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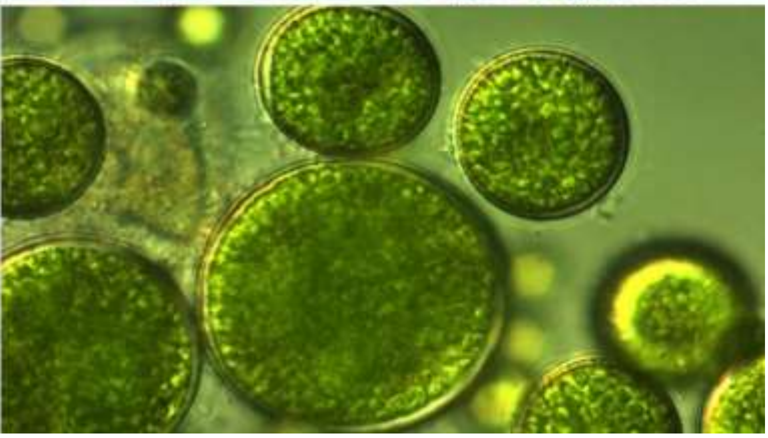

BLUE BIOECONOMY

Situation report and perspectives

LAST UPDATE: 2018

WWW.EUMOFA.EU

Maritime affairs and Fisheries

Manuscript completed in October 2018

Luxembourg: Publications Office of the European Union, 2018

PDF ISBN 978-92-79-96713-9 doi: 10.2771/053734

FOR MORE INFORMATION AND COMMENTS:

Directorate-General for Maritime Affairs and Fisheries

B-1049 Brussels

Tel: +32 229-50101

E-mail: contact-us@eumofa.eu

Contents

Foreword

The aim of this report is to provide a comprehensive overview of the blue bioeconomy sector in the European Union. By "blue bioeconomy", it is intended any economic activity associated with the use of renewable aquatic biological resources to make products. Examples of such products include novel foods and food additives, animal feeds, nutraceuticals, pharmaceuticals, cosmetics, materials (e.g. clothes and construction materials) and energy. Businesses that grow the raw materials for these products, that extract, refine, process and transform the biological compounds, as well as those developing the required technologies and equipment all form part of the blue bioeconomy. To avoid overlap in analysis of other maritime economic sectors, the Study considers that typical aquaculture and fisheries, where the fish or shellfish are caught or produced for human consumption, is excluded from the analysis. These sectors are already subject to several analysis and reports as standalone sectors, and are already monitored by EUMOFA as part of its ordinary activities. However, there are two exceptional cases: fish waste (the part not used for human consumption), which is not discarded but used as an input to other products (e.g. fish meal/fish oil), and algae (both macroalgae and microalgae). Although macroalgae can be considered as traditional aquaculture, they are closely integrated with the bioeconomy as intended in this Study, and furthermore they are often omitted from consideration in analysis of the aquaculture sector. Hence, algae are considered in this analysis, with a distinction between algae for direct human consumption and algae for processing in to other products/sectors.

The report is structured in five sections:

1. **Mapping non-food uses of fisheries and aquaculture biomass.** This section explores the types, geographic sources and potential food and non-food uses of fisheries and aquaculture biomass. It analyses the value and activities comprising the EU bioeconomy, the innovations in products, processes and markets and the main structural changes that are required for the progress of the sector.
2. **The size of demand.** It analyses the size of the EU demand, the main EU players at country, regional and sub-sector levels, and the global demand for products of the bioeconomy, mainly focusing on fish waste and algae.
3. **Top products and uses.** This section develops an examination of the top aquatic plants/animals (species) grown in the EU and globally by volume and value, what are their unit values and uses (i.e. eventual products). This includes a mapping of the current uses, unused quantities and new potential uses of by-products from fisheries and aquaculture, also by looking at experiences of different countries.
4. **Understanding the investment trends.** Over the large spectrum of investments covered by the blue bioeconomy sector, this section develops an indication of the type and the main driver for investments looking also at some specific case studies on current investments, before proposing some recommendations on how to foster investments in the sector.
5. **National strategies to support the blue bioeconomy.** Several European countries have adopted overarching science strategies, plans and policies, which include the blue bioeconomy to some extent. This section reports any relevant public policies and strategies promoting the biotechnology sector at national or regional level, also including experiences outside the EU.

The study team acknowledges with grateful thanks the input, feedback and expertise provided by the wide range of representatives from the bioeconomy sector who kindly cooperated in the compilation of this study. A special mention goes to Meredith Lloyd-Evans and Pierre Erwes for their contribution to Section I, IV and V of the Study. The Study "*Blue bioeconomy: situation report and perspectives*" will be carried out by EUMOFA every second year, providing updates and insights on the sector's most recent developments within the European Union.

Glossary

Agar: a jelly-like mixture of two components: the linear polysaccharide agarose, and a heterogeneous mixture of smaller molecules called agaropectin. It forms the supporting structure in the cell walls of certain species of algae, and is released on boiling. It is used as an ingredient in desserts throughout Asia, and also as a solid substrate to contain culture media for microbiological work. Agar can be used as a laxative, an appetite suppressant, a vegetarian substitute for gelatin, a thickener for soups, in fruit preserves, ice cream, and other desserts, as a clarifying agent in brewing, and for sizing paper and fabrics.

Alginate: an irreversible hydrocolloid consisting of salts of alginic acid, a colloidal acid polysaccharide obtained from seaweed and composed of mannuronic acid residues. In extracted form it absorbs water quickly; it is capable of absorbing 200-300 times its own weight in water.

Alkyds: synthetic resins that are used especially for protective coatings and in paint.

Anaerobic digestion: a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen.

Astaxanthins: a keto-carotenoid, used as a dietary supplement intended for human, animal, and aquaculture consumption.

Biochar: charcoal used as a soil amendment.

Biorefinery: a facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass.

Carotenoids: organic pigments that are produced by plants and algae. They are believed to provide health benefits in decreasing the risk of disease, particularly certain cancers and eye disease.

Carrageenans: a family of linear sulfated polysaccharides that are extracted from red edible seaweeds. They are widely used in the food industry, for their gelling, thickening, and stabilizing properties. Their main application is in dairy and meat products, due to their strong binding to food proteins.

Chitosan: a linear polysaccharide made by treating the chitin shells of shrimp and other crustaceans with an alkaline substance. Chitosan can be used in agriculture as a seed treatment and biopesticide, in winemaking as a fining agent, in industry in a self-healing polyurethane paint coating, in medicine in bandages to reduce bleeding and as an antibacterial agent. It can also be used to help deliver drugs through the skin.

Esterification: a chemical reaction that forms at least one ester (= a type of compound produced by reaction between acids and alcohols.

Extremophiles: organisms that thrives in physically or geochemically extreme conditions that are detrimental to most life on earth. Some of them are enzymes that can modify DNA, and so are used in clinical diagnostics and starch liquefaction are produced commercially by several biotechnology companies.

Flocculants: chemicals that promote flocculation (= a process wherein colloids come out of suspension in the form of floc) by causing colloids and other suspended particles in liquids to aggregate, forming a floc. Flocculants are used in water treatment processes to improve the sedimentation or filterability of small particles.

Fucoidans: sulfated polysaccharides found mainly in various species of brown algae and brown seaweed. They are used as an ingredient in some dietary supplement products.

Guanine: is one of the four main nucleobases found in the nucleic acids DNA and RNA.

Hydrocolloids: hydrocolloids are gums that are added to foodstuffs in order to control their functional properties, such as thickening or gelling.

Hydrolysates: proteins digested into smaller fragments, peptides, and its sole building blocks, the amino acids. They are used as nutrient and fluid replenishers in special diets or for patients unable to take ordinary food proteins.

Hydroxyapatite: a calcium phosphate similar to the human hard tissues in morphology and composition. It may be used in applications such as bone tissue engineering, bone void fillers, orthopedic and dental implant coating, restoration of periodontal defects, edentulous ridge augmentation, endodontic treatment like pulp capping, desensitizing agent in post teeth bleaching, remineralising agent in toothpastes, drug and gene delivering.

Macroalgae: large aquatic photosynthetic plants that can be seen without the aid of a microscope. he most familiar types can generally be divided into three groups: Green (Chlorophyta), Red (Rhodophyta), and Brown-Kelps (Phaeophyta - related to Chromista).

Microalgae: small microscopic aquatic photosynthetic plants that require the aid of a microscope to be seen. They live in both the water column and sediment. They are unicellular species which exist individually, or in chains or groups.

Milt: seminal fluid of fish, molluscs, and certain other water-dwelling animals who reproduce by spraying this fluid which contains the sperm, onto roe (fish eggs).

Nori: it is the Japanese name for edible seaweed species of the red algae genus Pyropia.

Peptides: chemical agents belonging to the protein family. A peptide is composed of a mixture of several amino acids. Because of the near-infinite number of structure combinations of the constituent amino acids, peptides are widely used in medicine and industry for everything from anti-aging creams to sweetening coffee.

Phlorotannins: tannins found in brown algae such as kelps and rockweeds or sargassacean species, and in a lower amount also in some red algae. Phlorotannins can have anti-diabetic, anti-cancer, anti-oxidation, antibacterial, radioprotective and anti-HIV properties.

Photobioreactor: a bioreactor which incorporates some type of light source. These organisms use photosynthesis to generate biomass from light and carbon dioxide and include plants, mosses, macroalgae, microalgae, cyanobacteria and purple bacteria.

Reduction fish: stocks of fish that are used for feed.

Rest raw material: what remains after the edible part of the animal, fish or plant has been removed.

Swim bladder: an internal gas-filled organ that contributes to the ability of many bony fish to control their buoyancy.

Thallus: the undifferentiated vegetative tissue.

Wakame: Japanese name for Undaria pinnatifida, a species of edible seaweed, a type of marine algae, and a sea vegetable. It has a subtly sweet, but distinctive and strong flavour and texture. It is most often served in soups and salads.

Acronyms and abbreviations

CFP	Common Fishery Policy
Defra	Department for Environment, Food and Rural Affairs
EC	European Commission
EIB	European Investment Bank
EIF	European Investment Fund
FAO	Food and Agriculture Organisation
FDF	Fully-Documented Fisheries
FP7	7th Framework Programme
FSC	Fish, Shellfish and Crustacea
GWH	GigaWatt hour
H2020	Horizon 2020
IFFO	International Fishmeal and Fish Oil
Kt	Thousand tonnes
LNS	Lower North Shore (Canada)
LO	Landing Obligation
Mt	Million tonnes
NACE	Nomenclature des Activités Économiques dans les Communautés Européennes
OECD	Organisation for Economic Co-operation and Development
OFIMER	Office national interprofessionnel des produits de la mer et de l'aquaculture. Since 2009, FranceAgriMer
pa	Per annum
PUFA	Polyunsaturated Fatty Acid
RRM	Rest Raw Material
SAM	Scientific Advice Mechanism
SAPEA	Science Advice for Policy by European Academies
SARF	Scottish Aquaculture Research Forum

Section 1 - Mapping non-food uses of fisheries and aquaculture biomass

0 Introduction & Summary

FAO has estimated that fish[1] represented one-sixth of animal protein supply and 6.5% of all protein for human consumption; and 20% of animal protein intake comes from fish for 3.2 billion of the world's population[2]. Biomass is derived from capture fisheries and wild harvesting and from aquaculture and mariculture. Current production according to FAO is summarised in Table 1.

Table 1 - Production of fish and seaweed 2015

Type	Total Mt	Aquaculture Mt	Capture/wild harvest Mt
FSC total Mt	169.2	76.6	92.6
FSC inland Mt	60.5	48.8	11.5
FSC marine Mt	108.2	27.8	81.2
Seaweeds	30.5	29.4	1.1
Total Mt	199.7	106	93.7
Microalgae	?	?	?

Source: FAO (2017); FSC = Fish, shellfish and crustacea

Estimates of the waste produced in fisheries and aquaculture include volumes as high as 130Mt and value-lost of up to $50B (about 43 billion EUR), as a result of poor management of seafood resources[3]. Comprehensive data is not available, though individual pieces of information can be retrieved from individual publications, without detailed quantification or enough background to know where data-collection has been consistent.

There is considerable pressure to improve biomass availability by a combination of changes in fishing and aquaculture focus and reduction in wastage. The Food from the Oceans report of the EC's Scientific Advice Mechanism (SAM)[4] confirms the conclusions of the evidence review by Science Advice for Policy by European Academies (SAPEA)[5]. In order to meet projected demands for food and biomass from the seas and aquaculture, >100Mt per year additional food output is needed from marine capture fisheries and aquaculture. The main points to take from this report are:

- Mariculture is seen as less constrained than land-based aquaculture and capture fisheries; as much as 160Mt extra biomass could be produced within 20 years or so, overwhelmingly by increasing production of lower-trophic marine biomass, e.g. algae and molluscs.
    - As this is largely exploitation of new or unfamiliar bioresources, or existing species but on a very much larger scale, this may well yield significant opportunities for development of new processes, products and markets using the by-products or wastes.

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1 In this report, the term fish may include shellfish and crustacea and, for capture fisheries, cephalopods, unless otherwise specified. FAO data often aggregates these. Where possible, specific information on molluscs, crustacea and invertebrates will be found in the specific sections.

2 The State of World Fisheries and Aquaculture: Opportunities and challenges, FAO 2014 ISBN 978-92-5-108276-8; Fishery and Aquaculture Statistics 2015 FAO 2017 ISBN 978-92-5-009987-3.

3 Ghosh P.R., Fawcett D. et al. (2016) Progress towards sustainable utilisation and management of food wastes in the global economy, Int J Food Sci 2016 e3563478, Doi: 10.1155/2016/3563478.

4 European Commission High Level Group of Scientific Advisors (2017) Food from the Oceans Scientific Opinion No. 3/2017 doi:10.2777/66235.

5 SAPEA (2017) SAPEA Evidence Review Report No. 1: Food from the Oceans https://www.sapea.info/wp-content/uploads/FFOFINALREPORT.pdf, Doi: 10.26356/foodfromtheoceans.

- Capture fisheries are expected to yield an extra 30Mt for human consumption by better management of established fisheries (20Mt) and reduction and elimination of discards (10Mt).
    - As the aim of development here will be to generate additional biomass for human consumption, it is more likely that any additional by-products or wastes will be used for existing types of non-food use.
- An additional >100Mt protein and oils is estimated to be needed, to service the expected growth in aquaculture; this is predicted to come from currently underused species such as krill and mesopelagic organisms (20Mt, but on a longer timescale), algae including seaweeds (>50Mt), and a better use of discards and processing waste (30Mt).
    - Since the aim in this is to free up for human food fish that are currently harvested for reduction to fishmeal and fish oils, there may be new non-food products and markets that can be developed from these sources.

Spoilage of seafood before it reaches the consumer has been estimated at 20% of the catch[6]. In addition, it is estimated that 30%-70% of all fish that reaches a processor becomes by-product, as processing the fish for human consumption generates materials that are not used for direct human consumption, so are potentially usable for industrial, non-food purposes. It is likely, however, that efforts to improve these figures will be directed towards making more food available for humans rather than making more biomass available for non-food uses.

0.1 Biomass inputs

Top-level figures: c. 170Mt fish, shellfish and crustacea, c. 30Mt seaweeds, unknown total production of microalgae.

Most data is available for finfish, shellfish and crustacea, mainly through FAO sources, and is often – though not always – aggregated by FAO and other sources for the purposes of reporting. Some data is available for seaweeds, top-level from FAO and occasionally at the level of industry use e.g. for marine hydrocolloids, or human consumption, e.g. by species sold (nori, wakame, etc.). Very little data is available for microalgae, mainly focused on volume of whole cells available for use in the nutritional supplement sector.

The major inputs we need to consider are finfish (bony and to a lesser extent cartilaginous), shellfish (molluscs and gastropods), crustacea, seaweeds and microalgae. These are produced either by capture fisheries, or by aquaculture in freshwater and marine environments. Some wild harvesting of seaweed also takes place. FAO (2017) gives top-level estimates of amounts available for utilisation[7]; together, c. 170Mt of fish, shellfish and crustacea were landed and harvested in 2015, c. 56% wild-caught, 44% from aquaculture, plus c. 31Mt aquatic plants, mainly seaweeds (see Tables 1-3).

Sea and ocean fishing predominates for capture fisheries (81Mt vs 11.5Mt freshwater); however, the opposite is true for aquaculture (28Mt marine vs. 49Mt freshwater). About 1.1Mt wet weight seaweed is wild-harvested; there is no information on the destination of this amount, or how much beached seaweed might be recoverable for industrial added-value uses world-wide. Data on global wild-harvesting of microalgae is impossible to find, but the technical challenges in doing this and the likely low-value uses (e.g. Anaerobic Digestion – AD for nuisance blooms) also militate against exploitation.

6 Gustavsson J., Cederberg L. et al. (2011) Global Food Losses and Food Waste, FAO ISBN 978-92-5-107205-9.

7 Fishery and Aquaculture Statistics 2015, FAO 2017 ISBN 978-92-5-009987-3. This ref. is quoted throughout as FAO (2017).

Table 2 - Production of fish and seaweed in capture fisheries and wild harvesting

Table 2: Type	Inland Mt	Marine Mt
Total	11.5	81
Fish	10.6	67.5
Crustacea	0.5	6.1
Molluscs	0.34	7.1
Seaweed	-	1.1

Source: FAO (2017)

Production of macro- and microalgae is much higher in aquaculture and mariculture than wild-harvested: the estimated harvest of farmed seaweeds (brown, red and green) is 29.4Mt; for microalgae, an estimated 16.7Kt dry mass of species used for healthfoods, nutritional supplements and antioxidant pigments for humans and animals, mainly Dunaliella, Spirulina, Haematococcus, was produced in 2016[8].

Table 3 - Production of fish and seaweed in aquaculture

Table 3: Type	Inland Mt	Marine Mt
Total	48.9	57.1
Fish	44.1	2.9
Fish diadromous	5.0	
Crustacea	7.4	
Molluscs	16.4	
Seaweed/plants	0.1	29.3
Microalgae for nutrition	0.017	

Source: FAO (2017), Transparency Market Research; Categories not split between inland and marine in original FAO report

The amounts of biomass available from each type of resource varies widely. As a rule of thumb, >50% of any finfish product does not directly enter the human food chain – "for each tonne of fish eaten, an equal volume of fish material is discarded either as waste or as a low value by-product"[9]. White fish such as cod may generate almost 60% waste, ocean fish such as tuna as much as 70%. For shellfish such as scallops, wastes are as high as 88% of catches and harvests[10]. Exceptions might include cephalopods (c. 65% of cuttlefish is edible[11]) and reduction fish[12], of which 100% is used for fishmeal and fish oils.

Assuming that the material that is available for innovative non-food uses derives from wastes, discards and losses during production and processing of fish and seafood for human consumption, both stage of the chain and geography seem important (see Figure 1)[13], which may have an implication for where to make the biggest impact with waste-avoiding or utilising processes.

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8 https://www.transparencymarketresearch.com/algae-market.html.

9 Quoted in Scottish Government (2005) Evaluation of Fish Waste management techniques http://www.gov.scot/Publications/2005/03/20717/52862.

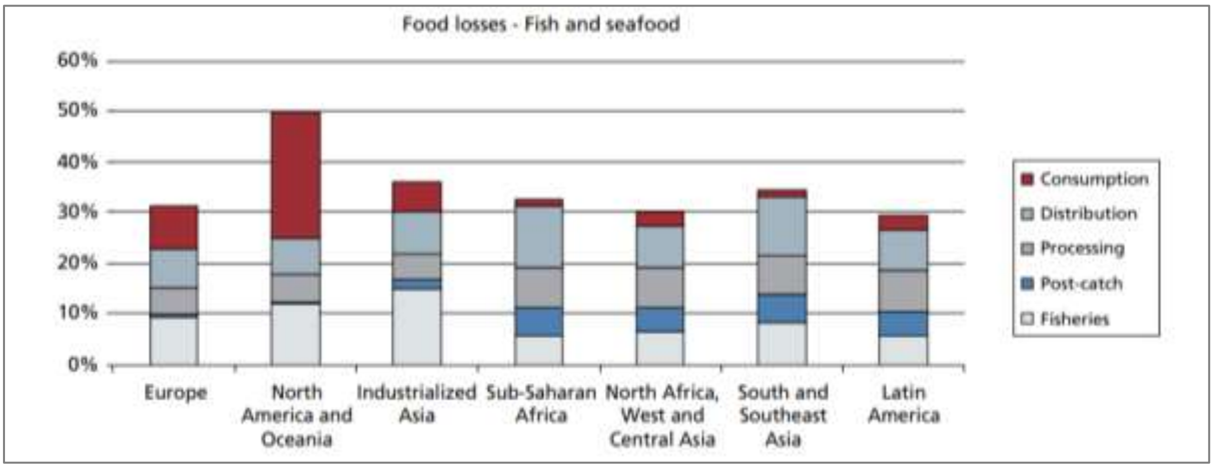
10 WRAP (2012) Sector guidance note: Preventing waste in the fish processing chain, June 2012.

11 Shodhganga@INFLIBNET Chapter VI Analysis of the supply chain in the fish processing industry and problems of seafood export processing sector http://shodhganga.inflibnet.ac.in/bitstream/10603/111440/7/16_chapter6.pdf.

12 Stocks of fish that are used for production of fishmeal and fish oils for aquaculture and animal feed are known as 'reduction fish'.

13 Gustavsson J., Cederberg C. et al. (2011) Global Food Losses and Food Waste, FAO 2011, ISBN 978-92-5-107205-9.

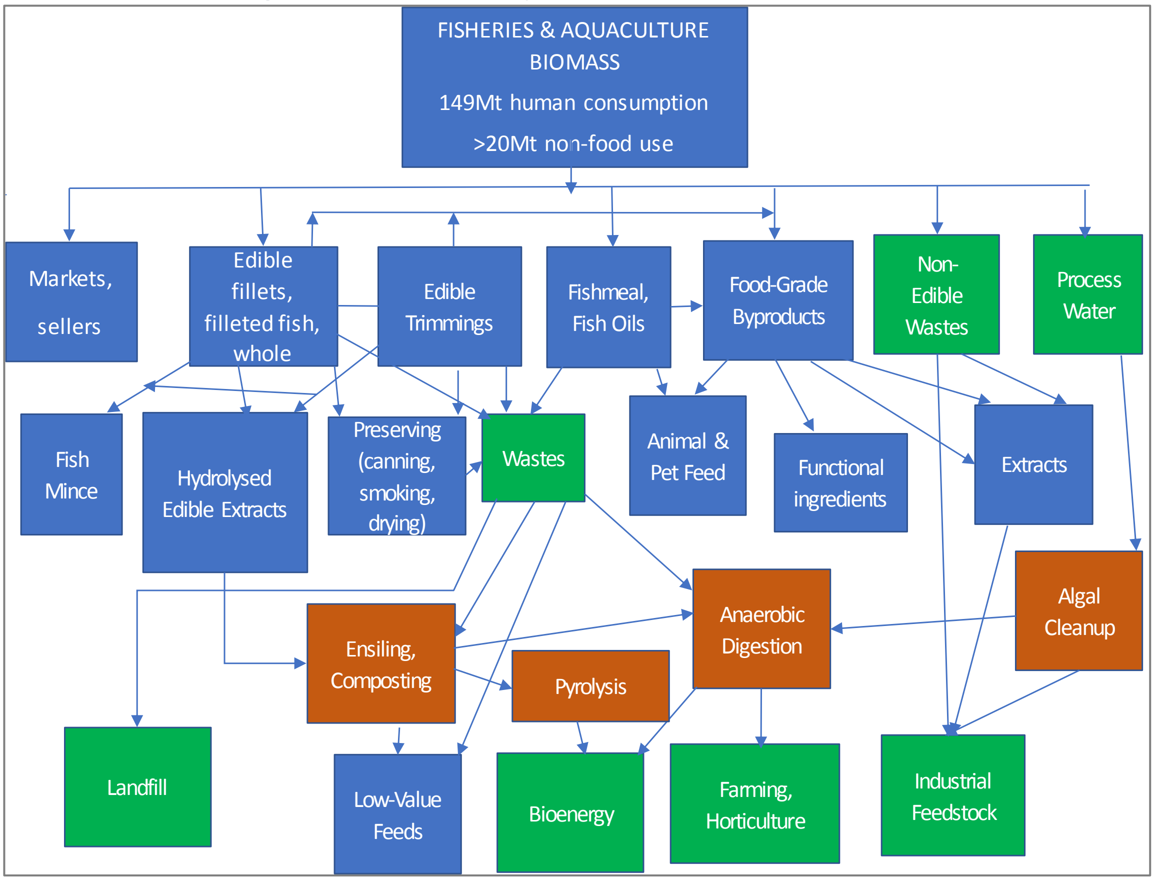
Figure 1 - Losses through the supply chain by discards, disposals and wastage by stage and region



Source: Gustavsson et al. (2011)

Outputs are far more difficult to quantify or even estimate, except in the case of fishmeal and fish oils production. The complex web of materials flows is shown in Figure 2 - Fisheries and aquaculture biomass - materials flow. Here, it is important to note that there is already a great deal of activity that takes material from one processing stage that might in the past have been discarded, e.g. trimmings, and uses them as inputs to other stages e.g. processing for fish mince products or hydrolysis for flavourings or peptides, for human consumption or, if of lesser quality, for fishmeal and fish oils for animal and aquaculture feeds. Activities like these account for the complexity of the web.

Figure 2 - Fisheries and aquaculture biomass - materials flow



0.2 Types of biomass

0.2.1 Finfish

These form the majority of capture fisheries and aquaculture activities and the majority of international trade. In aquaculture, salmon and trout predominate in Canada, South America, Norway, Scotland and are the most valuable sector in trade. Carp and Tilapia are the most important species for on-land aquaculture in most parts of the world; catfish are also important in the USA. Other species are local, regional (such as Southeast Asian milkfish in aquaculture, or Alaskan pollock and anchoveta) or niche (such as eel).

The biomass they produce for potential non-food uses includes:

- Whole fish (dead, diseased, damaged, undersize, inappropriate species, unsaleable species)
- Initial processing by-products such as body slime, wash-waters, scales
- Fish trimmings (essentially all the fish except for the fillets and, in some cases, the roes)
- Specific tissues and rest raw materials (such as skins, livers, other viscera, bones)
- Processing waste-waters (which have a recoverable protein content)
- Fish trimmings and rest raw materials may arise on-board vessels, on-shore at markets or with primary purchasers, or further along the supply chain with secondary processors.

0.2.2 Cartilaginous fish

These include shark, skate, rays and dogfish, all from marine capture fisheries.

The biomass they produce for potential non-food uses includes the same categories as for finfish.

0.2.3 Molluscs

The highest tonnages of mollusc fisheries and aquaculture are for clams, oysters, mussels and scallops; other important species include gastropods such as whelks.

The biomass they produce for potential non-food uses includes shells, flesh-waste adhering to shells and processing debris including trimmings, viscera and other inedible material. The utility of flesh-waste from molluscs for non-food uses is totally overshadowed by the challenges of making good use of the shells. An unknown amount of shells is discarded at sea.

0.2.4 Crustacea

The main crustacea are prawns, shrimp, crab and lobsters; planktonic crustacea such as krill are also harvested in increasing amounts.

The biomass they produce for potential non-food uses includes shells (carapaces), flesh-waste adhering to these and processing debris including trimmings, viscera, roes and other inedible material. This biomass may become available on-board harvesting vessels, or may arise further down the supply chain.

0.2.5 Invertebrates

The majority of invertebrates in the seafood chain are cephalopods – octopuses, squids and cuttlefish.

Octopus produce only 10-20% biomass for non-food use, squid as high as 52%: cuttlebones, squid pens, ink sacs, viscera, eyes and beaks.

Sea urchins, starfish and sea cucumbers, salps and tunicates are also caught and traded and, in some cases (sea urchins, sea cucumbers) 'farmed' in semi-managed marine environments.

0.2.6 Seaweeds

Small but substantial wild harvests; very large farming of seaweeds especially in China.

0.2.7 Microalgae

Pond culture in high sunlight areas of carotenoid and omega-3 fatty acid rich algae and Cyanobacteriaceae, estimated at c. 16,700 tonnes each year; an unknown total of photobioreactor and closed fermenter tonnage for high-value nutritional ingredients and biofuel oils and fatty acids.

0.3 Supply chains

Capture fisheries and aquaculture farms supply their catch to a range of supply chain actors – to consumers, in the case of artisanal fisheries and small aquaculture establishments, either direct via off-boat and off-farm sales or local markets, or indirect via restaurants or to on-shore processing plants. Industrial-scale fishing vessels perform primary processing and preservation on-board, supplying mainly to further processors and wholesale purchasers, with some supply to integrated food retailers. Traders, dealers, distributors and transporters may also be involved. A large-scale production-to-consumer integrated chain may be in place, operated by individual companies who own boats, processing plants, shippers and retailers. We can expect some losses of produce at any stage in a chain, but accessing this may be difficult.

Seaweed producers will in the main be either supplying to producers of alginates and other marine hydrocolloids, under contract, or be linked in to a human food supply chain. Casual collection of beached seaweeds is mainly a hazard disposal exercise. Following its review of seaweed production and its contribution to food and economies, the World Bank Group is focused on persuading stakeholders such as the US Department of Energy and companies to invest in this[14]. Microalgae producers are often part of an integrated activity supplying ingredients or whole-cell preparations into the human nutritional supply chain, have close links with organisations that will trial and purchase biofuels, or are service companies working with engineering contractors to provide bioremediation. The Algae Biomass Organization is currently working on a roadmap for integration of algal food and feed chains[15].

To identify the most efficient points for intervention and the scope for conversion for non-food uses requires a more-detailed study of supply-chain dynamics in fisheries and aquaculture, taking into account specifics related to types of biomass. An estimate or assumption for wastes by stage of chain is provided by FAO; this suggests that, for fish and seafood, the most important stages in the supply chain in Europe are the consumer, the food retailer and the production stages (see Table 4).

[14] *Pers. comm.* Brummett R. (2018), World Bank Group.

[15] *Pers. comm* Carr M. (2018) Algae Biomass Organization.

Table 4 - Estimated waste percentage waste of fish and seafood and some other foods in Europe

Food commodity	Supply chain stage				
	Production	Handling and storage	Processing	Distribution and retail	Consumer
Fish and seafood	9.4%	0.5%	6%	9%	11%
Cereals	2%	4%	10.5%	2%	25%
Roots and tubers	20%	9%	15%	7%	17%
Oilseeds and pulses	10%	1%	5%	1%	4%
Fruit and vegetables	20%	5%	2%	10%	19%
Meat	3.1%	0.7%	5%	4%	11%
Milk	3.5%	0.5%	1.2%	0.5%	7%

Source: Gustavsson et al. (2011)

The structure of the industry and its dynamics may also affect availability of material or cohesion in the value chain. The fish processing industry in the UK in 2016 consisted of 376 sites employing c. 18,000 FTE, with a total turnover in 2014 of >£3.1B (€3.5B)[16]; 54% of sites combined primary and further processing; 32% dealt with primary processing alone, 12% with secondary processing. It can be imagined, though this needs to be investigated, that the economic balances of each segment are different and that their abilities to valorise the materials they have access to will differ widely. In addition, since 2008 there has been consolidation of almost 40%. Although there is use of by-products, there is limited data for the UK on amounts and utilisation, and Norway is given as the reference country[17].

0.4 Geographic sources of biomass

China has a commanding position in supply of biomass. Table 5 shows that it is at No 1 position for fisheries and aquaculture and No 1 or 2 for seaweed production. No other country besides Indonesia features consistently in the Top 10 in all categories, at 23Mt cf China's 79Mt; Japan, Chile and Norway appear in three categories. For the rest of Europe, Ireland, France and Iceland are in the top 10 only for wild-harvesting of seaweed.

