

# The Future of Underwater Technology: Challenges and Opportunities for Indonesia in the Global Ocean Economy

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## Abstrak

Sebagai negara kepulauan terbesar di dunia, Indonesia memiliki potensi yang sangat besar dalam ekonomi kelautan global. Teknologi bawah air menjadi infrastruktur strategis yang mendukung eksplorasi energi laut, komunikasi digital melalui kabel bawah laut, pemantauan lingkungan, serta keamanan dan pengawasan wilayah maritim. Namun, penguasaan teknologi bawah air di Indonesia masih menghadapi berbagai tantangan, termasuk ketergantungan pada teknologi impor, keterbatasan transfer teknologi, rendahnya investasi riset dan pengembangan (R&D), serta belum optimalnya kapasitas sumber daya manusia dan ekosistem inovasi nasional. Artikel perspektif ini membahas peran strategis teknologi bawah air dalam mendukung pembangunan maritim Indonesia, mengidentifikasi hambatan utama yang menghambat kemandirian teknologi, serta mengeksplorasi peluang pengembangan melalui penguatan riset, industrialisasi teknologi maritim, dan penerapan kebijakan ekonomi biru berbasis inovasi. Penulis berpendapat bahwa penguasaan teknologi bawah air harus menjadi agenda strategis nasional untuk memperkuat kedaulatan maritim, meningkatkan daya saing industri kelautan, dan mendukung pembangunan ekonomi yang berkelanjutan. Melalui investasi yang lebih besar pada penelitian, kolaborasi pemerintah–industri–akademisi, serta pengembangan kapasitas teknologi domestik, Indonesia memiliki peluang untuk bertransformasi dari pengguna teknologi menjadi inovator dalam industri maritim global.

**Kata Kunci:** Teknologi Bawah Air, Ekonomi Biru, Kemandirian Teknologi, Keamanan Maritim, Inovasi Kelautan.

## Abstract

*As the world's largest archipelagic nation, Indonesia possesses immense potential within the global ocean economy. Underwater technology has become a strategic infrastructure supporting marine energy exploration, digital communications through submarine cable networks, environmental monitoring, and maritime security and surveillance. However, Indonesia's capability in underwater technology continues to face significant challenges, including dependency on imported technologies, limited technology transfer, low investment in research and development (R&D), and insufficient human resource capacity and innovation ecosystems. This perspective article examines the strategic role of underwater technology in supporting Indonesia's maritime development, identifies the key barriers to technological independence, and explores opportunities for advancement through research strengthening, maritime technology industrialization, and innovation-driven blue economy policies. The author argues that mastery of underwater technology should become a national strategic agenda to strengthen maritime sovereignty, enhance the competitiveness of marine industries, and support sustainable economic development. Through greater investment in research, stronger government–industry–academia collaboration, and the development of domestic technological capabilities, Indonesia has the opportunity to transform from a technology user into an innovator in the global maritime industry.*

**Keywords:** Underwater Technology, Blue Economy, Technological Independence, Maritime Security, Marine Innovation.

## INTRODUCTION

The ocean plays a central role in Indonesia's development. With a maritime territory covering approximately two-thirds of the total national area, Indonesia holds vast potential in energy, fisheries, transportation, and communications. The concept of the Blue Economy emphasizes the sustainable use of marine resources to drive economic growth and community welfare [3], [4]. In addition, the increasing global demand for marine resources and ocean-based industries has elevated the strategic importance of maritime nations in supporting sustainable economic development. As the world's largest archipelagic state, Indonesia possesses significant opportunities to benefit from emerging sectors within the ocean economy, including offshore energy, marine environmental services, and underwater infrastructure development [3], [4].

In this context, underwater technology serves as a vital foundation. This technology includes Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV), sensor and sonar systems, submarine cable infrastructure, underwater imaging systems, acoustic communication networks, and deep-sea energy exploration technology [5], [6], [13], [14]. These technologies enable a wide range of activities such as seabed mapping, marine habitat monitoring, underwater inspection, environmental assessment, offshore resource exploration, and the maintenance of critical underwater infrastructure [7], [12].



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[16], [17], [18]. Furthermore, advances in underwater robotics and autonomous systems have significantly improved the efficiency, safety, and accuracy of marine operations in environments that are difficult or hazardous for human intervention [1], [10], [15].

