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Investigating the role of marine plant biotechnology in carbon capture and sequestration initiatives

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Abstract

Objective

This study shows the potential of the biofuel produced by the seaweeds (SW) provides a significant biomass (BM) source for manufacturing third-generation biofuels (BF). The main objective of this study is to evaluate the effect of seaweed as a biomass in third-generation biofuel production and its efficacy in decreasing the environmental carbon dioxide. Considering these attributes jointly, Seaweeds comparatively elevated carbohydrate content has been proposed as an optimal solution for CO₂ collection and biofuel generation. Despite the emergence of third-generation Biofuels as superior alternatives to petroleum and diesel, large-scale manufacturing and widespread use remain absent owing to several technological obstacles and elevated production costs.

Materials and methods

This paper elucidates the notion of coastal marine Biological Refineries (BR) as the most economical and ecological method for biofuel generation from aquatic plants, with atmospheric Carbon Capture and Sequestration (CCS). The proposed refinery technology utilizes marine resources, including saltwater, seaweed, and aquatic microbes. Initially, a comprehensive review of the existing literature was conducted to identify the technologies that would facilitate the development of an innovative bioreactor system and its advantages over traditional refineries. In addition, the research examines several scenarios evaluating the capacity of seaweeds for Carbon Capture and Sequestration.

Results

The study illustrates that seaweed cultivation facilities accomplish the extraction of 120 Gigatons of surplus CO₂ within a timeframe of around 5 months rather than 13 years, contingent upon the region of cultivation and the type of seaweed used, the amount of bioethanol produced from the collected biomass amounts to approximately 5 trillion liters. The High-Value Compounds (HVC) extracted from the process signify a substantial possibility with multi-billion-dollar economic potential.

Conclusions

Based on this study this coastal marine biorefinery represents a highly promising but still emerging technology for addressing climate change and the energy needs. By the current technology, the achievement of the biofuel is theoretically best but in reality, it is difficult. But the combination of the marine biomass, marine microbes that can break down the seaweed, and the advanced technology can improve the efficiency of producing the biofuel on a large scale. Also, the large-scale production can give multiple by-products that can be economically important in the market.

Keywords: bioethanol, biorefineries, coastal sustainability, renewable energy, seaweed biorefinery

Paper Type: Review Paper.

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Introduction

Environmental and climatic concerns: Worldwide land-ocean temperatures have increased by at least of 1.2°C since the preindustrial era (Clark et al., 2024). Some research indicates that Earth is technically in a long-term ice age (the Quaternary period), it is currently in a warmer interglacial phase. This would suggest a natural cooling trend over geological timescales. However, the recent rapid warming due to human activities is an anomaly in this context. Climate change involves more than quantitative increments; its consequences must not

be undervalued (Chatterjee & Sanyal, 2024). The natural environment is among the first to experience its' adverse effects. For example, increasing temperatures enhance water loss, expedite the melting of glaciers, and improve the hydrological cycle, leading to more humid regions and drier places (Liyanarachchi et al., 2021). This results in increased extreme weather events, including but not limited to storms, droughts, and wildfires. The indigenous species will encounter substantial destruction due to considerable changes in the natural environment. Statistics indicate that since the onset of manufacturing, the global rate of species disappearance has increased by nearly 100-1000 times (Vakhguelt & Jianzhong, 2023; Singhal et al., 2024). Climate change significantly influences both the ecosystem and human civilization. The increase in severe weather phenomena, such as floods and droughts, causes economic pressures worldwide (Assegid & Ketema, 2023; Kaul & Prasad, 2024). Statistics reveal that a 3°C increase in worldwide temperatures might result in an estimated 4% decline in Global Domestic Product (GDP); a 4°C rise reduces 8% to 14% (Löckenhoff et al., 2009). The principal cause of climate change has been linked to actions since the onset of civilization. Since the industrial revolution, humanity has relied significantly on fossil fuels such as natural gas, petroleum, and coal, which constitute over 82% of the world's energy use. The widespread consumption of oil and coal has resulted in significant CO₂ releases that disturb the planet's carbon cycle and swiftly elevate atmospheric CO₂ levels (Leng, 2025). Atmospheric concentrations of CO₂ have risen from approximately 280 ppm before industrialization to almost 430 ppm (Cheng et al., 2022; Sahu & Kumar, 2024). The Paris Agreement aims to limit the increase in annual temperatures to less than 3°C relative to the time before industrialization, while striving to keep it under 1.6°C, to reduce the effects of climate change. To achieve the 3°C warming objective, net-zero CO₂ emissions must be reached by 2050 (Melendez et al., 2022). To attain the more aggressive objective of limiting heating to 1.6°C, mankind must decrease CO₂ emissions by 42% from the peak levels reached in 2015 by 2035 and eventually achieve net-zero emission levels by 2040 (Sato et al., 2019; Luo & Tang, 2024). Techniques for CO₂ elimination, such as Carbon Capture and Sequestration (CCS) (Gridnev et al., 2020), are essential for promptly achieving net-zero emission goals. CCS denotes the capture of CO₂ from industrial processes, energy consumption, or directly from the environment, followed by its usage or storage at designated sites to reduce atmospheric CO₂ levels. Minimizing the use of resources and enhancing co-product possibilities in the production processes are essential for advancing the creation of seaweed (SW) Biological Refineries. Coastal marine Biological Refineries (BRs) are emerging as promising alternatives to traditional land-based biorefineries, offering unique environmental and economic benefits. This research primarily examines these coastline marine BR systems and evaluates their advantages over conventional setups, particularly in terms of sustainability, carbon efficiency, and resource circularity. By comparing these

