# Deliverable 2.1

# Report on Understanding Blue Bioeconomy Value Chains

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| **Abstract** | Values chains within the different partner regions have been defined. This pointed to obvious areas of common industries between some regions. For most regions and within the EU as a whole, common themes included macroalgae/seaweeds, microalgae and shellfish. At a high level, there was a general lack of information on how these industries utilised processed biomass and the value of any side streams. |
| **Keywords** | Bluebioclusters, Blue economy, Value Chains |

# Table of Contents

# List of Figures

# List of Tables

# Glossary

**Anaerobic digestion** is a biological process that involves a set of bacteria breaking down organic waste material to produce methane gas and also potentially a liquid fertiliser.

**Aquaculture** is the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants, including algae.

**A biorefinery** is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass.

**Base Commodities** include energy and animal feed products with prices in the range of US$1/kg. Energy products include liquid biofuels, such as fatty acid methyl ester (biodiesel), ethanol and jet fuel, and biogas from anaerobic digestion (AD).

**Carotenoids** are organic pigments that are found in the chloroplasts and chromoplasts of plants and some other photosynthetic organisms, widely used as colourants and antioxidants.

**Cosmeceuticals** are cosmetic products with biologically active ingredients purporting to have medical or drug-like benefits.

**Cyanobacteria** are bacteria that obtain their energy through photosynthesis. They have commonly been considered to be algae and were historically called ‘blue-green algae’ because of their distinctive colour.

**Extremophiles** are organisms, generally microorganisms, that can thrive in extreme conditions of temperature, pressure or chemical concentration, such as in very hot, salty environments, that are unsuitable for, or may be lethal for, the vast majority of organisms.

**Functional foods** are foods with health benefits that go beyond their basic nutritional value.

**Metabolites** are the intermediates and products of metabolism. The term **metabolite** is usually restricted to small molecules.

**Nutraceuticals** are products that range from isolated nutrients, dietary supplements and herbal products to foods for specific diets and processed foods such as cereals, soups and beverages.

**Photobioreactors** are bioreactors (i.e. specialised culturing systems) that utilise a light source to grow algae.

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# Executive Summary

This report has been prepared for the BBC project WP2.1. Its aim is to identify the project's value chains. In order to understand existing Blue Bioeconomy value chains, a comprehensive set of databases and reports (i.e., BlueBioEconomy Forum, MarineBioTechRoadmap) have been assessed through desk research. Value chains within different regions utilising integrated circularity have been initially defined as having their resulting products and services. This involved understanding region-specific and cross-regional generic value chains. It will be important to understand the traceability of the value chains from biomass production up to resulting products and ancillary services/business users, particularly within a circular economy context and to highlight gaps within current value chains and the challenge this poses to the adoption of the Blue Bioeconomy. This includes the regions within the BBC project and at a border level. For example, value chains in terms of the circular economy currently do not exist for pelagic fishing. The most common cross-regional chains included the following:

- Microalgae for aquaculture feed, cosmetics, pigments, and proteins- France, Portugal, Scotland, Estonia, Norway, and Iceland
- Macroalgae/seaweed animal feed, alginate, cosmetics- France, Portugal, Sweden, Scotland, Estonia, Iceland, Norway, and Belgium.
- Shellfish- Sweden, Estonia, Scotland, Portugal, France, Belgium and Scotland
- Whitefish- Iceland, Lithuania, Sweden, and Norway
- Finfish (salmon), Norway and Scotland.

At the second project partner meeting, which will take place on 28-29 March 2023 in Porto (Portugal), these results will be discussed to understand value chains of importance to all, only a few (but potentially being very important value chains), and regional-specific ones.

# Introduction

The oceans encompass about 70% of the surface of our planet but over 99% of the biosphere (since organisms are found throughout the water column), and they represent the greatest extremes of temperature, light, and pressure encountered by life. Adaptation to these harsh environments has led to a rich marine bio- and genetic diversity with potential applications related to drug discovery, environmental remediation, increasing seafood supply and safety and developing new resources and industrial processes to support the Blue Bioeconomy, which is a key component of the European Green Deal.

The Blue Bioeconomy has no one definition, but in simplest terms, it is industries which utilise living aquatic resources such as algae, sponges, jellyfish or microorganisms to deliver a wide variety of products, processes and services (World Bank). Figure 1 from the Scottish Blue Economy document (2022) demonstrates the complexity of its definition. It is also defined within the context of sustainable economic growth, social development and food security whilst reducing negative environmental impacts from this sector. There is a direct relationship to the Sustainable Development Goals (SDGs), including goal 14, "Life Below Water". The EU (the EU Blue Economy report 2022) highlights that across all the sectors, 4.45 million people are employed within this sector, and it generates around €667.2 billion in turnover and €183.9 billion in gross value added (EU Blue Economy Observatory). It is difficult to get an exact figure for the Blue Bioeconomy, but previously this sector was at €2.8 billion in 2010 (Børresen et al. 2010), with a cumulative annual growth rate of 5-10%. This may be an underestimate, as Lloyd-Evans (2010) suggested; if including antioxidants and other functional ingredients that can be derived from marine sources, the market may be in the range of $6.7 – 29 billion.


*Figure 1 Scotland's definition of the Blue Economy (2022)*

## Blue Bioeconomy – Opportunities across the Value Pyramid

According to a report published by the Sustainable Development Working Group of the Arctic Council (2022), only half of all harvested or cultivated marine biomass goes for human consumption. The rest is either discarded or used for low-value products. There is a need within the Blue Bioeconomy to introduce innovation to improve and create higher-value products. This has involved the development of various toolkits to support commercially viable products and processes (Fig 2). But to do this and to move this sector forward, it is necessary to understand the current value chains.