Submarine cable systems, which carry the majority of global digital communications, have become increasingly important for national connectivity and economic resilience, particularly for archipelagic countries such as Indonesia [2], [20]. Likewise, underwater observation and monitoring technologies provide essential data for marine resource management, environmental protection, disaster mitigation, and maritime security [11], [12], [14]. The integration of autonomous vehicles, navigation systems, acoustic sensors, and advanced imaging technologies has transformed the way ocean environments are explored and managed [8], [9], [13].

However, to date, Indonesia remains reliant on imported technology. Many sophisticated underwater systems, including AUVs, ROVs, sonar equipment, underwater communication devices, and deep-sea exploration platforms, are still largely sourced from foreign manufacturers [5], [6], [15]. This dependence not only increases operational costs but also limits domestic technological capability, industrial competitiveness, and strategic autonomy in managing national marine resources. This article offers the perspective that underwater technological independence must become a national strategic agenda to strengthen Indonesia's position in the global ocean economy. Strengthening domestic research, fostering collaboration among government, academia, and industry, and investing in indigenous underwater technology development are essential steps toward achieving sustainable maritime sovereignty and long-term economic competitiveness [1], [3], [4], [12].

## UNDERWATER TECHNOLOGY AS STRATEGIC INFRASTRUCTURE

### Energy and Deep-Sea Exploration

Offshore oil and gas exploration relies heavily on subsea technology, particularly for inspection, maintenance, and seabed mapping [5], [6]. Autonomous and remotely operated underwater systems have become indispensable for conducting operations in deep and hazardous marine environments where direct human intervention is costly and risky [1], [15]. Advanced underwater imaging, navigation, and bathymetric mapping technologies further support the identification of geological formations, resource deposits, and underwater infrastructure conditions, enabling more efficient and safer offshore operations [13], [16], [18].

Beyond fossil fuels, the potential for marine renewable energy such as ocean currents, waves, and Ocean Thermal Energy Conversion (OTEC) requires sophisticated underwater installation and monitoring systems [9], [12]. The deployment of marine energy facilities depends on reliable underwater sensing, control, communication, and maintenance technologies capable of operating under dynamic ocean conditions [9], [14]. Environmental monitoring systems are also essential to ensure that energy development activities remain compatible with marine ecosystem sustainability [12].

Indonesia possesses significant ocean current energy potential, especially in its eastern regions. However, domestic technological limitations have hindered optimal utilization. The dependence on imported underwater equipment, specialized sensors, and autonomous marine platforms remains a major challenge for the development of national marine energy projects [5], [6], [15]. From the author's perspective, investing in marine energy technology research impacts not only energy security but also national technological sovereignty. Strengthening indigenous capabilities in underwater robotics, ocean observation systems, and subsea engineering would provide long-term benefits for economic resilience and sustainable resource management [1], [3], [4].

### Global Communication and Digital Resilience

More than 95% of international data traffic is transmitted via submarine fiber optic cables [2], [20]. This infrastructure is the backbone of the global digital economy, supporting international communications, financial transactions, cloud computing services, and data exchange across continents [2], [20]. As digitalization continues to accelerate worldwide, the strategic importance of submarine cable networks has increased significantly, making them critical assets for both economic development and national competitiveness.

As an archipelagic nation, Indonesia is highly dependent on submarine cable networks for both domestic and international connectivity. Thousands of islands separated by vast stretches of ocean require reliable undersea communication infrastructure to support government services, business activities, education, healthcare, and digital inclusion. Submarine cable systems play a crucial role in reducing connectivity gaps and enabling equitable access to information across the country [2], [20].

Disruptions to submarine cables can jeopardize economic stability and national security. Cable damage caused by natural hazards, fishing activities, shipping operations, or deliberate interference can result in substantial communication outages and economic losses [2]. Therefore, technology for the detection, monitoring, and protection of submarine cables must be prioritized as strategic infrastructure [2], [20]. The integration of underwater sensors, autonomous inspection vehicles, acoustic monitoring systems, and real-time surveillance technologies can improve the resilience and security of critical communication networks while reducing maintenance costs and response times [5], [6], [14].

### Marine Security and Territorial Surveillance



Given its vast sea area and high maritime activity, underwater surveillance poses a major challenge. Sonar technology, acoustic sensors, and autonomous underwater vehicles can enhance early detection capabilities against security threats [1], [14]. These technologies support the monitoring of maritime traffic, underwater activities, illegal resource exploitation, and potential intrusions within national waters. Continuous underwater observation can also contribute to improved situational awareness and more effective maritime domain management [6], [14].