systems, the study aims to highlight the potential of marine-based biorefineries to contribute to a low-carbon bioeconomy. Coastal-based Integrative Marine Biorefinery (CIMB) (Kabir et al., 2023) technologies were proposed to manufacture third-generation Biofuels (BF) effectively. These networks use marine assets (seaweed, maritime yeast, and maritime algae) to generate BFs and High-Value Compounds (HVC) (Menon & Patil, 2023) using combined biological processes of transformation (i.e., fermenting and anaerobic digesting). The amalgamation of these aquatic resources and conversion methods will improve manufacturing efficiency and eliminate the need for groundwater and arable land within the BF sector (Cao & Jiang, 2024). This augments the CO₂ sequestration capacity of the technique, thereby making BFs an increasingly viable and less environmentally harmful energy source. The CIMB technologies have not been extensively studied and need a comprehensive examination (Tong, 2010). In addition, climate change has widespread impacts on biodiversity and has posed survival challenges to many plant and animal species (Farahvashi et al., 2026a). Increasing temperatures, changing rainfall patterns, rising sea levels, and extreme weather events have led to habitat changes, species population declines, and even extinctions (Pakgohar et al., 2026). Climate change also affects ecological interactions such as food chains, species distribution, and the timing of biological activities (Mohammadabadi et al., 2021). Climate change is one of the major global challenges that has widespread impacts on ecosystems and biodiversity. Increasing temperatures, changing rainfall patterns, rising sea levels, and extreme weather events have led to changes in habitat conditions, species population declines, and even the extinction of some of them. This phenomenon not only disrupts the ecological balance, but also affects the relationships between species, such as food chains and competition for resources (Farahvashi et al., 2026b). Therefore, this research primarily examines coastline marine Biological Refineries (BR) and their advantages over traditional biorefinery setups. The study's second segment is to evaluate SWs' capacity for CO₂ sequestration by determining the duration necessary to eliminate 120 gigatons of atmospheric CO₂ via SW cultivation. The study quantifies the amount of ethanol and HVC derived from the generated SW material (Chen et al., 2021). Rising CO₂ levels and climate pressures demand sustainable solutions. Marine biorefineries using seaweed offer an eco-friendly alternative, requiring no farmland or freshwater. By integrating carbon capture with biofuel and high-value compound production, this study explores a scalable, low-impact approach aligned with global efforts toward a circular, low-carbon bioeconomy.

Carbon utilization via biotechnology

Biotechnology encompasses a wide range of applications for carbon usage, including biomass (BM) energy production, biofuel manufacturing, biogas usage, and the creation of bio-

based products and chemicals. This study mainly investigates three principal domains: ethanol synthesis as a biofuel (BF), energy generation via biomass (BM) burning, and the combined utilization of CO₂ and biomass to produce high-value compounds.