Table 5 - International landscape of fisheries, aquaculture and fishmeal production 2015

Position	Fisheries Mt	Aquaculture Mt	Wild-harvest seaweeds Mt	Farmed seaweeds Mt
#1	China 17.6	China 47.6	Chile 0.35	China 13.9
#2	Indonesia 6.5	India 5.2	China 0.26	Indonesia 11.3
#3	USA 5.0	Indonesia 4.3	Norway 0.15	Philippines 1.6
#4	India 4.8	Vietnam 3.4	Japan 0.09	South Korea 1.2
#5	Peru 4.8	Bangladesh 2.1	Indonesia 0.08	North Korea 0.5
#6	Russia 4.6	Norway 1.4	Ireland 0.03	Japan 0.4
#7	Japan 3.5	Egypt 1.2	France 0.019	Malaysia 0.26
#8	Chile 3.0	Myanmar 1.0	India 0.019	Zanzibar 0.17
#9	Vietnam 2.8	Chile 1.0	Iceland 0.017	Madagascar 0.015
#10	Norway 2.3	Thailand 0.9	Peru 0.015	Solomon Islands 0.012

Source FAO (2017)

16 Noble S., Moran Quintana M. and Curtis H. (2017) 2016 Seafood Processing Industry Report, Seafish Report No SR700, March 2017, ISBN 978-1-911073-06-02.

17 Noble S. et al. (2017).

Table 6 summarises the data for 2015 for total production in Europe[18]; FAO gives slightly different data for Europe: of total production of 16.4Mt, existing non-food uses occupied 2.64Mt (16%).

Table 6 - Global production and balance of fish for Europe 2015

Production	Mt
Total production	17.1
Capture fisheries	14.1
Aquaculture	3.0

Source FAO (2017)

0.4.1 Seaweeds

The FAO database has only general information for production or harvesting of seaweeds, including them in the category of aquatic plants. According to FAO, most of this category comprises seaweeds and 96% is farmed. The bulk of seaweeds are for human consumption and most of the remainder is for extraction of marine hydrocolloids for established food and industrial uses. Exploration of the concept of the seaweed biorefinery is underway, for example in USA, where the Department of Energy has launched a $30M (26M EUR) programme for scale-up of seaweed processing for biofuels and other products[19].

0.4.2 Microalgae

The FAO database has no information at all for production or harvesting of microalgae. There are some corporate, government-funded investments in microalgal production in bioreactors for biofuel production but corporate activity, even in USA, is moving from biofuels towards omega-3 fatty acids, algal protein and whole-algae products for fish feed[20]. The US Dept of Energy's review of biomass for energy has no data for the actual quantity of microalgae used for this[21], most likely because economic mass-production is not yet stabilised and markets are too dependent on the price of crude oil and bioenergy credits, tariffs and other policy instruments. There are, however, estimates of potential productivity for biofuel production. The dry mass of microalgae produced mainly in open-pond culture for nutritional supplements or ingredients for humans and animals was estimated at c. 15,000 tons/year, mainly *Spirulina*.

0.5 Wastes

We can assume there will be little incentive for public or private investment in processes and technologies to valorise otherwise wasted fisheries and aquaculture outputs unless a) there are markets for the resulting products, b) the supply chain allows appropriate interventions at the most appropriate points, and c) policies can be put in place that are not expensive or onerous to follow. For these reasons, a consideration of the dynamics of wastes is important.

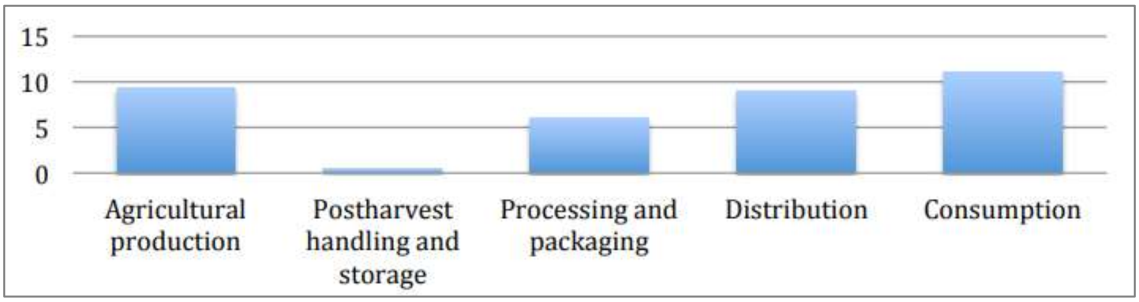
18 FAO (2017).

19 *pers. comm*. Carr M. (2018), Algae Biomass Association.

20 *pers. comm*. Carr M. (2018), Algae Biomass Association.

21 US Department of Energy, 2016 BILLION-TON REPORT Advancing domestic resources for a thriving bioeconomy – Vol 1 economic availability of feedstocks, Langholtz M.H., Stokes B.J. and Eaton L.M., Doi: 10.2172/1271651.

Figure 3 - Proportion of waste & by-products (% of original landings) by stage of supply



Source: Jouvenot (2015)

Analysis of waste production (Figure 3) suggests that the largest proportions occur at the stage of catch or during aquaculture, during distribution and retailing, and during consumption itself[22]. The total is in the region of 35% of original landings. Different approaches are likely to be needed to establish effective initiatives and policies to extract wastes from these different stages and make effective use of them for non-food purposes. There is a clear need for cross-departmental and cross-sectoral collaborations between different government departments and agencies and industries of different natures and with widely different economic imperatives.

However, the UK charity 'Waste and Resources Action Programme' (WRAP) reported in 2011 that 33% of the total fish and shellfish inputs into processing (350,000 tonnes of 1.04M) were regarded as non-edible, of which 40% was waste and co-products (including retail wastes) from finfish and shellfish[23]; most of the finfish material was sold to fishmeal plants but most of the material arising in the shellfish area was regarded as unavoidable waste. WRAP's (and the industry's) conclusion from the survey was that avoidable wastes generated by processing were low.

0.6 Food and non-food uses of fisheries and aquaculture biomass

Rest Raw Materials, or RRM, is a literal translation of the Norwegian term "restråstoff", and comprises all the potentially-useful material removed from fish, shellfish, crustacea and others species to prepare biomass for food use.

The world production of fish, shellfish and crustacea in 2015 was c. 169Mt, capture fisheries and aquaculture combined[24]; of this, 149Mt (88%) was for food use and 20Mt (12%) was for non-food uses. Of the 20Mt, FAO states that 15Mt is channelled into fishmeal and fish oils, and 5Mt is available for other uses, though these uses are not described. The proportion of landings and harvests intended for other non-food uses therefore represents about 3% of 2015's total. Non-food uses of the by-products and wastes from edible processing of fish and other seafood are not included, nor is usage of seaweeds.

As management techniques and landing obligations or taxes have been put in place, estimated global discards have dropped from c. 27Mt per yera in the early-to-mid 1990s (though one estimate puts this as high as 40Mt of fish[25]) to 7.3Mt per year in early-to-mid 2000s. For 2014, discards have been

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[22] Jouvenot L. (2015) Utilisation of rest raw materials from the fish industry: Business opportunities and logistics requirements, Master's Thesis Norwegian University of Science and Technology, NTNU Trondheim June 2015 https://brage.bibsys.no/xmlui/bitstream/handle/11250/2351183/13467_FULLTEXT.pdf?sequence=1.

[23] WRAP (2011) Resource maps for fish across retail & wholesale supply chains, Project code RSC009-001 & RSC009-003.

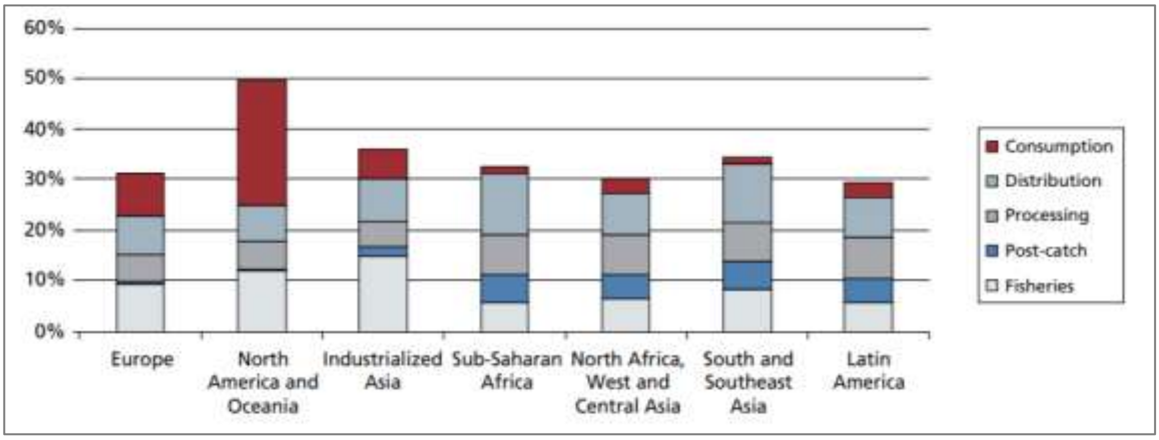
[24] FAO (2017).

[25] Seafish (2001) Fish Waste Production in the United Kingdom: The quantities produced and opportunities for better utilisation, SR537.

estimated at <10Mt per year, of a total estimated catch of 110Mt (c. 8-9%)[26]; the great majority, c. 93%, from large-scale industrial fishing vessels, and about 40% from the Atlantic, 60% from the Pacific. The large impact in the Pacific is from Russian fishing of Alaska pollock, with at-sea processing, retention only of the roes and discard of all RRM. The 'average' of 8% disguises very wide ranges: bony fish bycatch in crustacean fisheries (typically *Nephrops*) may be as high as 80%-90% of catch, with <50% retained. There are also wide ranges according to geography (see Figure 4 - Losses through the supply chain by discards, disposals and wastage by stage and region[27]), which may have an implication for where to make the biggest impact with waste-saving or utilising processes.

Where fish by-catch is prevalent, overall discard rates may be as high as 47%-50%. There is clearly a correlation between increasing the minimum landing size or age and an increase in discard rates; the discards could be retained and funnelled into non-food uses if survival rates are known to be low, or their condition cannot be guaranteed. Monitoring of catches and landings using closed circuit television and the Fully-Documented Fisheries (FDF) programmes may assist in quantifying catches that can be directed towards non-food uses.

Figure 4 - Losses through the supply chain by discards, disposals and wastage by stage and region



Source: Gustavsson et al. (2011)

Fisheries discards are monitored and reported under the European Data Collection Framework by observers on a sample of <2% of fishing boats, and the results are extrapolated to entire fleets. All figures are therefore estimates with unknown variances. In addition, the situation with discards is in flux, as the new regulations concerning landing obligations are changing what fishing crews can do with their fish catches and creating both problems and opportunities for the management of unwanted, underused and wasted fish. The phase-in period is 2015-2019, and the impact on availability of landed material for non-food use such as fishmeal and fish oil is yet undetermined.

0.7 Uses

Food or human nutritional uses of marine and aquaculture biomass include:

- **Direct-to-consumer** via artisan fishing, markets, retail sale and restaurants;
- **Fillets and other primary-processed material** such as roes, ex-shell molluscs and crustacea;
- **Fish oils** for nutritional supplements and omega-3 fatty acids;
- **Fishmeal extracts** for protein and oils for human nutrition;

[26] Zeller D., Cashion T. et al. (2017) Global marine fisheries discards: A synthesis of reconstructed data, Fish and Fisheries 19:30–39 Doi: 10.1111/faf.12233.

[27] Gustavsson J., Cederberg C. et al. (2011) Global Food Losses and Food Waste, FAO 2011, ISBN 978-92-5-107205-9.

- **Chopping/mincing** of edible trimmings for processed fish products such as surimi and prepared frozen or chilled foods;
- **Seaweed hydrocolloids** for food and pharmaceutical use;
- **Seaweed extracts** for nutritional supplements and anti-oxidants;
- **Whole and extracted microalgae** for nutritional supplements, antioxidants and omega-3 fatty acids;
- **Higher-value elements**: collagens, gelatins, minerals, chitin derivatives, carotenoids, enzymes, amino-acids, for nutrition and supplementation.

Non-food uses or treatments of marine and aquaculture biomass include:

- **Higher-value elements**: collagens, gelatins, minerals, chitin derivatives, carotenoids, enzymes, amino-acids, peptones, for animal nutrition, laboratory, chemical, agricultural uses – the same potential as for materials of food-grade quality, but essentially manufactured from biomass not of food grade;
- Fishmeal and fish oil for animal feed;
- **Minced fish** for petfoods;
- Fishmeal extracts for petfoods;
- **Ensiling** for protein concentrates and hydrolysates for animal nutrition;
- **Processed fish oils** for industrial uses;
- **Chopping/mincing/freezing** for direct baits, animal and fish feeds;
- **Composting** for fertiliser/soil improver;
- **Aerobic Digestion** for biogas and fertiliser/soil improver;
- **At-sea discards** (e.g. pollock RRM by Russian fisheries, and bycatch);
- **Landfill** (less so in Europe and other developed states).

Non-food uses of macroalgae (seaweeds) are as sources of bioactive compounds, sources of marine hydrocolloids for pharmaceutical use e.g. as formulation and encapsulation aids, or for laboratory use e.g. for microbiological media; and as potential sources of biofuels and proteins for animal feed. Non-food uses of microalgae revolve mainly around production of oils for biofuels, use in water remediation, wet biomass for anaerobic digestion, and potential for use as bioplastics. The quantities used for these purposes are not at the moment identifiable. Many developments are at an early stage or are not yet scaled up to full commercialisation. The approach for microalgal utilisation is purpose-production, rather than making use of wastes, residues and by-products from food use. Some evidence of product innovation based on nuisance algae (algal blooms) has been found, but data on quantities available or used are lacking. For both seaweeds and microalgae, one processing challenge for adding value is the need to remove water and the cost of doing this.

0.8 Innovations in products, processes and markets

The main structural changes that are required for progress in use of marine and aquatic biomass are:

- Better and more consistent information about biomass types and sources;
- Technological innovations for processing and value-preservation of biomass;
- Policy frameworks that support supply chains in developing and marketing new products

Improving the efficiency of capture fisheries requires radical change such as removing overcapacity in the world's fishing fleets, imposing management on over-exploitation, redressing the balance between the value retained by the capture businesses and that retained by the processers, retailers and aquaculture producers (estimated to be a 20:80 split of a $400B food fish market), and improving access to and use of under-used species[28]. Losses at production level due to structural problems are estimated at a mean of $50B (€43B) per year.

It is recognised that there is a need for improvement in the management of aquatic and marine biomass, for both food and non-food purposes. In October 2016, the European Commission (DG Research & Innovation) held a workshop on making better food use of marine and aquaculture biomass and the steps needed to achieve this[29]. The three main topics were Underused fish biomass, New algae value chains for food and Consumer acceptability of aquaculture products. This workshop could be a model for one focusing on non-food uses of fish, shellfish and seaweeds and new non-food uses for microalgae, organised by DG MARE.

Given that in some fish, up to 70% is RRM (e.g. tuna), additional ingenuity could be applied to the material other than turning it into fishmeal and fertiliser. The head may occupy 20-25% of the fish, the viscera including guts and roes a further 10%-25% of whole fish. Gutted fish is 62% edible flesh, including 46% skinless fillet, but is still 38% wastes. Headless fish may have >50% easily-usable meat (37% loin, 18% fillet), but there are still frames and dark meat 18%, viscera 13%, belly 6%, and frame scraps 8%.

The EU Aquatic Food Products workshop (2016) recommended a number of initiatives spanning these areas, including producing a roadmap, supporting regional pilot plants at semi-industrial scale and funding larger regional bio-refineries or algal lighthouse projects[30]. Discussion also mentioned a need to better monitor the types and amounts of marine and aquaculture biomass that might be directed to added value uses and the impact of rules such as management of Category 2 materials and the CFP landing obligation regulations.

It could be realistic to recommend that consideration of non-food uses of fishery and aquaculture biomass is always included in discussions of policy, regulation and development when food uses are being considered. This would, for example, have made the Strategic Guidelines for the sustainable development of EU aquaculture[31] more relevant in the context of the Circular [Blue] Bioeconomy.

0.9 Potential Case Studies

1. In 2017, **Norway** established the **Norwegian Mesopelagic Initiative**, an international consortium of researchers, to develop sustainable fishing of mesopelagic species and the gear, vessels and detection methods to help achieve this[32]. In addition, action will be taken to secure the output chains. The NMI is an international consortium of researchers working across 7 packages, of which 2 work-packages concern management of catch for valorisation, including on-board processing; land-based processing, analysis of components, generation of products and their validation as safe food and feed ingredients.

28 Willmann R., Kelleher K. et al. (2009) The Sunken Billions: The economic justification for fisheries reform, The International Bank for Reconstruction and Development/World Bank doi: 10.1596/978-0-8213-7790-1.

29 Aquatic food products and new marine value chains – reinforcing EU Research and Innovation policy for food & nutrition security. Report of a workshop, EU (2016). https://ec.europa.eu/info/sites/info/files/conferences/food2030_2016/w2_aquatic_food_new_marine_value_chains_full_report.pdf.

30 Report of the Aquatic Food Products workshop, EU (2016).

31 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, Strategic Guidelines for the sustainable development of EU aquaculture, COM (2013) 229 final 29.4.2013.

32 Institute of Marine Research, Nofima, University of Bergen and NIFES (2017) Mesopelagic Initiative: Unleashing new marine resources for a growing human population.

2. The **Sociedad Nacional de Pesquería** (SNP) of **Perú** is developing a suite of projects focused on improving the management and utilisation of anchoveta and other fishmeal reduction species[33]. Direct consumption of species used for fishmeal is extremely low world-wide; anchoveta begin to spoil rapidly after bringing on-board, partly because of their very high oil content and they have a strong flavour, so there are technical and consumer challenges. The projects include improved systems for on-board processing and preservation, improved processes for protein extraction and production of protein concentrates and development of new nutritional supplements based on deodorised omega-3 fatty acids from the fish oils. This programme will begin shortly and continue until the early 2020s. There is also a much larger $120M (€103M) innovation programme, funded jointly by the Government of Perú and the World Bank, to increase direct consumption through product innovations, launched in 2017[34].
3. As a result of work carried out under the **Nordic Bioeconomy Initiative**[35] into the utilisation of biodegradable wastes, the Environment Agency of **Iceland** has set up an on-line marketplace for different types of biowastes including fisheries and meat, the Resources Square or **Auðlindatorgið**[36]. It is expected to become fully-operational during 2018, to connect producers and users and help reduce the 50% of landfill that is estimated to be biodegradable, the related carbon emissions, and the amount of biowastes being incinerated.
4. **Iceland** has also instituted on-board processing using the **Héðinn Protein Plant**, which turns edible trims and wastes into fish oil and fish meal[37]. Héðinn is a long-standing Icelandic engineering company which has designed and built all the on-shore fishmeal and fish oil production plants. The key to the on-shore and the more compact on-board systems is replacement of the conventional screw-press and liquid evaporation process by a two-stage drying process that reduces the size and number of components and process tanks and uses a lower temperature, recycling drying air, thus reducing energy inputs. It uses half the fresh water for processing the material itself, compared with conventional methods, and uses 10% of the water usually needed in scrubbing and condensing.
5. In the **USA**, a company, **Bloom**, has been established as a merger between a long-standing algal clean-up and polymer manufacturing company, Algix, and a green product development consultancy, Effekt[38]. The company uses Algix's technology to harvest nuisance blue-green algae (*Cyanobacteriaceae*) with the aim of producing biopolymer-plastic flexible and compressible foams for a range of products including footwear, joint-support braces, surfboards and paddles, toys, fitness mats, gaskets and seals. Freshwater lakes and ponds containing algae are filtered through a recirculation system brought to the site when algal growth is seen; the microalgal material is heat-dried using solar energy to a powder and mixed at 15%-60% levels with [poly]ethylene vinyl acetate before extruding with air to form foam pellets. The technology is promoted as an ecologically-sound way of valorising microalgae that are wild-harvested.
6. In the **USA**, **Delmonte** has established an algal fertiliser system in Arizona in which microalgae are grown in simple photobioreactors adjacent to melon fields and algal cells are continuously

33 Innóvate Perú and Sociedad Nacional de Pesquería (2016) Agenda de Innovación Tecnológica para la Utilización de la anchoveta (Engraulis ringens) en el enriquecimiento de aliimentos de consumo humano.
34 http://projects.worldbank.org/P155902?lang=en.
35 Gíslason S. and Bragadóttir H. (2017) The Nordic Bioeconomy Initiative NordBio Final Report TemaNord 2017:526, doi: 10.6027/TN2017526.
36 http://www.audlindatorg.is/, Icelandic only.
37 https://hedinn.com/fishmeal-processing/.
38 http://bloomfoam.com.

distributed to the melon plants through the drip-irrigation system[39]; melons matured a week earlier and were 40%-50% larger than control fruit.

7. In the **UK**, seaweed and plant biomass is being turned into liquid containers by **Skipping Rocks Lab**[40], a small and young design company working in sustainable packaging. Their idea, OOho!, is a sphere intended for drinking water, soft drinks, spirits and liquid cosmetics. The company says that it is cheaper than conventional plastics, with a shelf-life of a few days, and completely biodegrades within 4-6 weeks, but can also be eaten. The material can be flavoured and coloured. In manufacturing analysis so far, it appears to have 20% the carbon impact and 11% the energy requirement of PET.
8. In **Spain**, the mussel producers **Frinsa** and **Amegrove** are providing mussel shells as crushed material for soil remediation and bulking in vineyards, via local wine cooperatives. Almost 100Kt mussel shells are produced each year in Galicia, where the mussel-growers and processors are based. Mussel shells are used as a pH-corrector and general fertiliser[41]; in **New Zealand**, a similar operation has been producing calcium-containing fertiliser from finely crushed mussel shells since 2014[42], as **Havelock Shell Processors**[43]. Currently tests are being carried out in New Zealand on edible horticulture soils to assess the possibility of controlling nematodes using crushed mussel shells; it has also been suggested that the reflectivity of the mussel shells round vines may enhance ripening of the grapes[44].
9. The **EU**-funded project **MIRACLES**, 2013-2017, worked on integrated biorefineries for microalgae[45]; the aim was to produce omega-3-rich microalgae for feeding to aquaculture fish and partners included Ewos, Unilever and DSM as well as SMEs involved in aquaculture, feed, cosmetic ingredients, biopolymers and processing.
10. Jellyfish are an increasing nuisance and hazard in Mediterranean and coastal waters. The **UK**-based company **Jellagen** uses jellyfish caught off the coast of Wales as the source of high-quality collagen for research and medical biomaterials.
11. **Benthos Bioscience** is a Chinese company which is developing its activities in USA, Canada, and Europe with focus on French outermost territories and Portugal. They are one of the largest producers of sea cucumbers. Sea cucumbers are a class of echinoderms widely distributed in the marine environment. The high market value demand for sea cucumbers lies in the use of its muscle as a source of protein. The total production of sea cucumbers in China was 100,000 tons in 2010; 80% of the production is from aquaculture and enhancement.

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39 Carr M. (2018) Can algae really do CCU? Status and potential of biological carbon capture and use USEA Technology Series, March 12 2018.
40 http://www.skippingrockslab.com.
41 Álvarez-Rodríguez E. et al. (2012) Use of mussel shells as a soil amendment: effects on bulk and rhizosphere soil and pasture production, Pedosphere 22(2): 152-164.
42 http://www.stuff.co.nz/business/farming/agribusiness/9849293/Farmer-develops-mussel-shell-fertiliser.
43 http://www.havelockshellprocessors.co.nz.
44 *pers. comm*. Brownlee B. (2018) Havelock Shell Processors.
45 http://miraclesproject.eu.

1 Fish

1.1 Introduction

FAO has estimated that fish[46] represented one-sixth of animal protein supply and 6.5% of all protein for human consumption; and 20% of animal protein intake comes from fish for 3.2 billion of the world's population[47]. Biomass is derived from capture fisheries and wild harvesting and from aquaculture and mariculture. Current production according to FAO is summarised in Table 7. However, it is estimated that 30%-70% of all fish becomes by-product, as processing the fish for human consumption also generates materials that may not be used for direct human consumption, so are potentially usable for industrial, non-food purposes (Figure 5).

There is considerable pressure to improve biomass availability by a combination of changes in fishing and aquaculture focus and reduction in wastage. The Food from the Oceans report of the EC's Scientific Advice Mechanism (SAM)[48] confirms the conclusions of the evidence review by Science Advice for Policy by European Academies (SAPEA)[49]. In order to meet projected demands for food and biomass from the seas and aquaculture, >100Mt per year additional food output is needed from marine capture fisheries and aquaculture:

- Mariculture is seen as less constrained than land-based aquaculture and capture fisheries; as much as 160Mt extra biomass could be achieved by the end of 20 years or so, overwhelmingly by increasing production of lower-trophic marine biomass, i.e. algae and molluscs.
    - As this is largely exploitation of new or unfamiliar bioresources, or existing species but on a very much larger scale, this may well yield significant opportunities for development of new processes, products and markets using the by-products or wastes.
- Capture fisheries are expected to yield an extra 30Mt by better management of established fisheries (20Mt) and discard reduction and elimination (10Mt).
    - As the aim of development here will be to generate additional biomass for human consumption, it is more likely that any additional by-products or wastes will be used for existing types of non-food use.
- An additional >100Mt protein and oils is estimated to be needed, to service the expected growth in aquaculture; this is predicted to come from currently underused species such as krill and mesopelagic organisms (20Mt, but on a longer timescale), algae including seaweeds (>50Mt), and a better use of discards and processing waste (30Mt).
    - Since the aim in this is to free up for human food fish that are currently harvested for reduction to fishmeal and fish oils, there may be new non-food products and markets that can be developed from these sources.

[46] In this report, the term fish includes shellfish and crustacea and, for capture fisheries, cephalopods, unless otherwise specified.

[47] The State of World Fisheries and Aquaculture: Opportunities and challenges, FAO 2014, ISBN 978-92-5-108276-8; Fishery and Aquaculture Statistics 2015, FAO 2017, ISBN 978-92-5-009987-3.

[48] European Commission High Level Group of Scientific Advisors (2017) Food from the Oceans Scientific Opinion No. 3/2017 doi:10.2777/66235.

[49] SAPEA (2017) SAPEA Evidence Review Report No. 1: Food from the Oceans https://www.sapea.info/wp-content/uploads/FFOFINALREPORT.pdf, doi: 10.26356/foodfromtheoceans.

1.2 Fish biomass origin

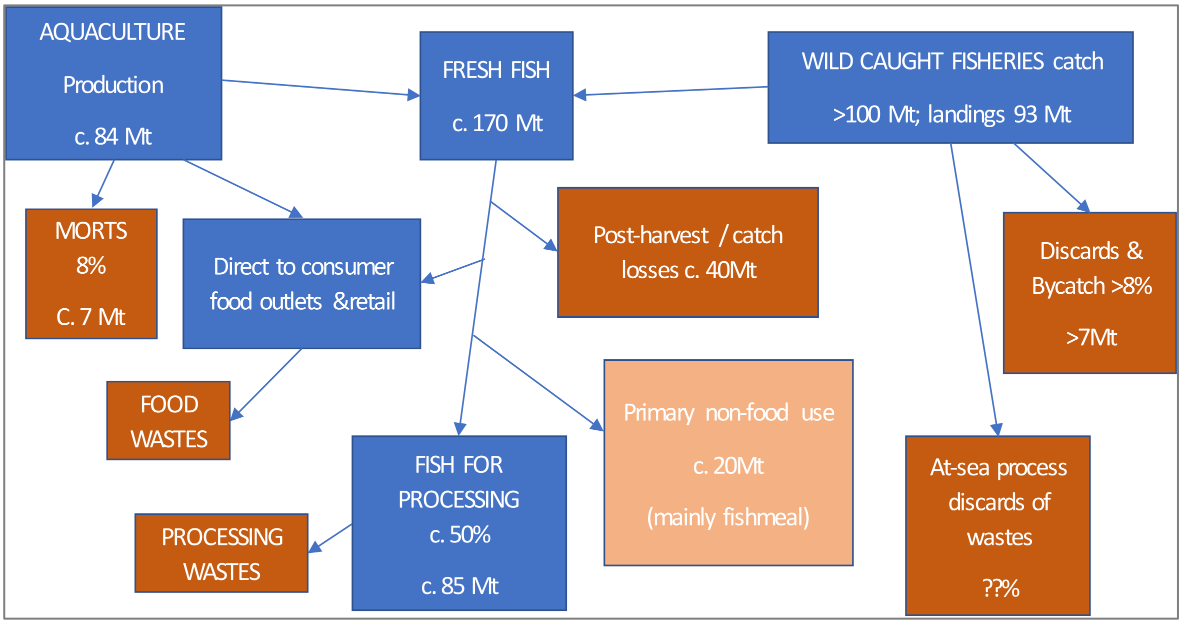
Fish biomass is produced either by capture fisheries, or by aquaculture in freshwater and marine environments. Some wild harvesting of seaweed also takes place. FAO (2017) gives top-level estimates of amounts available for utilisation[50]; together, c. 170Mt of fish, shellfish and crustacea were landed and harvested in 2015, c. 55% wild-caught, 45% from aquaculture (see Table 7). Sea and ocean fishing predominates for capture fisheries (81Mt vs 11.5Mt freshwater); however, the opposite is true for aquaculture (28Mt marine vs. 49Mt freshwater). The top-level distribution of incoming biomass can be seen in Tables 5, 6 and 7 and graphically in Figure 5 - Aquaculture and fisheries biomass profile – fish, which also shows the by-products of harvesting and primary processing.

Table 7 - Production of fish 2015

Type	Total Mt	Aquaculture Mt	Capture/wild harvest Mt
FSC total Mt	169.2	76.6	92.6
FSC inland Mt	60.5	48.8	11.5
FSC marine Mt	108.2	27.8	81.2

Source: FAO (2017); FSC = Fish, shellfish and crustacea

Figure 5 - Aquaculture and fisheries biomass profile – fish



Source: FAO (2017), New Economics Foundation (2014); fish = finfish, shellfish and crustacea; = biomass potentially available for food uses; = biomass potentially available for non-food uses; = biomass for fishmeal and fish oils, mainly for aquaculture and animal feed

[50] , FAO (2017) Fishery and Aquaculture Statistics 2015, ISBN 978-92-5-009987-3.

1.3 Types of fish biomass

In capture fisheries, the top 20 species account for c. 28Mt[51], (30%), of the total of 92.6Mt – 16/20 are bony finfish making up c. 90% of this, 2/20 are cephalopods - squid (7%) - and 2/20 are crustacea. The most-caught fish is however anchoveta, virtually 100% dedicated to reduction to fishmeal and fish oils, and very susceptible to El Niño/La Niña cycling. The second-most caught finfish is Alaskan pollock, most of which is discarded at sea after primary processing for roes, at least in the Pacific by the Russian fisheries.

Table 8 - Production of fish in capture fisheries and wild harvesting

Type	Inland Mt	Marine Mt
Total	11.5	82.3
Fish	10.6	67.5
Crustacea	0.5	6.1
Molluscs	0.34	7.1

Source: FAO (2017)

In aquaculture and mariculture, the top 20 species account for c. 46Mt (60%) of 77Mt harvest; 13/20 are finfish.

Table 9 - Production of fish and seaweed in aquaculture

Type	Inland Mt	Marine Mt
Total	48.9	57.1
Fish	44.1	2.9
Fish diadromous	5.0	
Crustacea	7.4	
Molluscs	16.4	

Source: FAO (2017); Categories not split between inland and marine in original

There may be more material available for non-food uses of fish catches and wastes than is recorded by FAO. Recalculation of fisheries landings for the period 1990-2010, using the method of catch reconstruction, suggests total landings, including artisanal fishing, recreational fishing, discards and bycatch and illegal landings, may be 50% higher each year than those reported to and consolidated by FAO[52]. This means that FAO's reported peak catch of 86Mt in 1996 may well have been landings of 130Mt. FAO's data shows an annual decline since then; the decline may be 3 times that reported (>1.2Mt pa cf 0.38Mt per year).

1.4 Geographic sources of fish biomass

China has a commanding position in supply of biomass. Table 10 shows that it is at No 1 position for fisheries and aquaculture. No other country besides Indonesia features consistently in the Top 10 in all categories, at 23Mt cf China's 79Mt; Japan, Chile and Norway appear in three categories; for the rest of Europe, Ireland, France and Iceland are in the top 10 only for wild-harvesting of seaweed.

51 All data in this section derived from FAO (2017) except where otherwise stated.

52 Pauly D. and Zeller D. (2016) Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining, Nature Comms 7:10244 Doi: 10.1038/ncomms10244.