Recent advances in autonomous marine systems have enabled longer-duration missions, wider coverage areas, and improved operational efficiency for surveillance applications [10], [19]. Integrated navigation systems, underwater communication networks, and autonomous decision-making capabilities allow modern underwater vehicles to operate effectively in complex and remote marine environments [8], [10]. In addition, seabed mapping and underwater imaging technologies provide valuable information for identifying strategic underwater features and monitoring changes in marine environments [7], [16], [17], [18].

In the geopolitical context of the Indo-Pacific region, mastery of underwater technology is closely linked to maritime stability and sovereignty. The ability to independently develop, deploy, and operate underwater surveillance systems enhances national preparedness in protecting territorial waters, safeguarding critical infrastructure, and supporting maritime law enforcement. Furthermore, technological capability in underwater operations strengthens a nation's strategic position in addressing emerging security challenges and maintaining stability in increasingly contested maritime regions [1], [14], [15].

## CHALLENGES: DEPENDENCY AND LIMITED NATIONAL CAPACITY

Despite its great marine resource potential, Indonesia faces several key obstacles, including dependency on imported technology, where the procurement of ROVs, AUVs, and sonar systems is still dominated by foreign products [5], [6]. Most advanced underwater platforms currently used for deep-sea exploration, offshore inspection, underwater mapping, and marine monitoring are designed and manufactured by technologically advanced countries with long-established marine industries [1], [6], [15]. As a result, Indonesia remains largely dependent on external suppliers for critical components, software systems, navigation technologies, acoustic sensors, and underwater communication equipment [8], [14]. This dependence increases procurement and maintenance costs while limiting the development of domestic industrial capabilities and technological competitiveness.

In addition, limited technology transfer means that international cooperation is often not followed by an increase in domestic production capacity. While collaborative projects and technology procurement agreements may provide access to operational equipment, they do not always facilitate the transfer of core knowledge, design expertise, or manufacturing capabilities required to develop indigenous systems [1], [5]. Consequently, local industries and research institutions often remain positioned as technology users rather than technology developers. This situation constrains the growth of a sustainable national ecosystem for underwater technology innovation and commercialization.

Another challenge is the low investment in Research and Development (R&D), as Indonesia's research spending remains relatively small compared to developed nations [3]. The development of underwater technology requires substantial and long-term investment in multidisciplinary fields such as robotics, ocean engineering, artificial intelligence, navigation systems, underwater acoustics, sensor technology, and marine data analytics [1], [9], [10], [14]. Furthermore, sophisticated testing facilities, ocean observation infrastructure, and specialized laboratories are necessary to support technology validation and deployment under real operational conditions [6], [12]. Limited funding often restricts the ability of universities, research institutions, and industries to conduct advanced research and accelerate technological innovation.

Human resource capacity also represents a significant challenge. The operation, design, and maintenance of advanced underwater systems require highly skilled engineers, scientists, and technicians with expertise in marine technology and ocean sciences [5], [6]. However, the availability of specialized educational programs, professional training opportunities, and industry-oriented research initiatives remains limited. This creates a gap between the increasing demand for underwater technology expertise and the national capacity to supply qualified personnel.

Another important issue is the limited availability of supporting infrastructure for marine technology development. Underwater robotics and ocean observation systems require access to testing sites, calibration facilities, research vessels, and integrated monitoring networks to ensure reliable performance and operational readiness [12], [16], [18]. Without adequate infrastructure, domestic innovation efforts face difficulties in progressing from laboratory-scale prototypes to commercially viable products and operational systems.



In the author's view, this dependency is not just an economic issue but also a strategic one. Without mastering core technologies, Indonesia will find it difficult to compete in the global value chain of the maritime sector. Technological dependence may reduce national flexibility in managing marine resources, securing critical underwater infrastructure, and responding to emerging challenges in the rapidly evolving ocean economy [3], [4]. Moreover, as underwater technology increasingly becomes a key enabler of energy development, environmental monitoring, digital connectivity, and maritime security, the ability to independently develop and operate such technologies will be an important determinant of national competitiveness and sovereignty in the future [1], [2], [20].

## **STRATEGIC OPPORTUNITIES: TOWARD TECHNOLOGICAL INDEPENDENCE**

### **Strengthening Human Resources and the Research Ecosystem**

Developing underwater technology requires multidisciplinary collaboration involving ocean engineering, robotics, oceanography, artificial intelligence, materials science, navigation systems, and underwater communications [1], [5], [8], [12], [14]. Universities and national research institutions must strengthen their focus on applied maritime technology through specialized research centers, industry partnerships, and technology-oriented education programs. The availability of testing facilities and research infrastructure is also essential to accelerate innovation and technology deployment [15], [18].