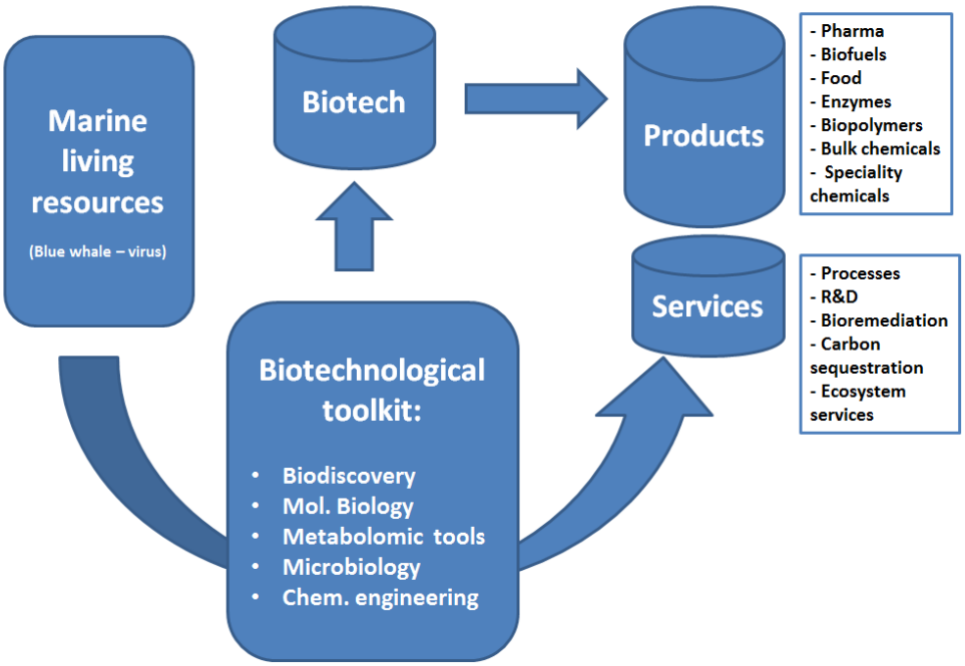


*Figure 2 Blue Bioeconomy work-flow- bioresources to create wealth*

The Blue Bioeconomy covers a wide set of activities and, as discussed above, can include everything from bioprocessing of harvested materials (fish, algae etc.) to cultivating marine microbes or developing an innovative buoy system for monitoring ocean pollution.

Figure 3 defines a range of different products/ services that can be generated from marine resources, categorising them based on their commercial value, from top-end pharmaceutical compounds to low-value bioenergy produced from organic waste. It is worth noting that special applications products are usually described as low volume and high value, and at the other end, the base commodities are invariably high volume and low value. In the following sections, case studies will highlight products and processes representing each level of the value pyramid.

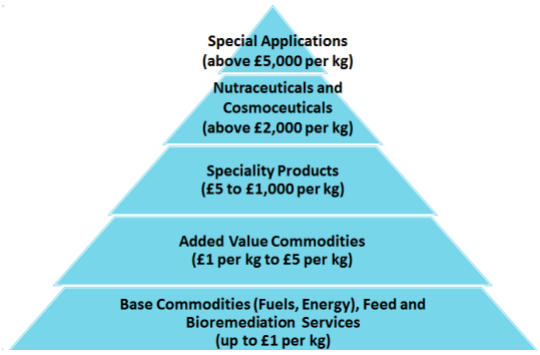


*Figure 3 Value pyramid of products obtained from the marine environment*

The value pyramid capitalises on unprecedented advances in life sciences and biotechnologies. Innovation in the Blue Bioeconomy includes

- novel foods, nutraceuticals, food additives, animal feeds
- pharmaceuticals and cosmetics
- green chemicals and materials
- enzymes for green industrial processing or decontamination

The drivers that stimulate interest in the Blue Economy are directly comparable to those that affect economies worldwide, namely:

- Food security & water availability,
- Energy security,
- Transport fuels,
- An ageing population in developed economies,
- Increased affluence and aspirations in developing economies,
- Increasing carbon dioxide levels & climate change.

Blue Bioeconomy's value chains and services have the potential to provide solutions that help address these major issues. For example, marine microalgae can, through using sunlight as their energy source, produce a range of products (oils, protein, antioxidants etc.) without compromising potable water supplies as they grow on seawater. It is worth noting that it is easy to focus too directly on the potentially huge rewards that new pharmaceuticals generate, but the investment needed to take a new product to market is in the range of US$4-12 billion. However, there is commercial value at each stage of the process (biological material to drug) and opportunities for how this could be achieved.

Integral to the development of the Blue Bioeconomy and the exploitation of marine resources are the concepts behind the circular economy, i.e., a departure from the current “take, make and dispose” approach that underlines much of modern manufacturing etc. Instead, in the circular economy model, consumer goods and other products would be designed so that they could be repaired and/or easily recycled rather than replaced, and biological materials would be managed so that they could be returned to the biosphere without contamination. In biotechnology, this is most commonly discussed in the context of developing an Integrated Biorefinery, i.e., a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass (Figure 4). The biorefinery concept is analogous to today’s petroleum refineries, which produce multiple fuels and products from petroleum. Industrial biorefineries have been identified as the most promising route to the creation of a new domestic bio-based industry. An example would be the potential to use waste streams from salmon where it could be possible to use fish heads and other waste materials to produce: high commercial-value protein supplements to sell into the “sports and wellness” sector. The protein could be incorporated into human, animal or aquaculture feeds; lipids could be marketed into the nutraceutical and food sectors; and finally, residual waste could be used for anaerobic digestion to produce gas generating heat and electrical power.