Bioethanol: Bioethanol is used widely as a renewable BF and is considered an acceptable substitute for petroleum (Ibigbami et al., 2024). Compared to petroleum gasoline, bioethanol has numerous benefits: (1) It is renewable, as it is derived from biomass farming; (2) Eco-friendly, it results in reduced CO₂ emissions; (3) Environmentally protective, it releases fewer toxic gases upon burning, thereby alleviating air pollution; (4) Biodegradable, it inflicts minor damage to the environment if released. Bioethanol cannot entirely replace oil owing to its elevated production costs and *its lower energy density and higher production costs compared to gasoline* (Balat et al., 2008). Bioethanol is derived from three distinct raw materials. First-generation materials involve sugar-based sources (cane, beet, rye, and fruits) and starch-based sources (maize, wheat, potatoes, and tapioca). The second type employs lignin plants or waste materials such as corncob, straw, and wood debris. The third generation utilizes algal biomass as a substrate. The selection of materials is significantly determined by location. In the country's southwestern part, substantial corn cultivation occurs, with grain as the basis for manufacturing bioethanol. Brazil, the world's foremost exporter of sugar cane, utilizes cane as its principal feedstock for bioethanol production. Despite variations in the starting materials, the manufacturing process fundamentally comprises three primary stages: (1) preprocessing and grinding of the initial supplies; (2) hydrolysis to transform them into fermented carbohydrates; (3) anaerobic breakdown of these carbohydrates into ethanol. Using lignocellulose as an instance, this method entails pre-treating chosen lignin-based materials such as wood, sphagnum or scrap paper for enhanced subsequent operations; enzyme hydrolysis by introducing these ingredients into a tank with suitable enzymes at designated conditions to convert them into fermented sugars; and ultimately sending those by enzymes broken down chemicals, along with fermenting varieties, into a fermenter for converting into alcohol and carbon monoxide (Sarkar et al., 2011). Unlike first-generation ethanol, which primarily utilizes food crops as substrate and employs relatively simple manufacturing methods, it fights for agricultural rights with feed plants and escalates costs (Bibi et al., 2016). Transitioning to lignin to manufacture bioethanol provides reduced costs, less land use, and plentiful raw materials at cheaper prices relative to maize, wheat, sugarcane, and other commodities. The preparatory expense associated with this approach is considerable. Algae, as a third-generation substance, have superior photosynthesis and can amass much more energy from the sun per unit of time than conventional energy crops. This offers an essential benefit in the manufacture of ethanol. Current research focuses on developing technologies to scale up algae-based ethanol production for industrial use.

Biomass burning energy production: Combustion represents the most straightforward and effective method for using BM (Arul Prakash & Khanna, 2024). Biomass combustion can be categorized as direct biomass burning or co-firing with coal. Clean BM burning involves using BM as a solid fuel via direct burning or post-combustion to capture the heat emitted for power production. The primary sources of raw materials derived from pure bioenergy are related to agriculture, municipal waste, and waste from industries. Unadulterated BM fuels demonstrate superior combustion and release reduced quantities of pollutants, including nitrogen and sulfur dioxide. They are often considered carbon-neutral, as the CO₂ released during combustion roughly equals the amount absorbed during biomass growth (McKendry, 2002). The straightforward burning of BM sometimes does not achieve complete oxidation, resulting in the emission of nitrogen oxides and particles that contribute to the contamination of the environment. BM fuels, including potassium (K) and chlorine (Cl), possess elevated inorganic material, generating substantial ash during direct burning (Werther et al., 2000). This ash readily impedes pipes or builds up in boilers. The heat transmission coefficient associated with these ash accumulations is just 1/30 that of steel, causing uneven heating inside boilers and possibly leading to pipeline ruptures or boiler bursts. Increased chlorine levels in the ash lead to corrosion problems that affect standard thermal power plant operations. Denmark BWE established a straw-based bio-burning energy facility and later planned and constructed pine chip and waste-burning generators in the following years. Elyan operated the biggest straw-based generator, with a current capacity of 35 MW. CO₂ partners with cellulose to synthesize HVC. The co-production technique employs carbon monoxide and BM to generate high-value compounds. BM is rich in carbon, oxygen, and intricate groups of functions, facilitating the generation of diverse chemicals via oxidation processes when BM is integrated with low-cost, non-toxic, and readily recyclable CO₂. Oxidation reactions or mild acidic conditions in aqueous media can enhance enzymatic activity and improve conversion efficiency (Artz et al., 2017). This cutting-edge technique employs two accessible carbon sources, BM and CO₂, to transform low-value carbon materials into HVC. It provides substantial economic advantages and decreases the conventional chemical industry's dependence on fossil fuels such as petroleum, while attaining no carbon emissions. The method can be integrated with other CO₂ utilization methods, such as BM combustion to produce electricity, where the collected high-concentration CO₂ from burning fuel in power plants is effectively converted into valuable carbon assets, thus improving cost-effectiveness and effectiveness. It is essential to acknowledge that this technique encounters obstacles due to its comparatively poor catalytic efficiency and stability. Tackling the intricacies of solid-liquid-gas three-phase absorption and transformation, including CO₂, poses more study challenges. Offshore seaweed-based biorefineries (SW BR) can operate independently, but integration with other