Table 10 - International landscape of fisheries production 2015

Position	Fisheries Mt	Aquaculture Mt
#1	China 17.6	China 47.6
#2	Indonesia 6.5	India 5.2
#3	USA 5.0	Indonesia 4.3
#4	India 4.8	Vietnam 3.4
#5	Peru 4.8	Bangladesh 2.1
#6	Russia 4.6	Norway 1.4
#7	Japan 3.5	Egypt 1.2
#8	Chile 3.0	Myanmar 1.0
#9	Vietnam 2.8	Chile 1.0
#10	Norway 2.3	Thailand 0.9

Source FAO (2017)

Table 11 summarises the data for 2015 for total production in Europe[53]; in 2016, there was a slight increase in fisheries catch to 14.4Mt, of which 89% was whitefish and the average per capita consumption of fish in the EU28 was 24.5Kg pa[54]. Taking into account the overall production, the 'raw material' balance from which co-products, by-products and RRM might arise was estimated at 12.7Mt of raw and processed fish. Some of this is inaccessible as the waste arises towards the consumer end of the supply chain. FAO gives slightly different data for Europe: of total production of 16.4Mt, existing non-food uses occupied 2.64Mt (16%).

Table 11 - Global production and balance of fish for Europe 2015

Production	Mt
Total production	17.1
Capture fisheries	14.1
Aquaculture	3.0

Source FAO (2017)

Iceland is in the top 15 marine fisheries countries world-wide, at landings of 1.4Mt[55]. The total estimated non-food uses of the catch was c. 500Kt (36.5%). The major fish is cod; the catch in 2013 was 236Kt, of which 84% was used for human food and in 2015 244Kt, of which 75% was for human food.

Norway is a major aquaculture producer (1.4Mt in 2015, making it No 1 in Europe), and has a major marine fishery activity (2.3Mt catch in 2015, making it No 2 in Europe after the Russian Federation, which caught 4.6Mt).

Scotland is a specific case within the UK as the main aquaculture producer (almost 170Kt fish in 2011, about 95% salmon at-sea and 5% trout on-land[56]) as well as having major capture fish landings. For 2013, Zero Waste Scotland, in the context of a roadmap and strategy for better use of biomass[57], reported aquaculture production of 176Kt, consisting of salmon and trout 169Kt and shellfish 7Kt, and fish and shellfish landings of 314Kt, consisting of pelagic fish 144Kt; demersal fish 117Kt; shellfish and crustacea 53Kt. This amounts to almost 0.5Mt biomass.

53 FAO (2017).
54 A.I.P.C.E.-C.E.P. EU Fish Processors and Traders Association (2017) Finfish study 2017.
55 FAO data, 2015.
56 Meacham T. (2014) The UK Aquaculture Industry, Food Security Insight Issue, 4 July 2014.
57 Zero Waste Scotland (2018) Sector study on beer, whisky and fish, Final report ZWS645.

In 2001, Seafish reported that of the estimated 852Kt catch of UK fish and shellfish, 492Kt, 57%, was waste[58]; about 60% of this was generated during on-shore processing, 10% through processing at sea, and the remaining 30% as discards at sea. Processing suitable wastes into fishmeal earned suppliers only £10(€11)-£30(€34)/tonne of raw material used, compared with payments of £60(€67)/tonne for landfill disposal. In 2004, wastes were estimated at >300Kt per year[59]; 80% of this was finfish wastes, 20% shellfish and crustacea. Before 2005, the estimate of waste production for Scotland was c. 77Kt per year, made up of 44Kt pelagic waste, 28Kt demersal waste and 4.7Kt *Nephrops* waste; Scottish Government provided data in 2005[60] estimating total aquaculture production at 157.5Kt with harvest of c. 151Kt and the remainder routine mortalities; fisheries yielded 355Kt, 47% pelagic, 45% demersal and 8% (28Kt) dumped at sea. From the total of c. 512Kt in 2005, c. 239Kt (47%) was processed for human consumption; 190Kt (37%) Category 3 wastes were produced, plus c. 25Kt wastes shipped outside Scotland.

In 2008, the wastes from mollusc fishing in Scotland were c. 75Kt pa: 20Kt flesh and 55Kt shells[61]. Difficulties were noted in making use of this, due to hygiene and the costs of separation, though shells have been separated from flesh ("free of flesh shell") for use in aggregates (roads etc.). In 2010 c. 10-20Kt wastes were derived from crabs and *Nephrops* in the UK; however, most prawns and shrimps are processed outside the UK and imported in-shell or de-shelled already, so their contribution is minimal. There is no data for UK-produced or processed shrimp. Zero Waste Scotland in 2013 estimated bycatch at 183Kt-257Kt (58%-82% more than actual landings), which could have been landed and made available for added-value industrial use with appropriate on-board technologies and fish-landing policies, plus inputs of fish and shellfish to aquaculture feeds at 238Kt. Total in-processing wastes for landed fish and aquaculture produce were estimated at 185Kt, including fish-processing by-products and discarded material 160Kt and shellfish wastes c. 25Kt.

Canada exported 596Kt of fish products in 2012, about 75% of total production, which is split 85% Atlantic, 14% Pacific and 1% freshwater[62]. Aquaculture production in 2011 reached 161Kt.

China is recognised as the world's largest producer, processor, exporter and consumer of fish and shellfish[63]; its aquaculture output was 40Mt in 2012 and c. 50Mt in 2015, when it consisted of 27Mt fish, 13.9Mt shellfish and 4.1Mt crustacea. Fisheries and freshwater catches totalled almost 15.5Mt in 2015. On 2014's FAO figures, China generated >37% of world aquatic output, including >60% of global aquaculture production[64]. Over 30% of its marine catches are unidentified in FAO statistics.

In 2015, the **USA's** total production was 5.4Mt, mainly fisheries catch of c. 5Mt (fish, molluscs, crustacea) and just over 0.4Mt aquaculture[65]. Other sources put total fisheries catch at >4.3Mt[66]; c. 88% was finfish and c. 12% shellfish, with aquaculture production of c. 0.3Mt of fish and shellfish, mainly pond-raised catfish.

58 Seafish (2001) Report SR537.
59 Reported in ADAS (2006) Review of the application of shellfish by-products to land, SR586, Seafish 2006, ISBN 0 903941 49 X.
60 Scottish Government (2005) Evaluation of Fish Waste management techniques.
61 Seafish (2008) Use of shell-fish by-products in bait.
62 Ghaly A.E., Ramakrishnan V.V. et al. (2013) Fish Processing Wastes as a Potential Source of Proteins, Amino Acids and Oils: A Critical Review, J Microb Biochem Technol 5: 107-129 doi:10.4172/1948-5948.1000110.
63 Cao L., Naylor R. et al. (2015) China's aquaculture and the world's wild fisheries. Science 347(6218): 133-135 doi: 10.1126/science.1260149.
64 Zhao W. and Shen H. (2016) A statistical analysis of China's fisheries in the 12th five-year period Aquaculture and Fisheries 1: 41-49 Doi: 10.1016/j.aaf.2016.11.001; data derived from FAO and from the China Fishery Statistics Yearbooks.
65 FAO (2017).
66 Delaware Sea Grant (2018) Overview of the Seafood Industry https://www.seafoodhealthfacts.org/seafood-choices/overview-seafood-industry.

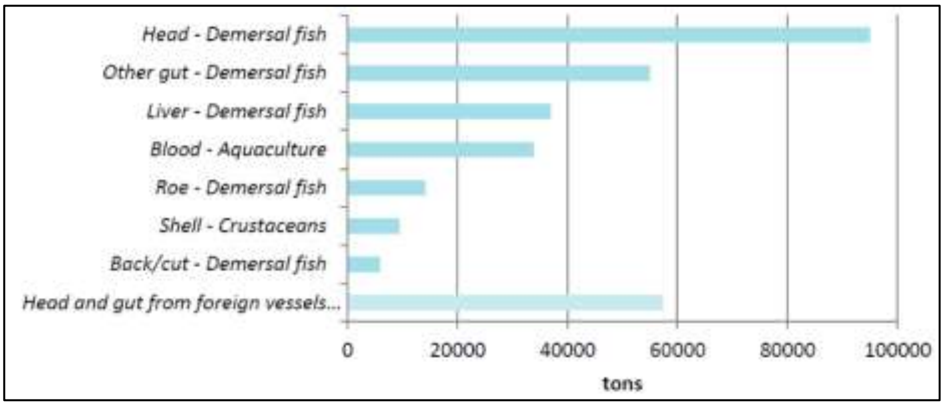
1.5 Non-food biomass from fish

Rest Raw Materials, or RRM, is a literal translation of the Norwegian term "restråstoff", and comprises all the potentially-useful material that is removed in order to prepare biomass for food use. Traditional processing of finfish such as Atlantic cod produces only the fillets for human consumption. In the past, everything else, the RRM, was either used for animal feed or simply wasted. Increasingly, efforts are being made to retrieve as much value as possible by processing RRM for human consumption. RRM are estimated at 27%-32% overall: heads 20%-25%, viscera 5%-7%, frames (skeletons), trimmings from primary and secondary processing and skins and scales.

Utilisation rates in **Norway** appear to be very high for whole fish, 97% for pelagic fisheries and 95%-99% for demersal[67]. However, utilisation of RRM from processing of demersal fish is thought to be much lower; for whitefish (except if exported gutted whole and gutted-without-head) discarded RRM is estimated at c. 37%[68]; the unused whitefish RRMs are 200Kt per year, mainly heads (80Kt), viscera (c. 58Kt), livers (c. 39Kt), roes (c. 16Kt) and frames and cut-offs (c. 8Kt), from a total catch of about 800Kt. On-board processing and freezing in addition involves at-sea disposal of heads and viscera. Better compact equipment for on-board processing of high-value parts of head e.g. cheeks and tongues, may reduce this. The comparative figures for processed pelagic fish are 98%, aquaculture (farmed salmon) 90% and crustacea 36%. It should however be noted that these might be overestimates, as there may be further preparation and processing of RRM into e.g. soups, extracts, sauces and flavourings based on fish. Surimi is well-established as a major use of edible RRM from various species of fish and squid meat[69].

However, the split of by-products between source and type of material reveals the importance of better management of heads, viscera and blood (Figure 6)[70].

Figure 6 - Estimates of volume of unused by-products, Norway, 2013



Source Olafsen et al. (2014)

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67 http://www.discardless.eu.

68 Jouvenot L.(2015), taken from various sources including:
Olafsen T., Richardsen R. et al. (2014) Analysis of marine by-products 2013, SINTEF Fisheries and Aquaculture http://www.kontali.no/%5Cpublic_files%5Cdocs%5CAnalysis_of_marine_by-products_2013_Summary_English.pdf;
Olsen R.L., Toppe J. and Karunasagar I. (2014) Challenges and realistic opportunities in the use of by-products from processing of fish and shellfish *TIFS Tech* 36(2): 144-151 doi: 10.1016/j.tifs.2014.01.007; and
Sandbakk M. (2002) Handling of by-products from cod-fish - a state of the art report from selected countries SINTEF Fisheries and Aquaculture.

69 Vidal-Giraud B. and Chateau D. (2007) World Surimi Market FAO GLOBEFISH Research programme Volume 89.

70 Olafsen T, Richardsen R. et al. (2014) Analysis of marine by-products 2013 English summary, SINTEF Fisheries & Aquaculture project No 6020 663, 6th May 2014 http://www.kontali.no/public_files/docs/Analysis_of_marine_by-products_2013_Summary_English.pdf.

Olafsen *et al*. (2014)[71] note that 67% of the by-products from demersal fisheries is unused, mainly due to discarding of processed rest raw materials on long-distance fleets that lack technical solutions for higher-level processing or storage on-board. In addition, there is a lack of economic incentives to land by-products. However, almost everything which is brought ashore is utilized as raw material for further processing if it cannot enter the human food chain. There are no by-products as such in pelagic fisheries, since all the fish are used for fishmeal and fish oils. In processing of aquaculture harvests, regulations control the use of blood, and morts need ensiling or otherwise treating; but only 11% of by-products are estimated to be unused. Carvajal (2014) mentions slightly different figures[72]; 62% for whitefish, 2% for pelagic fish and 10% for aquaculture. Richardsen *et al*. (2016) note for Norway that 3.44Mt fish and shellfish produced c. 0.89Mt RRM (c. 26%), of which c. 0.68Mt (76%) was utilised[73]; the non-usage rates for RRM from different classes of fish were 52% for whitefish, 0% for pelagic fish and 9% for aquaculture.

There are practical and technological difficulties concerning the space and resources on-board to handle volumes of obligated landings that are incidental to the main target fish and catch sizes. This would also have implications for making better use of by-catch, as some degree of on-board separation, management and even primary processing may be needed to retain maximal value[74]. Data for capture fisheries includes fish, crustacea and cephalopods but the data is not split. The rule-of-thumb has been that discards and bycatch disposed of before landing amount to about 8% of landings[75].

In 2012, the study for Cefas that reported on discards and their potential uses noted that 27% of UK discards were due to over-quota catches, 30% were unusable species (no markets or not popular to eat), 19% were under-size or under age, and 24% were fish caught when their markets or sortability were not optimal[76]. Observations made on-board vessels by Cefas observers showed that about 26Kt of fish and shellfish were discarded each year in the period 2009-2010, of which fish under quota made up c. 9.4Kt.

In the USA, the discards of fish from fisheries activities are estimated at 2 billion pounds fish per year, worth est. $1 billion (range $475 million to $2.6 billion, i.e. €406 million to €2.2 billion), based on landings of >10 billion pounds worth $5 billion (€4.3 billion)[77]. The data is founded on the National Marine Fisheries Service’s 2014 *National bycatch report*, which covers c. 60% of the national catch reported in 2010, assumptions and estimates for the remaining c. 40% and NOAA’s catch values by species reported in 2012, and is calculated as an aggregate based on regional data. Discards include bycatch as well as targeted fish surplus to requirements or not landable for other reasons, and were estimated at 5% of total catches by weight for larger pelagic fish (>75kg) and 10% for smaller fish, compared with an estimate of overall discards of 20% per year.

The world production of fish, shellfish and crustacea in 2013 was 163Mt, capture fisheries and aquaculture combined[78]; of this, 21.4Mt was estimated to be for non-food uses (i.e. 13%)[79]. China’s production alone was estimated at 60Mt, of which 3.4Mt was for non-food uses (5%-6%); the global

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71 Olafsen T. et al. (2014).

72 Carvajal A., (2014) Processing of marine oils – from catch to final product, SINTEF Fisheries and Aquaculture Temadag: Marine lipider – fra fisk til færdigvare, 25.juni, Aarhus.

73 Richardsen R. et al. (2016) Analyse marint restråstoff, 2015 SINTEF Aquaculture and fisheries Project No. 6022 353 30th May 2016.

74 http://www.discardless.eu.

75 Kelleher K. (2005) Discards in the world’s fisheries: an update, FAO Fisheries Technical Paper No. 470 http://www.fao.org/docrep/008/y5936e/y5936e01.htm.

76 Mangi S.C. and Catchpole T.L. (2012) SR661 – Utilising discards not intended for human consumption in bulk outlets.

77 Keledjian A., Young S. et al. (2014) Wasted cash: the price of waste in the US fishing industry Oceana 2014

78 FAO (2017).

79 According to the Food Balance Section of FAO Handbook.

ex-China proportion of non-food use is 17.5%. Estimates of the volumes of by-products are available for Norway from 2013[80]; from 3.1Mt of fish and crustacea from catches and farming, 0.9Mt of by-products were obtained, a yield of 28% overall. Some of the estimates are based on widely-accepted splits between edible elements and by-products, such as for crustacea, 50:50. The relative percentage contributions to overall by-products estimates are demersal fish 39%; aquaculture 39%; pelagic fish 21%; and crustacea 1.4%.

Table 12 - Estimates of catches and harvests and resulting by-products, Norway, 2013

	Total	Demersal fish	Pelagic fish	Aquaculture	Crustaceans
Basis for by-products (live weight)	3.066.000	775.000	965.000	1.301.000	25.000
Available by-products	867.000	340.000	178.000	336.000	12.500
Available by-products as share of basis for by-products	28%	44%	18%	26%	50%

Source Olafsen et al. (2014); "Basis for by-products" = total initial biomass

Bergé notes[81], with reference to tuna fisheries in the Pacific, that 40%-60% of each fish is not used directly for human food, and most of this is either wasted (discarded unused) or turned into low-value fish meal. Heads, which form 18% or more, can be sold as a low-cost food.

The DiscardLess project[82], running from 2015-2019 in Horizon 2020, seems highly relevant to policies related to better use of unused, under-used, discarded and waste fish materials. It has published on several aspects of the problems with discards and the transition from discard policies to discard bans under the Landing Obligation. Annual discards of unavoidable unwanted fish were estimated at >1.5Mt pa[83]; up to 23% of annual catches are discarded, and on-board processing, filleting and freezing result in discards of potentially usable material such as heads, skin, viscera and frames in amounts that are currently unquantifiable. Relevant projects from the European Fisheries Technology Platform's directory of discard projects[84], which aimed to standardise data collection, manage catches better, or valorise by-products, have been summarised by DiscardLess[85].

1.5.1 Post-harvest fishing losses

It is sometimes difficult to separate specific post-harvesting losses, due to escapes or quality-control checking, from other at-sea processing discards or processing losses further down the chain.

The UK charity 'Waste and Resources Action Programme' (WRAP) reported in 2011 that, of total fish and shellfish inputs of 1.044Mt, 350Kt was regarded as non-edible, of which 140Kt were waste and co-products (including retail wastes), with 105Kt arising from finfish and 29Kt from shellfish[86]; most of the finfish material is sold to fishmeal plants but most of the material arising in the shellfish area is

80 Olafsen T. et al. (2014).
81 Bergé J.P. et al. (2014) Adding value to fish processing by-products Policy Brief 21/2014 Secretariat of the Pacific Community https://www.researchgate.net/publication/262808270.
82 http://www.discardless.eu.
83 Viðarsson J.R., Guðjónsson Þ. and Sigurðardóttir S. (2015) Deliverable 5.1 Report on current practices in the handling of unavoidable, unwanted catches, DiscardLess project 7 December 2015.
84 Eds. Rodriguez M. and Fernandez R. (2011) Projects and Initiatives addressing fishing discards. Compilation of discard projects, The Secretariat of the European Fisheries Technology Platform.
85 Viðarsson J.R. et al. (2015).
86 WRAP (2011) Resource maps for fish across retail & wholesale supply chains, Project code RSC009-001 & RSC009-003.

regarded as unavoidable waste. The conclusion from surveying the industries was that avoidable wastes generated by processing are low.

1.5.2 At-sea process discards

At sea, 8-22% of white fish may be discarded during primary processing; oily pelagic fish, if processed at sea, are 98-100% utilised.

1.5.3 Aquaculture fish wastes

The main expectable losses in aquaculture are routine mortalities ('morts'), which are estimated to run at about 8%. Disease outbreaks may produce losses of 20%-50%, sometimes as high as 100%. In either case, fish cannot enter the human food chain or be processed for human consumption, and ensiling, anaerobic digestion, landfill or other disposal into the environment are the end-points.

For Scotland, the Scottish Government provided data in 2005[87] estimating total aquaculture production at 157.5Kt with routine losses of 6-8Kt morts, mainly rendered or dealt with by anaerobic digestion, occasional mass mortalities with a historic high of 6Kt. Scottish fisheries dumped 8% (28Kt) of their 355Kt catch at sea. The SARF report of 2008[88] estimated 9.3Kt wastes arising each year from salmon farming, mainly from marine production (c. 60% routine and c. 30% non-routine), where overall 35%, about 3Kt, were dead fish ('morts') and 35% was waste plastic.

1.5.4 Fish processing and processing wastes

Of the whole fish reaching processing plants (themselves about 50% of the total landing or harvest, for demersal catches), about 36% becomes fillets. However, it seems that the proportion of fish and fish processing volume made available for food uses has increased over the period 2000-2011[89], which is likely to be typical of progress in reducing waste over the past 2 decades.

Table 13 - Production of fish and seaweed in aquaculture

Element	% of whole fish
Head	21
Frame	14
Fins and lungs	10
Guts	7
Liver	5
Roes	4
Skin	3
Skinned fillets therefore	36

Source: Waterman (2001)[90], reused by Ghaly et al. (2013)

In typical fish processing, the critical early steps are stunning, de-sliming and de-scaling; after this, heads (up to 20% of weight) are round-cut or straight-cut off the fish; the total waste can be 27%-32% at this stage. Further stages, depending on product and market needs, generate increasing amounts of waste.

87 Scottish Government (2005) Evaluation of Fish Waste management techniques.
88 Scottish Aquaculture Research Forum (2008) Strategic Waste Management and Minimisation in Aquaculture.
89 Ghaly A.E., Ramakrishnan V.V. et al. (2013) Fish Processing Wastes as a Potential Source of Proteins, Amino Acids and Oils: A Critical Review, J Microb Biochem Technol 5: 107-129 doi:10.4172/1948-5948.1000110.
90 Waterman J.J. (2001) Measures, stowage rate and yields of fishery products Advisory Note No. 17, Torry Research Station, Aberdeen, Scotland.

Table 14 - Production of solid wastes from different fish processing steps

Stage	Waste and discarded materials	Total % removed
Gutting fish	5%-8% viscera	5-8
White fish filleting	skin 4-5%, heads 21-25%, frames 24%-34%	49-64
Oily fish filleting	40-45% wastes	40-45
Deheading white fish	27%-32% heads and debris	27-32
Filleting deheaded white fish	frames and off-cuts 20%-30%	20-30
Filleting ungutted oily fish	viscera, tails, heads, frames 40%	40
Skinning fish	4% skin	4
Canning without precooking	25% heads, 10%-15% frames	35-40
Precooking fish for canning	15% inedible discards	15
Cutting and gutting oily pelagic fish for canning	heads and viscera 15%, bones and discarded meat 10%-15%	25-30
Pressing oil from cooked fishmeal fish	10% residual press-cake	10

Source: Arvanitoyannis and Kassaveti (2008)[91], adapted from Ghaly et al. (2013)

The UK Waste minimisation organisation WRAP noted that >133Kt fish wastes and by-products are generated each year, about 12.7% of total inputs[92]; at retail level, 3%-8% of product is waste, about 6.8Kt, which is rendered along with meat wastes.

Sometimes it is not clear whether the recorded proportions of waste and the utilisation can be generalised from a local or regional report. For example, the amount of primary fish wastes in Victoria state, Australia, may amount to >11Kt per year, mainly finfish and shark processing waste (5-10Kt), squid and shellfish (1Kt) and market discards (2-2.5Kt), plus 500 m^3 of scallop shells and viscera and 1Kt wet microalgal biomass[93] from waste treatment ponds. Material from petfood manufactured in the state using fish by-products amounted to >3Kt of processing wastes and >11Kt of discharge sludge. No higher-value non-food uses were reported.

There is a useful study of by-products in France[94]; this benefited from access to the 2 fish by-products processors operating in France at the time, Copalis and Bioceval. For the period 2004-2005, the volume of fish-processing by-products was estimated at >215Kt, 0.4% of total landings in France; discards, to incineration, of unsold, out-of-date and defective fish products from food retailers were estimated at c. 6% of their total food wastes. Heads, tails, fins, roes, frames and viscera that are not used either direct or partly-processed for human foods are defined as 'by-products', and those parts of fish in addition to conventional fillets and gutted, de-headed, trimmed and prepared fish that can be eaten by humans, such as edible roes, cheeks, livers and tongues, are defined as 'co-products', to avoid using the term 'waste'.

In 2004, OFIMER[95] published an estimate of c. 144Kt of by-products produced on French territory (includes some external territories), of which white fish was the source of 40%, salmonids c. 31%,

91 Arvanitoyannis I.S. and Kassaveti A. (2008) Fish industry waste: treatments, environmental impacts, current and potential uses, Int J Food Sci Tech 43: 726-745.

92 WRAP (2012) Sector guidance note: Preventing waste in the fish processing chain June 2012.

93 Gavine F.M., Gunasekera R.M. et al. (1999) Value-adding to seafood, aquatic and fisheries waste through aquafeed development Project No 1999/424 Fisheries Research & Development Corporation, Victoria.

94 Penven A., Perez-Galvez R. and Berge J.P. (2013) *By-products from fish processing: a focus on French industry* in Perez-Galvez R. and Berge J.P. Eds. *Utilization of Fish Wastes* CRC Press 2013 ISBN 9781466585799.

95 Andrieux G. (2004) La filière française des co-produits de la pêche et de l'aquaculture, état des lieux et analyse OFIMER 2004.

pelagic fish 15%, sharks and rays 7.5% and other species 6.5%. In 2009, direct questioning of industry in the West Atlantic coastal area, including fresh fish processors, canneries, smokeries and other processors, generated an estimate of c. 45Kt of by-products. This region accounted for c. 47.5% of French landings in 2009; by-products represented 32% of all landings. Primary fish processors generated 58% of the total by-products, canneries 27% and smokeries 15%.

1.6 Uses of fish biomass

In Scotland, the SARF report[96] noted in 2008 that the handling of mortalities was a concern; ensiling followed by oil extraction was a new undertaking, and there were no proper facilities local to the main concentration of farms (Scotland's west coast) to incinerate morts and recover energy. As part of this report, a thorough table of potential destinations for RRM and by-products was drawn up (Table 15), which is still useful.

Table 15 - Outputs from processing fish wastes

Waste or discarded material	Process	Commodity	Use
Fisheries viscera	At-sea disposal	-	Could be processed on-board if good materials management and appropriate-scale equipment
Trimmings, heads and tails	Direct sales	Protein hydrolysate	Pig, poultry, fish feeds and petfoods
	Mechanical recovery	Fish mince and pastes	Human food and petfood depending on quality
Trimmings, heads and tails	Fishmeal processing	Oils	Pig, poultry, fish feeds and petfoods
Viscera		Oils and fish meals	Pig, poultry, fish feeds and petfoods
Frames		Oils	Pig, poultry, fish feeds and petfoods
Frames	Direct sales	Hydroxyapatite	Biomaterials, food supplements
Whole fish (Category 3 ABPR) including bycatch disposals, shells and surplus trimmings, heads, frames	Processing	Protein meals, extracts, oils	Pig, poultry, fish feeds and petfoods Biodiesel
	Anaerobic digestion	Biogas	energy
	Composting	fertiliser	Agriculture, horticulture
Aquaculture morts (Category 2 ABPR)	Ensiling, rendering, incineration	Industrial products only – eg biodiesel	Solid residues for landfill

Source: SARF (2008)

96 Scottish Aquaculture Research Forum (2008) Strategic Waste Management and Minimisation in Aquaculture.

The top 10 countries for non-food uses in Europe reported using about c. 95% of the total (Table 16).

Table 16 - Non-food uses of fisheries and aquaculture production in Europe, by country, 2015

Country	Non-food uses Kt
Norway	618
Iceland	501
Russian Federation	425
Denmark	416
Netherlands	124
Faroes	124
Spain	67
France	60
Poland	56
Finland	47

Source: FAO (2017), Fishery and Aquaculture Statistics 2015

Some of these countries appear to be relatively low users, with respect to their indigenous chemicals, biotechnology and bioactives-using industries, such as Austria 26 tonnes, Ireland 280 tonnes, Belgium 495 tonnes, Greece 1,109 tonnes, Germany 1,403 tonnes, UK 1,901 tonnes. Countries such as Malta, Italy, Lithuania, Portugal and Sweden were moderate users for non-food purposes, in the range of 15Kt - 38Kt per year. Although some of these figures may be correlated with fishmeal production for aquaculture, the reasons for low uptake may be worth investigating further.

1.6.1 Fishmeal and fish oils

The major use for parts of capture fish not used for direct human consumption is the production of fishmeal and accompanying fish oils, and such processing material joins the pelagic oil-rich fish caught in reduction fisheries[97].

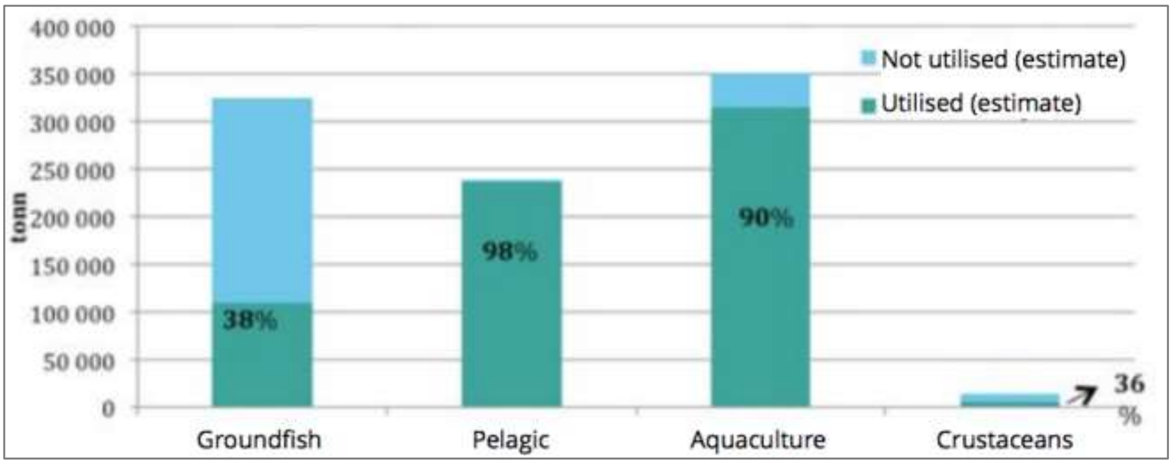
The high usage rate for pelagic fish is entirely due to their processing into fishmeal and fish oils of various grades, from those intended from human nutritional use to those for animal feed or for further processing into extracts or industrial oils. In addition, 35% of RRM is currently used to make fishmeal and fish oil of various qualities.

For low-volume fish processing regions, the range of outputs is only a little wider – e.g., in County Donegal, Ireland, the 3 fishing ports landed c. 157Kt fish in 2014, the vast majority pelagic fish (mackerels, herring, blue whiting and boarfish)[98]; 7 main processors produced filleted herring and mackerel (from c. 30% of the catch), whole cleaned fresh or frozen horse mackerel and blue whiting for export, and fishmeal. The filleting of 22.3Kt of fish was estimated to produce 8.5Kt RRM (38%), used as further input into fishmeal production for aquaculture use, ingredients for pet food and bait for lobster and crab fishing, with residual sludge used in the production of horticultural compost.

[97] Reduction fisheries are those, such as Latin American anchoveta fleets, that are dedicated to oil-rich small pelagic fish intended solely for fishmeal and fish oil production.

[98] Faulkner N. (2015) An Appraisal of Fish Waste in County Donegal, April 2015 (an activity of ReNEW – the Resource Innovation Network for European Waste).

Figure 7 - Extent of utilisation of rest raw materials by source



Source: Jouvenot (2015)

In the Baltic, the challenges are to handle and manage unwanted catches separately, and the long (and costly) distances to transport fish to treatment plants[99]. A smaller-scale protein production plant now exists that can be set up at any port where fish is landed and can also be installed on vessels too small to carry standard-size fishmeal or fish silage production systems[100]. This would be used for fishmeal and fish oils production and there is a potential, because of the freshness of the material, for higher-value products. Projected production of fishmeal in 2030 is 7.6Mt, c.40% from Latin America. The World Bank's projection model[101] assumes 15% of fishmeal will be derived from Rest Raw Material (RRM), compared with IFFO's estimate of 25%[102]. There has been a steady decline in the amounts of fishmeal and fish oils derived from capture fish since 2008 (Figure 8)[103].

99 Fitzpatrick M. and Nielsen K.N. (2016) Year 1 of the Landing Obligation: Key Issues from the Baltic and pelagic fisheries DiscardLess Policy Brief Number 1 doi:10.5281/zenodo.215155.

100 https://hedinn.com/.

101 Msangi S., Kobayashi M. et al. (2013) FISH TO 2030: Prospects for Fisheries and Aquaculture, World Bank Report Number 83177-GLB.

102 IFFO, quoted in The Marine Socio-Economics Project Sustainability Issues in Aquaculture: MSEP Facts & Figures Series 5, the New Economics Foundation, August 2014.

103 Carvajal A. (2014) Processing of marine oils – from catch to final product, SINTEF Fisheries and Aquaculture Temadag: Marine lipider – fra fisk til færdigvare, 25 juni 2014, Aarhus.