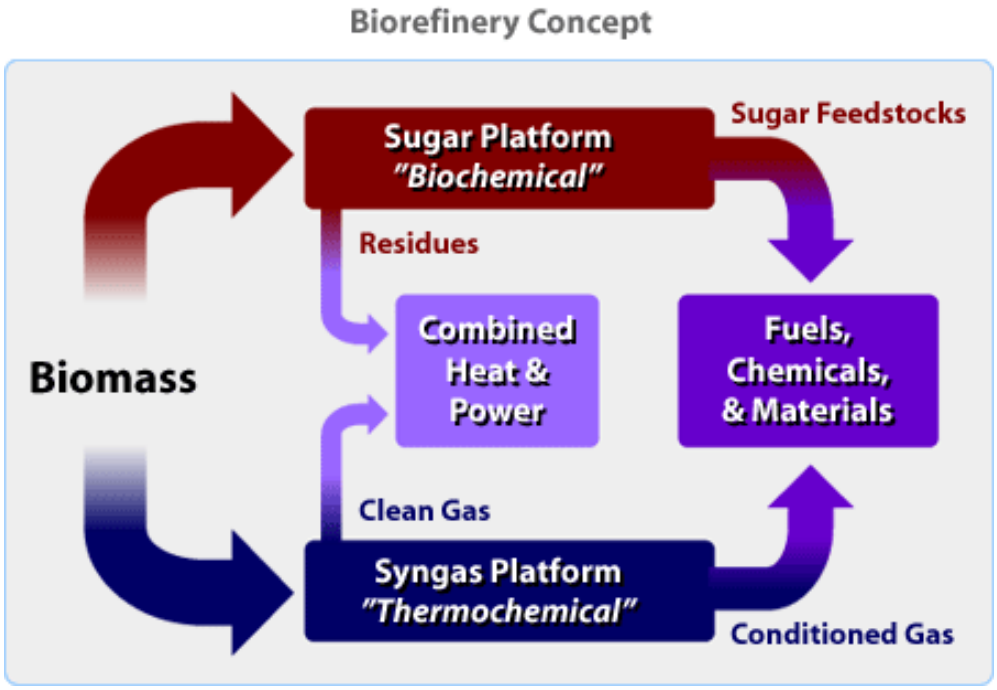


*Figure 4 The USA National Renewable Energy Laboratory Biorefinery Concept (Source: [http://www.nrel.gov/biomass/biorefinery.html](http://www.nrel.gov/biomass/biorefinery.html))*

An example of a Blue Bioeconomy refinery for the marine microalgae *Chromochloris zofingiensis* (Wood et al., 2022*)* is shown in figure 5.

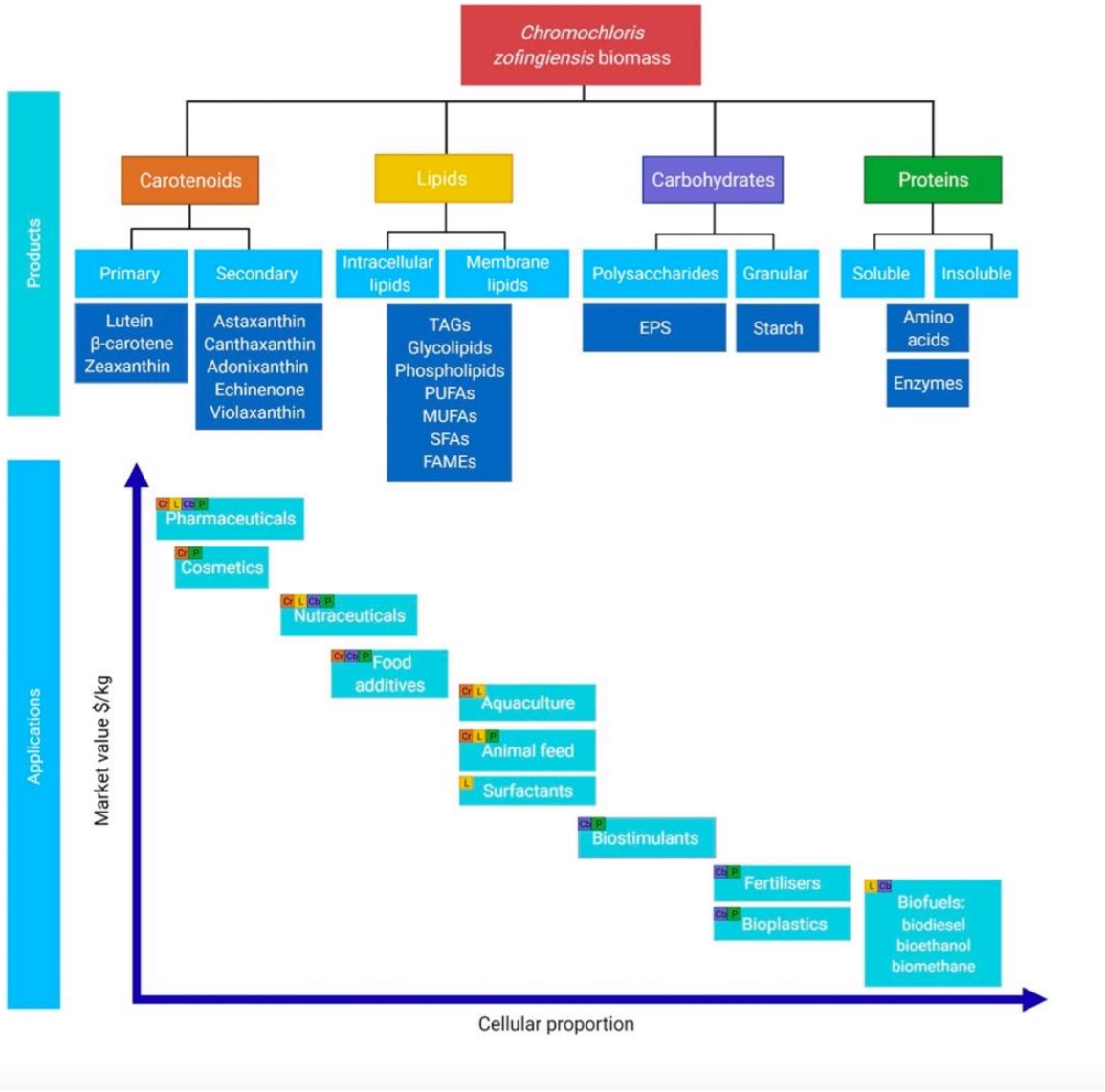


*Figure 5 Potential products and applications of extracted components from C. zofingiensis. The coloured squares represent the products that can be used for each application (Wood et al., 2022)*

There are very few examples of companies/SMEs taking this approach and offering more than one product line generated from the same source of biomass. One is ScotBiotech which sells both the pigment phycocyanin for the food market and protein generated from cultivated Spirulina.