systems may improve efficiency and cost-effectiveness (Figure. 1) (Janicek et al., 2013). These evolving hybrid systems are called CIMB. Integrated BR amalgamate seawater and microalgal factories, with specific by-products from one functioning as inputs for the other. CO₂ and wasted SW, the hydrolysate provides inorganic and organic carbon sources for microalgal development. Different components of phytoplankton biomass offer unique industrial applications. Lipids are removed and converted into biodiesel, peptides are marketed as animal feed, and sugars are digested into bioethanol. Beyond their primary metabolites, phytoplankton produce various high-value compounds with commercial potential.

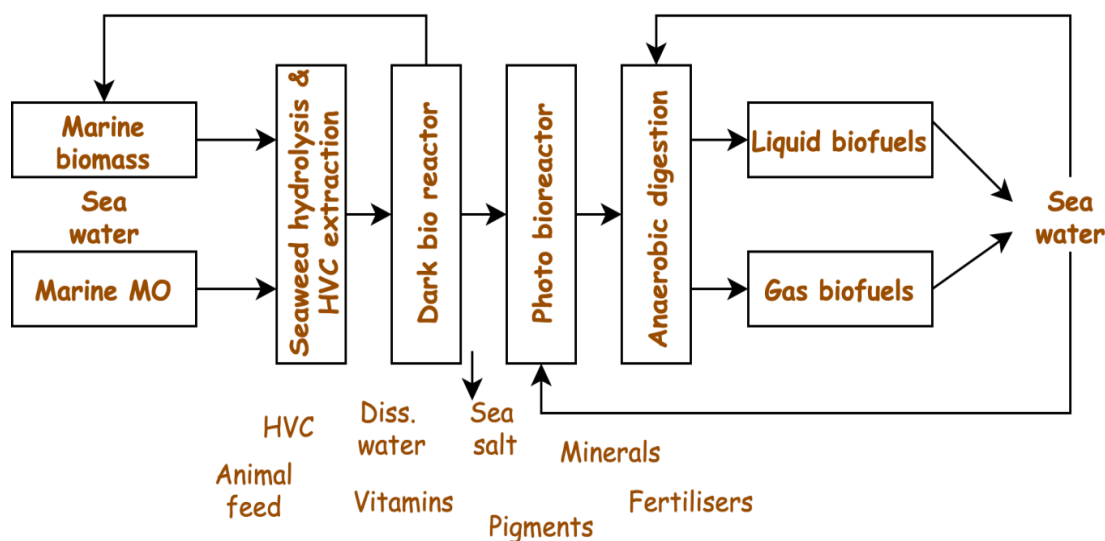


Figure 1. Coastal-based Integrative Marine Biorefinery for marine biomass conversion into high-value compounds and biofuels via sequential bioprocessing.

Carbon sequestration utilizing biotechnology

Carbon sequestration (CS) techniques are generally classified into abiotic and biotechnology-based methods. Abiotic CS includes geological, substance, marine, and several other methods accomplished by physical and chemical interactions. Biotechnological CS captures and stores atmospheric CO₂ via photosynthesis, a crucial component of the worldwide carbon cycle (Lal, 2007). Biological sequestration is seen as more dependable and economically efficient than abiotic approaches (Houghton, 2007). Biological CS is categorized as blue CS and terrestrial carbon sequestration, depending on environmental variances among species. Seaweed cultivation has emerged as one of the most efficient biological tools for atmospheric CO₂ removal due to its fast growth rate, minimal input requirements, and high photosynthetic efficiency (Duarte et al., 2017). Based on the availability growth data and productivity metrics, estimates suggest that seaweed farms, under optimal conditions, could collectively sequester up to 120 gigatons of atmospheric CO₂ within approximately 5 months (Figure 2). In contrast, terrestrial forests and

mangroves would require 13-20 years to archive similar outcomes (Krause-Jensen & Duarte, 2016).