Figure 8 – Yields of fishmeal and fish oils 2008-2013

Production

Fishmeal: 5 major producers

	2008	2009	2010	2011	2012	2013
	(1 000 tonnes)					
Peru/Chile	2063	2039	1274	2160	1161	855
Denmark/ Norway	302	274	345	256	140	190
Iceland	251	198	146	134	169	176
Total	2616	2511	1855	2607	1801	1477

Source: IFFO

* these figures refer only to IFFO member countries

Production

Fish oil: 5 major producers

	2008	2009	2010	2011	2012	2013
	(1 000 tonnes)					
Peru/Chile	459	410	279	450	295	181
Denmark/ Norway	93	79	116	92	50	57
Iceland	81	44	69	67	67	69
Total	633	532	471	612	479	441

Source: IFFO

* these figures refer only to IFFO member countries

Source: Carvajal (2014)

Table 17 - Global production and balance of fish for Europe 2015 – fishmeal and fish oils

Production	Mt
Total production	17.1
Capture fisheries	14.1
Aquaculture	3.0
Fishmeal production	0.5
Fish oil production	0.19

Source: FAO (2017); EUfishmeal[104]

Most fishmeal is produced direct from small oil-rich pelagic fishes and, overwhelmingly, the Chilean anchoveta caught by reduction fisheries. In general, 100% of these fish are used for production of fishmeal and fish oils; the overall contributions of capture fish, capture fish by-products and aquaculture by-products is shown in Figure 9. On average, in the EU, however, more than 50% of the need for fishmeal is provided by RRM and trimmings from fish processing[105].

104 http://www.eufishmeal.org.

105 IFFO *pers. comm*. (2018).

Table 18 shows the top 10 fishmeal producers[106], with China at No 3 for fishmeal production and No 1 for both capture fisheries and aquaculture.

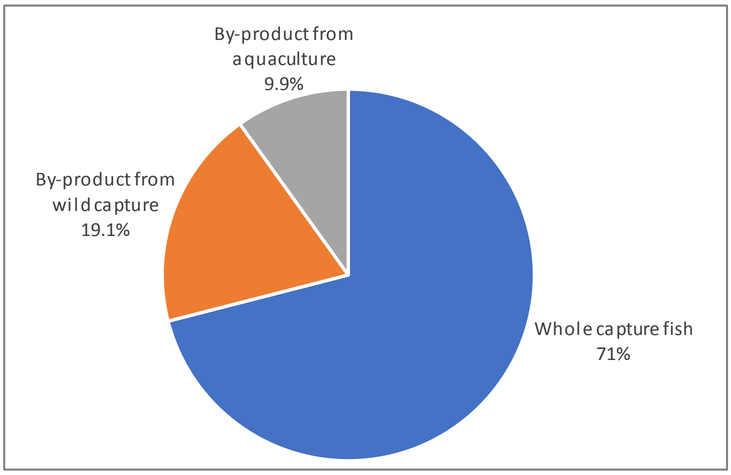
Table 18 – Fishmeal production 2015

Position	Fisheries Mt	Aquaculture Mt	Fishmeal production Kt
#1	China 17.6	China 47.6	Peru 852
#2	Indonesia 6.5	India 5.2	Thailand 420
#3	USA 5.0	Indonesia 4.3	China 400
#4	India 4.8	Vietnam 3.4	Chile 322
#5	Peru 4.8	Bangladesh 2.1	Vietnam 285
#6	Russia 4.6	Norway 1.4	USA 263
#7	Japan 3.5	Egypt 1.2	Denmark 206
#8	Chile 3.0	Myanmar 1.0	Japan 184
#9	Vietnam 2.8	Chile 1.0	Norway 167
#10	Norway 2.3	Thailand 0.9	Iceland 153

Sources FAO (2017), Seafish (2016)[107]; Kt = 10^3 tonnes

The total reduction catch in 2013 consisted of 1.23Mt of species not eaten by humans (such as sand eels, Norway pout), 11.8Mt of food grade fish from reduction fisheries (anchovies, capelin, whiting and sprats) and 6.25Mt of fish rejected from conventional capture fisheries as undersized, damaged or poor quality[108]. IFFO estimated that in 2009, 63% of global fishmeal production was used in aquaculture, almost equally for salmonids, marine fish, crustacea and other species; 81% of global fish oil production was used in aquaculture, the majority (almost 70%) for salmonids. Use for human foods is minuscule; most of the balance of fish oil enters pig and poultry feeds. Globally, the trend is to use more by-products and to process locally to aquaculture operations, as they grow in size and number. However, the change in pattern of input materials for fishmeal production may result in lower quality, especially for Asian production, and lower content of omega-3 fatty acids, as species utilisation changes[109].

Figure 9 - The main sources of biomass for fishmeal production



Source: Jackson and Newton (2016)

106 FAO (2017).
107 Seafish (2016) Fishmeal and fish oil facts and figures.
108 New Economics Foundation (2014).
109 Jackson A. and Newton R.W. (2016) Project to model the use of fisheries by-products in the production of marine ingredients with special reference to omega - 3 fatty acids, EPA and DHA IFFO & University of Stirling.

FAO[110] publishes estimates of fishmeal production and reports on market dynamics, including catches and production. Because of the predominance of Chile in reduction fisheries and fishmeal production, harvests are markedly affected by phenomena such as El Niño and aquaculture feed market demands. From 2008-2013, total production of fishmeal and fish oils declined tremendously, from 2.62Mt meal and 0.63Mt oil to 1.48Mt meal and 0.44Mt oil (Figure 8)[111]. In 2016, total production was about 1.6Mt fishmeal and 0.43Mt fish oils[112]; Peru, Chile, Denmark and Norway produce about 2/3 of total fishmeal and 60% of total fish oils between them. A price fall in the market in 2016 continued into 2017. Peru landed 2Mt of reduction fish in the first season of 2017, 85% of the quota, and produced 0.7Mt fishmeal in the first half of 2017; Chile produced 0.23Mt, both increases on the same period of 2016 (actually, 309% and 64% respectively).

Corresponding to its high share of global fish output (>60% of the world's aquaculture[113]), China has a correspondingly high fishmeal demand, of 1.4Mt in 2012, produced from c. 7Mt of reduction fisheries catch, plus the use of 0.25Mt of domestically-produced fishmeal from fish processing by-products. At least 3Mt of trash fish (bycatch, discards, edible but not eaten, below size, damaged etc.) were also used for direct feeding in aquaculture[114]. There is a potential production of up to 650Kt fishmeal and 160Kt fish oils from domestic activities. The patterns of non-food use of fish in China are not easy to discern and need further study, especially to work out the proportions used for energy, agriculture and higher-value components.

Some of the fishmeal and fish oils production is used for protein, peptides, hydrolysates, oils and refined oils (high in omega-3 fatty acids) for human consumption but the vast majority is used in animal feed, especially, though to a decreasing extent, in fish feeds for aquaculture. This is partly because of problems of collection, storage and spoilage of fish, viscera including livers, and trimmings.

The tuna catch in 2016 was over 4.9Mt[115], implying that >3Mt of material might be made available for higher-value human and animal use. However, this is not "non-food" use; conventionally, the tuna RRM is used as fishmeal and fertiliser except in those countries where e.g. the heads are used for food. Lower-grade material can be used to produce ingredients for animal and aquaculture feeds and petfood.

Fish oils have in the past been used as industrial lubricants and coatings, drying oils in paints and sealants, components of extreme-pressure paraffin-based oils, and fabric treatments[116]. 90% of the total US production of fish oils in 1966 was menhaden oil, amounting to 0.78Mt, of which about a third was used in drying oils. But these uses have largely been superseded. Production of isopropanol was being investigated in the mid- to late-1960s; most of the use now is after some kind of fractionation to fatty acids and esterification to promote stability, especially as alkyds; in lubricants for metals; and there is potential use as a source of biodiesel and as a feedstock for biomass production of lipophilic organisms and generation of platform chemicals such as some alcohols[117].

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110 FAO yearbook (2015), published 2017.
111 Carvajal A. (2014).
112 FAO (2017) Globefish Highlights, October 2017 Issue, with Jan-Jun 2017 statistics ISBN 978-92-5-130047-3.
113 Zhao W. and Shen H. (2016) A statistical analysis of China's fisheries in the 12th five-year period Aquaculture and Fisheries 1: 41-49 Doi: 10.1016/j.aaf.2016.11.001; data derived from FAO and from the China Fishery Statistics Yearbooks.
114 Cao L. et al. (2015).
115 Status of the World Fisheries for Tuna February (2018), ISSF Technical Report 2018-02.
116 Fineberg H. and Johanson A.G. Industrial use of fish oils, US Dept of the Interior Fish and Wildlife Service https://spo.nmfs.noaa.gov/Circulars/CIRC278.pdf.
117 Ahokas M. (2014) The quality of fish oil and its potential use in the chemical industry Aquarel project final seminar 18th September 2014 http://www.culmentor.com/aquarel/wordpress/wp-content/uploads/WEB_Ahokas_FishOil_Quality.pdf.

1.6.2 Other uses of fish RRM

Fish wastes were historically discarded at sea, used as landfill, or fed to animals, including other fish, as unprocessed material or processed into fishmeal and fish oils. With tightening controls on land disposal, anaerobic digestion maybe the first choice for undifferentiated fish or seaweed materials whose quality cannot be guaranteed or where there might be safety hazards for human, animal or environmental use. Seasonal variability in catch sizes may also be a factor in preventing establishment of new processing systems for valorising capture fish RRM. This is mostly ensiled (41%), converted to fishmeal and fish oil (23%), used for oil and protein for fish-feed (20%) or processed for oils and some other components for human use (14%)[118]. Fish silage can be further processed to fish protein concentrate for animal feed, mainly pigs (64Kt in 2014 in Norway), or fish protein hydrolysate, for human food and nutraceutical products and aquaculture feeds (17Kt in 2014). The production of fishmeal and other animal feed components from fish by-products will become increasingly important as pressure on wild-caught stocks grows, from the biological and ethical point of view.

Edible-quality RRM can be valorised successfully for further food use. RRM from whitefish filleting and production of emulsified foods can be exploited to generate fish protein isolates, fish protein hydrolysate, homogenized fish protein and gelatin for human consumption[119]. The resulting fish proteins can then be used in the production of fresh, frozen and salted fillets to reduce drip loss and increase cooking yield and protein content. In this case, RRM also includes processing water, which contains fish flesh and proteins, estimated at 1% of the original input by weight, of which about 25% can be recovered by drying and separating by vibrating sieve.

Some countries are advanced in their uses of fish by-products and discarded material from processing, notably Iceland (landing obligation from 1977) and Norway (discard ban fully since 1987). In Iceland, a range of derivatives of the major whitefish, cod, is reported, including "leather made from fish skins, pharmaceuticals and cosmetics made from bioactive compounds extracted from different parts, collagen made from fish skin, supplements and proteins made from different by-products, mineral supplements made from fish bones, enzymes extracted from viscera, skin and tissue repair patches made from fish skin, extracts from RRMs made into powder or bouillon (i.e. for making soups and sauces), silage made from viscera used for animal feed or as fertiliser, swim bladder and milt which are traditional products that have been utilized to a point in certain fisheries and markets"[120].

Tilapia production is one of the strongest-growing aquaculture sectors in the Americas and parts of Asia-Pacific. RRM from Tilapia are already used for a variety of non-food uses[121]. Most notably, the skins are sold as a leather and textile material for bags, purses and garments. Skin collagens are extracted and used as a substitute for mammalian gelatins in pharmaceutical capsules. Tilapia scales have been used as decorative items. Protein meal from Tilapia has also been investigated as a component of poultry feed.

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118 SINTEF Fisheries and Aquaculture, New value added products from rest raw material. Protein hydrolysates and lipids https://www.sintef.no/globalassets/upload/fiskeri_og_havbruk/foredling/forstehandtering/-nordic-pelagic-workshop/11_100830-rest-raw-materials-from-herring.pdf.

119 Arason S., Karlsdottir M. et al. (2009) Maximum resource utilisation – Value added fish by-products, Nordic Innovation Centre Project number 04275.

120 Viðarsson J.R., Guðjónsson Þ. and Sigurðardóttir S. (2015) Deliverable 5.1 Report on current practices in the handling of unavoidable, unwanted catches DiscardLess project, 7 December 2015.

121 Mentioned in South G.R., Morris C. et al. (2012) Value adding and supply chain development for fisheries and aquaculture products in Fiji, Samoa and Tonga: Scoping study for Tilapia (Oreochromis sp), IMR Technical Report 04/2012, Institute of Marine Resources, School of Marine Studies Fiji, ISBN: 978-982-9143-10-5.

Looking at less high-quality RRM such as viscera, heads and bones and morts from salmon aquaculture[122], the current usages include fish oils (Nutrimar, a Norwegian processor, can produce 10Kt salmon oil per year from 60Kt salmon co-streams per year), salmon fishmeal and hydrolysed protein concentrate. Heat-processed fish wastes have been tested and used as components of diets for animals, especially farmed fish and pigs, but the re-use of materials of animal origin is now tightly-regulated round the world. Frozen fish viscera can be fed to animals, for example, as feed for mink in Iceland or Denmark[123]; however, it is only small Icelandic boats that can land their catches daily who can take advantage of this use for lowest-value rest raw materials. Otherwise, they are ensiled.

Logistics and business cases can differ according to whether the processor is co-located with the major source of co-streams, or has a need for distributed collection[124]: Akva Ren, in **Norway**, collects biowastes from processors, restaurants, hotels and produces fractionated salmon oils and feed that are acceptable in fur-farming but do not go directly back into human nutrition. In **France**, OFIMER compared two by-products processing plants in a study of the importance of logistics and materials management for how well by-products can be valorised[125]: Copalis used 65Kt fish by-products per year, coming from 380Kt primary material from landings and fish products trade on their doorstep in Boulogne and generated 10 different end-products, some with high value; Bioceval collected 60Kt per year, but from a wide geographic area, and consequently was limited by logistics and freshness of material – its output of fishmeal and fish oils was all lower-value and destined for aquaculture use.

In **France**, OFIMER in 2004 estimated that c. 53% of fish by-products in France were converted to fishmeal and fish oils for animal feeds, 22% of material was used for petfoods, 21% was hydrolysed to add utility, and only 4% entered higher-value markets[126].

Of **Iceland's** total landings of 1.4Mt[127], the total estimated non-food uses of the catch was c. 500Kt (36.5%); fishmeal and fish oil production was c. 120Kt in 2014 (No 3 in Europe after Denmark and Norway).

Norway is in the top 10 fishmeal producers with Denmark, Iceland and the Russian Federation. In 2014, Norway had over 420 companies involved in some part of the marine and aquaculture bioresources supply chains, with a total value of production of c. 53B NOK (c. €5.54 billion)[128]; these are geographically spread, and many are SMEs.

Norway has a large proportion of by-products from herring and mackerel fisheries, amounting to 229Kt in 2012, which are mainly used for animal feed or as products after ensiling[129]. The yield of by-product processing includes c. 30Kt oils and c. 34.5Kt proteins. Oils are purified further to produce about 4Kt omega-3 PUFA (poly-unsaturated fatty acids). Depending on the quality of the oils and categorisation of the source, these can be used as human nutritional supplements. More of the by-products would be available for human use if the approach were adopted that valorising by-products means treating them in the same way as fish fillets, i.e. as food-grade materials.

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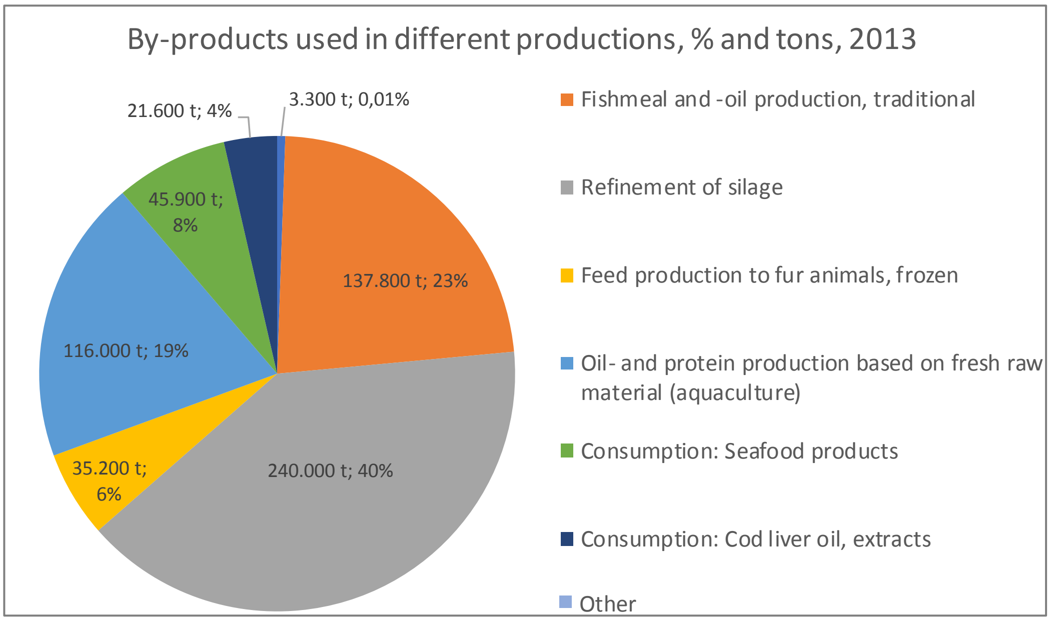
122 Seppälä J. (2014) Business case "Utilization of fish co-streams", Aquarel project final seminar, 18th September 2014 http://www.culmentor.com/aquarel/wordpress/wp-content/uploads/WEB_Business_case_18-09-2014.pdf.
123 Viðarsson J.R. et al. (2015).
124 Seppälä J. (2014).
125 Andrieux G. (2004).
126 Andrieux G. (2004).
127 FAO data (2015).
128 Forbord M., Falk-Andersson J. et al. (2017) Current Industrial uses of biological resources and products in Norway: A cross-sectoral view on the bio economy norut Report 12/2017 ISBN 978-82-7492-358-4.
129 Carvajal A. (2014).

In Norway, 40% of utilised by-products are ensiled, oils are extracted and the remainder is used to produce fish protein concentrate for feeds[130]; 23% are processed as is for fishmeal and fish oils, adding to the pelagic fish biomass used for this purpose. 19%, derived from aquaculture, is used fresh for salmon protein hydrolysate and salmon oils. Some by-product e.g. roes enter the human food chain directly (c. 8%) and a small proportion is used for nutritional supplements and extracts (see Figure 10). Overall, 87% us used for animal feeds (49% fish-feed, 25% fur animal feed, 21% farm animal feed, 5% petfood), 13% for human consumption and a tiny amount for bioenergy.

Figure 10 - By-product use, Norway



Source: Own elaboration from Industry survey, SINTEF

For Scotland in 2008, the increasing value of fishmeal and fish oils is seen as a partial brake on further innovation in adding value to wastes and surpluses[131]. Some possibilities are identified but structural changes would be needed to capitalise on these: better on-board sorting and storage is needed to supply e.g. livers of food-grade quality for higher-value liver oils; better methods are needed for meat removal from skins in order to produce collagens; if markets for fish guts e.g. China are to be accessed, space to store and process safely on-board is limited. The potential added value for fish wastes and discards lies in pressing to extract higher-value components, refining of crude extracts and hydrolysis of materials, to generate minerals, better-quality oils, proteins, peptides and amino-acids for human and animal nutrition, including specialised high-protein foods, and other derivatives such as peptone powders for lab media and petfoods; thermal treatment of frames to yield hydroxyapatite as a biomaterial and mineral supplement, direct extraction of enzymes and proteins from viscera, and extraction of skins and fins for carotenoids (especially astaxanthins) and other anti-oxidants, collagens and guanine for cosmetics. The conclusion for Scotland was that of the total amount of c. 190Kt available material, arising from 2.8Kt aquaculture fish, 160.3Kt fish processing waste and 24.4Kt landed fish, 100% was valorised. Farmed fish mortalities and fish discarded at sea were recognised as additional 'hidden' resources but were not quantified. The main technical added-value opportunity for fish wastes was seen as extracting proteins for human food supplements.

130 Richardsen R. et al. (2016).
131 Scottish Aquaculture Research Forum (2008), Strategic Waste Management and Minimisation in Aquaculture.

In **China**, about 12.4Mt (34%) of total available fish, 10.4Mt from fisheries, 24.4Mt from aquaculture and 2Mt imports, is estimated to enter processing, yielding 3.7Mt (30%) edible fish products, 5.4Mt (44%) by-products that might be further processed into human food, animal feed, industrial and fertiliser products[132]; and presumably 3.3Mt (26%) of discarded material that might be valorisable in some way. In China, processed fish and shellfish products, mainly as frozen foods, surimi, dry-cured and canned products, processed algae, fish oils and fishmeal, totalled c. 21Mt in 2015[133].

Materials not used for human or animal consumption such as aquaculture morts and diseased or damaged fish from landed catches or aquaculture can be used as is to produce biogas, or balanced with cellulosic wastes, as at the Biokraft plant in **Norway**, which adds pulp and paper outflows to salmon morts to generate liquefied bio gas[134]. Fish oils can also be fractionated to generate biodiesel.

2 Invertebrates

2.1 Crustacea

Crustacean biomass is derived from capture fisheries and wild harvesting and from aquaculture and mariculture. The Food from the Oceans report of the EC's Scientific Advice Mechanism (SAM)[135] pinpoints a role for currently underused species such as krill and other planktonic and mesopelagic crustacea in contributing to the task of finding >100Mt per year additional food output from marine capture fisheries and aquaculture to meet projected demands for food and biomass from the seas and aquaculture. In particular, they could provide as much as 20% of additional oils and proteins for aquaculture and farm animal nutrition.

2.2 Crustacean biomass types and amounts

Crustacean biomass is produced either by capture fisheries, or by aquaculture in freshwater and marine environments. FAO (2017) gives top-level estimates of amounts available for utilisation[136]; together, c. 170Mt of fish, shellfish and crustacea were landed and harvested in 2015, c. 55% wild-caught, 45% from aquaculture (see Table 19). Sea and ocean fishing predominates for capture fisheries (81Mt vs 11.5Mt freshwater); however, the opposite is true for aquaculture (28Mt marine vs. 49Mt freshwater). The top-level distribution of incoming biomass can be seen in Table 19-Table 21 and graphically in Figure 5, which also shows the by-products of harvesting and primary processing.

Table 19 - Production of fish 2015

Type	Total Mt	Aquaculture Mt	Capture/wild harvest Mt
FSC total Mt	169.2	76.6	92.6
FSC inland Mt	60.5	48.8	11.5
FSC marine Mt	108.2	27.8	81.2

Source: FAO (2017); FSC = Fish, shellfish and crustacea

[132] Cao L., Naylor R. et al. (2015) China's aquaculture and the world's wild fisheries, Science 347(6218): 133-135 Doi: 10.1126/science.1260149.
[133] Cao L. et al. (2015).
[134] https://www.adven.com/en/news-room/latest-news/biofuel-production-can-be-intensified-biokraft-and-adven-oy-start-cooperation-norway/?ccm_paging_p_b1853=9.
[135] European Commission High Level Group of Scientific Advisors (2017), Food from the Oceans Scientific Opinion No. 3/2017, Doi: 10.2777/66235.
[136] FAO (2017).

In capture fisheries, the top 20 species account for c. 28Mt[137], (30%), of the total of 92.6Mt – 2/20 of these are crustacea.

Table 20 - Production of crustacea in capture fisheries and wild harvesting

Type	Inland Mt	Marine Mt
Total FSC	11.5	82.3
Crustacea	0.5	6.1

Source: FAO (2017); FSC = finfish, shellfish and crustacea

In aquaculture and mariculture, the top 20 species account for c. 46Mt (60%) of 77Mt harvest; 4/20 are crustacea.

Table 21 - Production of crustacea in aquaculture

Type	Inland Mt	Marine Mt
Total FSC	48.9	57.1
Crustacea	7.4	

Source: FAO (2017); Categories not split between inland and marine in original

2.3 Geographic sources of biomass

China has a commanding position in supply of biomass. It is recognised as the world's largest producer, processor, exporter and consumer of fish and shellfish[138]; its aquaculture output was c. 50Mt in 2015, including 4.1Mt crustacea (c. 8%).

In 2015, the **USA's** total production was 5.4Mt, mainly fisheries catch of c. 5Mt (fish, molluscs, crustacea) and just over 0.4Mt aquaculture[139]. Other sources put total fisheries catch at >4.3Mt[140]; c. 88% was finfish and c. 12% shellfish, with aquaculture production of c. 0.3Mt of fish and shellfish, mainly pond-raised catfish.

For 2013, **Zero Waste Scotland**, in the context of a roadmap and strategy for better use of biomass[141], reported aquaculture production of 176Kt, of which shellfish constituted 7Kt (4%), and landings of 314Kt, of which shellfish and crustacea were 53Kt (17%).

Before 2005, the estimate of waste production for Scotland was c. 77Kt pa, mainly from pelagic and demersal fish, but including 4.7Kt *Nephrops* waste. In 2010 c. 10-20Kt wastes were derived from crabs and *Nephrops* in UK[142]; however, most prawns and shrimps are processed outside UK and imported in-shell or de-shelled already, so their contribution is minimal. There is no data for UK-produced or processed shrimp.

Zero Waste Scotland estimated bycatch in 2013 was 183Kt-257Kt (58%-82% more than actual landings), which could have been landed and made available for added-value industrial use with appropriate on-board technologies and fish-landing policies, plus inputs of fish and shellfish to aquaculture feeds at 238Kt[143]. Total in-processing wastes for landed fish and aquaculture produce

137 All data in this section derived from FAO (2017) except where otherwise stated.
138 Cao L. et al. (2015).
139 FAO (2017).
140 Delaware Sea Grant (2018) Overview of the Seafood Industry, https://www.seafoodhealthfacts.org/seafood-choices/overview-seafood-industry.
141 Zero Waste Scotland (2015) Sector study on beer, whisky and fish, Final report ZWS645.
142 Zero Waste Scotland (2015) Sector study on beer, whisky and fish, Final report ZWS645.
143 Zero Waste Scotland (2015) Sector study on beer, whisky and fish, Final report ZWS645.

were estimated at 185Kt, including fish-processing by-products and discarded material 160Kt and shellfish wastes c. 25Kt.

2.4 Biomass with potential for non-food uses

The world production of fish, shellfish and crustacea in 2013 was 163Mt, capture fisheries and aquaculture combined[144]; of this, 21.4Mt was estimated to be for non-food uses (i.e. 13%)[145]. China's production alone was estimated at 60Mt, of which 3.4Mt was for non-food uses (5%-6%); the global ex-China proportion of non-food use is 17.5%.

Estimates of the volumes of by-products are available for Norway from 2013[146]; from 3.1Mt of fish and crustacea from catches and farming, 0.9Mt of by-products were obtained, a yield of 28% overall. Some of the estimates are based on widely-accepted splits between edible elements and by-products, such as for crustacea, 50:50. The relative percentage contributions to overall by-products estimates are capture fish 60%; aquaculture 39%; and crustacea 1.4%.

Table 22 Estimates of catches and harvests and resulting by-products, Norway, 2013

	Total	Demersal fish	Pelagic fish	Aquaculture	Crustaceans
Basis for by-products (live weight)	3.066.000	775.000	965.000	1.301.000	25.000
Available by-products	867.000	340.000	178.000	336.000	12.500
Available by-products as share of basis for by-products	28%	44%	18%	26%	50%

Source Olafsen et al. (2014); "Basis for by-products" = total initial biomass

2.5 Uses of crustacea biomass

For crustacea, RRM includes the chitinous shells and the flesh left inside the carapaces.

For *Nephrops*, discard rates were 5%-25% in North Sea in 2011, in areas where minimum carapace length is 25 mm, and >40% where minimum landing size is 40 mm; a similar wide range was recorded in 2013, as high as 65% in small-scale fisheries. For crustacea the estimate of unused by-products is 59%-64%, mainly due to absence of easy processes for adding value to shells[147,148].

Even if RRM are available, they may be unused: Richardsen *et al*. (2016) report that the non-usage rate for RRM from crustacea was 71%.

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144 FAO (2017).
145 According to the Food Balance Section of FAO Handbook (2015).
146 Olafsen T. et al. (2014).
147 Olafsen T. et al. (2014).
148 Carvajal A. (2014).

2.5.1 Post-harvest losses

The UK'S Waste initiative WRAP reported in 2011 that, of total fish and shellfish inputs of 1,044Kt, 350Kt was regarded as non-edible, of which 140Kt were waste and co-products (including retail wastes), with 105Kt arising from finfish and 29Kt from shellfish[149]; most of the material arising in the shellfish area is regarded as unavoidable waste and the conclusion from surveying the industries was that avoidable wastes generated by processing are low.

2.5.2 At-sea process discards

At sea, >50% of *Nephrops* may be removed as heads and claws[150].

2.5.3 Uses of crustacea

In 2004, UK wastes were estimated at >300Kt pa[151]; 80% of this was finfish wastes, 20% shellfish & crustacea. The finfish wastes were mainly valorisable through production of fishmeal, and the logistics of collection and processing were well-established. Shellfish and crustacean wastes were more difficult to handle because of the amount of shells, and disposal was the usual management choice, costing an estimated £2.7 million (€3 million) per year to the harvesting and primary processing industries. By 2006, landfill had been withdrawn as an option for uncooked shellfish wastes, and treatment of wastes to produce fertiliser or soil improver was seen as the best and most economic option, particularly composting.

Non-food uses for crustacea presents challenges because of the high proportion of exoskeleton. Crustacean wastes already provide high-value materials, including chitins, chitosans and carotenoids such as astaxanthin, and very high-value laboratory reagents from e.g. shrimp meltwater.

In Scotland, a proof of concept project showed that flesh separated from waste shells, including crustacea, could be formed into baits for crabs, lobsters and whelks (seafood processing materials are legally usable for baits in the UK)[152]. At then-current bait prices of £400(€449)-£600(€673)/tonne, the bait required would be about 6-7Kt per year for the estimated catch of 30-35Kt of crab, lobster and whelk, giving a total potential value of bait from shellfish RRM of c. £3(€3.3)-£3.5(€3.9) million.

Planktonic crustacea are of increasing interest. Krill can be harvested and processed at sea using heating and pressing, to produce oil and meal; oils and other fatty components can be used for food or feed, or if not of edible quality standards can be used for coatings, paints, lubricants, surfactants and high-performance paraffins[153].

2.6 Molluscs

Molluscs consist of a wide range of bivalve and single-shelled aquatic organisms, including mussels, oysters, clams, scallops, abalone, whelks and other gastropods. As lower-trophic species, the EC's Scientific Advice Mechanism (SAM)[154] sees them as a contributor to meeting the food needs of the future. In capture fisheries, molluscs are not included in the top 20 species, but 3/20 of the top aquaculture species are molluscan.

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149 WRAP (2011) Resource maps for fish across retail & wholesale supply chains Project code RSC009-001 & RSC009-003.
150 Seafish (2011) Fish Waste Production in the United Kingdom.
151 Reported in ADAS (2006) Review of the application of shellfish by-products to land, SR586 Seafish 2006, ISBN 0 903941 49 X.
152 Seafish (2008) Use of shell-fish by-products in bait.
153 Ahokas M. (2014).
154 European Commission High Level Group of Scientific Advisors (2017) Food from the Oceans Scientific Opinion No. 3/2017 Doi:10.2777/66235.

Table 23 - Production of fish and seaweed in aquaculture

Type	Inland Mt	Marine Mt
Total	48.9	57.1
Fish	44.1	2.9
Fish diadromous	5.0	
Crustacea	7.4	
Molluscs	16.4	

Source: FAO (2017); Categories not split between inland and marine in original

Scotland is a specific case within the UK as the main aquaculture producer (almost 170Kt fish in 2011, about 95% salmon at-sea and 5% trout on-land[155]) as well as having major capture fish landings. For 2013, Zero Waste Scotland, in the context of a roadmap and strategy for better use of biomass[156], reported that c. 10% of the aquaculture production of 176Kt was shellfish, and about 17% of the landings of 314Kt, though the data does not separate molluscs and crustacea. In 2008, the wastes from mollusc fishing in Scotland were c. 75Kt per year: 20Kt flesh and 55Kt shells[157]. Difficulties were noted in making use of this, due to hygiene and the costs of separation, though shells have been separated from flesh ("free of flesh shell") for use in aggregates (roads etc.). In 2010 c. 10-20Kt wastes were derived from crabs and *Nephrops* in UK; Zero Waste Scotland in 2013 estimated total in-processing wastes for landed fish and aquaculture produce at 185Kt, including shellfish wastes c. 25Kt.