# Blue Bioeconomy Value chains within BBC Regions

To establish the value chains within the BBC partners' clusters and at a wider regional level, Table 1 (Appendix 1) was created. A major issue was that, at a higher level, there are very basic details linked to individual value chains. This can be seen in those value chains set out in the Blue Bioeconomy Forum report from 2020. This led to gaps in the table under some sections for some of the BBC partners. Few value chains are well-defined and linked to the technology they utilise, but there are some well-established ones, for example, linked to nutraceutical and cosmeceutical markets. This is not unsurprising as this market is very diverse, usually used in small volumes but at high prices. There are value chains which are common to several of the BBC regions, including:

- Microalgae for aquaculture feed, cosmetics, pigments and proteins- France, Portugal, Scotland, Estonia, Norway and Iceland
- Macroalgae/seaweed animal feed, alginate, cosmetics- France, Portugal, Sweden, Scotland, Estonia, Iceland, Norway and Belgium.
- Shellfish- Sweden, Estonia, Scotland, Portugal, France, Belgium and Scotland
- Whitefish- Iceland, Lithuania, Sweden, and Norway
- Finfish (salmon), Norway and Scotland.

Expanding markets include macro and micro-algal products for use in personal care, and there is potential for adding value. This is particularly linked to locally produced ranges, including regionally sourced/grown material feeding into the organic, natural and "free from" markets. Products can range from simple dried seaweeds for home baths to high-value spa and cosmetics, for example, the Blue Lagoon products from Iceland. Much of the evidence for the efficacy of these products is anecdotal, and many products are still marketed on the basis of traditional uses and "old wives" remedies. This has led market leaders to invest substantially in research and development to substantiate efficacy. This, in turn, justifies the image these products have as high-value products. The identified value chains in Table 1 (Appendix 1) need now to be taken forward for case studies. The case studies in the next section of the report have been initially identified.

## Cosmeceuticals Case Study

**The Blue Lagoon, Iceland:** Hot water production is a side effect of geothermal power generation, so as part of the operation of the Svartsengi power plant in Iceland, an artificial lagoon was built to hold this water. People then started bathing in the lagoon and noticed that it had great effects on their skin, and this led to the formation of spa facilities and associated cosmetic-based products. These products include

compounds extracted from two different algae species isolated from the Blue Lagoon. Due to commercial sensitivities, they are described purely as Blue Lagoon coccoid algae and Blue Lagoon filamentous algae. Both algae species are readily available and grow abundantly in the saline hot water conditions of the Blue Lagoon. Scientific research has demonstrated that both species of algal contain biologically active compounds, which act as barriers against UV damage from sunlight and skin ageing (Grether-Beck et al. 2008). This forms the scientific basis for the claims associated with Blue Lagoon products. It also helps to justify the price that these products sell for, which ranges from €25 for a body wash to €105 for a face cream (http://www.bluelagoon.com/shop/). However, it is worth noting that other companies are using marine algae, which grow naturally in less extreme environments.

## Added Value Commodities Case Studies

**Macroalgae for hydrocolloids:** The global hydrocolloids market was worth $3.30 billion in 2010, with the European market for Carrageenan, a hydrocolloid extracted from red macroalgal species, worth $127.9 million ($10-12/kg) and the agar/alginate market, hydrocolloid extracted from brown macroalgae, worth $29.6 million ($20-23/kg). This is a well-established market and has not really grown in the last 50 years, but there is an increasing potential in the use of macroalgal-based hydrocolloids for health and value-added functionalities for speciality applications, including pharma. The Norwegian company AlgiPharma AS have taken the hydrocolloid alginate and alternated it to form what they call Oligo-G. This pharma-grade product has been formulated into several products aiming to treat microbial infections and respiratory diseases and to treat and improve the healing of infected wounds and burns. The product has also just undergone stage 2 clinical trials with cystic fibrous (CF) patients, where it is used to disrupt bacterial lung infections. This should result in more effective treatment and has the potential to reduce the need for antibiotic treatment in CF patients.

**Marine Omega 3:** The Omega3 market includes fish oils, fish liver oils, some mammal (seal), crustacean (krill) and molluscan (squid) oils, as well as single cell oils from marine and freshwater algae, genetically modified yeast, and genetically modified oilseeds. The demand for these types of supplements has been increasing, particularly with the rise of spending power within Brazil, Russia, China, and India. The global market has grown by 12% over the last year, and demand will begin to outstrip supply. According to the Food and Agriculture Organization (FAO), fish by-products from the edible fisheries, such as cuttings from filleting operations, fish cannery waste, roe fishery waste and more recently, surimi (a paste made from grinding up fish) processing waste, represent a potential source of Omega 3, especially from both salmon and tuna heads. Deepika et al. (2014) investigated the levels of Omega 3 in the gut, head, and frame of salmon waste. Their research confirmed that the waste material contains 0.95-1.07g/100g of good quality Omega3. But one of the issues of Omega 3 extracted from fish waste has been traceability, and

there have been cases where the oil has been contaminated with heavy metals or was not even fish Omega3. Companies, including Nori Oil in Norway, currently sell premium Omega 3 extracted from salmon because they can offer a fully traceable product.