The Triple Helix collaboration model (government–industry–academia) can be an effective approach to accelerating innovation. Through coordinated funding, research, and industrial participation, this model can facilitate knowledge transfer, technology commercialization, and the development of indigenous underwater technologies [1], [3], [4].

### **Industrialization of Marine Technology**

Indonesia has the opportunity to develop a domestic industry for mid-scale ROV components, oceanographic sensors, and underwater survey services [6], [17]. Growing demand for seabed mapping, marine monitoring, offshore energy development, and underwater infrastructure inspection provides significant opportunities for local industries [2], [20].

The development of local capabilities can begin with sensor systems, underwater imaging equipment, navigation devices, and marine software platforms before progressing toward more advanced underwater vehicles and integrated observation systems [5], [6], [13]. An import substitution strategy based on local innovation could be the first step toward global competitiveness while strengthening national technological sovereignty [3], [4].

### **Technology-Based Blue Economy Policy**

The blue economy is not just about resource exploitation; it is about technological innovation and sustainability [3], [4]. Underwater technologies support sustainable ocean development through marine monitoring, resource management, environmental protection, and infrastructure maintenance [11], [12], [17].

Therefore, national maritime policies need to include a roadmap for underwater technology development as a long-term strategic priority. Such a roadmap should support research and development, human resource capacity building, industrial growth, and investment in strategic maritime technologies. In the long term, stronger underwater technological capabilities will enhance Indonesia's competitiveness, sustainability, and position in the global ocean economy [3], [4], [20].

## **CONCLUSION AND PERSPECTIVE RECOMMENDATIONS**

Underwater technology is a strategic infrastructure that supports national energy, communications, and security [1], [2], [5]. Its applications extend from offshore resource exploration and marine environmental monitoring to submarine cable protection, seabed mapping, and maritime surveillance [6], [12], [17], [18], [20]. As technological advancements continue to transform the global ocean economy, underwater systems are becoming increasingly important for improving operational efficiency, supporting sustainable resource management, and strengthening national resilience in maritime domains [3], [4], [10].

In the era of the global ocean economy, mastering this technology is an indicator of a nation's maritime sovereignty. Countries that possess strong capabilities in underwater robotics, ocean observation, acoustic communication, navigation systems, and subsea infrastructure management are better positioned to secure strategic marine resources, protect critical infrastructure, and participate competitively in emerging ocean-based industries [1], [6], [14], [15]. For an archipelagic nation such as Indonesia, technological capability beneath the sea is as important as capability on land and in the air.

From the author's perspective, Indonesia needs to establish underwater technology as a national priority in research policy, significantly increase marine R&D investment, encourage technology transfer through strategic partnerships based on domestic production, and integrate the underwater technology agenda into the National Blue Economy Strategy [3], [4]. In addition, strengthening human resource development, expanding research infrastructure, supporting domestic maritime industries, and fostering collaboration among government, industry, and academia are essential to building a sustainable underwater technology ecosystem [1], [5], [12].

A long-term roadmap is also required to guide the development of indigenous underwater technologies, including autonomous underwater vehicles, ocean observation systems, underwater sensors, acoustic communication networks, and subsea monitoring platforms [6], [8], [10], [14]. Such a roadmap would help align research activities, industrial development, investment priorities, and national maritime objectives.

With these steps, Indonesia will not only be a user of technology but also an innovator in the global maritime industry. By strengthening technological independence and building a competitive maritime innovation ecosystem, Indonesia can maximize the benefits of its vast marine resources, enhance national security, support sustainable economic growth, and reinforce its position as a leading maritime nation in the global ocean economy [3], [4], [20].

