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臺灣淨零科技方案推動小組
Taiwan Science and Technology Office for Net-zero Emission

複合式淨零科技前瞻布局
Net Zero Science & Technology policy :
The systematic and integrated resource planning approach

Carbon Negative
Humanities and Social Sciences

Ocean Carbon Sink

Background

The ocean serves as a critical carbon reservoir for Earth, absorbing approximately 30% to 40% of anthropogenic carbon dioxide emissions [2]. Ocean carbon sink (hereinafter referred to as "blue carbon") enhancement technologies are promising negative emissions technologies. Consequently, in recent years, global efforts have intensified in research and development for blue carbon enhancement, establishment of Measurement, Monitoring, Reporting, and Verification (MRV) mechanisms, and integration into the national greenhouse gas inventory. Taiwan's Carbon Reduction Flagship Program for the Agricultural Sector has also set a clear target of increasing marine carbon sequestration to 340,000 tons of CO_2e by 2030 [17].

From the perspective of ecosystems, the scope of blue carbon includes coastal blue carbon (mangroves, seagrass beds, tidal salt marshes, and macroalgae), open ocean blue carbon (phytoplankton and deep-sea sedimentation), shallow marine blue carbon (Aquatic Organisms Propagation and Conservation Zones), and coastal artificial wetlands (aquaculture sites).

Enhancement technologies include the restoration of mangrove and seagrass beds, seaweed cultivation, ocean alkalinity enhancement, ocean fertilization, and artificial upwelling. While Taiwan has a mature foundation in coastal blue carbon, with the Ministry of Environment passing the methodology for "Mangrove Afforestation" and "Seagrass Restoration" in July 2025, scientific gaps remain regarding ecological impacts. Other technologies are currently in small-scale testing phases and are lacking MRV mechanisms. To this end, the Net-zero Science and Technology Innovation Program(draft) aims to facilitate technology verification in the sea through cross-departmental collaboration and strengthen regulatory frameworks to ensure that blue carbon enhancement achieves its maximum effectiveness.

Global Outlook and Domestic Progress

(1) Global Outlook

The report "Strategy for NOAA Carbon Dioxide Removal Research" published by the National Oceanic and Atmospheric Administration (NOAA) compiled relevant information about carbon removal technologies, such as the Technology Readiness Level (TRL), carbon removal potential, sequestration duration [7]. When it comes to TRL, coastal blue carbon exhibits the highest TRL, followed by ocean fertilization and seaweed cultivation, then ocean alkalinity enhancement, with artificial upwelling ranking as the lowest. Regarding sequestration potential, ocean alkalinity enhancement holds the greatest potential (1,000 – 15,000 Mt CO2), followed by ocean fertilization and artificial upwelling (100 – 1,000 Mt CO_2), and coastal blue carbon (100 – 400 Mt CO_2).

(2) Domestic Progress

Taiwan has officially initiated marine carbon sink baseline surveys and assessments for various carbon sequestration enhancement technologies [16]. The survey scope covers coastal blue carbon, open ocean blue carbon (oceanic habitats), shallow marine blue carbon (aquatic organisms propagation and conservation zones) and coastal artificial wetlands (aquaculture sites) and coastal natural habitats (natural seaweed).

In terms of blue carbon enhancement technologies, Taiwan has already established methodologies for "Mangrove Afforestation" and "Seagrass Restoration" and has conducted an inventory of the relevant sequestration potential. Furthermore, research teams are exploring the integration of seaweed cultivation with offshore cage aquaculture, set-net fishing, or offshore wind farms [8]. This includes the cultivation of species such as Sarcodia montagneana, Agardhiella subulata, Gracilaria seaweed, Caulerpa microphysa, Eucheuma perplexum Doty, Ulva reticulata Forsskal. Preliminary assessments have identified Penghu and the waters off western Taiwan (the coasts of Changhua, Tainan, Kaohsiung, and Pingtung) as potential areas for macroalgae cultivation, which can be combined with offshore wind turbines [10]. Simultaneously, the Ministry of Agriculture and the Ocean Affairs Council are promoting the inclusion of blue carbon into the “National Greenhouse Gas Inventory Report”. They are also developing high-value-added algae products to enhance economic incentives for seaweed cultivation.