## Base Commodities case study

**Anaerobic Digestion of fish waste:** AD, as previously described, is a biological process involving bacteria breaking down organic waste material to produce methane gas and potentially a liquid fertiliser. This gas can then be used to power combined heat and power (CHP) plants to generate electricity. There Over the last ten years, there has been interest in processing waste through AD. The UK generates approximately 301,037 tonnes of fish waste annually as by-products of the fish processing industry. This traditionally has gone to landfill, but AD represents a better option. Recent research in Sweden has demonstrated that fish waste can be converted into methane gas, plus a high-quality fertiliser (Achu Nges et al., 2012). However, it should be noted that the waste had to be digested with other waste because of the high content of ammonia in the material. In the case of this study, it was a crop residue, but other groups have previously used sewage. As already stated, there is a need to expand on this case and to develop others. Where possible, the technology utilised needs to be defined, and this will be included as part of WP4.

# Appendix I

*Table 1 Blue Bioeconomy value chains for the BBC partners*

| **WP2.2 Value chains** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Country/Area** | **Original biomass** | **Cultivated or wild harvest** | **Pre-processing** | **Processing** | **Extraction of product** | **Product** | **Side products**<br>**Other info** |
| Belgium | macroalgae | seaweed seeding lines facilities present | | | | | |
| Belgium | macroalgae and bivalve | technology development for harvesting | | | | | |
| Belgium | mussel beds for ecosystem services | for coastal protection, ecosystem reinforcing | | | | | |
| Belgium | seaweed cultivation for semi-preps for food industry | food processing- on-land tank systems. Recirculating aquaculture system (RAS) mainly red and greens | net harvested-small quantities. Washed sold fresh | Food whole seaweed | functional food ingredients | food | |
| Belgium | marine compounds - bioprospecting | | | | enzymes, chitin etc. | bio coatings, | |

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| Estonia | Mussels | Cultivated on rope. Suitable harvester is under development. | Washed in fresh water and cleaned. | Ground to form a powder and the meat is removed from shells | Potential for the use of meat mass (protein powder) | Protein bars/powder/supplements and poultry and/or animal feed | Shell fragment with some protein content (~4%) - the fine fraction and protein content after milling make the material a potential source of bird feed |
| | | | | Technology varies in terms of the machinery employed | | | Estonian Maritime Academy of Tallinn University of Technology |
| Estonia | Macroalgae/Seaweed | wild harvest | | extraction of different compounds from macroalgae | Red colourant (Phycoerythrin), producing different seaweed extracts, compounds for cosmetics producers | compounds to cosmetics producers | Biomass from which furcellaran has been extracted- is used as a fertiliser. |
| | | | | | | | Vetik is developing the production of a natural (marine algae based) red colourant which is healthy and has potentially skin rejuvenating properties. https://vetik.ee/ Berrichi produces variety of skincare products that contain furcellaran, which has a powerful anti-aging and deep moisturising effect. /https://berrichi.eu/ |
| Estonia | Seaweed | wild harvest | Dried and washed | Hot extraction of furcellaran from seaweed, filtering the extract via roller-drying or gel precipitation | Extraction of furcellaran | Furcellaran can be used as stabilising, thickening and gelling agent in the food, agricultural, cosmetics and pharmaceutical industries. | Biomass from which furcellaran has been extracted- is used as a fertiliser. |

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|---|---|---|---|---|---|---|---|
| | | | | | | | Est-Agar AS, https://estagar.ee/ |
| Estonia | Microalgae | cultivated. | | Developing the valorisation of the whole biomass of the seaweed for cosmetics and other industries e.g producing different seaweed extracts. | microalgae photobioreactor system, feed/food compounds from microalgae | cosmetic, pharmaceutical, food/feed producers | Photobioreactor ideal for research and lab experiments, as well as for small-scale algae farming for high value compounds. ALGACAP is a modular microalgae photobioreactor system, designed to be integrated into an industrial chimney for CO2 sequestration from flue gas. They can provide the system on a turnkey basis, or we can offer the technology as a flue gas cleaning service. POWER ALGAE can supply various microalgae-based ingredients for food and feed producers. |

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|---|---|---|---|---|---|---|---|
| Estonia | Fish | aquaculture (Rainbow trout ~85%, the European crayfish, tench, eel, the African sharptooth catfish, carp, catfish, sturgeon, grass carp, etc.) | Fresh/ cleaned/ filleted | | | Food - fillets, smoked, canned, fresh | |
| France | Ulva vulgais (macro) | natural harvest | | | | | |
| France | Ulva vulgais (macro) | land based cultivation to feed abelone | | | | | |
| France | Cyanobacteria | land based cultivation | | | | | |
| France | Cyanobacteria | Cosmetics | | | | | |
| France | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | liquid, spray, frozen paste, powder | compounds to feed aquaculture hatcheries for fish, shrimp, and shellfish larviculture | |
| France | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | spray, frozen paste, powder | whole-cell microalgae as a raw material for further extractions compounds to cosmetics | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| France | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | liquid, spray, frozen paste, powder | Food & nutraceuticals - whole cell, alpha-carotene/beta-carotene, Lutein, Lycopene, Omega3, Astaxanthin, fucoxanthin | |
| France | Microalgae | Closed (tubular / flat panel) open systems (cascade /conventional) | fermentation, autotrophic reactor, pasteurisation | Centrifuge spray dryer \| raceways inoculum/production, solar dryer | paste / powder (spirulina, chlorella, Dunaliella, Nannochloropsis, Haemtococcus) | waste water treatment, biofertilisers, bioplastics, biofuels | |
| France | Mussels (Mytilus edulis) | | | | | | |
| France | Macroalgae/Seaweed-chemical | Wild harvest mechanical- mostly Laminaria digitata/hyperborea Plus other brown species | Washed, “bark” from stipe peeled off or dried and ground before further processing. | Extraction of alginate through traditionally through acidification, alkaline extraction, solid/liquid separation, precipitation and drying | Range of uses, primarily as a gelling agent, surfactants | | |
| France | Seaweed- food | Cultivated- mainly sugar kelp and Alaria esculenta - semi-mechanical technology development, still outstanding here. Line seeded through | Washed in either seawater or fresh water and cleaned. | Chopped or combined with other compounds, including sea salt, snack food | N/A | | |

