underwater communication and navigation, intelligent control systems, pressure- and corrosion-resistant materials, and seabed observation networks all involve long research cycles, high testing costs, and difficult engineering validation. Without stable pilot platforms, open sea-trial scenarios, and first-unit application mechanisms, research achievements can easily remain at the level of papers, prototypes, or demonstration projects and fail to enter scaled industrial chains.

Third, coastal regional layout shows a tendency toward fragmentation. Shandong has many coastal cities, high port density, and diverse industrial foundations. Yet these advantages may also give rise to another problem: different localities may all seek to develop offshore engineering equipment, marine ranching, offshore new energy, and marine information platforms, resulting in similar project names, overlapping functional positioning, and ultimately low-level duplication. Deep-sea industries require high investment and long cycles. If coordination at the provincial level is insufficient, dispersed layouts will weaken resource allocation efficiency and make it harder for Shandong to establish a distinctive position in national competition in deep-sea industries.

Fourth, institutional supply and factor support remain relatively weak. Deep-sea industries are not ordinary investment-attraction projects. They are characterized by high input, long cycles, high risks, and difficult validation, and enterprises, especially small and medium-sized technology firms, find it difficult to bear early-stage R&D and sea-trial risks independently. Sumaila et al. note that the sustainable ocean economy requires more suitable financial instruments, risk-sharing mechanisms, and capital performance evaluation systems [12]. For Shandong, fiscal funds, government-guided funds, technology loans, marine insurance, first-unit procurement, intellectual property protection, testing and certification, and safety regulation should all be organized around the full life cycle of deep-sea industries.

Fifth, the data foundation and public validation capacity remain insufficient. Modern deep-sea industries increasingly depend on marine environmental data, equipment operation data, ecological monitoring data, and industrial-chain coordination data. Without a continuous, stable, and credible data foundation, it is difficult to achieve rapid iteration in deep-sea equipment R&D and offshore operation and maintenance. At the same time, many enterprises need open, standardized, and affordable sea-trial scenarios to validate product performance. Although Shandong has a strong research platform base, its mechanisms for cross-departmental data sharing, sea-trial approval, enterprise sea-trial cost sharing, standardized testing and evaluation, and data security compliance still need further improvement.

Sixth, composite talent and international rule-making capabilities need to be strengthened. Deep-sea industries require not a single type of disciplinary talent, but a combination of expertise in engineering equipment, materials science, communications and navigation, artificial intelligence, marine ecology, international law, finance and insurance, and safety regulation. Shandong's universities and research institutions provide a good foundation, but there remains room to improve composite talent training for deep-sea industrial chains, enterprise engineering teams, and participation in international standards. In particular, talent gaps in deep-sea development, marine environmental assessment, distant-water operation safety, and international rule coordination will directly affect the industry's long-term competitiveness.

V. Implementation Pathways for Building Shandong's Modern Deep-Sea Industrial System

First, Shandong should consolidate the industrial foundation through breakthroughs in key core technologies. The province should establish a provincial list of key technologies in areas such as deep-sea equipment, deep-sea communication and navigation, marine information sensing, intelligent control, underwater robotics, pressure- and corrosion-resistant materials, and deep-sea energy equipment. Technological breakthroughs should not be advanced solely according to the logic of research projects; they should be designed in parallel with industrial scenarios, leading enterprises, first-unit applications, and sea-trial validation. An organizational model combining open competition, scenario opening, first-unit application, and insurance compensation could be explored to guide universities, research institutes, leading enterprises, and specialized and innovative firms to participate jointly and to improve the engineering transformation rate of R&D achievements.

Second, overall planning of major bays should be used to promote coordination among coastal cities. Shandong should treat bays as important units of industrial organization and spatial governance and prepare specialized plans for modern deep-sea industries in key bay areas as soon as possible. These plans should clarify the functional positioning of different bay areas in research and development, manufacturing, testing, application, services, and ecological protection. Qingdao may focus on marine scientific and technological origination, marine big data, international cooperation, and standard setting; Yantai and Weihai may focus on deep-sea equipment manufacturing, underwater robotics, offshore aquaculture equipment, and green ship and offshore applications; while Dongying, Weifang, Binzhou, and Rizhao may focus on marine energy, materials manufacturing, port and shipping support, and port-adjacent industrial services. Such division of labor can reduce homogeneous competition and enhance the overall distinctiveness of Shandong's deep-sea industries.

Third, breakthroughs in leading industries should be used to generate chain-cluster traction. Shandong may give priority to three types of industries. The first is to strengthen the deep-sea equipment industry by focusing on deepwater drilling and production platforms, ROVs and AUVs, underwater operation systems, deep-sea observation systems, offshore aquaculture vessels, and offshore wind operation and maintenance equipment, thereby forming integrated capacities in R&D, manufacturing, testing, and operation and maintenance. The second is to improve offshore and deep-sea aquaculture by upgrading marine ranches into "deep-blue ranches" and connecting equipment, breeding, feed, farming, cold chain, processing, branding, and sales, so that offshore aquaculture does not remain limited to isolated facility construction. The third is to expand the marine new energy industry by cultivating new industrial growth around far-offshore wind power, marine energy, seawater desalination, and green-electricity-based hydrogen and ammonia production.

Fourth, deep-sea data and public sea-trial platforms should be used to improve the efficiency of achievement transformation. Relying on existing marine research platforms, Shandong should accelerate the construction of deep-sea pilot validation platforms, open sea-trial scenarios, and marine big-data platforms, thereby forming a closed loop of "R&D - testing - application - feedback." In fields such as underwater communications, seabed observation, unmanned equipment, offshore aquaculture equipment, and marine new energy equipment, stable and open public testing service mechanisms should be established to reduce sea-trial costs for enterprises and accelerate technological iteration. At the same time, Shandong should promote the standardization, graded and categorized opening, and secure and compliant use of marine data, so that marine data can be transformed from research data into industrial and governance data.