(3) Challenges of Developing Domestic Blue Carbon

Currently, the development of blue carbon both domestically and internationally is primarily regulated by the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention). Annex 1 of the Convention lists substances that are prohibited from being dumped, while substances in Annex 2 require a special permit; all other substances require a general permit [4]. Due to restrictions from the 2013 amendment, ocean fertilization is currently limited strictly to projects of a scientific research nature [5]. Any expansion toward broader application still requires further clarification within the framework of the London Convention.

Strategic Planning Framework

Based on domestic progress and challenges in blue carbon development, the Taiwan Science and Technology Office for Net-zero Emission has formulated a strategic planning framework for blue carbon. This framework was developed after consulting with domestic experts and aligning with the core pillars of the Net-zero Science and Technology Innovation Program (draft). The framework encompasses four strategies: (1) advanced carbon sink baseline surveys and enhancement techniques; (2) field verification of blue carbon enhancement technologies; (3) regulatory adaptation and supporting measures for blue carbon.

Strategy 1: Advanced Carbon Sink Baseline Surveys and Enhancement Technologies

Although Net-Zero Science & Technology Program (2023–2026) has already invested in carbon sink baseline surveys within territorial zones, data collection across the expansive 53,000 km2 territory is difficult. Furthermore, due to typhoons in summer and harsh sea conditions in winter, the current data remains significantly insufficient. The Net-zero Science and Technology Innovation Program (draft) will need to further strengthen survey capacity, with priorities including marine and sediment carbon sink baselines as well as natural algae carbon sink baselines.

Regarding marine and sediment carbon sinks, Taiwan has conducted baseline surveys for carbon sinks driven by the biological pump within the Exclusive Economic Zones (EEZ) and territorial zones [3]. The methodology integrates sediment traps, satellite data, and ship-based measurements, such as carbon chemical parameters, nutrients, and particulate carbon. Looking ahead, Taiwan may reference NOAA’s Ocean Carbon Observing Science Plan to develop multi-parameter, autonomous observation platforms. These platforms will utilize specialized sensors for the continuous monitoring of biogeochemical parameters, including DIC, pCO2, pH, etc [9]. This measuring procedure is expected to be conducted on a seasonal basis and expanded to regional observation stations. Ultimately, actual carbon sink measurements will be combined with biogeochemical modeling to provide ongoing updates on the carbon sequestration capacity of Taiwan's territorial waters.

Regarding natural seaweed carbon sink baselines, the biomass of macroalgae in Taiwan's natural habitats has been surveyed and estimated [10]. Surveys conducted from 2000 to 2015 found higher abundances of algae during the winter and spring, leading to the recommendation that surveys continue to focus on these seasons. While potential areas for seaweed cultivation have been preliminarily evaluated, a lack of carbon sink baselines for these specific regions necessitates further investment in baseline assessments. Current seaweed cultivation is in the small-scale testing phase and has yet to fully account for marine carbon cycle effects; therefore, the development of Measurement, Monitoring, Reporting, and Verification (MRV) mechanisms for seaweed farming is recommended. Furthermore, scaling up cultivation requires developing eco-adaptive physiological traits, such as wide temperature tolerance, regenerative capacity, light adaptation, and salinity tolerance, alongside deployment strategies tailored to specific sea areas, including Taiwan's rocky coasts, Penghu, Kinmen, and Matsu. Certain areas are better suited for sessile algae (e.g., Sargassum), while others are ideal for fragmenting renewable species (e.g., red algae); prioritizing species that grow year-round is suggested to maximize efficiency [10]. Additionally, a model for matching infrastructure requirements with on-site sea conditions should be established.

Regarding coastal blue carbon enhancement technologies, current efforts primarily focus on seagrass transplantation. However, there is a significant shortage in the supply of seagrass seedlings; consequently, it is recommended to invest in seedling breeding techniques and establish specialized nurseries [13]. Furthermore, recent research highlights that seagrass beds with high organic matter and calcium carbonate content serve as hotspots for the natural generation of marine alkalinity [1]. This phenomenon can further boost the carbon sequestration benefits of seagrass restoration. Therefore, it is suggested that future initiatives should prioritize research and technological development regarding seagrass carbon sink mechanisms across varying substrate conditions to facilitate more effective ecological restoration and maximize carbon sink efficiency.

