SEAWEED: A HIGH-PROFILE MATERIAL FOR DECARBONIZATION

— SIGNS OF SUPPLY CHAIN TRANSFORMATION —

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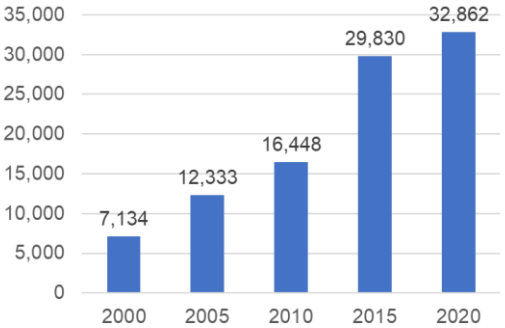
SUMMARY

- Seaweed, which has been used for food, fertilizer, etc., has been attracting attention in recent years as a material that can aid in decarbonization. Promising applications include biostimulants (a type of agricultural material), alternative proteins, and feed additives to reduce methane in the belches of cattle and other animals.
- Moves are underway to change the supply chain of seaweed production, distribution, and processing in preparation for future market expansion, with an eye towards climate change measures.
- Blue carbon refers to the carbon that is captured by seaweed beds and other components of the marine ecosystem, and is subsequently credited and traded. This is anticipated to drive the entry of companies into seaweed aquaculture in the near future.

1. DECARBONIZATION BY SEAWEED

Seaweed has long been used as a food and fertilizer. Currently, about 78% of its production volume is consumed directly as food, while 11% is used as food additives and the like.[1] Against the backdrop of increasing demand as a food additive, the production of main seaweeds has grown approximately 4.6 times in the 20 years since the year 2000 (Figure 1).[2]

Figure 1 Seaweed production trends



Note: Total production volume of 8 major species is shown.
Source: Compiled by MGSSI based on FAO, "The state of world fisheries and aquaculture 2022"

In recent years, seaweed aquaculture has attracted attention from the perspective of environmental protection. Seaweed grows in the sea by photosynthesis, which can be expected to directly reduce carbon dioxide emissions. It also benefits the ecosystem by improving water quality by absorbing nitrogen and other nutrients from the sea, and providing a home for fish and other organisms. Furthermore, studies have shown that seaweed also indirectly contributes to the reduction of carbon dioxide emissions.[3] Examples of this include alternative foods, feeds, and biofuels made from seaweed. Promoting the use of seaweed in these fields, which traditionally rely on agricultural products, can reduce the burden on agriculture and decrease carbon dioxide emissions.

While the value of seaweed is gaining recognition in terms of decarbonization and biodiversity, there is also the potential to expand its applications into a variety of fields. This report focuses on the agricultural and food sectors, and describes how seaweed is beginning to attract attention.

[1] Reviews in Fisheries Science & Aquaculture, April 2021, Thierry Chopin et al. "Importance of Seaweeds and Extractive Species in Global Aquaculture Production"
[2] FAO, "The state of world fisheries and aquaculture 2022"
[3] Nature Sustainability, "Reducing global land-use pressures with seaweed farming"

2. PROMISING APPLICATIONS FOR SEAWEED

Figure 2 shows the new applications of seaweed that are attracting attention from the perspective of decarbonization, as well as the market size and the issue. The underlying issues are scaling-up in anticipation of market expansion and the stabilization of raw material supply.

Figure 2 New applications, market size, and issues for seaweed, which is attracting attention from the perspective of decarbonization

Application		Market size		Issue
		2022	2030	
(1)	Methane-reducing feed additives	N/A*	USD 306 million	• Development of mass aquaculture technology: Mass aquaculture technology for methane-reducing seaweeds such as *Asparagopsis* • Increased feed costs: Increased feed costs due to the addition of feed additives • Measurement, reporting, and verification of reduction of methane in belches from cows, etc.: Reduction of labor and cost
(2)	Biostimulants	USD 1 billion	USD 1.88 billion	• Stabilization of raw material procurement: Seasonal fluctuations in the active ingredients contained in seaweed • Extraction technology: Development of efficient active ingredient extraction technology • Awareness among farmers: Increasing awareness of the effectiveness of biostimulants
(3)	Alternative proteins	N/A	USD 448 million	• Market development: Improving consumer awareness of seaweed foods • Cost reduction: Reduction of costs for processes such as drying and protein extraction • Stabilization of quality: Stabilization of seaweed protein content