Fifth, institutional innovation should be used to improve full-life-cycle support for deep-sea industries. Deep-sea industrial policy should not focus only on investment attraction and project landing; it should cover the entire process of R&D input, prototype development, pilot validation, first-unit application, scaled production, offshore operation and maintenance, risk insurance, and market promotion. Shandong may establish special support policies for deep-sea industries and improve government-guided funds, technology loans, marine insurance, risk compensation, and government procurement mechanisms. For key areas such as deep-sea equipment, marine information, marine biology, and marine energy, coordinated mechanisms for standards, testing and certification, intellectual property rights, and safety regulation should be established to provide enterprises with stable expectations.

Sixth, talent cultivation and open cooperation should be used to enhance the resilience of the industrial ecosystem. Shandong may establish a special "blue talent" mechanism around key industrial chains and promote coordination among university disciplinary layouts, research platform tasks, enterprise job requirements, and local talent policies. Talent policy should not target only high-level researchers; it should also value engineers, sea-trial technicians, data governance professionals, marine finance specialists, and professionals familiar with international rules. At the same time, Shandong should strengthen cooperation with international marine research organizations, port cities, marine engineering enterprises, and international standard-setting bodies, and improve its technological level, rule-participation capacity, and adaptability to international markets through open cooperation.

VI. Discussion: The Logical Shift from a Major Marine Province to a Strong Deep-Sea Province

The construction of a modern deep-sea industrial system in Shandong appears on the surface to be an issue of industrial upgrading, but in essence it is a shift in development logic. The traditional marine economy relies more heavily on shorelines, ports, resources, and location conditions, and its development mode has a strong factor-input character. Modern deep-sea industries depend more on scientific and technological innovation, data systems, equipment reliability, complex scenario organization, and institutional supply. In other words, for Shandong to move from being a major marine province to a strong deep-sea province, it should not focus only on changes in the scale of gross ocean product; it should pay greater attention to whether it can form technological control, chain-cluster coordination, and rule-based support oriented toward deep-sea industries.

This shift includes at least three dimensions. First, it requires a transition from a resource-development logic to a capability-building logic. The core of competition in deep-sea industries is not who possesses more sea-area resources, but who can safely, stably, and cost-effectively enter, perceive, develop, and serve the deep sea. Second, it requires a transition from a project-growth logic to a system-integration logic. A single project can generate short-term investment and output, but a modern deep-sea industrial system needs the joint support of R&D, manufacturing, sea trials, application, operation and maintenance, and standards. Third, it requires a transition from fragmented local competition to provincial-level collaborative governance. Shandong's coastal cities have different foundations, and only through differentiated division of labor and benefit-sharing mechanisms can scattered advantages be transformed into overall competitiveness.

Modern deep-sea industries also clearly embody the characteristics of new quality productive forces. Their "newness" is reflected not only in new equipment, new materials, new energy, and new application scenarios, but also in data-driven development, intelligent control, system integration, and institutional innovation. If Shandong can take modern deep-sea industries as a breakthrough point, it is likely to promote the marine economy's transition from resource-dependent growth to innovation-driven growth, from single-industry expansion to chain-cluster ecosystem cultivation, and from a traditional major marine economic province to a strong modern deep-sea industrial province.

VII. Conclusions and Implications

Drawing on studies of the blue economy, blue acceleration, deep-sea governance, and regional innovation systems, and in light of the foundation of Shandong's marine economic development, this paper analyzes the practical conditions, main constraints, and pathway choices for building a modern deep-sea industrial system in Shandong. The study finds that Shandong has advantages in the large scale of its marine economy, the agglomeration of research platforms, and a strong foundation in shipbuilding, offshore engineering, and ports. However, it also faces problems such as a relatively shallow industrial level, insufficient key core technologies, fragmented regional layout, inadequate systematic institutional supply, and incomplete data and sea-trial platforms.

Looking toward the Fifteenth Five-Year Plan period, Shandong should regard the construction of a modern deep-sea industrial system as an important lever for cultivating new quality productive forces in the marine economy. In terms of its overall pathway, the province should coordinate technological breakthroughs, scenario-based demand, chain-cluster agglomeration, and institutional guarantees, and seek breakthroughs in key fields such as deep-sea equipment, offshore and deep-sea aquaculture, marine new energy, marine information sensing, and marine biomanufacturing. In terms of spatial layout, Shandong should build a pattern of "one core, two belts, and multiple supporting nodes": Qingdao as the core for deep-sea scientific and technological innovation and platform origination; Yantai and Weihai as a demonstration belt for deep-sea equipment manufacturing and offshore applications; and Dongying, Weifang, Binzhou, and Rizhao as an expansion belt for marine energy, materials manufacturing, and port and shipping support.

The policy implication is that deep-sea industrial development cannot rely solely on industrial planning and project construction; it also requires long-term and stable institutional supply. Shandong should coordinate policy instruments including key technological breakthroughs, overall planning of major bays, leading-industry breakthroughs, data and testing platforms, finance and insurance, talent cultivation, standards and certification, and safety regulation, and form a full-life-cycle support system for deep-sea industries. Only in this way can Shandong truly transform its marine resource advantages, scientific platform advantages, and industrial foundation advantages into advantages in a modern deep-sea industrial system, and thereby move from being a major marine province to a strong deep-sea province.

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