Furthermore, technologies such as ocean fertilization and ocean alkalinity enhancement have not yet received investment under the current Net-Zero Technology Program (2023–2026). It is recommended that these be initiated in the Net-zero Science and Technology Innovation Program (draft). Ocean fertilization can begin with large-scale container (mesocosm) trials, while exploring potential integration with artificial upwelling and offshore wind turbines. For instance, underwater vertical pipes made of High-Density Polyethylene (HDPE) could be installed beneath offshore floating platforms or wind turbine foundations [14]. Using air pumps to generate bubbles can drive nutrient-rich deep seawater upward, which aids in the cultivation of seaweed and the growth of microalgae, thereby increasing the carbon sequestration capacity of the marine biological pump. Ocean alkalinity enhancement is currently a mainstream focus for marine carbon capture investments in both the European Union and the United States. It is recommended that initial trials be conducted at wastewater treatment plants, which offer several distinct advantages [11]:

- Easier Dissolution: the lower pH of wastewater facilitates the dissolution of alkaline minerals.
- Regulatory Compliance: according to current regulations, treated water can be discharged if the pH remains below 9.
- Environmental Mitigation: increasing alkalinity can help mitigate the negative ecological impacts typically caused by the low-pH discharge of treated wastewater into the ocean.

International research indicates that while there may be short-term nutrient limitation effects on zooplankton, the overall structure and stability of the food web remain unaffected [6].

Strategy 2: Field verification of blue carbon enhancement technologies

Some sequestration enhancement technologies have already undergone small-scale field testing and verification under the Net-Zero Program (2023–2026). In the future, it is essential to scale up these capacities and introduce emerging technologies. Existing items needing scaling-up include Mangroves, seagrass beds, and macroalgae cultivation. Emerging technologies needing investment include alkalinity addition, ocean fertilization, and artificial upwelling. It is recommended that Measurement, Monitoring, Reporting, and Verification (MRV) mechanisms be established for all technologies, alongside simultaneous assessments of their impacts on marine ecology and the environment. The objective of this strategy within the Net-zero Science and Technology Innovation Program (draft) is to achieve a 10,000-ton scale of carbon sequestration enhancement by 2030. Therefore, large-scale integrated field technology verification is the critical key to advancing toward this 10,000-ton goal and eventually reaching commercial operation. This progress requires using verification sites to accumulate integrated technologies, key marine biogeochemical parameters, and marine meteorological conditions to provide evidence-based scientific data.

Strategy 3: Regulatory Adaptation and Supporting Measures for Blue Carbon

Currently, domestic efforts are focused on assessing the feasibility of various enhancement technologies and establishing MRV (Measurement, Monitoring, Reporting, and Verification) mechanisms. To ensure that the benefits of marine carbon sequestration contribute to Taiwan's Nationally Determined Contributions (NDC), cross-departmental collaboration is essential to integrate marine carbon sink methodologies into the National Greenhouse Gas Inventory. Furthermore, the construction of demonstration sites or the expanded application of enhancement technologies involves marine spatial planning, management, and proactive communication with stakeholders [15]. For instance, relevant authorities should clarify and designate diverse marine functional zones based on an integrated resource planning framework. This includes developing GIS spatial distribution data for various marine resource uses to facilitate efficient integrated planning, inter-departmental coordination, and social communication. Beyond regulatory adaptation, the development of business models is critical for attracting more resources and improving management efficiency, while specifically increasing the added value of marine carbon sinks. For example, efforts have already begun in developing seaweed products; the Net-zero Science and Technology Innovation Program (draft) must continue to deepen these initiatives to build a comprehensive industrial value chain.

Expected Benefits

The Net-zero Science and Technology Innovation Program (draft) will focus on strengthening carbon sink baseline surveys, field verification, and regulatory supporting measures. In addition to these efforts, the program aims to promote scaling-up of marine carbon sinks technologies, expand overall capacity, refine marine spatial planning, enhance communication with key stakeholders, and establish business models to increase the added value of marine carbon sinks. The goal is to achieve a 10,000-ton scale of sequestration enhancement by 2030. This mission will be carried out while prioritizing the core values of sustainable development, ensuring a balance between biodiversity and ecological co-benefits.

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