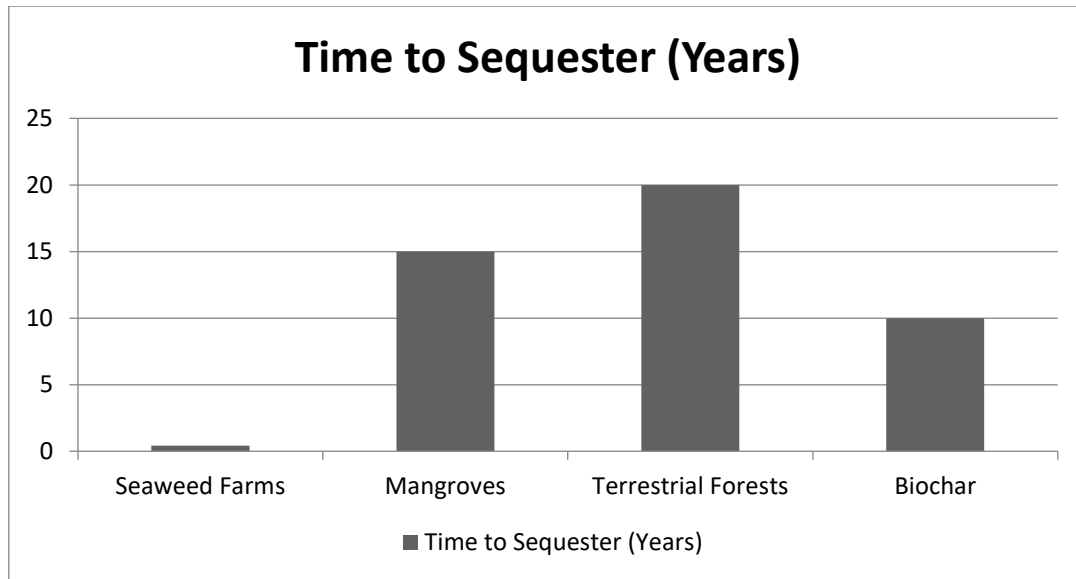


Figure 2. Comparative time required for CO₂ sequestration across natural systems

Figure 3 compares the estimated time required by different natural systems to sequester 120 gigatons of atmospheric CO₂. Seaweed farms demonstrate a drastically shorter sequestration period (~0.5 years), whereas mangroves and terrestrial forests require 15 and 20 years, respectively. Biochar systems offer a moderate rate, achieving similar sequestration in 10 years. Figure 3. compares the total CO₂ sequestration potential of various ecosystems. Seaweed farms exhibit the highest capacity at 120 gigatons, followed by mangroves (100 Gt), terrestrial forests (90 Gt), and biochar-based systems (80 Gt). This highlights the significant role of marine-based systems in large-scale carbon capture strategies. These findings highlight seaweed farming as a scalable and rapid climate solution. Its high carbon uptake over short periods suggests that marine-based biorefineries can act not only as biofuel production units but also as strategic carbon sinks, supporting global climate targets.

Blue CS: The ocean significantly influences the carbon cycle, since marine creatures contribute to over half of the carbon stored by every living thing. *Blue carbon refers to the carbon captured and stored in coastal and marine ecosystems, including seagrasses, mangroves, and tidal marshes.* Its sinks have significantly extended storage durations in contrast to terrestrial counterparts. Terrestrial environments such as forests and grasslands generally sequester their collected CO₂ for a maximum of a few decades, while oceanic carbon sinks can store CO₂ for hundreds to thousands of years (Mcleod et al., 2011). Thus, blue CS has significant retention capacities and long-lasting impacts on mitigating atmospheric emissions of Greenhouse Gases (GHG). The natural setting will profoundly influence aquatic ecosystems' CO₂ sequestration

potential. Marine ecosystems are more vulnerable to uncontrollable factors such as storms and warming, making their carbon sequestration potential less predictable than terrestrial systems. This introduces uncertainty regarding the long-term carbon sequestration potential of blue carbon ecosystems (Pendleton et al., 2012).