Sometimes it is not clear whether the recorded proportions of waste and the utilisation can be generalised from a local or regional report. For example, the amount of primary fish wastes in Victoria state, Australia, may amount to >11Kt per year; though this is mainly finfish and shark wastes or market discards, c. 10% of this is squid and shellfish wastes, plus 500 m^3 of scallop shells and viscera.

2.6.1 Uses of molluscan biomass

In Scotland, the SARF report[158] in 2008 noted non-food uses of shellfish wastes as part of their analysis of the potential for better use of aquaculture wastes (Table 24).

Table 24 - Outputs from processing shellfish wastes

Waste or discarded material	Process	Commodity	Use
Shellfish flesh wastes	Composting, AD, heat-treatment		Digestates and residues as liquid fertiliser and solid soil improver
Shellfish shell wastes	Heat treatment, crushing		Aggregate, cement; lime fertiliser; Calcium source for eg laying hens
Shellfish viscera	Extraction	Enzymes	Laboratory and bioprocess reagents eg proteases
Shellfish and crustacean mixed wastes	Crushing, binding, moulding	Baits	Whelk harvesting

Source: SARF (2008)

155 Meacham T. (2014).
156 Zero Waste Scotland (2015) Sector study on beer, whisky and fish, Final report ZWS645.
157 Seafish (2008) Use of shell-fish by-products in bait.
158 Scottish Aquaculture Research Forum (2008).

Non-food uses for molluscs presents challenges because of the high proportion of shell, which is most likely to be used as landfill, where this is legally possible, or crushed to provide calcareous fertiliser and soil improver. Molluscan shell wastes do not provide anything like the high-value chitosans and glucosamines obtainable from crustacean shells. They have been used as aggregate for road-building.

In Scotland, flesh from waste mollusc and crustacean shells has been used as bait for crabs, lobster and whelks, with a potential value of £3-3.5M (€3.3-3.9) per year[159]. Several initiatives round the world exist to turn ground mollusc shells into fertiliser, soil improver and material that might have some pesticidal properties.

2.7 Cephalopods

The percentage of RRM available from cephalopods varies according to type: octopus produce only 10-20% biomass for non-food use, squid 20%-40%, sometimes as high as 52%. Octopus RRM consist of ink sacs, viscera, eyes and beaks; squid RRM also includes skin, fins, the head and tentacles, the internal support (the squid pen) and liver (male squid milt is eaten as a delicacy in East Asia); cuttlefish in addition have a more substantial internal support, the cuttlebone.

2.7.1 Uses of cephalopods

Octopus RRM (viscera) have been converted into a histamine and tyrosine-free low-microbe count material using microbial fermentation and ensiling[160]. Cephalopod meat is used as bait for sport and commercial line-fishing. Inks are used as natural pigments and as flavourings for e.g. pastas. Cuttlebone is used as a natural calcium supplement for pet birds and other pets. Squid pens, squid skins and sucker ring cartilages may be used as sources of chitin/chitosan and collagens; nutritional and pharmaceutical ingredients such as high-omega-3 fatty acids, taurine, anti-cancer peptides and protamine can also be isolated from livers, viscera oil, ink and milt[161]. Squid Rest Raw Materials can be hydrolysed as for fish trimmings to produce a liquid fertiliser[162].

3 Seaweeds & microalgae

3.1 Seaweeds

There is considerable pressure to improve biomass availability by a combination of changes in fishing and aquaculture focus and reduction in wastage. The Food from the Oceans report of the EC's Scientific Advice Mechanism (SAM)[163] and the evidence review by Science Advice for Policy by European Academies (SAPEA)[164] pinpoint seaweeds as being a contributor to satisfying the projected >100Mt additional biomass demand for human food in the next 20 years. This is partly a direct contribution to more effective production, as lower-trophic organisms, and a contributor of c. 50% of the estimated alternative sources of oils and proteins needed for aquaculture and farm animals.

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159 Seafish (2008) Use of shell-fish by-products in bait.

160 Harrabi H., Leroi F. et al. (2017) Biological silages from Tunisian shrimp and octopus by-products, J Aquatic Food Prod Tech 26(3): Doi: 10.1080/10498850.2016.1145160.

161 Kim S.M., Gangneung-Wonju National University, Republic of Korea, Reduction and Utilization of Squid Wastes http://www.fftc.agnet.org/library.php?func=view&id=20150106145750.

162 See https://www.ams.usda.gov/sites/default/files/media/Squid-TR-011216.pdf.

163 European Commission High Level Group of Scientific Advisors (2017) Food from the Oceans Scientific Opinion No. 3/2017 Doi: 10.2777/66235.

164 SAPEA (2017) SAPEA Evidence Review Report No. 1: Food from the Oceans https://www.sapea.info/wp-content/uploads/FFOFINALREPORT.pdf, Doi: 10.26356/foodfromtheoceans.

3.1.1 Biomass amounts of seaweeds

FAO (2017) gives top-level estimates of amounts available for utilisation[165]; c. 31Mt aquatic plants, mainly seaweeds were produced in 2015, 1.1Mt wild-harvested and 29Mt from seaweed farming.

Table 25 - Production of fish and seaweed 2015

Type	Aquaculture Mt	Capture/wild harvest Mt
Seaweeds	29.4	1.1
of which		
Inland	0.1	-
Marine	29.3	1.1

Source: FAO (2017); FSC = Fish, shellfish and crustacea.

About 1.1Mt wet weight seaweed is wild-harvested; there is no information on the destination of this amount, or how much beached seaweed might be recoverable for industrial added-value uses world-wide.

Production of macro- and microalgae is much higher in aquaculture and mariculture than wild-harvested: the estimated harvest of farmed seaweeds (brown, red and green) is 29.4Mt; for microalgae, an estimated 16.7Kt dry mass of species used for healthfoods, nutritional supplements and antioxidant pigments for humans and animals, mainly *Dunaliella*, *Spirulina*, *Haematococcus*, was produced in 2016[166].

3.1.2 Geographic sources of seaweed biomass

Again, China has a commanding position in supply of biomass. Table 26 shows that it is at No 1 or 2 for seaweed production. European countries are in the top 10, but only for wild-harvesting of seaweed.

Table 26 - International landscape of seaweed production 2015

Position	Wild-harvest seaweeds Mt	Farmed seaweeds Mt
#1	Chile 0.35	China 13.9
#2	China 0.26	Indonesia 11.3
#3	Norway 0.15	Philippines 1.6
#4	Japan 0.09	South Korea 1.2
#5	Indonesia 0.08	North Korea 0.5
#6	Ireland 0.03	Japan 0.4
#7	France 0.019	Malaysia 0.26
#8	India 0.019	Zanzibar 0.17
#9	Iceland 0.017	Madagascar 0.015
#10	Peru 0.015	Solomon Islands 0.012

Source: FAO (2017)

165 FAO (2017).

166 Algae Market, By Application, By Cultivation Technology, and Geography - Global Industry Analysis, Size, Share, Growth, Trends, and Forecast - 2016-2024, Report ID TMRGL14804, Transparency Market Research 2016 https://www.transparencymarketresearch.com/algae-market.html.

Norway is No 3 in the world for wild-harvested seaweed after Chile and China.

In 2015, **China** produced 2Mt algae. It is also a massive consumer of seaweeds.

The FAO database has only general information for production or harvesting of seaweeds, and none for some countries such as the UK, for which there are no other comprehensive estimates of seaweed production including wild-harvested, farmed and storm-cast[167]. The total wild harvest in the UK was estimated at c. 6Kt in 2012[168]; the UK macroalgae industry of 15 SMEs had a turnover of c. £1(€1.12)-£1.3(€1.46) million. Beach-cast seaweeds, unquantified amounts, are used mainly for soil improvement and fertilisation[169]. Another estimate puts dry-weight harvest at 2-3Kt[170]; this is equivalent to wet weight of 20-30Kt, in the same range as estimates for sustainable harvestable stocks of 15-25Kt yield per year from c. 170Kt in the Outer Hebrides (Burrows *et* al. 2010)[171].

3.1.3 Seaweed potential for non-food uses

FAO data (2017) gives the weight of wild-harvested seaweeds as 1.1Mt and farmed seaweeds as 27Mt. This is wet weight; some sources of information do not specify whether the weights they mention are wet weights or dry weights.

Macroalgae (seaweeds) mainly enter the human food-chain, but also have large established markets for processed food ingredients, as valuable marine hydrocolloids, and non-food uses in farming, animal nutrition and increasingly for bioactive molecules (see Figure 11, which gives amounts in dry weight)[172]. There is a drive to increase production of farmed seaweed to develop new uses, including ingredients for human and animal nutrition, biomass for production of bioenergy and biomaterials, and sources of bioactive molecules so far not widely exploited.

Figure 11 - Seaweeds – inputs and processed seaweed products 2010

SEAWEED PRODUCTS	MARKET VALUE (Million US$)	RAW MATERIAL Quantity (t)	RAW MATERIAL Value (US$/t)	FINAL PRODUCT Quantity (t)	FINAL PRODUCT Value (US$/t)
Carrageenan	527	400,000	1,400	50,000	10,500
Alginate	318	460,000	950	26,500	12,000
Agar	173	125,000	1,200	9,600	18,000
Soil additives	~30	550,000	18	~510,000	20
Fertilizer (seaweed extract)	~10	10,000	500	~1,000	5000
Seaweed meal	~10	50,000	100	~10,000	500
Pharmaceuticals, cosmeceuticals, nutraceuticals, bioactives, etc.	~5	3,000	Not known	600	Not known
TOTAL	~1,073	1,598,000		~607,700	

Source: Nayar and Bott (2014)

167 Capuzzo E. and McKie T. (2016) Seaweed in the UK and abroad – status, products, limitations, gaps and Cefas role, Cefas contract report FC0021, 22 April 2016.

168 Viking Fish Farm Ltd. (2012). UK macroalgae industry. Poster presentation, Interreg program Netalgae http://www.netalgae.eu/uploadedfiles/UK_1.pdf.

169 James M.A. (2010) A review of initiatives and related R&D undertaken in the UK and internationally regarding the use of macroalgae as a basis for biofuel production and other non-food uses relevant to Scotland. Report commissioned by Marine Scotland.

170 Schlarb-Ridley B. and Parker B. (2013) A UK Roadmap for Algal Technologies, NERC-TSB Algal Bioenergy-SIG.

171 Burrows M.T., Macleod M. and Orr K. (2010) Mapping the intertidal seaweed resources of the Outer Hebrides SAMS Internal Report No 269 SAMS/Hebridean Seaweed.

172 Nayar S. and Bott K. (2014) Current status of global cultivated seaweed production and markets, World Aquaculture, June 2014.

In Ireland and France, a heavily-calcified seaweed, maerl (*Phymatolithon calcareum* and *Lithothamnion glaciale*), is dredged and used as a soil improver and a nutritional supplement for humans and animals; maerl beds are increasingly being protected, with bans on commercial exploitation.

80% of the seaweed farmed or harvested from the 30 or so species commonly used is directly consumed as food or processed for food ingredients such as flavourings. 20% is used for its hydrocolloid content (agar, alginates and carrageenans), with a long history as ingredients in foods, microbiology media, pharmaceutical excipients, cosmetic ingredients, research reagents, water-treatment flocculants and other specific uses. Approx. 1Mt wet weight of seaweeds yields 55Kt of hydrocolloids[173]. Derivatised hydrocolloids and other components of seaweeds such as phlorotannins and fucoidans have also been used in cosmetics, cosmeceuticals and nutraceuticals. Some seaweeds are used for animal feed – Norway pioneered the use of seaweed meal in feed; it takes 5kt of wet seaweed to produce 1kt of dried and milled meal. Seaweed is also used in agriculture and horticulture, dried and applied as fertiliser or liquefied as an extract; it takes 10kt wet weight to yield 1kt extract. Residual material may be processed for its content of phlorotannins and other bioactive ingredients and is then suitable for anaerobic digestion. Newer uses might include production of biochar and pyrolytic conversion for biodiesel, or deliberate use within multitrophic aquaculture systems as remediators of nutrient over-supply, and there are also moves to establish seaweed biorefineries. It is difficult to see what categories of 'wastes' or 'under-used' materials can be considered for seaweed: examples might be the residues from extraction of hydrocolloids; and storm- or tidal-cast seaweed.

More optimistically, it has been proposed that seaweed farming be intensified to yield 500Mt dry weight per year by 2050[174]. This amount could produce 150Mt of algal protein for animal feeds, and c. 15Mt of algal oil, with positive impacts on the marine environment through removal of 135Mt carbon, 10Mt nitrogen and 1Mt phosphorus and on the terrestrial environment by sparing 1M Km^2 of agricultural land. However, in 2015, c. 27M tonnes wet weight of seaweed were produced[175]; it is difficult to see how and where sufficient wet weight to produce 500Mt dry weight might be farmed, even if the estimate is that only 0.03% of the surface area of the oceans would be needed.

3.2 Microalgae

3.2.1 Biomass amounts of microalgae

Production of microalgae is much higher in aquaculture and mariculture than wild-harvested. An estimated 16.7Kt dry mass of species used for healthfoods, nutritional supplements and antioxidant pigments for humans and animals, mainly *Dunaliella*, *Spirulina*, *Haematococcus*, was produced in 2016[176]. The global market is projected to grow in value by 7.4% per year between 2016 and 2024, from \$0.6B (€0.5B) to \$1.1B (€0.9B), and in volume by 5.3% per year to reach 27.6Kt dry weight.

3.2.2 Microalgal biomass with potential for non-food uses

Microalgae are not usually wild-harvested and there are no estimates of the total mass of wild microalgae that could be utilised. Farmed algae include *Dunaliella* and *Spirulina*, used for their carotenoid, antioxidant and pigment content as powdered whole organisms or extracts, cultivated in ponds or raceways in warmer and sunnier countries. These and other microalgae are currently under research and development for water remediation, production of algal oils (replacing fish oils),

173 McHugh D.J. (2003) A guide to the seaweed industry. FAO Technical Paper No. 441.
174 Seaweed Aquaculture for food security, income generation and environmental health in tropical developing countries, World Bank Group.
175 FAO (2017).
176 Transparency Market Research (2016) https://www.transparencymarketresearch.com/algae-market.html.

production of algal proteins for animal and human feeding, and high-energy oils for biofuels. Microalgae require open ponds with access to sunlight, photobioreactors with daylight-wavelength artificial light or fermentation vessels with added nutrients.

The major uses are oil production for biofuel, docosahexaenoic acid for nutritional and pharmaceutical uses, residual proteins and carotenoid anti-oxidants. Algal biomass provides c. 42% of current biofuels including biodiesel, fuel alcohols, kerosene and jet fuel. In 2015, c. 54% of the total market revenue came from DHA sales. Production is mainly low-technology; open ponds, concentrated in sub-tropical regions and zones of high sunshine, provided almost $0.5B (€0.42B) product sales. Photobioreactors and fermenters are a growing segment mainly dedicated to higher-value products. North America, which houses >130 companies active in microalgal production and processing, has developed this position due to heavy investment in biofuels – one tonne of algae yields >100L biodiesel. In other regions, algal systems are emerging for wastewater processing and CO_2 capture and use. Algal bioplastics are also being developed.

Because of the costs of establishing large-scale facilities, the concept of algal biorefineries is driving the use of microalgae in the Circular Bioeconomy. Therefore, the focus is already on making maximal use of biomass and it is probably premature to try to consider what proportion of microalgal production is being neglected, that might be available for other value-added uses. Although nutrient-rich waste waters may contribute to nuisance and harmful algal blooms, there is increasing interest in the potential of controlled microalgal systems to recover water to industrial and even near-potable quality. Data for several fish and shellfish processing activities from Canada suggests that biological oxygen demand (BOD) and total suspended solids are far higher than for meat rendering and household wastewater outflows[177]; this would make them good candidates for microalgal remediation.

Table 27 – Typical wastewater discharge characteristics

Processing sector	BOD mg/L	TSS mg/L	NH_3 mg/L
Crab processing	180-1280	80-815	6-13
Shrimp processing	530-1240	240-660	
Ground fish production	27-1775	7-1550	20
Herring processing	33500	7955	
Stickwater discharges	34000	54000	
Salmon processing	397-3082	40-1600	42
Potato processing	61	8	2
Meat rendering	22	64	8
Raw municipal wastewater	220	220	25
Treated municipal wastewater	20	20	20

Source: Park and Thomas (2003)

Microalgae can be used for water remediation of processing plants, but there are inevitable residues to deal with, e.g. in Victoria state, Australia, the management of >11Kt fish wastes pa involves the production of 1Kt wet microalgal biomass from the waste treatment ponds[178]. Material from petfood manufactured in the state using fish by-products amounted to >3Kt of processing wastes and >11Kt of discharge sludge, but there is no mention of whether microalgae were used for remediation or digestion.

177 Park L. and Thomas T. (2003) Management of Wastes from Seafood Processing http://coinatlantic.ca/images/documents/presentations/46mfpw.pdf.

178 Gavine F.M., Gunasekera R.M. et al. (1999) Value-adding to seafood, aquatic and fisheries waste through aquafeed development Project No 1999/424 Fisheries Research & Development Corporation, Victoria.

4 Current practices and the need for innovation

4.1 Introduction

Seafish and Cefas commissioned a report in 2012 that examined what might be done with fish not used for human consumption that would now be brought to port because of the landing obligation, rather than being discarded at sea[179]. This confirmed that the existing opportunities for utilising discards not fit for human consumption, reduction to fishmeal and fish oil, ensiling, composting, anaerobic digestion with energy recovery, and freezing (prior to use as bait), were the likeliest to be used by existing processors. Apart from the potential uses of fish oil in the oleochemical industries, high-value industrial uses were not considered. The general view for finfish is that the largest potential for by-product valorisation lies in better utilisation of the wastes from on-board processing[180]. Therefore, there is some way to go in overcoming entrenched attitudes, if innovative approaches are to be developed and taken up.

It is recognised that there is a need for improvement in the management of aquatic and marine biomass, for both food and non-food purposes. In October 2016, the European Commission (DG Research & Innovation) held a workshop on making better food use of marine and aquaculture biomass and the steps needed to achieve this[181]. The three main topics were Underused fish biomass, New algae value chains for food and Consumer acceptability of aquaculture products. This workshop could be a model for one focusing on non-food uses of fish, shellfish and seaweeds and new non-food uses for microalgae, organised by DG MARE.

The World Bank projection[182] is that, by 2030, total fish supply will be c. 187 million tonnes (Mt), 50:50 capture and aquaculture; c. 152Mt will be used for human consumption, 58Mt of 93.2Mt capture fish (c. 62%) and 93.6Mt aquaculture fish (100%), leaving 35Mt of catch available for further processing for non-food uses (including fishmeal), an increase of 16% biomass volume since 2008. Aquaculture is expected to show the greatest growth in supply, with production increased by >75% over a 20+-year period and consumption almost doubling, but the World Bank expects all of the aquaculture production to be used for human food (see Table 28). In this scenario, development of additional non-food uses is dependent on the gap between a small increase in landings from capture fisheries and fall in their overall consumption. This in turn suggests that the influence points in the value chain are in processing the catch and in managing consumption.

Table 28 - Projections for capture fisheries, aquaculture and consumption in 2030

Source of fish	Total supply (Mt)			Total consumption (Mt)		
	2008	Projected to 2030	Growth %	2008	Projected to 2030	Growth %
Capture fisheries	89.4	93.2	+4.2%	64.5	58.2	-9.0%
Aquaculture	52.8	93.6	+77%	47.2	93.6	+98%
Total	142.3	186.8	+31%	111.7	151.2	+35%
Surplus for non-food use				30.6	35.6	+16%

Source: adapted from Msangi et al. (2013)

179 Mangi S.C. and Catchpole T.L. (2012) SR661 – Utilising discards not intended for human consumption in bulk outlets, Cefas and Seafish ISBN 978-1-906634-67-4.

180 Jouvenot L. (2015).

181 Aquatic food products and new marine value chains – reinforcing EU Research and Innovation policy for food & nutrition security. Report of a workshop, EU (2016). https://ec.europa.eu/info/sites/info/files/conferences/food2030_2016/w2_aquatic_food_new_marine_value_chains_full_report.pdf.

182 Msangi S. et al. (2013).

In the World Bank's scenario, the harvests in Europe and Central Asia (including the Caspian, Aral and Black Seas and landlocked aquaculture areas between Russia and China) increase by 8.5% from 14.6Mt in 2008 to 15.8Mt in 2030, when they represent 8.45% of the total. Comparable figures for China and for the rest of Asia, including Asia-Pacific, are an increase of 40% to 70Mt and 60.5Mt respectively, representing 37% and 32.4% resp. of the total. The majority of production, and of biomass available for non-food uses, may thus take place in parts of the world where EU policy is not influential, which represents an additional challenge.

Given that in some fish, up to 70% is RRM (e.g. tuna), additional ingenuity could be applied to the material other than turning it into fishmeal and fertiliser. The head may occupy 20-25% of the fish, the viscera including guts and roes a further 10%-25% of whole fish. Gutted fish is 62% edible flesh, including 46% skinless fillet, but is still 38% wastes. Headless fish may have >50% easily-usable meat (37% loin, 18% fillet), but there are still frames and dark meat 18%, viscera 13%, belly 6%, and frame scraps 8%.

Consumer behaviour is often cited as a reason for slow rate of change in sectors where change is needed for improved use of resources. Consumption patterns show that consumer preferences can change over a period. In the US, for example, annual consumption of aquaculture salmon tripled from 0.3 kg per person to 1 kg in the period 1990-2016 and annual tilapia consumption rose from c. 0.2 kg per person each year to c. 0.7Kg between 2001 and 2010[183]. With landing obligations and other instruments bringing unfamiliar species to land, and projected increases in aquaculture output targets, there will be increased biomass available, where ingenuity and market adaptations will be needed to make use of any materials not entering the human food chain directly.

4.2 Structural challenges

The main structural changes that are require for progress in use of marine and aquatic biomass are:

- Better and more consistent information about biomass types and sources;
- Technological innovations for processing and value-preservation of biomass;
- Policy frameworks that support supply chains in developing and marketing new products.

Improving the efficiency of capture fisheries requires radical change such as removing overcapacity in the world's fishing fleets, imposing management on over-exploitation, redressing the balance between the value retained by the capture businesses and that retained by the processers, retailers and aquaculture producers (estimated to be a 20:80 split of a $400B, i.e. €342B, food fish market), and improving access to and use of under-used species[184]. Losses at production level due to structural problems are estimated at a mean of $50B (€43B) per year.

Policy changes that incorporate technological changes to capture methods and fishing equipment may be needed to deal with some structural challenges to reduction of discards. Historical figures for the North, Celtic and Baltic Seas and west of Scotland show the scale of loss of biomass to further use[185]. For cod, in 2011 overall 25%-35% of total catch was discarded, mainly due to undersize/underage – the majority of discards from 1-2-year-old fish. For the Celtic Sea, 35% of a total catch of 7.3Kt was discarded (est. 9% in 2013); west of Scotland, 92% of a total catch of 6.4Kt was discarded (80% of 1.5Kt

183 Delaware Sea Grant (2018) Overview of the US seafood supply https://www.seafoodhealthfacts.org/seafood-choices/overview-us-seafood-supply.

184 Willmann R., Kelleher K. et al. (2009) The Sunken Billions: The economic justification for fisheries reform, The International Bank for Reconstruction and Development/World Bank, Doi: 10.1596/978-0-8213-7790-1.

185 Green K. (2012, 2013, 2014) ICES advice - commentary on discards, Seafish.

in 2013); the Irish Sea 36% of 324Kt in 2013; the Baltic Sea, about 7% of the cod catch was discarded, but unwanted flatfish (unquantified) are also caught in trawl-nets. For haddock from Celtic Sea and west of Scotland, discard rates ranged from 20%-53%, except in Irish Sea from *Nephrops* fleets, where haddock by-catch discards were as high as 93%-100% of fish aged 1-2 years, due to the type of gear used; discard rates (unquantified) in 2013 were the lowest on record in parts of North Sea, west of Scotland and Skaggerak, but increased or remained high in Rockall, the Irish Sea, and other areas, seriously impacting young stock for following years. Hake discards from the recorded fisheries are mainly the result of young and undersized fish, by-catch and mismatch between net mesh sizes and fish sizes and reached 17% of est. 109Kt catches in 2013. For plaice, mismatch between mesh size and minimum landing size also results in high to very high discard rates, of 30%-70%. The multiplicity of reasons for discards, even though the overall rates may now be falling, means there is not likely to be a 'one size fits all' opportunity.

The EU Aquatic Food Products workshop (2016) recommended a number of initiatives spanning these areas, including producing a roadmap, supporting regional pilot plants at semi-industrial scale and funding larger regional bio-refineries or algal lighthouse projects[186]. Discussion also mentioned a need to better monitor the types and amounts of marine and aquaculture biomass that might be directed to added value uses and the impact of rules such as management of Category 2 materials and the CFP landing obligation regulations.

It could be realistic to recommend that consideration of non-food uses of fishery and aquaculture biomass is always included in discussions of policy, regulation and development when food uses are being considered. This would, for example, have made the Strategic Guidelines for the sustainable development of EU aquaculture[187] more relevant in the context of the Circular [Blue] Bioeconomy.

An analysis of Pacific tuna fisheries noted a number of structural aspects of ensuring that the full value of wasted or under-used material could be retrieved[188]. These included consistent quantity and geographical concentration of by-products; suitable type and quality of by-products for their proposed applications; suitable infrastructure to maintain quality and facilitate market access; the ability to comply with sanitary standards; the financial capacity to invest in value adding technology; and the availability of research and development to support decision-making for development. Policy recommendations were to quantify the types, volumes and locations of material and their current uses; decide whether sorting the material is required, or undifferentiated biomass is to be used, or both approaches are needed; encourage cooperation between biomass producers to create enough volume for new business opportunities; improve sanitary standards in managing by-product materials; and enhance distribution channels for market development (i.e. promote enhancement of existing value chains and development of new ones). This analysis and recommendation, though developed in the Pacific, could equally apply to Europe.

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186 Aquatic food products and new marine value chains – reinforcing EU Research and Innovation policy for food & nutrition security. Report of a workshop, EU (2016) https://ec.europa.eu/info/sites/info/files/conferences/food2030_2016/w2_aquatic_food_new_marine_value_chains_full_report.pdf .

187 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Strategic Guidelines for the sustainable development of EU aquaculture, COM (2013), 229 final, 29.4.2013.

188 Bergé et al. (2014).

4.2.1 Better information

The EC's SAM[189] and the SAPEA[190] note that it is difficult to take action on eliminating waste from harvested wild stocks because of lack of data and traceability mechanisms. They advise that the EUROSTAT/EUMOFA EU data collection framework should be used to record more reliable data.

The Scottish Aquaculture Research Forum has noted that, to understand and make better use of the materials, more-detailed definitions are needed, especially in terms of classifying waste in relation to its constituent parts, and getting more-detailed data, rather than top-line aggregated data[191].

4.2.2 Technological needs

Within Europe and North America, current constraints on better non-food use of aquaculture and marine biomass are a lack of easy-to-access appropriate-scale processing systems for transformations such as better-quality fish oils, and absence of rigorous sorting, lower temperature processes and rigorous traceability, for the highest-value transformations such as pharmaceuticals and nutraceuticals.

Innovation and technology development is needed to provide more capacity for on-board storage, delivery and processing of discards and offal and on-board assessment of the suitability of the processed material for feed ingredient use further along the value chain[192].

For shellfish and crustacea, waste processing plants need to be built into the food processing plants to avoid the usual charges for collection and disposal by anaerobic digestion, landfill, incineration, rendering, ensiling or composting; in 2007, charges ranged from £25-£160 (€28-€180) per tonne, plus transport costs[193]. Disposal costs for shellfish wastes can be high – in Scotland, £30-£60/t (€34-€67/t) was reported in 2008[194], which might be thought of as providing an incentive for innovation in finding added-value uses - in 2009, c. 63Kt shellfish waste cost almost £3 million (€3.4 million) to dispose of[195].

4.2.3 Policy initiatives

In the USA, the policies suggested to reduce bycatch and at-sea discards include bycatch quotas, bycatch taxes combine with full observer coverage and landings inspection, a 'deemed value' approach as in New Zealand, over-quota auctions as in Iceland, and value-chain approaches such as eco-labelling and traceability[196]. Better recording of bycatch and discards and improved fishing gear with associated incentive funding will also contribute.

Drivers for change include both availability and price: in the period 2000-2008, global aquaculture production increased by 62% while fishmeal supply fell by 12%, indicating strong efforts to make fish-feeds less reliant on inclusion of fishmeal and fish oils. However, in the run to 2030, given the projected increase in aquaculture production, the real price of fishmeal is expected to increase by 90% and fish

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189 European Commission High Level Group of Scientific Advisors (2017) Food from the Oceans Scientific Opinion No. 3/2017 doi:10.2777/66235.
190 SAPEA (2017) SAPEA Evidence Review Report No. 1: Food from the Oceans https://www.sapea.info/wp-content/uploads/FFOFINALREPORT.pdf, Doi: 10.26356/foodfromtheoceans.
191 Scottish Aquaculture Research Forum (2008).
192 SAM (2017) and SAPEA (2017).
193 Seafish (2008) Crustacea processing waste management.
194 Seafish (2008) Use of shell-fish by-products in bait.
195 Seafish (2009) Use of anaerobic digestion for shellfish waste in Orkney.
196 Keledjian A., Young S. et al. (2014) Wasted cash: the price of waste in the US fishing industry, Oceana 2014.

oils by 70%, but with only an 85% increase in availability from reduction fisheries and capture fishery RRM[197]. Use of alternative sources for protein and oils and lower-trophic species is expected to grow.

The current re-working of the EU Bioeconomy Strategy, to recognise the changes since 2012 in what is feasible and what is needed in terms of updating policy and actions, supports better understanding of the environmental impacts of biomass production and an increased use of waste and aquatic resources not competing with food production[198].

There are also ecological challenges to reducing discards. In the Mediterranean, though there are only 30 regularly-marketed fish, crustacea and mollusc species, there are 300 that are regularly caught, of the 714 fish spp, >2200 crustacea spp and >2,100 mollusc spp that exist[199]. A full listing is available of the extensive range of species that may eventually be brought to land in the EU with no obvious market for them[200]. These species might be usable for non-food purposes but the difficulty lies in managing inconsistent quantities through the year.

Some factors to consider in biomass availability for non-food use:

- 75%+ of fish is potential by-product source; uses are already established and practices may be difficult to change.
- Geography of major fishing/production: of the Top Ten countries, 6 in marine fisheries and 6 in Freshwater capture, and the majority of aquaculture and seaweed producers are in Asia not Europe, so may not be influenceable directly.
- Trends in fisheries catches: discards and landing obligation; species brought to market; fishing technologies to reduce bycatch – may decrease or increase available non-food biomass.
- Trends in shifting small oil-rich pelagic fish from fishmeal to human consumption; increased retention and use of all edible trimmings for fish mince, extracts, fishmeal/fish oil may decrease availability of higher-value RRM.
- Smaller-scale on-land and on-board technical systems for more efficient processing will decrease availability of RRM.
- Geographical logistics of collecting and transporting make valorisation difficult in some areas.

4.3 End procedures

Currently, the final procedures used for different types of fisheries and aquaculture by-products and wastes include:

- Chemical or enzymatic hydrolysis
- Composting
- Ensiling
- Anaerobic digestion
- Landfill.

There is no data on how much material enters the current final-stage processes. Hydrolysis has the potential to generate higher-value material if the inputs are of high quality and indeed is used on edible trimmings and other food-grade materials to produce fish protein hydrolysates, concentrates and flavouring products for human consumption. Especially in fisheries where a high percentage of

[197] Msangi S. et al. (2013) World Bank.

[198] https://ec.europa.eu/info/law/betaater-regulation/initiatives/ares-2018-975361_en.

[199] Fitzpatrick M., Quetglas T. et al. (2017) Year 2 of the Landing Obligation: Key Issues in Mediterranean fisheries DiscardLess Policy Brief Number 2 doi:10.5281/zenodo.573666.

[200] EU Discard Annex: Studies in the Field of the Common Fisheries Policy and Maritime Affairs, Lot 4: Impact Assessment Studies related to the CFP, EU, March 2011.

the fish remains after filleting, such as tuna, where only about 30% is used directly for food, hydrolysis to high-quality fish protein hydrolysate and concentrate seems promising[201].