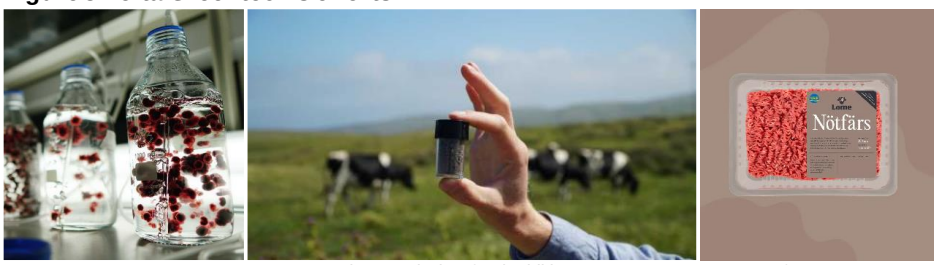
Reference: The total market for methane-reducing feed additives, not just those derived from seaweed, is USD 47 million.
Source: Compiled by MGSSI based on the World Bank, "Global Seaweed New and Emerging Markets Report 2023"

2-1. Methane-reducing feed additives

The technology for adding seaweed to cattle feed to reduce methane contained in belches and flatulence is relatively recent, with patents first filed from around 2015. Methane, which has a global warming effect 20 times greater than carbon dioxide, is generated by microbial activity in the intestines of cattle and other ruminants, but this activity is inhibited by compounds in seaweed. In particular, the *Asparagopsis* genus of seaweed contains a component that inhibits methanogenic bacteria and is highly effective in reducing methane even when added in small amounts. For this reason, many startups developing methane-reducing feed additives are utilizing this seaweed.

Volta Greentech (Sweden) has developed a feed additive called Lome. Feeding a cow 100 grams per day can reduce its methane emissions by up to 90%. The company has developed a bioreactor-based *Asparagopsis* aquaculture system that controls temperature and light levels with sensors and the like to achieve optimal conditions for growth (Figure 3, left). Volta Greentech sells beef produced by cows fed its feed additive (Figure 3, center) under the brand name Lome Beef (Figure 3, right), appealing to environmentally-conscious consumers. Figure 4 shows examples of other companies' efforts in this area.

Figure 3 Volta Greentech's efforts



Aquaculture of *Asparagopsis* | Lome, a methane-reducing feed additive | Lome Beef
Source: Volta Greentech
https://www.voltagreentech.com/solution/ (left, centre)
https://www.voltagreentech.com/lome/ (right) (accessed September 27, 2023)

Figure 4 Examples of companies working on methane-reducing feed additives

Company name	Effort
FutureFeed (Australia)	Holds patents on *Asparagopsis* and licenses them to various companies
Rumin8 (Australia)	Working on synthesizing methane-reducing compounds rather than cultivating the seaweed itself
Symbrosia (US)	Working to expand seaweed production on a pilot scale in Hawaii. Announced financing from Danone (France) in June 2022
ALNUR (Japan)	Announced in May 2023 that it will work with the fisheries cooperative association in Yamagawa-cho, Kagoshima Prefecture on the development of *Asparagopsis* aquaculture technology in Japan.
Nissui (Japan)	Announced in May 2023 capital participation and business alliance with Immersion Group (Australia), which aims for onshore aquaculture of Asparagopsis

Source: Compiled by MGSSI based on the above companies' websites

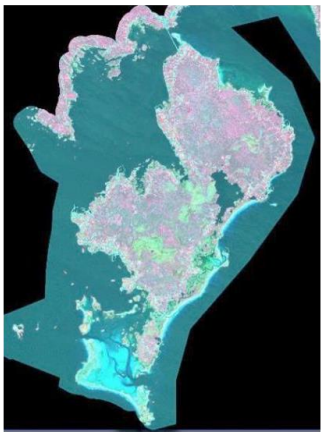
The main issues in this area are the establishment of mass aquaculture technology and the lowering of costs. Regarding mass aquaculture technology, CH4 Global (US) began construction of an onshore aquaculture facility in 2022 and plans to begin production in 2023.[4] Regarding lowering of costs, the price of feed additives acceptable to livestock farmers is said to be USD 0.14 per cow per day,[5] and the cost must be kept below that level for them to be widely adopted by the livestock industry in the future. Moreover, developing a less labor-intensive and costly approach for measuring methane reductions in cattle is imperative as the current method requires cattle to spend several days in a specialized facility.