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| | | seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Food market is early in the season to reduce biofouling | Simple soaking is employed, but there are bubble washers coming onto the market. Dried in at low heat or dehumidifier. It can be frozen and bought at this stage by others, who will then dry the biomass | | | | |
| France | Seaweed chemicals | Cultivated- mainly sugar kelp and Alaria esulenta- semi-mechanical technology development still outstanding here. Line seeded through seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest affects what the biomass is used for. Usually harvested slightly later to ensure higher carbohydrate content of the seaweed. Small amount of wild harvest | Washed in either sea water or fresh water. Dried in at low heat or dehumidifier. It can be frozen and bought at this stage by others, who will then dry the biomass. Important aspect here is wet processing. Also move to ensiling- biomass would be chopped first before being ensiled | Chopped into smaller particles. Size of particles will depend on the extraction and conversion stage | Fermentation into biopolymers for everything from single use plastics which are compositable through to vegan leather and textiles. Involves extraction with water/acid/alkaline then fermentation with a usual a bacteria. Various faction steps can also be employed to remove other compounds of interest which includes pigments for antioxidants and as potential textile dyes | | |
| France | Fish | very limited applications done in France. | | | | | |

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|---|---|---|---|---|---|---|---|
| France | Oysters | both, but mostly cultivated | | | | | |
| France | Shrimp | both, but mostly cultivated | | | | | |
| France | Ascidians | both, but mostly cultivated | | | | | |
| Iceland | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | liquid, spray, frozen paste, powder | | |
| Iceland | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | spray, frozen paste, powder | | |
| Lithuania | Fish | wild harvested - coastal and inland fishery | sold to Latvia for further processing | | | Food | fish meal |
| Lithuania | Fish | wild harvested - open sea fishery | freezing, landed in Latvia and Denmark for further processing | | | Food - salted, dried, smoked, canned | fish meal and oil |
| Lithuania | Fish | aquaculture (carp, arctic char, African catfish, rainbow trout, grass carp, pike, sturgeon) | Cleaned | | | Food - sold fresh or chilled | |
| Lithuania | Fish | aquaculture (African catfish, sturgeon, carp, rainbow trout) | Cleaned, filleted | | | Food - fillets, smoked, canned | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Norway | Macroalgae/Seaweed- chemical | Wild harvest mechanical- mostly Laminaria digitata/hyperborea. Plus other brown species | Washed, “bark” from stipe peeled off | Extraction of alginate through traditionally through acidification, alkaline extraction, solid/liquid separation, precipitation and drying | Range of uses as a primarily as a gelling agent | | |
| Norway | Seaweed- food | Cultivated- mainly sugar kelp and Alaria esculenta- semi mechanical technology development still outstanding here. Line seeded through seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Food market it is early in the season to reduce biofouling | Washed in either sea water or fresh water and cleaned.<br>Simple soaking employed but there are bubble washers coming on to the market. Dried in at low heat or dehumidifier. Can be frozen and bought at this stage by others who will then dry the biomass | Chopped or combined with other compounds including seasalt, snack food | N/A | Food | |

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| Norway | Seaweed chemicals | Cultivated- mainly sugar kelp and Alaria esulenta- semi mechanical technology development still outstanding here. Line seeded through seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Usually harvested slightly later to ensure higher carbohydrate content of the seaweed. Small amount of wild harvest | Washed in either sea water or fresh water. Dried in at low heat or dehumidifier. Can be frozen and bought at this stage by others who will then dry the biomass. Important aspect here is wet processing. Also move to ensiling- biomass would be chopped first before being ensiled | Chopped into smaller particles. Size of particles will depend on the extraction and conversion stage | Fermentation into biopolymers for everything from single use plastics which are compositable through to vegan leather and textiles. Involves extraction with water/acid/alkaline then fermentation with a usual a bacteria. Various faction steps can also be employed to remove other compounds of interest which includes pigments for antioxidants and as potential textile dyes | Chemical, biopolymers, compositable bioplastics and textile dying | |
| Norway | Scallops | Wild harvested either by dragging or hand dived. Small cultivated market and there is interested here- see other column | Washed and graded | Either sold directly in shells or will be shucked. Sold fresh or frozen. Can be depurated to remove contaminates | N/A | Food | |
| Norway | King Crab | Wild harvested by inshore creel | Once harvested kept in tanks for gradin g | Either sold direct into EU or processed for the meat | Potential fermentation of shells using chitin as the feedstock | Food | |

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| Norway | Sea urchins | Considered a pest | Harvested by diving- kept on land in recirculating system until ready for market | Sold whole to restaurants | Small quantities sold | Food | |
| Norway | Salmon | Farming plus onland production of smolts | Graded on size and the flesh. The fish are washed and gutted. | Sold whole, sliced or smoked will depend on the market the salmon is intended for. | Potential for the use of by products including skin, trimmings, bones and dead fish at various stages of the life cycle. Extraction of omega 3 for health food market | Food | |
| Norway | Microalgae-aquaculture | Grown in PBRs for the marine molluscs and larval stages of fish | Harvested mainly through natural settlement to keep prices down | feed as whole cells | | | |
| Norway | Microalgae bio actives | Grown in PBRs | Harvested via centrifugation and membrane filtration | Still relatively new and extraction methods depend on the final use. | Movement towards biorefinery to help with cost of production. Extracted for bio actives, carbohydrates, lipids, pigments and proteins. Plus secondary metabolites | | |
| | | | Centrifugation high energy consumption | Not yet standardised | | | |
| Portugal | Seaweed | Integrated Multi-Trophic Aquaculture, IMTA | Dried \| fresh | whole, flaked and flour | fresh seaweeds | nutraceutical, pet care, food, beverage cosmetics, fertilisers | |
| | | | excess nutrients released in fish farming | | | | Final products also mixed with microalgae for food market |