Anaerobic digestion could deal with mollusc shell+flesh wastes and crustacean carapace wastes, generating biogas, reducing volume of material, and yielding land or horticulture fertiliser as residue, but the mineral content makes the process rather difficult. Dealing with crustacean shell e.g. crab requires a redesign of conventional anaerobic digestion to prevent particles settling and clogging the anaerobic digestion reactor, but it is possible: shells are crushed and pasteurised then heated at >90degC for one hour before adding to the anaerobic digestion reactor, then >70degC for 1 hr. before adding digestate then fermenting[202]. This work was done in Orkney where there is no market for the eventual residue, an outcome which suggests better project forethought and validation of the value and supply chains before large-scale work is commissioned. However, anaerobic digestion as a means of disposing of such wastes is still viable here, provided smaller-scale digesters are used that can be transported as needed, according to the supply-points of material; this argues for appropriate logistics to cope with geography.

Composting fish waste, including co-composting with seaweeds, has been shown to produce a high-performance fertiliser for horticulture[203]. Ensiling fish using acids (formic, propionic, sulphuric, phosphoric) is one way to generate a more stable liquid that can then be used for a variety of purposes depending on the classification of the source biomass (food-quality or not), including extraction of oils, phospholipids, soluble proteins, fish protein isolate, astaxanthins and other antioxidants. As it is often used for materials such as fish morts or diseased and damaged material, there will usually be regulations controlling what the outputs can then be used for. AD is a useful tool for reducing plant energy costs.

Norway possibly leads the way in in Europe in developing new value-added uses, or making existing ones more feasible technically and logistically[204]. SINTEF notes that 290Kt of high-quality RRM is capable of producing 43Kt lipids, which can be fractionated to yield 6.5Kt of higher-value omega-3 lipids for human consumption, and 58Kt fish proteins for human consumption also. The oils come from RRM from salmon and trout aquaculture and the pelagic filleting industry, livers from cod or other white fish species (both wild and farmed), and oils from crustacea such as *Calanus* and krill. Fish proteins from RRM can be further processed by hydrolysis to Fish Protein Concentrate or Fish Protein Hydrolysate. Herring RRM is also suitable for production of functional oils, fatty acids, proteins and peptides.

4.4 Trends

Some important changes affecting the production and availability of wastes, approximately in degree of ease and timescales for achievement, are:

- Fisheries management tools such as landing obligation and quotas, and other policy tools in place or under development such as landing taxes and bycatch landing incentives.

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201 Herpandi N.H., Rosma A. and Wan Nadiah W.A. (2011) The tuna fishing industry: a new outlook on fish protein isolates, Comp Rev Food Sci Food Safety 10: 195-207 Doi: 10.1111/j.1541-4337.2011.00155.x.

202 SeaFish Authority (2009) Anaerobic digestion food waste, Orkney.

203 Illera-Vives M., Seoane Labandeira S. et al. (2015) Evaluation of compost from seaweed and fish waste as a fertilizer for horticultural use, Scientia Hort 186: 101-107.

204 SINTEF Fisheries and Aquaculture, New value added products from rest raw material. Protein hydrolysates and lipids, https://www.sintef.no/globalassets/upload/fiskeri_og_havbruk/foredling/forstehandtering/-nordic-pelagic-workshop/11_100830-rest-raw-materials-from-herring.pdf.

- Moving the utilisation of pelagic catches from reduction for fishmeal and fish oils to human consumption.
- Innovation in aquaculture feeds, replacing fish-origin materials by plant-, algal- and insect-origin materials (proteins, oils, bioactives), releasing fish biomass for other uses.
- Maturing technologies for cultivating microalgae on a larger scale.
- Growing interest in macroalgae (seaweeds) as a source of more components than marine hydrocolloids.
- Growing interest in farmable marine invertebrates as food and sources of bioactives – an example is sea cucumbers.
- Exploration of the potential of mesopelagic catches (fish and invertebrates) for by-products conversion or for direct human consumption.

Conventional fisheries take demersal (bottom-dwellers such as flatfish) or pelagic (upper-layer) species. A new trend is exploitation of mesopelagic areas of the seas. The imposition of landing obligations for species currently covered by quota, fish from target species that would previously have been disposed of, and bycatch may well increase fishing for mesopelagic species[205]. Mesopelagic biomass lies at depths between 100 metres and 1000 metres below sea-level and often undertakes diurnal migrations from lower to upper depths of the water column. It has been estimated there is anywhere between 1 billion and 10 billion tonnes[206] of harvestable biomass. Squid fisheries are an example of an established mesopelagic activity, and krill trawling is an example of a developing mesopelagic fishery. Fishing for the copepod *Calanus finmarchicus* has been in experimental status in Norwegian waters for some time[207]. Because of size (often small), appearance (e.g. large eyes, large teeth) or body composition (very ‘fishy’ oils and waxy esters), it is thought that most if not all mesopelagic fish would not be suitable for human food as is, but for fishmeal production or direct feeding in aquaculture, as is already the case on a small scale. This would contribute to a move in use of pelagic oil-rich fish from animal feed to human food. Purification of oils to generate omega-3 polyunsaturated fatty acids (PUFAs) for nutraceutical use is also possible and seen as one economic driver for exploitation.

Iceland has been exploring mesopelagic potential since the early 2000s[208]. The Icelandic experience has not been completely successful[209]; early work in local deeper waters found 99 species from 43 families of fish, including the beaked redfish *Sebastes mentella*, a target for mesopelagic fishing, plus krill and jellyfish. Experimental fishing for pearlside (*Maurolicus* spp) began in the late 2000s; total catch size fell from >46Kt in 2009 to 18Kt in 2010 and none in 2013-2016, when lanternfishes, krill and jellyfish formed the major part of the catch.

Some mesopelagic organisms such as lanternfishes appear to have a very large role in carbon cycling and sequestration, and most are an essential resource for fish and marine mammals at higher trophic levels, including squids, sharks and sunfish. Excessive fishing of mesopelagic stock would have impacts on several important aspects of ocean ecosystems. However, success in increasing catches from

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205 Prellezo R. (2018) Exploring the economic viability of a mesopelagic fishery in the Bay of Biscay, ICES J Marine Sci, Doi: 10.1093/icesjms/fsy001.

206 St John M.A., Borja A. et al. (2016) A dark hole in our understanding of marine ecosystems and their services: Perspectives from the mesopelagic community, Frontiers Marine Sci 3:31, Doi: 10.3389/fmars.2016.00031.

207 Forbord M., Falk-Andersson J. et al. (2017) Current Industrial uses of biological resources and products in Norway: A cross-sectoral view on the bio economy, Norut Report 12/2017 ISBN 978-82-7492-358-4.

208 Sigurðsson þ. (2017) Mesopelagic fish. The Icelandic case, North Atlantic Seafood Forum 2017, Bergen 7.3.2017.

209 Sigurðsson þ. (2017) Mesopelagic fish. The Icelandic case, North Atlantic Seafood Forum 2017, Bergen 7.3.2017.

mesopelagic depths may well have a significant upward impact on the amount of by-products and rest raw materials available for non-food uses.

What also prevents larger-scale mesopelagic fishing at the moment is the cost and effort of access to these deeper waters and the need to redesign fishing gear to catch the target fish and not by-catch. Technology innovation is needed, with a focus on efficiency and cost of capture and processing.

Other wild catches with potential non-food use include invertebrates such as krill and other planktonic crustacea (251Kt wild-caught in 2015); jellyfish; seasquirts and tunicates (3.8Kt); coelenterates such as sea cucumbers (30Kt-50Kt est. in 2008[210]; $4.6B (€4B) global sales[211]); echinoderms (114.5Kt); and aquatic plants other than seaweeds.

Currently underutilised resources of increasing interest are mesopelagic fish and invertebrates, low-trophic plankton & vegetation eaters, macro- and microalgae, if suitable cost-effective ways can be found of catching or wild-harvesting them. This may generate additional biomass for non-food uses, including e.g. high-value pharmaceutical molecules, nutritional ingredients for animals and humans, seaweed for bioplastics.

In the context of trends in policy, DiscardLess[212] has reviewed the situation in Alaska, where a discard ban was introduced in 1998 and stringently enforced since then; discard rates for Pacific cod fell from c. 7% to 0.4% and for pollock to <1%. Bycatch rates are <2% for mandatory pelagic trawls. Such policy changes, if successful, have the effect of reducing the amount of biomass that might be available for non-food utilisation.

The OECD's report on marine biotechnology points to integrated marine biorefineries as being the most viable way forward[213]. However, discussion of marine and aquaculture biomass is confined to microalgae and seaweeds, and there is no mention of the contribution of RRM from fisheries and aquaculture. The concepts involved in the Circular Economy and Circular Bioeconomy have meshed with the concept of biorefineries, originally envisaged for carbohydrate-rich cereals or sugarcane waste as an extension of fermentation, but now applied to a wide range of biomass types. Increasingly, the biorefinery is seen as a valorising and value-recovering tool to deal with undifferentiated biomass of variable quality and input specifications. This approach is partly developed for fish and algal biomass:

- fish oils may be further processed to generate a fuel oil;
- microalgal biomass may be grown on fish-processing waters (a waste material not considered often enough as a source of value) or on hydrolysed fish and shellfish wastes, for direct feeding to animals;
- the residues from biorefineries and from microalgal cultivation, liquid or solid, may be used in anaerobic digesters or other energy-recovery systems as the final stage after extracting other components or functions at a higher value plane.

In horticulture, vertical farming and aquaponics are growing in importance. Composting fish wastes and seaweeds together have been shown to produce a fertiliser with higher nutrient content. The combined biomass may be ensiled, or hydrolysed chemically or enzymatically, to produce liquid nutrient materials, for human and animal foods, or for agriculture and horticulture, depending on the quality and designation of the source material. Ensiling and hydrolysing combined biomasses to make

210 FAO (2008) Sea cucumbers: a global review of fisheries and trade, FAO Fisheries and Aquaculture Technical Paper 516.
211 Mentioned (no background data) on http://www.pacinternational.org/Sea_Cucumber_Projects.html.
212 http://www.discardless.eu.
213 OECD (2015) The long term prospects for marine biotechnology, OECD working party on biotechnology, nanotechnology and converging technologies 2015, report DSTI/STP/BNCT(2015)21.

liquid fertilisers may therefore become more viable. A challenge would be overcoming regulatory hurdles based on formulaic definition of materials as wastes, limiting their uses.

4.4.1 Seaweeds

To make better use of seaweeds, there is a need for a full-scale programme that determines the seaweed standing stock and the amount of seaweed that can be sustainably harvested; sets up a system for obtaining and recording comprehensive figures of annual seaweed production; develops and updates regulations and licensing procedures, to account for seaweed aquaculture; puts in place pilot farms for investigating the farming of seaweed species or strains; identifies methods for storage of surplus algal biomass; carries out Life Cycle Analysis of potential products; fosters and develops supply chains for seaweed-related products; and establishes knowledge transfer between research and industry, with development of algal business clusters. This approach, proposed for the UK[214], is likely to be similarly useful if not necessary for other countries and regions with potential for seaweed harvesting or farming.

4.4.2 Fish

The DAFIA project[215] notes that >1.3Mt of RRM are produced in Europe each year and the fact that there are established industries, particularly fishmeal processing, and accepted management routes, such as ensiling and composting, will make it more difficult to turn fish viscera and skin, not valorised by hydrolysis, into profitable products.

The Aquarel project, a Finnish-Russian collaboration 2012-2014, looked at bioenergy from fish wastes[216]. Transesterification of fish oils using alcohol and a catalyst results in 100% conversion to biodiesel, with glycerol production by conversion of the added alcohol. This produces >2x the energy content than the combined heat and power from anaerobic digestion. The potential for Karelia was seen as 2.6Kt fish waste pa yielding 10GWH of power per year, with a higher greenhouse gas reduction than conversion of the same amount of waste to fishmeal.

Some countries manage utilisation better than others, e.g. Iceland's approach to cod: "everything except the oink". Of **Iceland's** total landings of 1.4Mt[217], the major fish is cod; 84% of the 2013 catch of 236Kt of cod was eaten or exported for human food, including parts that would in other countries be discarded during processing, such as heads (28% of total catch-weight), livers (4.5%), edible trimmings used for mince (2%) and roes (1.3%)[218]. The catch in 2015 was 244Kt, of which 75% was used for human food. High-value non-food uses include leather from fish skin, skin & tissue repair patches from skin collagen, which are regulated medical devices, and cosmetics ingredients. A more recent estimate of 'waste' materials from fish, available for higher-value processing, was 43%[219].

The R&D support programme HAVBRUK2 in **Norway** provides funding for projects into cultivation and use of lower-trophic species (including seaweeds, microalgae and molluscs) as biomass for non-food uses such as bioenergy[220]. This is partly to expand Norway's aquaculture away from an enormous

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214 Capuzzo E. et al. (2016).

215 http://www.dafia-project.eu/.

216 Havukainen J. (2014) Fish waste utilization in Republic of Karelia – potential and environmental impact, Aquarel project final seminar, 18th September 2014 http://www.culmentor.com/aquarel/wordpress/wp-content/uploads/WEB_Havukainen-Bioresources-utilization.pdf.

217 FAO data (2015).

218 http://www.discardless.eu.

219 Fish Waste for Profit 2nd Icelandic Fisheries Conference, 14 September 2017.

220 The Research Council of Norway (2016) Work programme from 2016, Large-scale programme for Aquaculture Research (HAVBRUK2), ISBN 978-82-12-03514-0.

reliance on salmon and partly to provide substitutes for fishmeal and fish oils in aquaculture feeds. Interaction with other national funding programmes in energy, biotechnology and sustainable innovation in the food and biobased industries is expected.

The **Nordic Council** exists to provide inter-parliamentary cooperation and includes representatives of Denmark, Finland, Iceland, Norway and Sweden and the autonomous regions of Greenland, the Faroe Islands and the Åland Islands. The Nordic Bioeconomy Initiative was a cooperation programme between the Nordic Councils of Ministers, 2014-2016, that generated 5 programmes and 4 further projects and has also established a Nordic Bioeconomy Panel[221] (phase 1 2016-2018) and Nordic Bioeconomy Strategy (version 1, 2017) to take recommendations forward. The programmes relevant to aquaculture and fisheries included 'Innovation in the Nordic Bioeconomy', which supported projects to increase the sustainability of food production and create value from side-streams of food processing, in Faroes, Greenland and Iceland, by making innovation vouchers available for specific challenges identified by the food companies themselves; and 'Bioeconomy consortiums', one of which focused on agricultural side streams and rest raw materials and another on new methods of aquaculture feed production using wastes and insects. Of the further projects, Mapping the Nordic bioresources and Innovation from organic waste (primarily fish and meat, with some domestic wastes) are relevant.

The Panel identified 25 case studies falling into the four 'Strongholds' of the Nordic bioeconomy - Replace, Upgrade, Circulate and Collaborate. BlueGreenFuture in the Faroes aims to process 10Kt seaweed into protein, oil, vitamins and minerals, antioxidants and pigments for use in fish feed and consumer products, recycling 4.3Kt of CO_2 and using the residual materials as fertilisers and bioenergy biomass; a 4-University collaboration, Seafarm in Sweden, is similarly using seaweed as biorefinery input, for fatty acids, protein and other elements. Codland in Iceland is developing new products from underutilised or waste parts of cod, and also integrating the processes needed for this alongside a conventional fish-drying plant. The main target is to convert viscera and skin into higher-value products, such as good-quality fish oils and collagen peptides, using non-chemical processes. Polar Seafood of Greenland has moved on from processing and selling only halibut fillets to making use of the heads, tails and frames (bones), increasing catch utilisation from 50% to 90% and targeting higher-value uses of the rest raw materials than pet-food. Biomega Norway uses enzymatic hydrolysis to release nutrients from fish rest raw materials (heads, fins, frames, guts and tails) from salmon processing plants, producing salmon oil, salmon meal and peptides for human and pet nutrition. Royal Greenland converts prawn shells, formerly disposed of in the coastal waters or processed for animal feeds, into high-quality flour for human nutrition.

4.5 Potential Case Studies

1. In 2017, **Norway** established the **Norwegian Mesopelagic Initiative**, an international consortium of researchers, to develop sustainable fishing of mesopelagic species and the gear, vessels and detection methods to help achieve this[222]. In addition, action will be taken to secure the output chains. The NMI is an international consortium of researchers working across 7 packages, of which 2 work-packages concern management of catch for valorisation,

[221] http://www.norden.org/en/theme/nordic-bioeconomy/nordic-bioeconomy-panel/about-the-nordic-bioeconomy-panel.

[222] Institute of Marine Research, Nofima, University of Bergen and NIFES (2017) Mesopelagic Initiative: Unleashing new marine resources for a growing population.

including on-board processing; land-based processing, analysis of components, generation of products and their validation as safe food and feed ingredients.

2. The **Sociedad Nacional de Pesquería** (SNP) of **Perú** is developing a suite of projects focused on improving the management and utilisation of anchoveta and other fishmeal reduction species[223]. Direct consumption of species used for fishmeal is extremely low world-wide; anchoveta begin to spoil rapidly after bringing on-board, partly because of their very high oil content and they have a strong flavour, so there are technical and consumer challenges. The projects include improved systems for on-board processing and preservation, improved processes for protein extraction and production of protein concentrates and development of new nutritional supplements based on deodorised omega-3 fatty acids from the fish oils. This programme will begin shortly and continue until the early 2020s. There is also a much larger $120M (€103M) innovation programme, funded jointly by the Government of Perú and the World Bank, to increase direct consumption through product innovations, launched in 2017[224].

3. As a result of work carried out under the **Nordic Bioeconomy Initiative**[225] into the utilisation of biodegradable wastes, the Environment Agency of **Iceland** has set up an on-line marketplace for different types of biowastes including fisheries and meat, the Resources Square or **Auðlindatorgið**[226]. It is expected to become fully-operational during 2018, to connect producers and users and help reduce the 50% of landfill that is estimated to be biodegradable, the related carbon emissions, and the amount of biowastes being incinerated.

4. **Iceland** has also instituted on-board processing using the **Héðinn Protein Plant**, which turns edible trims and wastes into fish oil and fish meal[227]. Héðinn is a long-standing Icelandic engineering company which has designed and built all the on-shore fishmeal and fish oil production plants. The key to the on-shore and the more compact on-board systems is replacement of the conventional screw-press and liquid evaporation process by a two-stage drying process that reduces the size and number of components and process tanks and uses a lower temperature, recycling drying air, thus reducing energy inputs. It uses half the fresh water for processing the material itself, compared with conventional methods, and uses 10% of the water usually needed in scrubbing and condensing.

5. In the **USA**, a company, **Bloom**, has been established as a merger between a long-standing algal clean-up and polymer manufacturing company, Algix, and a green product development consultancy, Effekt[228]. The company uses Algix's technology to harvest nuisance blue-green algae (*Cyanobacteriaceae*) with the aim of producing biopolymer-plastic flexible and compressible foams for a range of products including footwear, joint-support braces, surfboards and paddles, toys, fitness mats, gaskets and seals. Freshwater lakes and ponds containing algae are filtered through a recirculation system brought to the site when algal growth is seen; the microalgal material is heat-dried using solar energy to a powder and mixed at 15%-60% levels with [poly]ethylene vinyl acetate before extruding with air to form foam

223 Innóvate Perú/Sociedad Nacional de Pesquería (2016) Agenda de Innovación Tecnológica para la Utilización de la anchoveta (Engraulis ringens) en el enriquecimiento de aliimentos de consumo humano.
224 http://projects.worldbank.org/P155902?lang=en.
225 Gíslason S. and Bragadóttir H. (2017) The Nordic Bioeconomy Initiative NordBio Final Report TemaNord 2017:526, Doi: 10.6027/TN2017526.
226 http://www.audlindatorg.is/, Icelandic only.
227 https://hedinn.com/fishmeal-processing/.
228 http://bloomfoam.com.

pellets. The technology is promoted as an ecologically-sound way of valorising microalgae that are wild-harvested.

6. In the **USA**, **Delmonte** has established an algal fertiliser system in Arizona in which microalgae are grown in simple photobioreactors adjacent to melon fields and algal cells are continuously distributed to the melon plants through the drip-irrigation system[229]; melons matured a week earlier and were 40%-50% larger than control fruit.

7. In the **UK**, seaweed and plant biomass is being turned into liquid containers by **Skipping Rocks Lab**[230], a small and young design company working in sustainable packaging. Their idea, OOho!, is a sphere intended for drinking water, soft drinks, spirits and liquid cosmetics. The company says that it is cheaper than conventional plastics, with a shelf-life of a few days, and completely biodegrades within 4-6 weeks, but can also be eaten. The material can be flavoured and coloured. In manufacturing analysis so far, it appears to have 20% the carbon impact and 11% the energy requirement of PET.

8. In **Spain**, the mussel producers **Frinsa** and **Amegrove** are providing mussel shells as crushed material for soil remediation and bulking in vineyards, via local wine cooperatives. Almost 100Kt mussel shells are produced each year in Galicia, where the mussel-growers and processors are based. Mussel shells are used as a pH-corrector and general fertiliser[231]. In **New Zealand**, a similar operation has been producing calcium-containing fertiliser from finely crushed mussel shells since 2014[232], as **Havelock Shell Processors**[233]. Currently tests are being carried out in New Zealand on edible horticulture soils to assess the possibility of controlling nematodes using crushed mussel shells; it has also been suggested that the reflectivity of the mussel shells round vines may enhance ripening of the grapes[234].

9. The **EU**-funded project **MIRACLES**, 2013-2017, worked on integrated biorefineries for microalgae[235]. The aim was to produce omega-3-rich microalgae for feeding to aquaculture fish and partners included Ewos, Unilever and DSM as well as SMEs involved in aquaculture, feed, cosmetic ingredients, biopolymers and processing.

10. Jellyfish are an increasing nuisance and hazard in Mediterranean and coastal waters. The **UK**-based company **Jellagen** uses jellyfish caught off the coast of Wales as the source of high-quality collagen for research and medical biomaterials.

11. **Benthos Bioscience** is a Chinese company which is developing its activities in USA, Canada, and Europe with focus on French outermost territories and Portugal. They are one of the largest producers of sea cucumbers. Sea cucumbers are a class of echinoderms widely distributed in the marine environment. The high market value demand for sea cucumbers lies in the use of its muscle as a source of protein. The total production of sea cucumbers in China was 100,000 tons in 2010; 80% of the production is from aquaculture and enhancement.

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[229] Carr M. (2018) Can algae really do CCU? Status and potential of biological carbon capture and use USEA Technology Series, March 12 2018.
[230] http://www.skippingrockslab.com.
[231] Álvarez-Rodríguez E. et al. (2012) Use of mussel shells as a soil amendment: effects on bulk and rhizosphere soil and pasture production, Pedosphere 22(2): 152-164.
[232] http://www.stuff.co.nz/business/farming/agribusiness/9849293/Farmer-develops-mussel-shell-fertiliser.
[233] http://www.havelockshellprocessors.co.nz.
[234] *pers. comm*. B Brownlee (2018) Havelock Shell Processors.
[235] http://miraclesproject.eu.

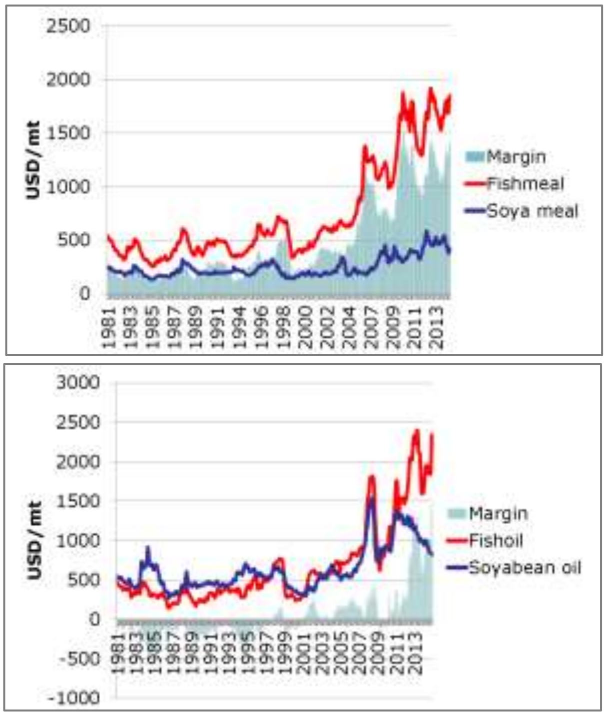
Section 2 - The size of demand

5 Introduction – some main trends

5.1 Fish waste and fishery by-products

One of the main non-food uses (by-products) from seafood is fishmeal and fish oil[236]. There is a growing demand for fishmeal and fish oil, in particular from the aquaculture industry, and together with declining pelagic (anchoveta) fisheries, fish oil and meal are becoming limited resources thus leading to higher prices, see figures below.

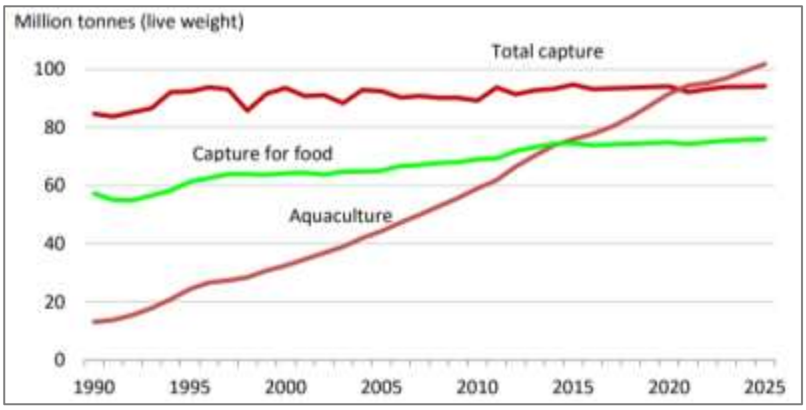
Figure 12 - Fishmeal and Fish oil prices from 1981 to 2014



Source: FAO (2016)

The aquaculture sector is expected to grow, while captures – for food and in total – are expected to more or less remain at the level of today, see figure below. Thus, fishmeal and fish oil resources are expected to remain scarce resources in the future.

Figure 13 - Expectation for capture and aquaculture



Source: Vannuccini (2016)[237]

[236] FAO (2016) The State of World Fisheries and Aquaculture (SOFIA).
[237] Vannuccini S. (2016) The Importance of Forage Fisheries Linking Forage Fisheries to Food Security, Perspectives for Fishmeal and Fishoil, presentation at the Symposium on future perspectives of fishmeal and fish oil, Hirtshals, Denmark, 29-30 August 2016.

Today most fish oil still goes into aquaculture feed. However due to high prices both for fishmeal and fish oil, volumes used show a downward trend, and these limited resources are being used more strategically. Initiatives for finding replacements to be used, e.g. for aquaculture feed, are many, but cannot be expected to scale up and replace the need for fishmeal or fish oil in the near future.

The observed trend of more processing of fish products will increase the volumes of rest raw material and by-products, and the utilisation of fish by-products has been gaining attention. In some countries, the utilisation of by-products has become an important industry, and improved processing technologies are leading to more efficient utilisation.

High volumes of post-harvest losses remove large quantities of fish from the market – up to 25% in many developing countries[117] – and the reasons according to the FAO include lack of infrastructure and adequate policy measures, lack of access to credit, lack of knowledge (limited education), little or no access to technology.

In general, the biomass not used directly for human food ends up as (c.f. chap. 0 Introduction & Summary):

- **At-sea discards** (e.g. pollock RRM by Russian fisheries, and bycatch);
- **Fishmeal and fish oil** for animal feed;
- **Fishmeal extracts** for protein and oils for human nutrition;
- **Aerobic Digestion** for biogas and fertiliser/soil improver;
- **Composting** for fertiliser/soil improver;
- **Ensiling** for protein concentrates and hydrolysates for animal nutrition;
- **Landfill** (less so in Europe and other developed states);
- **Processed fish oils** for industrial uses;
- **Chopping/mincing/freezing** for direct baits, animal and fish feeds;
- **Higher-value elements**: collagen, gelatin, minerals, chitin, carotenoids, enzymes, amino-acids, peptones.

Different parts of the fish are used for different purposes as described in the table below.

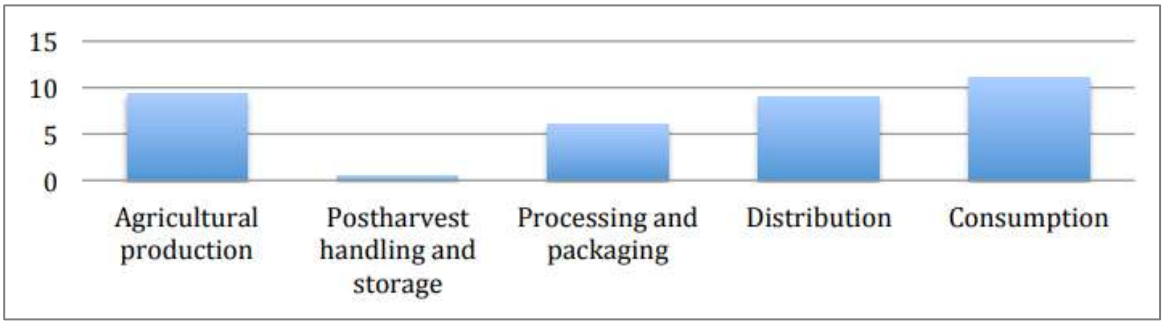
RRM	Possible uses
Red meat	Pet foods
Frames	Minerals for feed and fertilisers; hydroxyapatite for medical devices
Loin or fillet pieces	Premium petfoods
Heads, trimmings and frames	Steaming, crushing, pressing to yield oils; fractionation to yield omega-3 fatty acids
Skin, frames and fins	Collagen, gelatin
Any material	Extraction of proteins and peptides; bioactive compounds; anti-oxidants
Viscera	Enzymes for industrial and laboratory use; peptones for microbiological media

Waste or potential rest raw materials occur at different stages in the supply chain, c.f. Figure 14 (from *Task 1, 0.5* Wastes)[238]. These figures are based on a Norwegian study, but reflect a general situation where significant levels of waste occur at different stages in the supply chain. The challenge with making use of these resources increases as they move down the supply chain. At distribution and consumption level, about it becomes less germane to talk about 'seafood waste' as such, but rather a

[238] Jouvenot L. (2015) Utilisation of rest raw materials from the fish industry: Business opportunities and logistics requirements, Master's Thesis Norwegian University of Science and Technology NTNU, Trondheim June 2015 https://brage.bibsys.no/xmlui/bitstream/handle/11250/2351183/13467_FULLTEXT.pdf?sequence=1.

mix of food waste. Food waste can also be taken care of and used, but this is regarded to be outside the scope of this section (for further reading se among others the DAFIA Horizon2020 project).

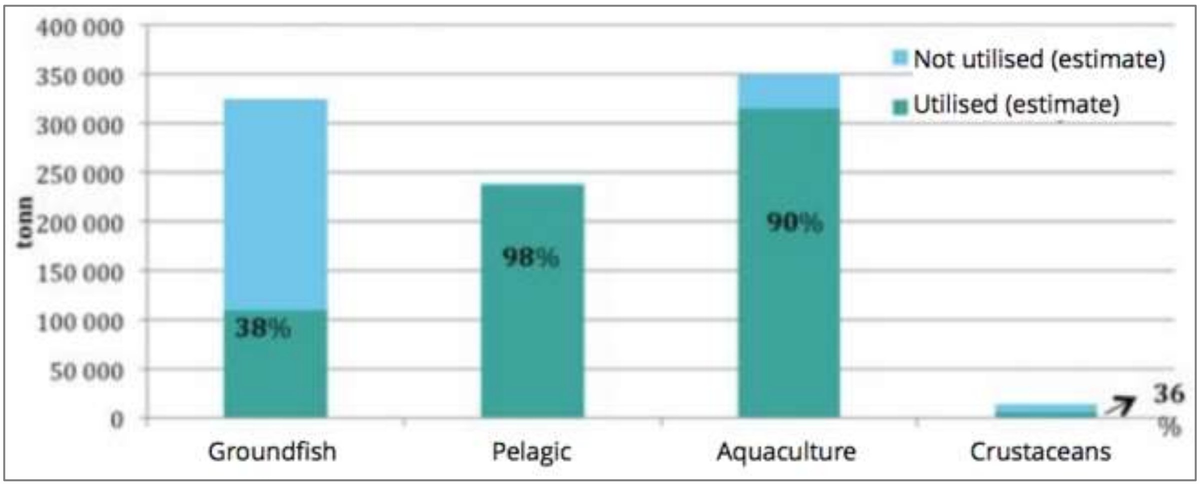
Figure 14 - Proportion of waste & by-products (% of original landings) by stage of supply



Source: Jouvenot, 2015

The different seafood sectors provide different utilisation of the RRM or 'by-products'[239], and so have a different potential for making better use of the resources. We observe that the groundfish (demersal) sector still has a way to go before available resources are taken well care of.