2-2. Biostimulants: An environmentally friendly agricultural material made from seaweed

Biostimulants are a type of agricultural material that reduces abiotic stress on crops, such as poor climate or soil, and elicits their natural growth potential. Biostimulant raw materials include extracts, microorganisms, and amino acids taken from humus and seaweed. Of these, extracts from seaweed (alginic acid, vitamins, etc.) are highly effective in enhancing growth in crops and account for about 40% of the biostimulant market. Reducing the rate of chemical fertilizer use through the use of biostimulants would lead to decarbonization and a reduction in other environmental impacts. In recent years, rising natural gas prices[6] and fertilizer prices (to a maximum of 2.8 times[7]) triggered by Russia's invasion of Ukraine have also raised the profile of biostimulants as an alternative to chemical fertilizers.

Acadian Seaplants (Canada) cultivates its own seaweed in the sea, and produces and sells biostimulant products. The company's aquaculture is characterized by the fact that, in addition to controlling quality, the harvest rate is managed to be less than the growth rate of the seaweed in order to protect the seaweed resources. The distribution of seaweed beds along the coastline is measured by mapping them using satellite images and drone photography (Figure 5, left). Acadian Seaplants launched a brand called "Sea Beyond" to support regenerative agriculture (an agricultural method that preserves and restores farmland ecosystems) in February 2023, and is promoting the effectiveness of its products in an easy-to-understand manner (Figure 5, right). It is worth following such companies that develop biostimulants and other agricultural materials that conserve seaweed resources while also reducing the burden on the environment. Figure 6 shows examples of other companies' efforts in this area.

Figure 5 Acadian Seaplants' efforts



Utilization of satellite imagery

Tomatoes with increased yields due to the company's product

Source: Acadian Seaplants
https://www.acadianseaplants.com/seaweed-natural-resources-assessment/ (left)
https://acadianplanthealth.com/our-technology/crop-quality/ (right)
(accessed September 27, 2023)

[4] https://www.ch4global.com/2022/08/25/ch4-global-subsidiary-in-new-zealand-to-build-first-full-scale-ecopark/
[5] The World Bank, "Global Seaweed New and Emerging Markets Report 2023"
[6] https://blogs.worldbank.org/opendata/fertilizer-prices-expected-remain-higher-longer
[7] Calculated as USD 925/MT (April 22, 2022) versus USD 335/MT (February 21, 2021) for urea price from https://openknowledge.worldbank.org/server/api/core/bitstreams/6864d537-d407-4cab-8ef1-868dbf7e07e2/content.

Figure 6 Examples of companies working on biostimulants

Company name	Effort
Bayer (Germany)	Started sales of biostimulant fertilizer containing seaweed extract in Japan in 2022
The Seaweed Company (Netherlands)	Cultivates its own seaweed, and is involved in alternative proteins, etc. in addition to seaweed-derived biostimulants
Algaia (France)	Develops and sells biostimulants using raw materials extracted from seaweed, etc. Was acquired by JRS Group (Germany) in March 2023, which is involved in functional fibers, etc.

Source: Compiled by MGSSI based on the above companies' websites

The main issues in this field include stabilization of the active ingredients contained in seaweed against seasonal fluctuations, and improving the efficiency of the active ingredient extraction technology. Another more fundamental issue is to raise awareness of the effectiveness of biostimulants among farmers.

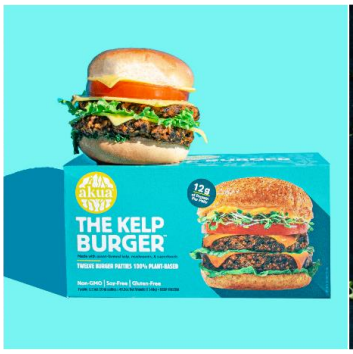
2-3. Seaweed attracting attention as an alternative protein in Europe and the US

Seaweed is rich in protein and also contains abundant glutamic acid, which adds to flavor. There are moves to take advantage of this feature and use seaweed in alternative protein products for vegans. Studies have shown that seaweed yields five times more protein per unit area than soybeans.[8] The spread of alternative proteins derived from seaweed in addition to conventional plant-based protein product ingredients would contribute to decarbonization.