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| Portugal | Seaweed | wild harvesting (Asparagopsis armata, Asparagopsis taxiformis, Gongolaria abis-marina, Cystoseira humilis, Halopteris scoparia, Padina pavonica, Pterocladiella capillacea, Sargassum vulgare, Zonaria tournefortii, Gelidium,Ulva Gracilari, Fucos e Palmaria) | freeze-dried \| sun dried \|<br>dried in the dark | no-procees (natural form) \| grinded (different granulometric | | cosmetics, biotech, pet food, nutraceutical | |
| Portugal | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | liquid, spray, frozen paste, powder | compounds to feed aquaculture hatcheries for fish, shrimp, and shellfish larviculture | |
| Portugal | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | spray, frozen paste, powder | whole-cell microalgae as a raw-material for further extractions compounds to cosmetics | |
| Portugal | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | liquid, spray, frozen paste, powder | Food & nutraceuticals - whole cell, alpha carotene/beta-carotene, Lutein, Lycopene, Omega3, Astaxanthin, fucoxanthin | |

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| Portugal | Microalgae | Closed (tubular / flat panel) open systems (cascade /conventional) | fermentation, autotrophic reactor, pasteurisation | centrifuge, spray dryer \| raceways inoculum/production, solar dryer | paste / powder (spirulina, chlorella, Dunaliella, Nannochloropsis, Haemtococcus) | waste water treatment, biofertilisers, bioplastics, biofuels | |
| Portugal | Fish | aquaculture | salt water open circuit | | | fresh sea bass, sea bream | |
| Portugal | Fish | aquaculture - Recirculating Aquaculture System (RAS) | | | | Meagre | |
| Portugal | Fish | onshore tanks | | | | turbot and sole | |
| Portugal | Oysters | hatchery (IMTA) | depurating (filter and clean) | | | fresh oyster | |
| Portugal | clams | born in hatchery grow off-shore | larval cultivation / seed cultivation | | | | |
| Scotland | Seaweed | Wild harvested- mechanical harvesting (Ascophyllum- 10,000tonnes annually) | Dried by heat | Chopped into small particles and bagged. Added to sea salt and also ground to form a powder, added to capsules for health food market. | For cosmetics will usually be bought from the harvester/ processor, buyer either uses whole in products such as soaps or extracted for onward formulation- for fucoidan or alginate. Pigment also extracted for antioxidant market- fucoxanthin | animal feed supplement whole chopped product. Capsules human health supplements and also added to oil for cooking and salad dressings. | |
| | | | Industrial conveyer or belt drier. Energy from kerosene or wood biomass boiler | Technology varies in terms of the machinery employed | | | Heavy metal content will be checked |
| Scotland | Seaweed | Wild harvest mechanical- mostly Ascophyllum | Dried or left wet | Ground or chopped | Extracted either in wet, or through acid or alkaline hydrolysis. Other technologies not | plant growth stimulant | |

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| | | | Industrial tumble drier or belt drier. Energy from kerosene or wood biomass boiler if dried. | Screw press, cell lysis under pressure | currently used in Scotland include microwave and ultrasound cost is a factor here | | |
| Scotland | Seaweed | Variety of species- wild harvest mostly by hand | Washed and dried at low heat | Chopped or ground. Depending on species maybe smoked | Small cosmetic market which will purchase the dried chopped product to extract (water/acid/alkaline extraction) will include alginate, pigments and other compounds with potential bioactivity? | Food/ cosmetics | |
| | | | No specific machine for washing linked to small volumes. Dehumidifier- freeze drying may also be an option | Technology varies in terms of the machinery employed | | | Microbial loads are checked, as is heavy metal content if going into food. Also wash step important to reduce iodine content and important for removal of salt. For cosmetic market will also be necessary too carryout testing to ensure the product is safe to use- no adverse skin reactions. |
| Scotland | Seaweed- food | Cultivated- mainly sugar kelp *Saccharina latissima* and Alaria esulenta- semi mechanical technology development still outstanding here. Line seeded through seaweed nursery | Washed in either sea water or fresh water and cleaned. | Chopped or combined with other compounds including seasalt, snack food | N/A | Food | |

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| | | either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Food market it is early in the season to reduce biofouling | Simple soaking employed but there are bubble washers coming on to the market. Dried in at low heat or dehumidifier. Can be frozen and bought at this stage by others who will then dry the biomass | | | | Microbial loads are checked, as is heavy metal content if going into food. |
| Scotland | Seaweed chemicals | Cultivated- mainly sugar kelp *Saccharina latissima* and Alaria esulenta- semi mechanical technology development still outstanding here. Line seeded through seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Usually harvested slightly later to ensure higher carbohydrate content of the seaweed. Small amount of wild harvest | Washed in either sea water or fresh water. Dried in at low heat or dehumidifier. Can be frozen and bought at this stage by others who will then dry the biomass. Important aspect here is wet processing. Also move to ensiling- biomass would be chopped first before being ensiled | Chopped into smaller particles. Size of particles will depend on the extraction and conversion stage | Fermentation into biopolymers for everything from single use plastics which are compositable through to vegan leather and textiles. Involves extraction with water/acid/alkaline then fermentation with a usual a bacteria. Various faction steps can also be employed to remove other compounds of interest which includes pigments for antioxidants and as potential textile dyes | Chemical, biopolymers, compositable bioplastics and textile dying | See Oceanium and Notpla |
| Scotland | Mussels | | | | N/A | Food | |