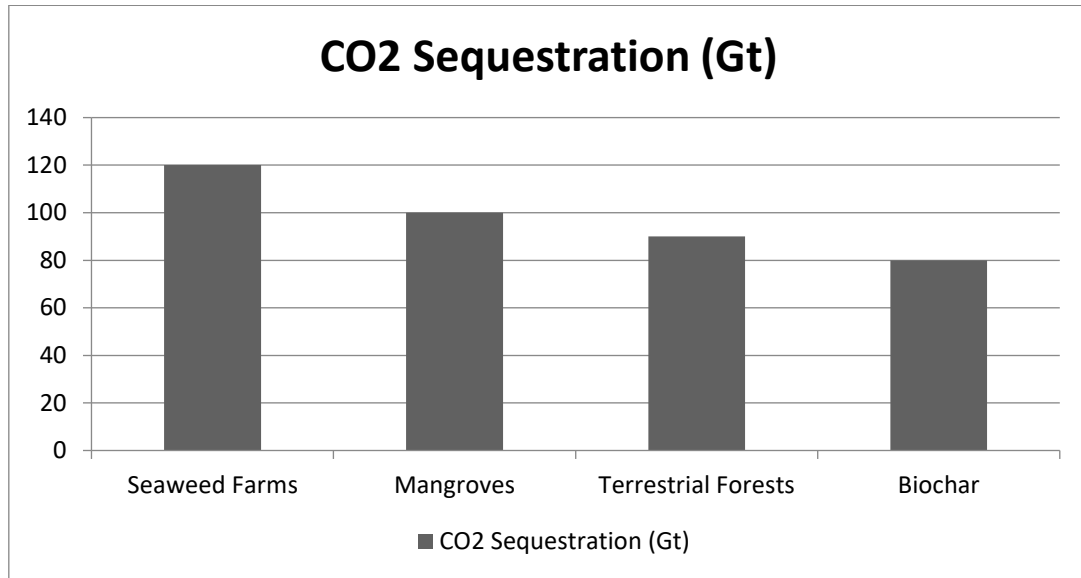


Figure 3. CO₂ sequestration capacity of different natural systems

Blue CS: The ocean significantly influences the carbon cycle, since marine creatures contribute to over half of the carbon stored by every living thing. *Blue carbon refers to the carbon captured and stored in coastal and marine ecosystems, including seagrasses, mangroves, and tidal marshes.* Its sinks have significantly extended storage durations in contrast to terrestrial counterparts. Terrestrial environments such as forests and grasslands generally sequester their collected CO₂ for a maximum of a few decades, while oceanic carbon sinks can store CO₂ for hundreds to thousands of years (McLeod et al., 2011). Thus, blue CS has significant retention capacities and long-lasting impacts on mitigating atmospheric emissions of Greenhouse Gases (GHG). The natural setting will profoundly influence aquatic ecosystems' CO₂ sequestration potential. Marine ecosystems are more vulnerable to uncontrollable factors such as storms and warming, making their carbon sequestration potential less predictable than terrestrial systems. This introduces uncertainty regarding the long-term carbon sequestration potential of blue carbon ecosystems (Pendleton et al., 2012). Coastal habitats, such as mangroves, beds of seagrass, and tidal marshes, are internationally recognized as functional blue carbon environments with considerable CS capacity per unit area. These delicate coastal ecosystems are vulnerable to pollution-related deterioration, which occurs swiftly, resulting in the loss of blue carbon ecosystem processes and the release of CO₂ deposited in marine sediments (Howard et al., 2021). Owing to warming temperatures and other influences, some elements of the marine environment

have shifted from functioning as CO₂ sinks to acting as CO₂ sources, exemplified by coral reefs (Suzuki & Kawahata, 2003). For example, coral reef systems such as the Great Barrier Reef have shown evidence of releasing more CO₂ than they absorb during periods of thermal stress and bleaching, due to the breakdown of calcification processes and increased organic matter decomposition. This shift is partly due to increased absorption of atmospheric CO₂ by seawater, which leads to ocean acidification and may convert ecosystems like coral reefs into net carbon sources. Therefore, this mechanism interacts with CaCO₃ to liberate supplementary CO₂. Several academics assert that calcifying organisms release CO₂ throughout their calcification processes (Gattuso et al., 1998).