Figure 15 – Extent of utilization of rest raw material by source



Source: Sintef/Kontali, Analysis of marine by-products, 2015

In the figure developed by Whitaker and Fylling-Jensen at Nofima, below, the product pyramid for RRM is sketched and systematised with respect to the estimated time for development, the cost of development, the availability of the relevant resource for the product, the need for documentation, potential market value and the skills and competence needed for delivering at the respective levels. Until recently, the focus on use of RRM has been most at the lower part – the high-volume part – of the pyramid, but as fishery resources have become more limited and their value has increased, there is an increasing focus towards the high (upper) value part.

239 Jouvenot L. (2015) taken from various sources including Olafsen T., Richardsen R. et al. (2014) Analysis of marine by-products 2013, SINTEF Fisheries and Aquaculture http://www.kontali.no/%5Cpublic_files%5Cdocs%5CAnalysis_of_marine_by-products_2013_Summary_English.pdf; Olsen R.L., Toppe J. and Karunasagar I. (2014) Challenges and realistic opportunities in the use of by-products from processing of fish and shellfish, TIFS Tech 36(2): 144-151, Doi: 10.1016/j.tifs.2014.01.007; and Sandbakk M. (2002) Handling of by-products from cod-fish - a state of the art report from selected countries, SINTEF Fisheries and Aquaculture.

Figure 16: Product pyramid for rest raw material and some main aspects

Products	Time to market Years	Cost of development	Resource availability	Need for documentation	Potential market value	Skills and competencies
Pharmaceuticals	10 – 15 +	Very high	Limited	Very high	Very high	Extensive medical and market
Cosmetics	3 – 5 +	Low to high	Fair	Medium	High	Toxicology, effects
Nutraceuticals	3 – 5 +	Medium to high	Fair	Medium to high	High	Nutrition and medicine
Food	2 – 5 +	Low to medium	Good	Medium	Medium to High	Nutrition, Food science
Feed	2 – 5 +	Low to medium	Very good	Medium	Medium to high	Nutrition, animal science
Bioenergy	2 – 5 +	Low to medium	Very good	Low to medium	Moderate	Energy
Fertilizers	1 – 2	Low	Very good	Low to medium	Moderate	Agriculture, agronomy etc

Increased complexity of processing
Reduced volume

Source: Whitaker and Fylling-Jensen, Nofima

5.2 Algae

Marine macroalgae, or seaweeds, are aquatic plants that generally live attached to rock or other hard substrata in coastal areas. They are divided in three different groups, empirically distinguished on the basis of thallus (the algal body) colour: brown algae, also known as kelp (phylum *Ochrophyta, class Phaeophyceae*), red algae (phylum *Rhodophyta*; below Gelidium in Ireland), and green algae (phylum *Chlorophyta*, classes *Bryopsidophyceae*, Chlorophyceae, *Dasycladophyceae*, *Prasinophyceae*, and *Ulvophyceae*).

Red and brown algae are almost exclusively marine, whereas green algae can also be found in inland freshwater, and even on land.

In Europe, the main exploited algae species are *Laminaria hyperborea*, *Laminaria digitata* and *Ascophyllum nodosum*. These species, and especially kelp forests, are considered among the world most ecologically dynamic and biologically diverse habitats. Other species are found on the European Atlantic coast, but few of them currently have a commercial value. However, although seaweed is a product widely used for food in direct human consumption, it is also an ingredient for the global food and cosmetics industries and is used as fertilizer and as an animal feed additive.

In Europe, production of algae is traditionally focused on seaweed harvesting to supply the processing industry of hydrocolloids extraction for industrial purposes. However, the EU macroalgae production is limited in its development perspectives and the competition with non-EU countries has become significant.

Whilst Asian production is mostly based on cultivation of algae, the European seaweed industry is mainly based on the harvesting of macroalgae. On the European Atlantic coast, macroalgae have been harvested by coastal populations for centuries. The volume of seaweed harvested for human consumption remains marginal compared to the production aimed at industrial uses (with the exception of southern Europe).

The commercial value and the quantities landed for each species vary and depend on harvesting techniques. The most important, in terms of landings and value, are *Laminaria digitata*, *Laminaria* *hyperborea* and *Ascophyllum nodosum*, because these species are harvested mechanically by boat in France and Norway. *Ascophyllum nodosum*, is harvested by boat in Norway, whereas in France and Ireland it is harvested manually. All other species are harvested manually either on foot or by diving[240].

Mechanical harvesting is undertaken by boats and is mainly practiced in Norway (Rogaland to Sør-Trøndelag), France (Brittany), Spain (Galicia and Asturias) and to a lesser degree in the Basque country (France) and Ireland.

Manual harvesting of seaweed and gathering of storm cast seaweed are important in France, Ireland, Spain and Portugal. Harvesters either gather the cast or cut seaweed at low tide. Diving is another way to harvest seaweed manually and is practiced mostly in Portugal.

The management tools implemented differ according to the country, the species and the harvesting technique. Seaweed harvesting is regulated with different tools: licenses or harvesting authorisations, quotas by harvesting zone, individual quotas by boat, harvesting size and rotation systems. In most of the harvesting areas, the biomass is not well known, and several current projects aim to assess the importance of the resource in order to adjust the harvesting effort.

However, the preservation of kelp has become a strong environmental concern and some countries have decided to protect these habitats by restricting the use of mechanical harvesting or by creating protected areas around them. Kelp harvesting is blamed for harming the ecosystem because of the damage it can cause to substrates and to the habitats of certain species. For example, seaweed harvesting has been recently forbidden in the Spanish Basque country due to the implementation of a Natura 2000 marine area.

In the world, the market demand for seaweed has been increasing over the recent years because of the increasing demand from the algae extracts (agars, alginate & carrageenan) industry. These processed seaweeds in form of hydrocolloids find various applications such as meat & poultry processing, dairy, canned fish, desserts & jelly, along with in non-food applications such as textiles, pharma & medical, pet food, textile printing, paper products & other industrial products. These products have experienced a strong development in European and Asian markets mostly because of the rising interest for products providing health benefits. Other applications of commercial seaweeds in end-user industries, such as wastewater treatment and the generation of biofuels & cosmetics, are further projected to boost the global demand for commercial seaweeds over the coming years.

5.3 Focus on making better use of marine and aquaculture resources

There is a global focus on making better food use of marine and aquaculture biomass in the EU. In a workshop held in October 2016[241], some policy initiatives were recommended, including producing a roadmap, supporting regional pilot plants at semi-industrial scale and funding larger regional bio-refineries or algal lighthouse projects. In addition, the workshop discussed the need for monitoring the types and amounts of marine and aquaculture biomass that might be directed to added-value uses, the impact of rules such as those governing the management of Category 2 waste materials, and the Landing Obligation regulations of the Common Fisheries Policy.

[240] Netalgae project http://www.netalgae.eu/uploadedfiles/Filieres_12p_UK.pdf.

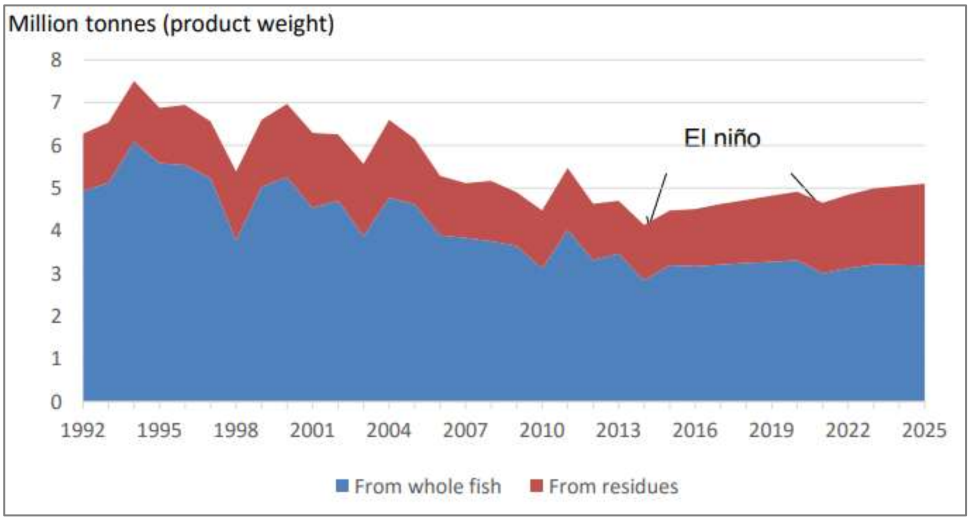
[241] Aquatic food products and new marine value chains – reinforcing EU Research and Innovation policy for food & nutrition security. Report of a workshop, EU (2016) https://ec.europa.eu/info/sites/info/files/conferences/food2030_2016/w2_aquatic_food_new_marine_value_chains_full_report.pdf.

6 The size of demand

6.1 Fish waste

Associated with the expected growth in aquaculture, the demand for fishmeal and fish oil is expected to increase. This increasing demand is expected to be satisfied by more efficient use and greater availability of RRM from fish and seafood rather than an increased volume of marine catches, as suggested by Vannuccini, FAO.[242].

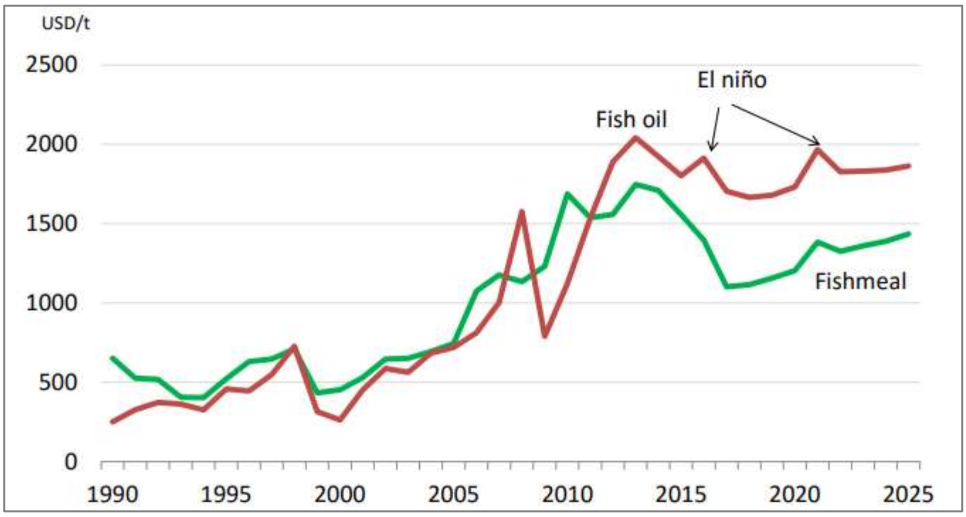
Figure 17: Fishmeal historical global volumes and expectation, FAO



Source: Vannuccini (2016)

In addition, prices are expected to remain high, and more so for fish oil than for fish meal. However, both are limited resources highly sought in aquaculture, and also for other food productions (livestock sector like pigs and poultry) as well as in a growing pet food industry.

Figure 18: Fishmeal and fish oil prices

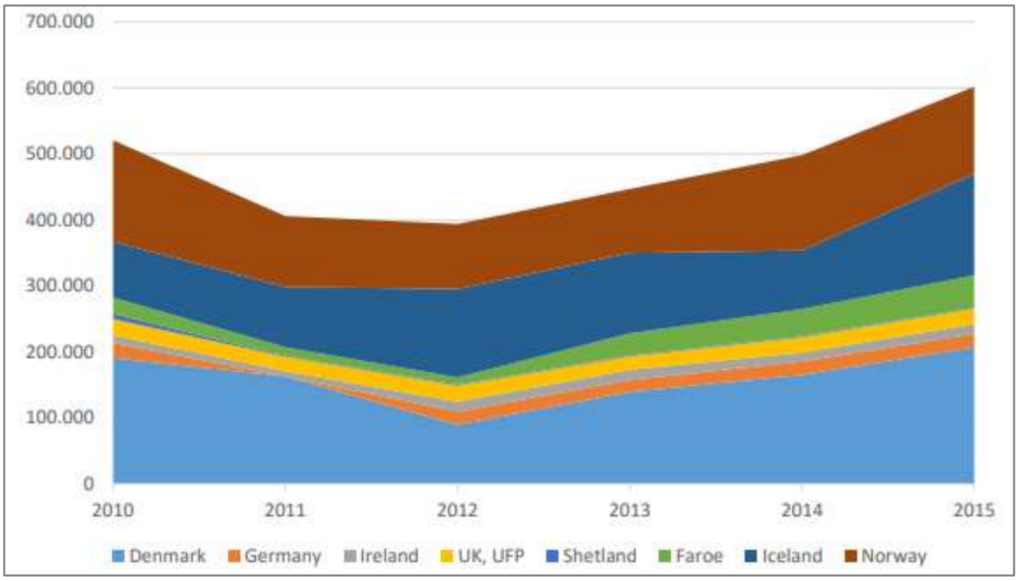


Source: Vannuccini (2016)

242 Vannuccini S. (2016) The importance of Forage Fisheries Linking Forage Fisheries to Food Security, Persepctive for Fishmeal and Fish Oil, Hirthals, Denmark, August 2016, http://www.eufishmeal.org/cm-webpic/symposium%20pr%C3%A6sentataioner/stefania%20vannuccini.pdf.

The fish meal production is expected to increase, taking better care of resources both from fisheries and from aquaculture. The growth might be driven by increased prices, since demand will exceed supplies, see figure below[243].

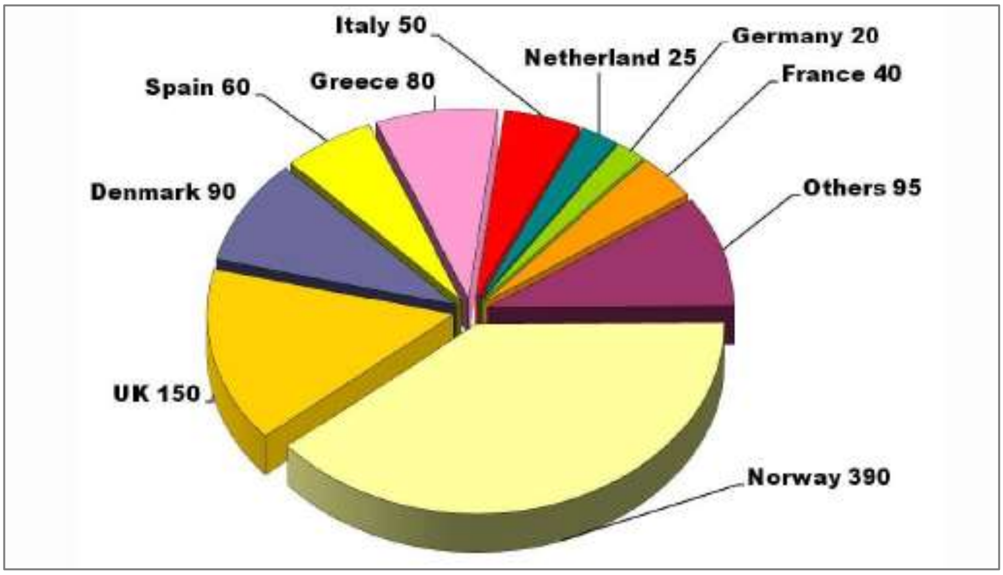
Figure 19: EU Fishmeal production



Source: Palsson (2016)

The usage of fishmeal (and fish oil) in Europe can is outlined in the figure below, and coincides with high activity both with respect to aquaculture and fish feed industry. Even though the exercise dates back to 2009, the picture overall picture remains unchanged.

Figure 20: European fishmeal consumption 2009 (EU-27 + Norway)

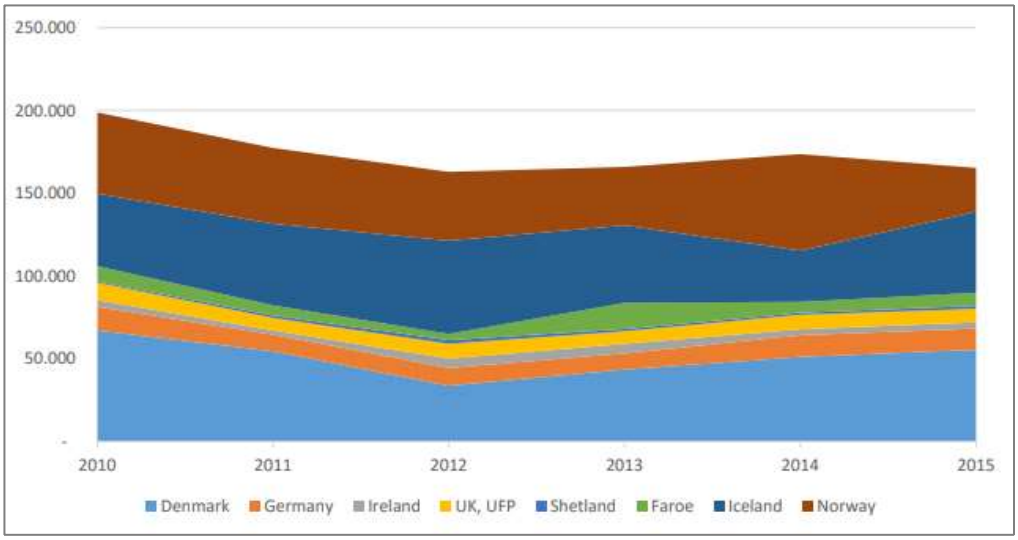


Source: Resource supply from sustainably managed sources – using the example of fishmeal. Michael Lutz, Köster Marine Proteins (2010)

243 SEAFISH (2016) Fish meal and fish oil facts and figures
http://www.seafish.org/media/publications/SeafishFishmealandFishOilFactsandFigures_201612.pdf.

The production of fish oil is not expected to increase to the same extent as fish meal. Hence, fish oil can be seen as a scarcer resource, which also explains the prices for oil increasing to a higher level and staying as high as shown in Figure 21 below.

Figure 21: European fish oil production 2010 to 2015 (tonnes)

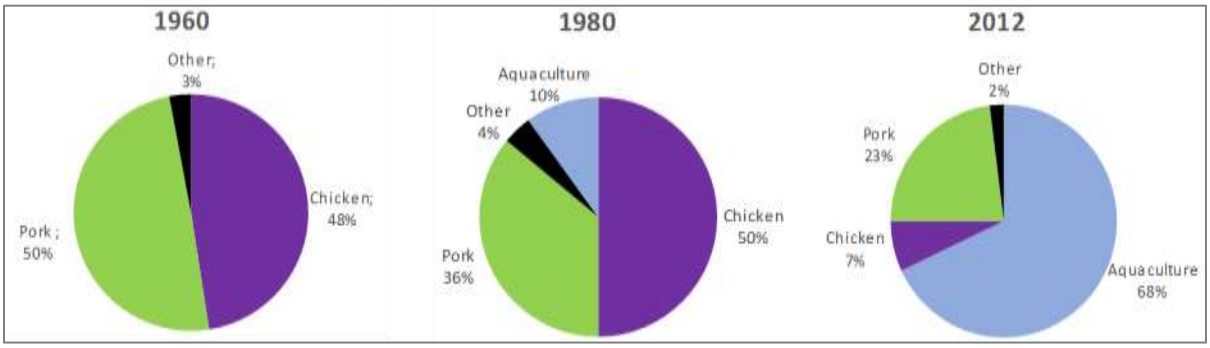


Source: Palsson (2016)

6.1.1 *Feed demand for aquaculture increases*

The demand for fishmeal and fish oil within the feed industry will increase in accordance with the growth of the aquaculture sector globally, and the changes described by Asche in the figure below are expected to continue.

Figure 22: Changes in the fish meal and fish oil markets from 1960, 1980 to 2012



Source: F. Asche, UiS, Hirtshals, (2016)[244]

6.1.2 *Feed demand for livestock and other will remain high*

The demand for ingredients to livestock feed will also remain high, while, judging from Norway, the request from the fur sector might be reduced depending on political decisions regarding the practice of using animal fur for the clothing industry. However, the growth in demand from the pet food industry, e.g. for high quality proteins, will likely increase the need for fishmeal more than the potential drop in the fur sector.

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[244] Asche F. (2016) Fishmeal and fish oil: Why bother? Opportunities and challenges, Hirtshals, Denmark, August 2016 http://www.eufishmeal.org/cm-webpic/symposium%20pr%C3%A6sentataioner/frank%20asche.pdf.

6.1.3 Demand for human consumption

Other uses of fish meal, and in particular fish oil for direct human consumption, is expected to increase. Being a high value usage, this will likely increase the competition for scarce resources and keep the prices for rest raw materials high. However, the separation between high-quality and low-quality resources might be significant, thus increasing the pressure on proper disposal of rest raw material.

6.1.4 Usage for bio gas/energy

Low quality outputs from rest raw materials (such as dead fish from Norwegian aquaculture) are today being used for bio gas/energy production, and the demand within this area is also expected to increase. However, efficient logistics and up-scaling for high volumes is seen to be a necessary factor for this usage.

6.1.5 High value usage

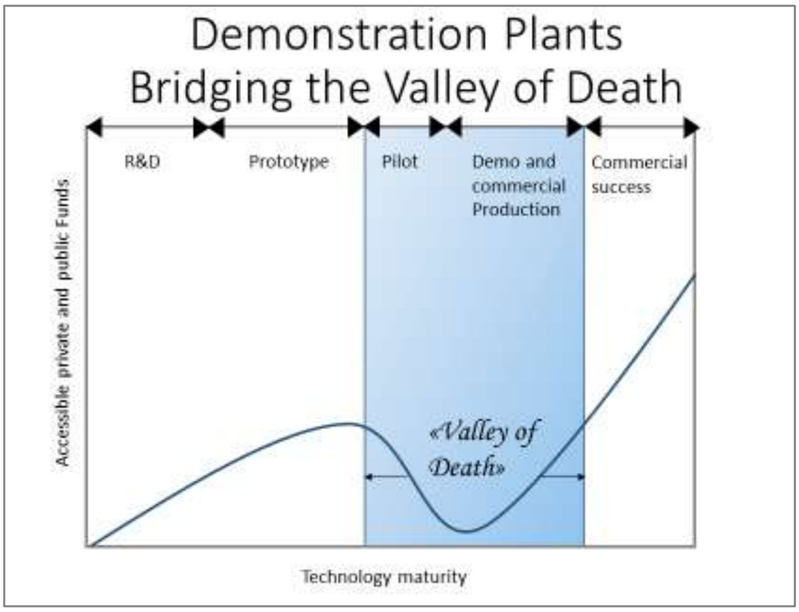
In countries with advanced usage of rest raw materials, it seems that these are steadily climbing up the value pyramid towards more advanced and high value uses. The demand for healthy good resources from marine and aquaculture origin is also likely to have a positive impact on value further down in the value pyramid, through higher competition about the resources.

When it comes to the high-end products/uses that are currently being developed, the demand may be difficult to estimate. However, because several of these high-end products possess health promoting properties, the outlook of the segment is bright, in view of an ever-increasing share of the population placing value on a healthy lifestyle.

At the same time, it should be noted that for much of the research, innovation and development focusing on making good use of seafood resources, the cost of development is high and the time to market long, thus significant financial resources are needed. This has been addressed among others by the EC workshop held in October 2016, whose report states[245] that it is necessary to provide *«… direct financial support to actions to develop pilot plants and bio-refineries as «lighthouse» projects to encourage further investment."* i.e. beyond the R&D and prototype phases. There is still a long way to go, and Whitaker (Nofima), exemplifies this in a picture (see below), adapted from Randall, where the emphasis is on the availability (or lack of) of financial resources in the critical pilot and demo phases – the so-called "Valley of Death" – is limited. The history from the Ocean Cluster in Iceland (§ 8.1.2.1) the business incubators suggested in Denmark (§ 8.1.3.2) showcase how strategic certain moves might be – moves that are assessed to be critical to whether an idea survives all the way to a commercial successful product.

[245] Aquatic food products and new marine value chains – reinforcing EU Research and Innovation policy for food & nutrition security. Report of a workshop EU (2016) https://ec.europa.eu/info/sites/info/files/conferences/food2030_2016/w2_aquatic_food_new_marine_value_chains_full_report.pdf.

Figure 23: "Bridging the valley of Death"



Source: adapted by Whitaker, NOFIMA, from Randall, Q. (2016), Invest Medicine Hat

6.1.6 Conclusion for fish waste demand

In the future, oil, meal and concentrate products will register the main output in terms of volume, and the feed sector will experience the largest growth will be seen in. However, there is also good potential for the high end/high value markets – though more demanding.

6.2 Algae

6.2.1 Global production of algae: main figures and trends

In FAO production statistics, algae are included in the aquatic plants category (brown, red and green algae as well as other species such as spirulina).

Global algae production, all species included, amounted to 31,2 million tonnes in 2016, experiencing an +103% increase in the last decade.

The leading producers are China and Indonesia, which provided respectively 47% and 37% of total world production in 2016 (production respectively reached 14.7 and 11.7 million tonnes). Other important producers were Republic of Korea with 1.8 million tonnes produced in 2016 (6% of world production) and Philippines with 1,4 million tonnes (4%). EU production ranked 10th in 2016, behind Japan, Chile, Malaysia, Norway and Tanzania (Zanzibar).

In terms of evolution, during the past ten years (2006-2016), total algae production remained relatively stable in Chile (+2%) and Philippines (–4%), it slightly increased in Norway (+17%) and it strongly increased in China (+47%), Korea (+51%), Zanzibar (+45%) and the EU (+76%). In Indonesia and Malaysia, it soared (respectively +893% and +243%). Among the major producers, the only decreasing trends in production during the past decade were observed for Japan (-22%) and India (-32%). However, in recent years (from 2011 mostly) most of the leading producers have experienced a strong slowdown of this growth or even a slight decrease of the production (in Philippines for instance).

Table 29: world production of aquatic plants (in 1000 tonnes)

Country	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
China	10.015	10.074	10.300	10.772	11.339	11.824	13.090	13.844	13.572	14.186	14.719
Indonesia	1.175	1.733	2.148	2.967	3.918	5.176	6.522	9.316	9.042	11.318	11.672
Korea	1.224	1.255	1.379	1.314	1.359	1.451	1.477	1.584	1.586	1.694	1.850
Philippines	1.469	1.505	1.667	1.740	1.802	1.841	1.751	1.559	1.550	1.567	1.405
Japan	604	618	561	561	530	438	539	503	466	494	471
Chile	339	340	412	456	381	418	440	530	430	358	345
Malaysia	60	90	111	139	208	239	331	-	245	-	206
Norway	145	135	154	160	159	152	141	154	154	147	169
Zanzibar	77	-	108	-	125	130	151	110	133	172	111
EU 28	52	73	73	52	56	81	75	104	92	53	91
India	34	34	34	35	31	30	28	27	22	22	24
Other	184	136	137	153	160	107	135	158	148	153	156
World total	**15.378**	**15.992**	**17.086**	**18.349**	**20.066**	**21.887**	**24.681**	**27.889**	**27.440**	**30.165**	**31.218**

Source: FAO

6.2.2 Market trends and outlook

The European macroalgae industry is based on the harvesting of natural resources of macroalgae, and the production has decreased in the last 10 years. To face a series of several challenges such as stock reduction, increasing processing production and labour costs and environmental constraints of the seaweed harvest in protected areas, the share of local algae in the processing industry in Europe has been mostly declining. These factors have negatively impacted the European processing industries local supply, which has conducted to an increase of imports of seaweed unfit for human consumption.

However, the potential for the development of the algae market in Europe is still considerable. There is an increase of public concerns about the use of "chemicals" (herbicides, pesticides and fertilisers) which calls for finding biological and organic alternatives, something that strengthens the potential for seaweed extracts market. Moreover, the trend in EU and national legislation to limit the use of synthetic additives and antibiotics[246] in feed ingredients. This is a powerful market driver for sustainable feed ingredients, and a good opportunity for algae extracts.

The extraction of high value-added substances from algae is technology demanding and associated with high investment costs. More knowledge is also required regarding the market potential of seaweed bioactive compounds to identify commercial opportunities. The current European market for liquid seaweed extracts is estimated at US$ 30 million (€ 26 million).

On the other hand, there is a growing interest for seaweed cultivation and a wide range of industrial application in western countries. But tools ad methods (especially in Norway) for establishing a seaweed industry still need to be developed or adapted from Asian models to fit European frameworks. However, it is very unlikely that the aquaculture of carrageenan-producing seaweeds will succeed in Europe because it would be very difficult for European producers to compete with

[246] https://ec.europa.eu/health//sites/health/files/antimicrobial_resistance/docs/2015_prudent_use_guidelines_en.pdf.

producers in south-east Asia (particularly in the Philippines and Indonesia) and in eastern Africa (Tanzania and Zanzibar). European producers will have great difficulty in penetrating the fastidious and regulation-intensive Japanese market as very high standards are expected and achieved, particularly for food products.

However, several niche markets are growing, providing new opportunities for algae products. For instance, in Ireland, seaweed baths are becoming increasingly popular. The market for algotherapy, which is expected to expand, could represent a very attractive area for niche companies to exploit. (The equivalent in France is called "le health-farm weekend").

The article *A decade of change in the seaweed hydrocolloids industry*[247], provided in 2011 a good synthesis of the current stakes in the industry:

On a global perspective, seaweed hydrocolloid markets continue to grow, but instead of the 3–5% achieved in the 1980s and 1990s, the growth rate has fallen to 1–3% per year. This growth has been largely driven by emerging markets in China, Eastern Europe, Brazil, etc. Sales of agar, alginates and carrageenans in the US and Europe are holding up reasonably well in spite of the recession. However, price increases to offset costs in 2008 and 2009 have begun to have a dampening effect on sales, especially in markets where substitution or extension with less expensive ingredients is possible. These higher prices have been driven by higher energy, chemicals and seaweed costs. The higher seaweed costs reflect seaweed shortages, particularly for carrageenan-bearing seaweeds. The Philippines and Indonesia are the dominant producers of the farmed Kappaphycus and Eucheuma species upon which the carrageenan industry depends and both countries are experiencing factors limiting seaweed production. Similar tightening of seaweed supplies are beginning to show up in brown seaweeds used for extracting alginates, and in the red seaweeds for extracting agar. The structure of the industry is also undergoing change. Producers in China are getting stronger, and while they have not yet developed the marketing skills to compete effectively in the developed world markets, they have captured much of their home market. China does not produce the red and brown seaweeds needed for higher end food hydrocolloid production. Stocking their factories with raw material has led to the supply problems. Sales growth continues to suffer from few new product development successes in recent years; although some health care applications are showing some promise, i.e., carrageenan gel capsules and alginate micro-beads.

[247] https://link.springer.com/article/10.1007/s10811-010-9529-3.

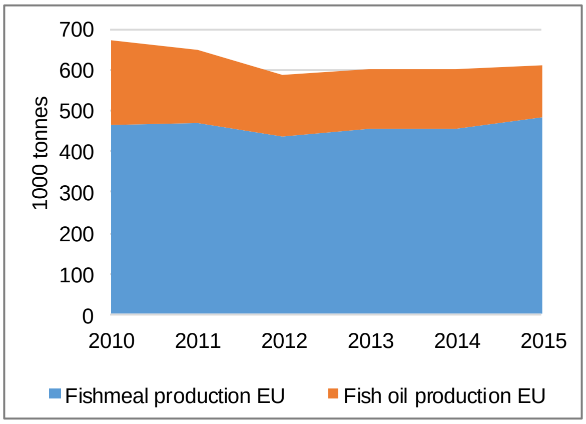
Section 3 - Top products and uses

7 Top non-food product and uses

7.1 The EU production and trade for fish waste

According to EUMOFA[248], EU fisheries for non-food use constituted approximately 20 % of the catches in volume and 3 % in value in 2016. The main catching Member State was Denmark, accounting for 78% of total EU landings in volume. The catches for non-food use go mainly to the production of fishmeal and fish oil, while small volumes are utilised as bait in fisheries or feed in zoos. The EU produces approximately 500,000 tonnes of fishmeal and 120,000 tonnes of fish oil each year, for which Denmark is the largest producing nation. Fishmeal and fish oil are in great demand as an ingredient in the feed used in aquaculture in the EU and Norway. Due to significant variations in the quotas for non-food use species, the availability in EU fisheries varies strongly from year to year. Total values of non-food-use fisheries in the EU were nearly EUR 222 million in 2016 (i.e. 3% of total value of EU fisheries). Total landings for non-food use in the EU reached 786,000 tonnes in 2016.