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| | | Cultivated on rope through natural sprat settlement But there have been issues with the failure of sprat generation. Usually happens every 10 years. | Washed and packaged either in small batches (supermarkets) or sold directly to customers | Small batches can be smoked and sold in oil | | | Relatively cheap to produce. Enquires an aquaculture license and there is an issue in some areas on a soft shelled species. Also there is harmful algal bloom monitoring in place to protect the public from toxins. Seen as sustainable |
| Scotland | Oysters | Cultivated- mainly intertidal. Spat will be obtained from a commercial hatchery and must be of the same genetic stock as the area where it will be grown | Will be washed, graded for example of size, banded and potential depuration to remove contaminates | N/A | | Food | Increased interest in native oysters for re-wilding projects plus for clearing up water- improve water quality. Grown in lantern nets and not generally for the food market. Best example is the Deep project lead by the whiskey distillery Glenmorgie |
| Scotland | Scallops | | | | N/A | Food | |

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| | | Wild harvested either by dragging or hand dived. Small cultivated market and there is interested here | Washed and graded | Either sold directly in shells or will be shucked. Sold fresh or frozen. Can be depurated to remove contaminates | | | Shells are currently a waste product. Cultivation in lantern nets is starting to increase but there is a need for a hatchery as spat is usually taken from the surrounding area. Limits again on movement within the growing area and surrounding areas out within growing site. |
| Scotland | Crab | Wild harvested by inshore creel | Graded on size | Either sold direct into EU or processed for the meat | Potential fermentation of shells using chitin as the feedstock | Food | Waste is in the form of the shells- some interest in the chitin the shells contain and companies like Cuantec using the shells for the production of single use plastics, pharma, cosmetics. Involves a fermentation step |
| Scotland | Langoustine | Wild harvested by inshore creel, also by dragging. Company in Clyde have a system that causes less damage that current conventional methods. | Graded on size | Either sold whole or cooked and the meat is removed from shells | Potential fermentation from the shells using chitin as the feedstock | Food | Waste is in the form of the shells- some interest in the chitin the shells contain and companies like Cuantec using the shells for the production of single use plastics, pharma, cosmetics. Involves a fermentation step |

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| Scotland | Salmon | Farming plus on land production of smolts | Graded on size and the flesh. The fish are washed and gutted. | Sold whole, sliced or smoked will depend on the market the salmon is intended for. | Potential for the use of by products including skin, trimmings, bones and dead fish at various stages of the life cycle | Food | At the moment it is currently unclear about whether the industry will start using the by-products for other markets. Although there is beginning to be some movement on how the waste from on land smolt production is being treated and whether value can be added here. |

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| Sweden | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | liquid, spray, frozen paste, powder | compounds to feed aquaculture hatcheries for fish, shrimp, and shellfish larviculture | |
| Sweden | Microalgae | freshwater and marine microalgae, ranging from open to closed systems | | spray-dried, freeze-dried | spray, frozen paste, powder | whole-cell microalgae as a raw-material for further extractions compounds to cosmetics | |
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| Sweden | Microalgae - material | | | | | | |
| Sweden | Seaweed - food | cultivation in lab first (some wild), attached to ropes that are then | harvested kelp is rinsed first on boat then taken to land | As dried, it is chopped up for packaging in vacuum packed plastic | Dried seaweed mixed with seasalt another application is in drink | End product to consumer is dried or frozen | Waste streams are sent to bioplastic/bio packaging test facility |

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| | | placed in ocean for growth (sugar kelp, *Saccharina latissima*), harvested by hand onto boat | hanged up for air drying under tents outside or sent to drying machine; Alternative is blanching then freezing (iodine reducing method) | bags. As frozen, it is sent to a industrial food processing company to be chopped for packaging in freezer. | form making seaweed "tea" for extraction of vitamins/minerals | packaged seaweed for use directly. | Iodine and heavy metal content is a concern. Processing practices are being examined to find if they can reduce the iodine. But also more frequent testing being done during cultivation to understand if there are ways to reduce this content in cultivation or during harvesting. |
| Sweden | Seaweed - nutrition | cultivation in lab first (some wild), attached to ropes that are then placed in ocean for growth (sugar kelp, *Saccharina latissima*), harvested by hand onto boat | harvested kelp is rinsed first on boat then taken to land<br>hanged up for air drying under tents outside or sent to drying machine; Alternative is blanching then freezing (iodine reducing method) | | | | |
| Sweden | Seaweed - materials | cultivation in lab first (some wild), attached to ropes that are then placed in ocean for growth (sugar kelp, *Saccharina latissima*), harvested by hand onto boat | harvested kelp is rinsed first on boat then taken to land<br>hanged up for air drying under tents outside or sent to drying machine; Alternative is blanching then freezing (iodine reducing method) | | | | |
| Sweden | Mussels (*Mytilus edulis*) - food | | | | | | |
| Sweden | Mussels (*Mytilus edulis*) - nutrition | | | | | | |

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| Sweden | Mussels (*Mytilus edulis*) - materials | | | | | | |
| Sweden | Herring (*Clupea harengus*) - food sidestreams | | | | | | |
| Sweden | Sea Squirts - Ciona intestinalis | The cultivating of sea squirts is very similar to that of mussel farming. Growing under the water at ropes hanging from buoys, The method is governed by environmental permissions and totally natural – there is no need of fertilisers or pesticide to make the sea squirts grow. Rope with seeds are saved from earlier harvest and when the water becomes + 10 degrees, the seeds start to reproduce themself and attach to the new ropes. The grow primarily during April - September, and then they are harvested during winter. | The ropes are being collected and transported to shore by boat. In the harbour the sea squirts are cut from the rope and then immediately boiled. | Minced meat: After boiling the solid mass are being chopped into mince meat and mixed with egg-, beetroot and pea flower. After that it is being fried and vacuum packed for selling as minced seasquirt meat. | | Food - minced meat, liquid bullion extract, umami creme | Zero waste production, everything is being used. |
| | | | Steam boiling | After boiling the liquid are further boiled and reduced to a, liquid bullion extract, which is bottled for selling as a food ingredient in cooking. The small solid parts that are left after the boiling-reduction are packaged in jars as seasquirt creme - that also can be used as a cooking ingredient. Both the creme and the liquid bullion extract contains a lot of umami, and is a good flavour maker in different kinds of food. | | | |