Terrestrial CS - biochar technologies: Biochar's carbon sequestration potential is influenced by its aromatic structure and interactions with soil biology and chemistry throughout its lifespan. A significant use of lowland biochar is its integration into soil, which improves soil carbon levels and aids in rehabilitating damaged soil (Jeffery et al., 2011). The distinctive aromatic shape of biochar dictates its CS and is affected by its abiotic and biological relationships with soil constituents over its surrounding life cycle. Biochar is highly stable, with studies suggesting carbon retention times exceeding 1,000 years in some conditions. In addition, biochar has diverse pore architectures, a substantial surface area, and exhibits robust adsorption properties for soil nutrients, CO₂, and other GHG emissions. Thirdly, rocks and microbes actively engage in the mining or association of unstable (soluble and readily degraded) or even refractory elements within biochar. Thus, enhancing soil fertility and promoting microbial activity, which in turn supports plant growth. Thus, it makes a resilient carbon cycle from BM to charcoal and back to the BM, demonstrating a carbon ecological cycle. The use of biochar encounters certain obstacles. In some cases, biochar may alter soil pH or nutrient availability negatively. Additionally, the high production and application costs limit its widespread use (Garza-Alonso et al., 2019). In China, biochar has been applied to over 400 acres of rice fields to mitigate emissions and enhance carbon sequestration. This application has led to a notable 10% rise in productivity, the CS of around 125.5 tons of CO₂, and an average decrease in net release of GHG of 52%. This novel strategy significantly reduces illness rates and insect infestations compared with rice paddies without the biochar usage, with recorded reductions of 20% in sheath blight incidence and 16% in borer infestations compared to untreated fields (Suominen, 2018).

Discussion

A coastal marine biorefinery is an innovative biorefinery platform that utilizes marine resources to generate environmentally friendly biofuels. Seaweeds serve as an optimal substrate for bioethanol manufacturing, since they need neither arable land nor freshwater and demand

require less intensive pre-treatment and enzymatic hydrolysis than lignocellulosic biomass. All groups of seaweed possess High-Value Compounds (e.g., pigments, antioxidant's, bioactive peptides) with economic potential. Traditional procedures for seawater pre-treatment and High-Value Compounds extraction is often not environmentally friendly, prompting the development of more sustainable alternatives. These systems often integrate biomass processing and product recovery into a unified procedure, using less energy and organic solvents than traditional processes. Each technique has inherent disadvantages. Further study is necessary to optimize the various extraction techniques due to their uniqueness. In the framework of a seaweed marine bio refinery, halotolerant proteins and marine microbes are essential for scavenging and fermenting in bioethanol production. Marine sources or genetic engineering have obtained a range of enzymes proficient in degrading seaweed polysaccharides. A primary constraint of their use is the associated manufacturing expenses. Several microbes capable of seaweed fermentation have been found in marine habitats. Co-products from the manufacture of bioethanol might provide additional income streams or act as inputs for other sectors, facilitating the evolution of maritime biological refineries into unified structures. These technologies offer optimal biomass use while minimizing waste. Due to their exceptional efficiency in carbon capture, an investigation was performed to examine SWs' CO₂ storage capability. The literature estimates of seagrass net primary production over three distinct surface regions were used to ascertain the necessary time and biomass to extract 120 gigatons of CO₂. All surplus CO₂ is eliminated within 10 years. The BM projected throughout the three scenarios yields enough bioethanol to satisfy world energy requirements and substitute for the petrochemical sector. The recoverable high-value compounds possess a multiple-billion-dollar price, making SW BR a lucrative enterprise. Although now just theoretical, coastal marine biological refineries have an opportunity to enter the biofuel sector due to the availability of existing technology. Through further study, the specific components of these biological refineries might be optimized and more effectively developed. The transition to coastal ocean biological refineries might facilitate carbon-neutral power generation and foster a cleaner, environmentally friendly, marine-oriented future.

Conclusion: The coastal marine biorefinery is a well-structured and sustainable platform for producing biofuels and high-value compounds using marine biomass produced by seaweed. These methods have plenty of advantages over traditional land-based refineries. They don't land for farming or water for cultivating. The biomass can be produced with less energy, on the other hand, it will reduce the atmospheric carbon dioxide more efficiently. The seaweed was selected for several conditions like it will grow quickly and it will produce more amount of carbohydrates than it takes for its growth. The produced carbohydrate was then used to produce biofuels like bioethanol through the fermentation process. And by-products like bagasse will be used to

produce paper like other economically important products. But the technology is still developing. The advanced process like combining the marine biomass, marine microbes, and modern biotechnological methods can lead the technology to produce more efficient biofuel that can compete with fossil fuel. Advanced research is needed to break down seaweed, achieve low production costs, and develop biorefinery processes to produce on a large scale. If the goal is achieved, coastal marine biorefineries will play a major role in fighting against climate change by producing renewable energy and capturing carbon from the atmosphere.