The bacon developed and marketed by Umaro (US) is made from chickpea protein and the like blended with the main ingredient of high-protein seaweed, and has achieved a price equivalent to that of ordinary bacon. Startups such as AKUA (US) and The Dutch Weed Burger (Netherlands) are also developing products based on seaweed-derived protein mixed with vegetable protein (Figure 7). Figure 8 shows examples of other companies' efforts in this area.

Figure 7 Alternative protein products made from

Seaweed bacon by Umaro



Kelp burger by AKUA

Nuggets by The Dutch Weed Burger

Source: Umaro https://www.umarofoods.com/add-umaro-bacon-to-your-menu
AKUA https://akua.co/collections/all/products/kelp-burger
The Dutch Weed Burger https://dutchweedburger.com/en/products-2/ (accessed September 26, 2023)

Figure 8 Examples of companies working on alternative proteins

Company name	Effort
The Seaweed Company (Netherlands)	Cultivates its own seaweed, and sells SeaMeat, an alternative protein made from seaweed
Sea & Believe (Ireland)	Sells alternative fish products combining plant-derived ingredients and seaweed to reproduce the texture of cod
NH Foods (Japan)	Selling NatuMeat Fish Fry, which does not use fish, from 2023. Reproduces the texture of fish meat using ingredients derived from seaweed

Source: Compiled by MGSSI based on the above companies' websites

The main issues in this area are market development and cost reduction. Although there is a movement in Europe and the US to develop alternative protein products as above, it is less common to eat seaweed in these regions compared to Asia. Therefore, market development in these regions will be crucial. In addition, the cell

[8] The World Bank, "Global Seaweed New and Emerging Markets Report 2023"

walls of seaweed are tough, making the process of protein extraction both energy- and cost-intensive.[9] Moreover, the inconsistency in seaweed protein content may hinder potential market growth.

3. SIGNS OF TRANSFORMATION IN THE SUPPLY CHAIN SURROUNDING SEAWEED

As the applications of seaweed expand, there are new initiatives to transform its supply chain. This section focuses on the trends of notable companies in terms of production, distribution, and processing.

3-1. Production: Land-based seaweed aquaculture

Efforts are underway to mitigate seasonal fluctuations in seaweed yields and poor harvests through onshore aquaculture. In 2020, Mishima Foods (Japan) was forced to suspend sales of its Aonori seaweed product, which had been sold year-round, due to record low harvests of the ingredient, *Ulva prolifera*, in domestic production areas. Therefore, in order to increase the yield of *Ulva prolifera* on land, which the company had been cultivating, Mishima Foods built a new facility in Hiroshima Prefecture and resumed selling the product in 2021 (Figure 9). Changes in sea water temperature are thought to be the cause of poor harvests, which makes land-based seaweed aquaculture attractive because it enables the effects of such external environmental fluctuations to be eliminated, ensuring a stable supply of raw material throughout the year. Another advantage is that there is no contamination by impurities. It is noteworthy that a food company, which typically sources raw materials, has ventured into onshore aquaculture as a seaweed producer. Given the potential to stabilize supply, it is likely that an increasing number of businesses will explore land-based aquaculture in the future. Land-based seaweed aquaculture has the potential to become a prominent technique for large-scale production.

Figure 9 Mishima Foods' land-based aquaculture project

Marine resource development center in Hashirijima, which conducts land-based aquaculture of *Ulva prolifera*

A product using *Ulva prolifera*

Source: Mishima Foods
https://www.mishima.co.jp/product/seaweed/（left）
https://www.mishima.co.jp/enjoy/torikumi/aquaculture/（right） （accessed September 26, 2023）

3-2. Distribution and processing: Consolidation of the distribution networks

Seaweed has a moisture content of as much as 80–90% when harvested, which would make distribution expensive without drying and other processing. In addition, the types of seaweed that can be harvested vary by region, and each is expected to be used in various fields, necessitating processing and distribution according to the intended use. Some companies are starting to address these distribution and processing issues. The Crop Project (US) sources seaweed from small-scale aquaculture businesses, processes it by drying and grinding, and sells it as a functional ingredient used in foods, supplements, etc. The company currently operates primarily in North America, but seaweed distribution and processing issues are common to all regions. This type of business is poised to expand in the seaweed industry, which is projected to experience growth in the coming years, leading to a crucial role in providing high-value-added materials associated with decarbonization.