## REFERENCES

- [1] J. G. Bellingham and K. Rajan, "Robotics in remote and hostile environments," *Science*, vol. 318, no. 5853, pp. 1098–1102, 2007. Available: <https://doi.org/10.1126/science.1146230>
- [2] D. R. Burnett, R. C. Beckman, and T. M. Davenport, *Submarine Cables: The Handbook of Law and Policy*. Leiden, The Netherlands: Martinus Nijhoff Publishers, 2014. Available: <https://brill.com/display/title/20889>
- [3] OECD, *The Ocean Economy in 2030*. Paris, France: OECD Publishing, 2016. Available: <https://doi.org/10.1787/9789264251724-en>
- [4] World Bank, *The Potential of the Blue Economy: Increasing Long-Term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries*. Washington, DC, USA: World Bank, 2017. Available: <https://openknowledge.worldbank.org/handle/10986/26843>
- [5] J. Yuh and M. West, "Underwater robotics," *Advanced Robotics*, vol. 15, no. 5, pp. 609–639, 2001. Available: <https://doi.org/10.1163/156855301750419902>
- [6] R. B. Wynn *et al.*, "Autonomous underwater vehicles (AUVs): Their past, present and future contributions to the advancement of marine geoscience," *Marine Geology*, vol. 352, pp. 451–468, 2014. Available: <https://doi.org/10.1016/j.margeo.2014.03.012>
- [7] H. Singh, J. Howland, and D. Yoerger, "Quantitative photomosaicking of underwater imagery," in *Proc. OCEANS Conf.*, 2004, pp. 263–266. Available: <https://doi.org/10.1109/OCEANS.2004.1406331>
- [8] B. Jalving, K. Gade, O. K. Hagen, and K. Vestgård, "A toolbox of aiding techniques for the HUGIN AUV integrated inertial navigation system," in *Proc. IEEE OCEANS Conf.*, 2003, pp. 1146–1153. Available: <https://doi.org/10.1109/OCEANS.2003.178489>
- [9] T. I. Fossen, *Guidance and Control of Ocean Vehicles*. Chichester, U.K.: Wiley, 1994. Available: <https://onlinelibrary.wiley.com/doi/book/10.1002/9781119994138>
- [10] M. R. Benjamin, H. Schmidt, P. M. Newman, and J. J. Leonard, "Nested autonomy for unmanned marine vehicles with MOOS-IvP," *J. Field Robotics*, vol. 27, no. 6, pp. 834–875, 2010. Available: <https://doi.org/10.1002/rob.20370>
- [11] R. Camilli *et al.*, "Tracking hydrocarbon plume transport and biodegradation at Deepwater Horizon," *Science*, vol. 330, no. 6001, pp. 201–204, 2010. Available: <https://doi.org/10.1126/science.1195223>
- [12] M. Dunbabin and L. Marques, "Robots for environmental monitoring: Significant advancements and applications," *IEEE Robotics Autom. Mag.*, vol. 19, no. 1, pp. 24–39, 2012. Available: <https://doi.org/10.1109/MRA.2011.2181683>
- [13] J. Jaffe, "Computer modeling and the design of optimal underwater imaging systems," *IEEE J. Oceanic Eng.*, vol. 15, no. 2, pp. 101–111, 1990. Available: <https://doi.org/10.1109/48.50694>
- [14] P. A. Wilson, "Challenges and opportunities in underwater acoustic communications," in *Proc. IEEE OCEANS Conf.*, 2004, pp. 228–235. Available: <https://doi.org/10.1109/OCEANS.2004.1405583>
- [15] A. Bowen *et al.*, "The Nereus hybrid underwater robotic vehicle for global ocean science operations to 11,000 m depth," in *Proc. IEEE OCEANS Conf.*, 2009, pp. 1–10. Available: <https://doi.org/10.23919/OCEANS.2009.5422196>
- [16] S. B. Williams *et al.*, "Autonomous underwater vehicle navigation and terrain mapping for reef monitoring," in *Proc. IEEE Int. Conf. Robotics and Automation*, 2010, pp. 5426–5431. Available: <https://doi.org/10.1109/ROBOT.2010.5509404>



- [17] E. Fakiris *et al.*, “Object-based image analysis of underwater scenes for marine habitat mapping,” *Sensors*, vol. 19, no. 16, p. 3531, 2019. Available: <https://doi.org/10.3390/s19163531>
- [18] C. Roman and H. Singh, “A self-consistent bathymetric mapping algorithm,” *J. Field Robotics*, vol. 24, no. 1–2, pp. 23–50, 2007. Available: <https://doi.org/10.1002/rob.20164>
- [19] M. Bibuli, G. Bruzzone, M. Caccia, and L. Lapierre, “Path-following algorithms and experiments for an unmanned surface vehicle,” *J. Field Robotics*, vol. 26, no. 8, pp. 669–688, 2009. Available: <https://doi.org/10.1002/rob.20303>
- [20] K. D. LePage, “Undersea fiber optic networks and submarine cable systems,” *IEEE Commun. Mag.*, vol. 53, no. 2, pp. 42–48, 2015. Available: <https://doi.org/10.1109/MCOM.2015.7045392>