Author contributions

All authors contributed equally to all stages of the research. Both authors were involved in conceptualization the study, methodology, data collection, analysis, and interpretation.

Data availability statement

No new data were generated or analyzed during this study. All information presented is derived from previously published sources, which are appropriately cited.

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Ethical considerations

This study did not involve any human or animal participants and therefore did not require ethical approval.

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Conflict of interest

The authors declare no conflict of interest.

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بررسی نقش زیست‌فناوری گیاهان دریایی در طرح‌های جذب و ذخیره‌سازی کربن

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چکیده

هدف: این مطالعه به بررسی ظرفیت زیست‌سوخت‌های تولیدشده از جلبک‌های دریایی به‌عنوان منبع زیست‌توده‌ای مهم برای تولید زیست‌سوخت‌های نسل سوم می‌پردازد. هدف اصلی پژوهش، ارزیابی نقش جلبک‌های دریایی به‌عنوان منبع زیست‌توده در تولید زیست‌سوخت‌های نسل سوم و کارایی آن‌ها در کاهش دی‌اکسیدکربن محیط‌زیست است. با توجه به محتوای نسبتاً بالای کربوهیدرات در جلبک‌های دریایی، این موجودات به‌عنوان گزینه‌ای مناسب برای جذب CO_2 و تولید زیست‌سوخت پیشنهاد شده‌اند. با وجود آن‌که زیست‌سوخت‌های نسل سوم به‌عنوان جایگزین‌های برتر برای نفت و گازوئیل مطرح شده‌اند، تولید در مقیاس وسیع و استفاده گسترده از آن‌ها همچنان به دلیل چالش‌های فناورانه و هزینه‌های بالای تولید محدود باقی مانده است.

مواد و روش‌ها: در این مقاله، مفهوم پالایشگاه‌های زیستی دریایی ساحلی به‌عنوان روشی اقتصادی و سازگار با محیط‌زیست برای تولید زیست‌سوخت از گیاهان آبی همراه با فناوری جذب و ذخیره‌سازی کربن (CCS) تشریح شده است. فناوری پیشنهادی از منابع دریایی شامل آب شور، جلبک‌های دریایی و میکروارگانیسم‌های آبی بهره می‌گیرد. ابتدا مرور جامعی بر مطالعات پیشین انجام شد تا فناوری‌های لازم برای توسعه یک سامانه نوآورانه بیوراکتور و مزایای آن نسبت به پالایشگاه‌های سنتی شناسایی شود. همچنین، سناریوهای مختلفی برای ارزیابی ظرفیت جلبک‌های دریایی در جذب و ذخیره‌سازی کربن مورد بررسی قرار گرفت.

نتایج: نتایج نشان داد که مزارع کشت جلبک دریایی می‌توانند حدود ۱۲۰ گیگاتن CO_2 اضافی را در بازه زمانی تقریبی ۵ ماه (در مقایسه با ۱۳ سال در شرایط معمول) جذب کنند؛ این میزان به منطقه کشت و نوع جلبک مورد استفاده بستگی دارد. از زیست‌توده جمع‌آوری‌شده، حدود ۵ تریلیون لیتر بیواتانول قابل تولید است. همچنین، ترکیبات با ارزش افزوده بالا (HVC) استخراج‌شده از این فرآیند دارای ظرفیت اقتصادی چند میلیارد دلاری هستند.

نتیجه‌گیری: بر اساس یافته‌های این پژوهش، پالایشگاه زیستی دریایی ساحلی فناوری نوظهور و بسیار امیدبخشی برای مقابله با تغییرات اقلیمی و تأمین نیازهای انرژی به شمار می‌رود. اگرچه از نظر تئوری، تولید زیست‌سوخت با این فناوری امکان‌پذیر و مطلوب است، اما در عمل چالش‌هایی وجود دارد. ترکیب زیست‌توده دریایی، میکروارگانیسم‌های تجزیه‌کننده جلبک و فناوری‌های پیشرفته می‌تواند کارایی تولید زیست‌سوخت در مقیاس صنعتی را افزایش دهد. همچنین، تولید در مقیاس بزرگ می‌تواند منجر به تولید محصولات جانبی متعددی شود که از نظر اقتصادی در بازار ارزشمند هستند.

کلمات کلیدی: انرژی تجدیدپذیر، بیواتانول، پالایشگاه زیستی جلبک دریایی، پالایشگاه‌های زیستی، پایداری ساحلی

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