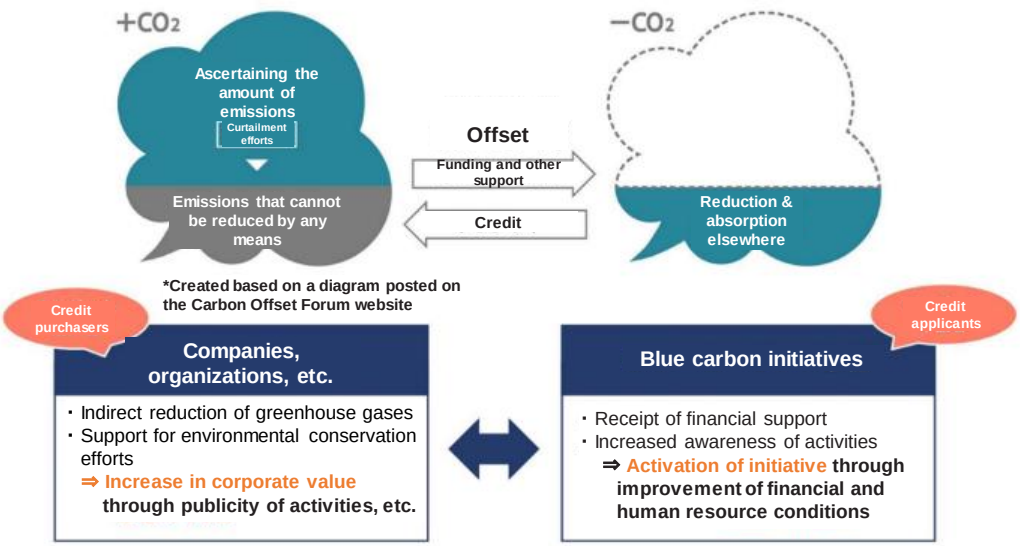
9 https://www.sciencedirect.com/science/article/pii/S146685642300108X#:~:text=This%20encourages%20the%20use%20of,yield%2C%20which%20limit%20their%20application.

4. SUMMARY AND PROSPECTS: EXPECTATIONS FOR BLUE CARBON CREDITS

Seaweed is a promising raw material for products such as methane-reducing feed additives, biostimulants, and alternative proteins, all of which facilitate decarbonization. The market sees constant new entries from startups that bring innovative technologies to tackle existing issues. The emergence of companies specializing in onshore seaweed aquaculture, distribution, and processing, which contribute to year-round production stabilization, indicates a shift in the supply chain. It is worth keeping a close eye on the transformation of the seaweed market.

This report concludes with a discussion of blue carbon as an important prospect for seaweed utilization. Blue carbon is carbon that is incorporated into marine ecosystems such as seaweed beds and mangrove forests.[10] In Japan, J Blue Credits (Figure 10) issued by the Japan Blue Economy Association are traded at about 78,000 yen/t-CO_2. According to the World Bank, blue carbon is traded at around USD 13–35/t-CO_2,[11] making J Blue credits quite expensive. Activities for which credits can be received include the removal of sea urchins that eat seaweed, seaweed bed restoration through seaweed transplantation, and seaweed aquaculture. The high price of the credits may indicate the expectation of added value, such as the restoration of biodiversity. Seaweed and other algae serve as food and habitats for fish, thus this activity has the additional benefit of luring fish to return to the area. The credits are expected to promote the entry of private companies into seaweed aquaculture.

Figure 10 Overview of J Blue Credit carbon offsetting



Soure: Japan Blue Economy Association, J-Blue Credit Guideline
https://www.blueeconomy.jp/files/jbc2022/20230331_J-BlueCredit_Guideline_v2.2.1.pdf
（accessed September 26, 2023）

[10] There are some opinions that continued scientific research and discussion is needed regarding the quantification of blue carbon.
[11] The World Bank, "Global Seaweed New and Emerging Markets Report 2023"