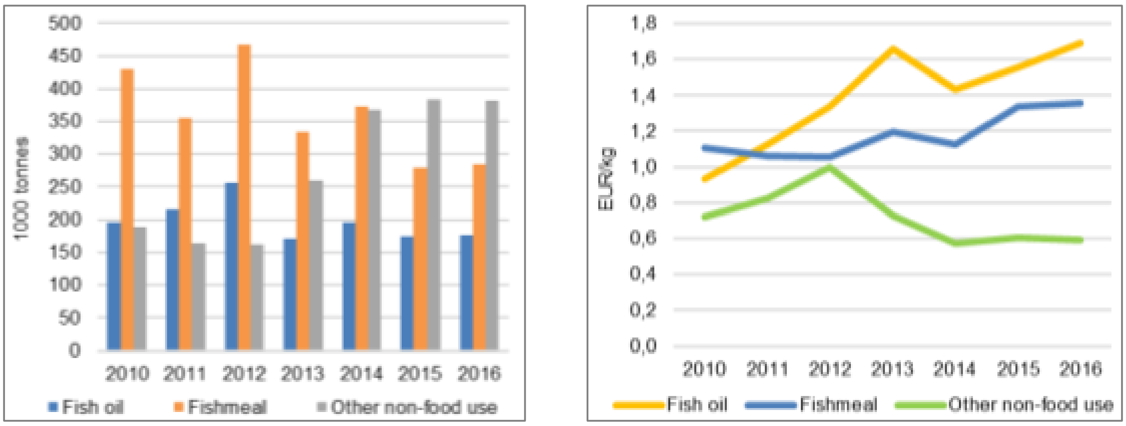
Figure 24: EU production of fish meal and fish oil, 2010 to 2015



Source: FAO

In 2016, the volume of imported non-food products totaled 844,000 tonnes, a slight increase over the year before, when they were 837,000 tonnes. The nonfood-use commodity, one of the most important in terms of volume among extra-EU imports, attained 284,000 tonnes of fishmeal, 177,000 tonnes of fish oil, and 383,000 tonnes of other non-food products (fish waste, crustaceans, seaweed, and ornamental fish).

Figure 25: Extra-EU imports (volume) of non-food products and prices

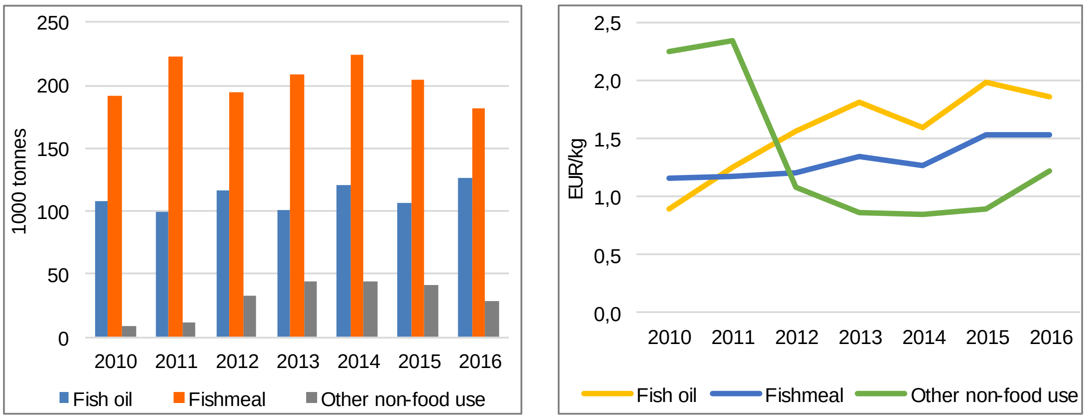


Source: EUMOFA

248 EUMOFA (2017) Non-Food fisheries in the EU, Monthly highlights, No. 10/2017, pp. 16-23, https://www.eumofa.eu/documents/20178/109202/MH+10+2017.pdf.

Denmark and Germany were the top EU importers in 2016 with 421,000 tonnes and 139,000 tonnes, respectively. The main uses for fishmeal and fish oil are as ingredients in aquaculture feed (i.e. salmon in Norway and Scotland and Sea bass/Sea bream in Greece), as well as an ingredient in feed for Denmark's pork industry. In smaller scales, volumes of non-food use are utilszed for bait in fisheries and for feed in zoos. Imports of fishmeal and fish oil to Germany are mainly re-exported to Norway and other European markets.

Figure 26: Exports (volume and prices) of non-food products from the EU



Source: EUMOFA

In 2016, extra-EU exports for non-food use totalled 338,000 tonnes, a 4% decrease from the year before. Exports of fishmeal were 182,000 tonnes, and fish oil amounted to 128,000 tonnes. Exports of other non-food use reached 28,000 tonnes. Extra-EU export prices for fishmeal and fish oil follow the increasing global trend observed in recent years.

The largest extra-EU exporters of non-food products in 2016 were Denmark and Germany, with 202,000 tonnes and 60,000 tonnes, respectively. The overall largest market for extra-EU exports of fishmeal and fish oil is Norway, accounting for 65% of total volume and value for fish meal and 90% of the volume and 80% of the value for fish oil.

7.2 The EU production and trade for algae

EU production amounted to more than 90,000 tonnes in 2014, providing approximately 0.3% of the world supply. France and Ireland are the main producers, representing respectively 61% and 33% of the EU total in 2016. Their production consists almost exclusively of brown algae. Other important EU producers are Spain (1.9%, mostly red algae) and Italy (1.3%, green and red algae). From 2006 to 2016, EU algae production increased by 76%, with a peak reached in 2013 at 104,000 tonnes. However, among the major producers, the evolution of production over the decade has been different: significantly increasing in France (+189%) and Spain (+248%), stable in Ireland (+0,2%) and slightly decreasing in Italy (–14%).

Table 30: EU production of aquatic plants (in tonnes)

Country	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
France	19,192	39,792	39,757	18,897	23,037	47,811	41,733	69,430	59,022	19,600	55,541
Ireland	29,500	29,503	29,500	29,500	29,503	29,503	29,500	29,500	29,600	29,570	29,550
Spain	485	130	97	64	124	261	525	432	1,696	2,115	1,690
Italy	1,400	1,400	1,400	1,400	1,400	1,200	1,200	1,200	1,200	1,200	1,200
Estonia	394	1,608	1,483	1,032	351	690	430	249	626	413	348
Others	765	495	1,198	1,352	1,498	1,659	1,975	2,732	226	248	2,526
EU total	**51,736**	**72,928**	**73,435**	**52,245**	**55,913**	**81,124**	**75,363**	**103,543**	**92,370**	**53,146**	**90,855**

Source: FAO Fishtat.

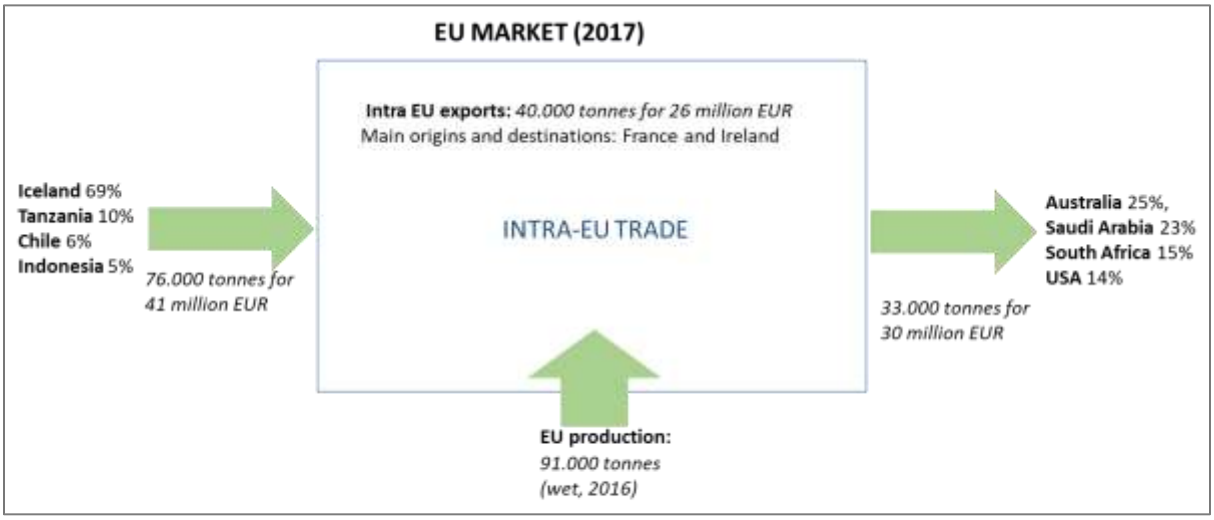
The local seaweed production is not fully sufficient to satisfy the high demand of the processing industries, especially for those extracting alginates. Those industries having access to the raw material locally (e.g. in France and Ireland) also import dried seaweed when local supplies are out of season or not sufficient. Some processors can also choose to delocalise their processing plants to non-EU countries, where they can access cheaper raw materials and labour (Chile, Philippines and China for instance).

Since 2012, EU trade data nomenclature distinguishes seaweeds and other algae[249] fit for human consumption and those unfit for human consumption. In 2017, the EU had a trade deficit of EUR 11 million for algae unfit for human consumption, which has experienced a strong decrease since 2015 (EUR 40 million deficit), mostly due to the drop of average import price. The deficits may be attributable to the imports of macroalgae for the processing industry (mainly from Iceland).

For algae unfit for human consumption, extra-EU imports reached almost 76,000 tonnes in 2017, for a value of 41 million euros. The main countries of origin are Iceland (52,300 tonnes in 2015), Tanzania (7,600 tonnes), Chile (4,500 tonnes) and Indonesia (3,500 tonnes).

However, exports of algae unfit for human consumption reached 33,000 tonnes in 2015, mainly sold to Australia (11,300 tonnes), Saudi Arabia (6,400 tonnes) and South Africa (3,700 tonnes).

Figure 27: EU market for seaweed unfit for human consumption (2017)



Source: COMEXT

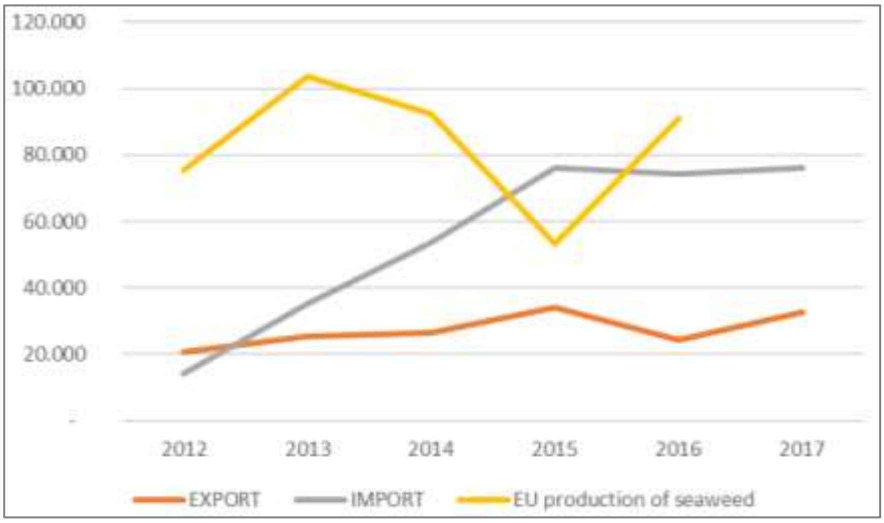
When looking at historical series, it is clear that the level of imports of seaweed unfit for human consumption depends on the availability of raw material in EU, i.e. the level of production of seaweed by EU producers. For instance, from 2013 to 2015, EU seaweed production experienced a significant drop (-49%, due to strongly decreasing harvests in France). As a consequence, extra-EU imports experienced a +118% increase. In 2016, the EU production recovered to reach its average level (around 90,000 tonnes) and imports stayed stable at 75,000 tonnes.

Australia remains the major partner of EU exports with 8,351 tonnes exported in 2017. However, a reduction of 26% is observed between 2015 and 2017.

Global EU exports have stayed stable between 2015 and 2017, with only a decrease of 4%.

[249] Seaweeds and other algae, fresh, chilled, frozen or dried whether or not ground.

Figure 28: Evolution of extra EU trade flows for seaweed unfit for human consumption and EU seaweed production (volume in tonnes)

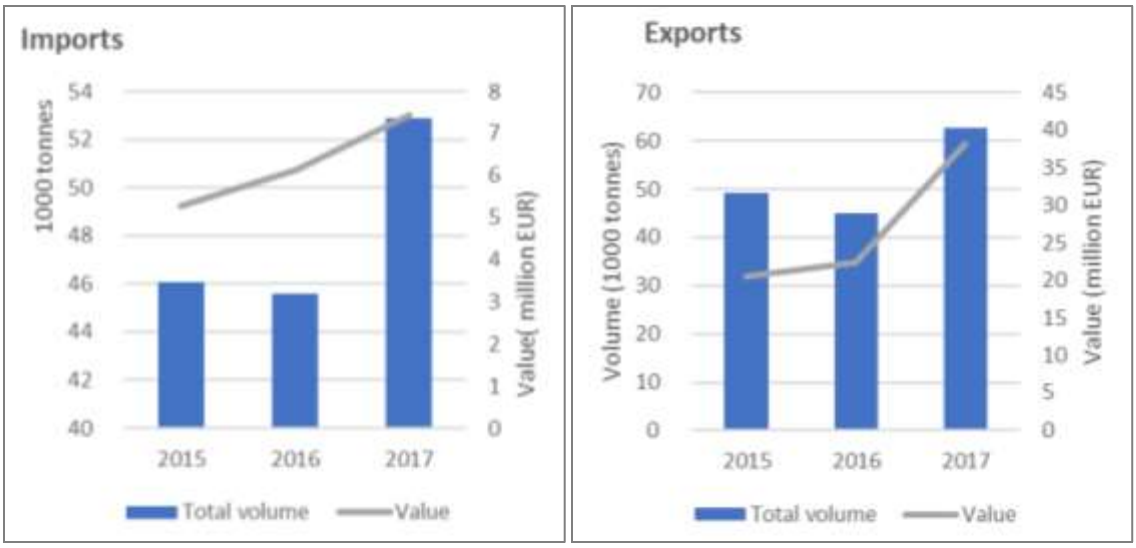


Source: COMEXT

In the meantime, extra EU exports did not experience such significant variations.

With a total of 62,762 tonnes of exports in 2017, Ireland is the main EU exporter for algae unfit for human consumption. For Irish imports, Iceland is the major supplier.

Figure 29: Ireland trade flows of algae unfit for human consumption (2015-2017)

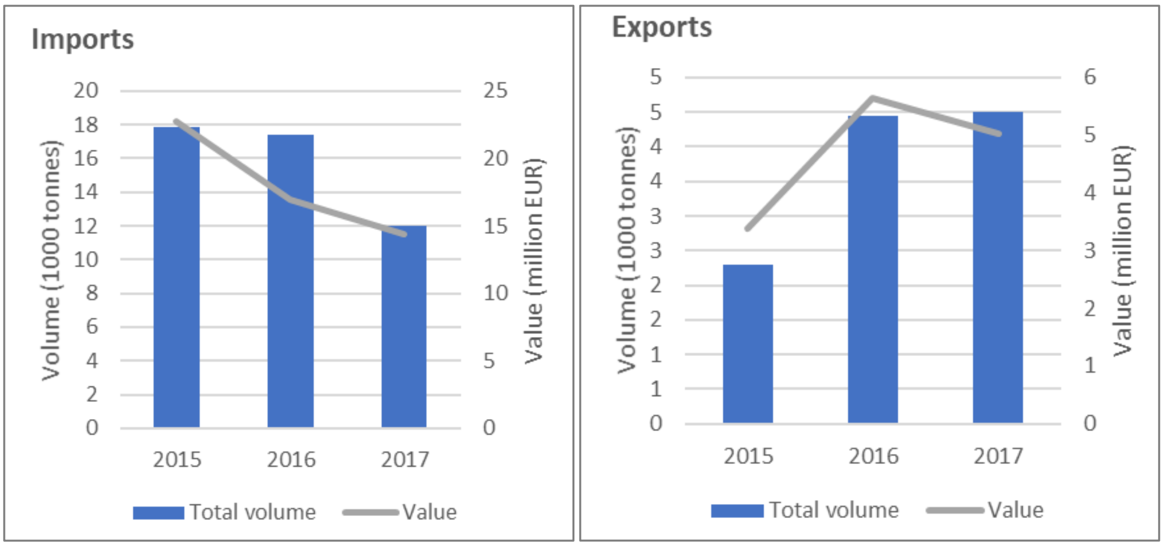


Source: COMEXT

For French imports, the first partner in 2017 was Chile (before 2015, Tanzania was the main supplier). French imports experienced a +33% decrease between 2015 and 2017.

However, France doubled its exports since 2015 (from 2,293 tonnes in 2015 to 4,448 tonnes in 2017), mostly due to the strong increase of Spanish imports. However, unlike Ireland, its exportations are less geographically spread, and mainly localised in Europe (its main identified partners are Spain, the UK, Austria, Germany).

Figure 30: France trade flows of algae unfit for human consumption (2015-2017)



Source: COMEXT

8 Main non-food product and uses

8.1 Fish waste: Norway, Iceland, Faroe Iceland, Denmark and others

In the following paragraphs, information on the top uses and products of seafood not directly used for human consumption is described from a few selected (case) countries, i.e. Norway and Iceland and a few others to exemplify where we stand and where we might be moving with respect to taking better care seafood resources. Norway and Iceland are the countries with the highest uses for non-food purposes in Europe, i.e. with 618 and 501 tonnes in 2015, respectively, and likely at the forefront of the development for better use of seafood resources together with Iceland.

8.1.1 Norway

The RRM base for 2016 was estimated to 3.28 mill. tonnes (live fish weight) fish and shellfish from the fishery and aquaculture industries, where of 0.91 mill. tonnes is RRM.[250] It is estimates that 76% of RRM was used i.e. about 688,000 tonnes. The table below show the RRM base and RRM split over the main sectors.

	Demersal fish	Pelagic fish*	Aquaculture	Crustaceans	Total
Basis for by-products (live weight)	746,400	1,090,000	1,394,000	49,200	3,279,600
Avaialble rest raw material	319,000	177,600	400,842	12,300	909,742
Avaialble rest raw material as share of basis for by-products	43%	16%	29%	25%	28%

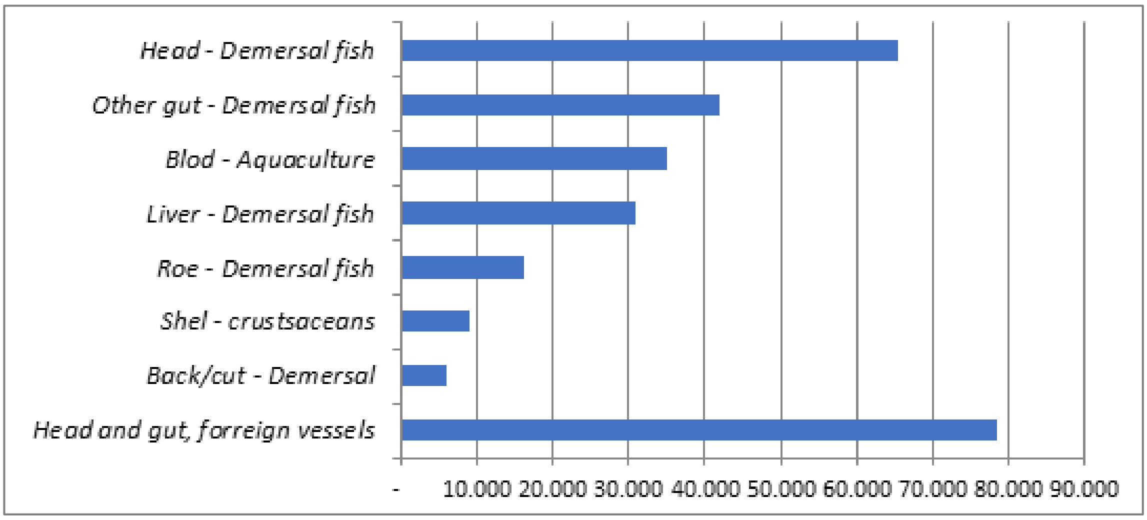
**Rest raw material (RRM) basis are the species herring, mackerel, blue whiting and capelin i.e. those generating RRM.*

Source: Kontali Analyse AS based on statistics from Directorate of fisheries, SSB, first sale companies

[250] Sintef (2017) Analyse marint restråstoff, 2016 – Tilgang og anvendelse av marint restråstoff i Norge.

The unused resources – I.e. potential for further developing the use of RRM – can be seen from the graph below.

Figure 31: Estimates of volume of unused rest raw material, Norway, 2016 (in tonnes)



Source: Kontali Analyse AS based on statistics from Directorate of fisheries, SSB, first sale companies

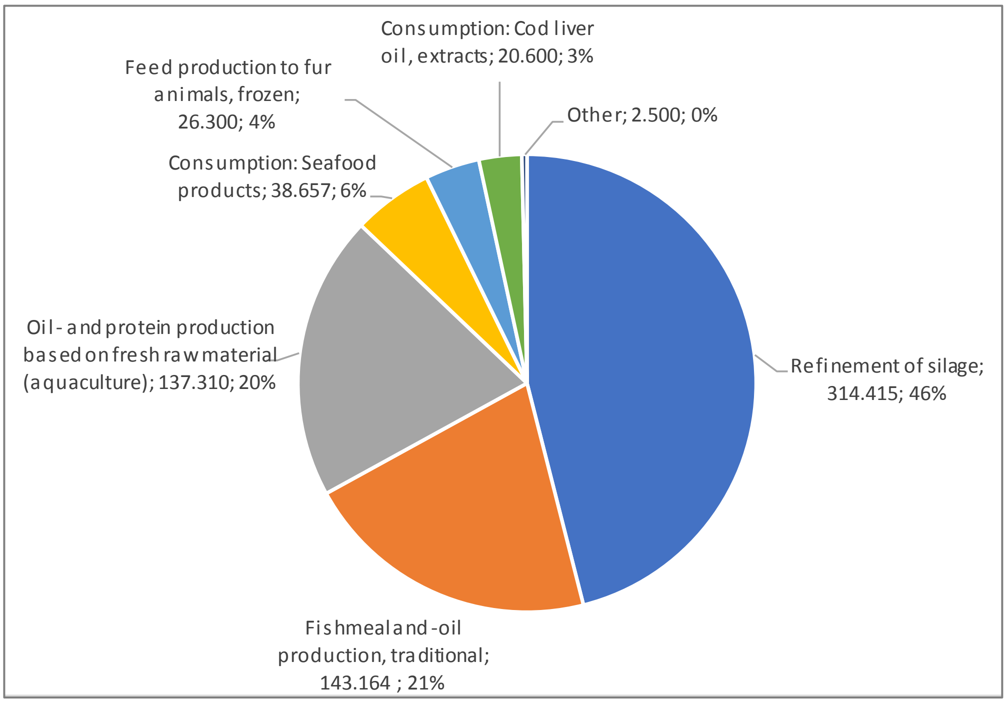
When it comes to fisheries and aquaculture, the RRM that is being used goes into different productions, depending in part i) on it being of "white" or "red" fish origin, and in part ii) on the quality of the material. Some is going directly to consumption as fresh or frozen seafood products, while most goes through some kind of processing.

Almost half of the RRM is used in the processing of silage, see Figure 32. Together with the use for traditional fishmeal and oil this represented almost 70% of the RRM from fisheries and aquaculture in Norway in 2016. Especially the silage industry has built up logistics covering most of Norway (and some from abroad) making them able to process large volumes in the high seasons.

The large and stable volumes from the aquaculture sector have created a basis for a growing industry based on fresh RRM for extraction of fresh salmon oil and protein hydrolysate. Volume-wise this use is equal to the traditional meal and oil industry based on RRM.

About 10 % is used directly for consumption as seafood products like tried fish heads, roe, liver, tongue or belly flaps from salmon filleting. An additional 3 % of by-products is being used indirectly for human consumption via processing to cod liver oil or protein extract and there is a small heterogeneous category containing among others chitin/chitosan for use in cosmetics, etc.

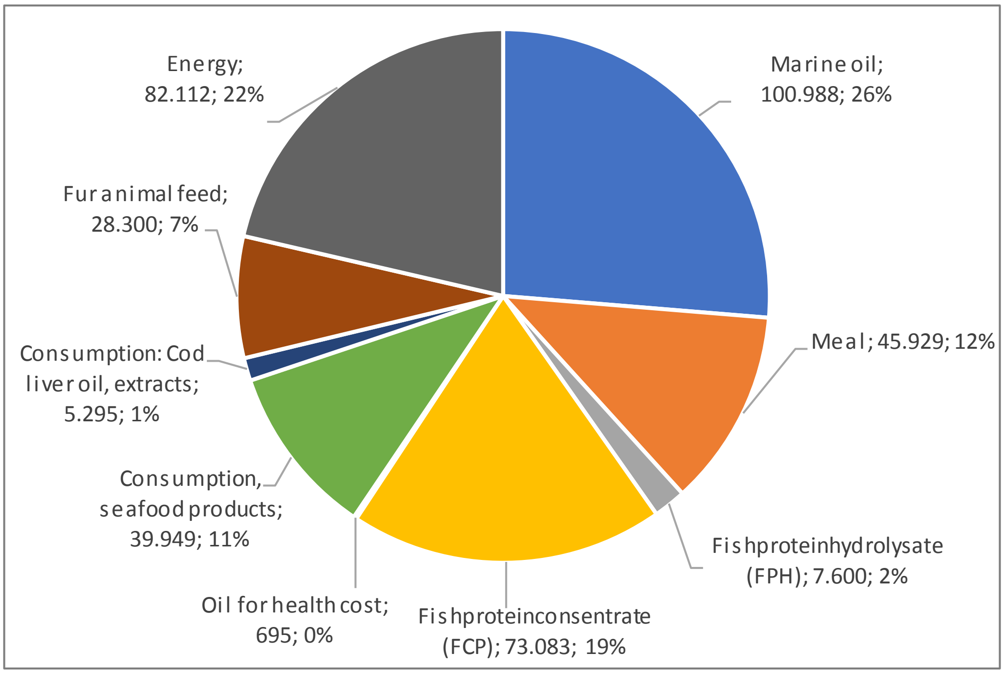
Figure 32: The use of RRM for different productions in 2016



Source: Company interviews, export statistics, SINTEF

The figure below shows the most important product categories based on the main processing of the RRM for 2016.

Figure 33: Product categories of marine RRM (in tonnes), in 2016



Source: Company interviews, export statistics, SINTEF

Via processing in the industry, 688,000 tonnes of RRM were converted to products and semi-finished products equivalent to 384,000 tonnes, see Figure 33. The largest product category measured in product weight is marine oil, which accounts for over 100,000 tonnes in 2016. This is fish oil from both pelagic, white fish and salmon going for different uses in the market. Oil from salmon and trout represents ca. 77 % of this, while oil from pelagic is just below 20 %.

More than 45,000 tonnes are classified as consumer products in the form of seafood products, cod liver oil and extracts. Due to the growth in cod fisheries, the volume for consumption has increased in the last few years.

Fish protein concentrate (FPC) and Fish protein hydrolysate (FPH) represent together about 81,000 tonnes in 2016. A larger part of the protein fraction from fresh processing of salmon entrails/cut-off goes to drying for meal, with evident product advantages in the market. Volume and share of meal is therefore increasing.

There is also production of “functional food”, cosmetics, food supplements and pharmacy products; however, volume-wise these products are small in relation to the bulk products. They do; however, achieve a higher price in the market compared to the bulk products.

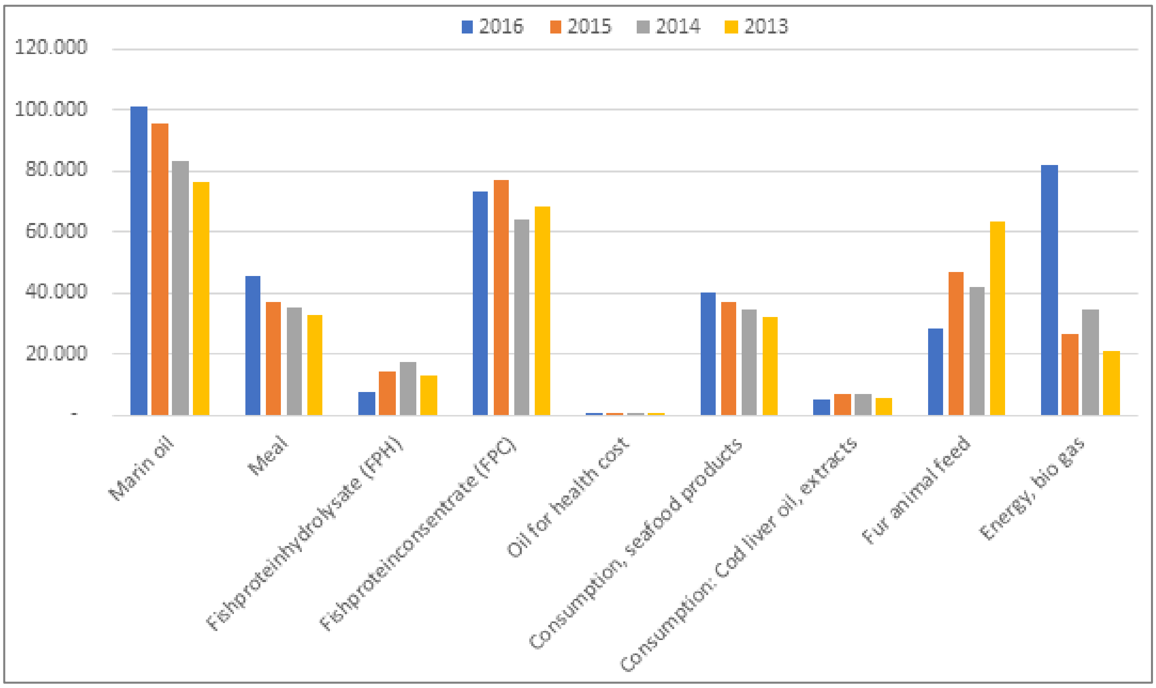
The amount of marine oils has shown an increasing trend over the last 4 years, see Figure 34. It includes both pelagic residual oil, which in turn is increasing in access, and salmon oil extracted from fresh residues from the large salmon packing facilities. Marine oils from the raw material industry are important and valuable ingredients for the fish feed industry, both in Norway and parts of southern Europe. In Norway, oil and protein from whitefish and pelagic species are included in a circular economy as an important feed ingredient for the production of salmonids. Salmon oil and proteins from residual salmon are essentially a food ingredient for the cultivation of other marine species, for example Seabream and Seabass in Europe.

The silage industry produces stable total volumes of fish protein concentrate (in addition to oil). The volumes stated in this report used for silage are excluding imported raw materials.

The amount of fishmeal from residues rises in 2016 due to increasing production of fish meal from the protein concentrate of salmon entrails and cut-off, and increasing volumes from filleting herring. Salmon fish meal is sought in the pet-food market. There is also fishmeal from whitefish produced on board some trawlers, and although it does not have a significant share in volume, it is on an upward trend, as the ocean-going fleet is experimenting with ways to safeguard gutting and cut-off from on-board processing.

Direct consumption has increased steadily in recent years, based on increasing access in the whitefish industry in particular. Use in fur animal feed decreases significantly in line with a reduced market, while down-class silage (category II) had a peak in 2016, due to the significant increase of 'dead fish' in the aquaculture industry in 2015 and 2016.

Figure 34: Annual volumes for product categories of marine RRM in the period from 2013 - 2016



Source: Company interviews, export statistics, SINTEF

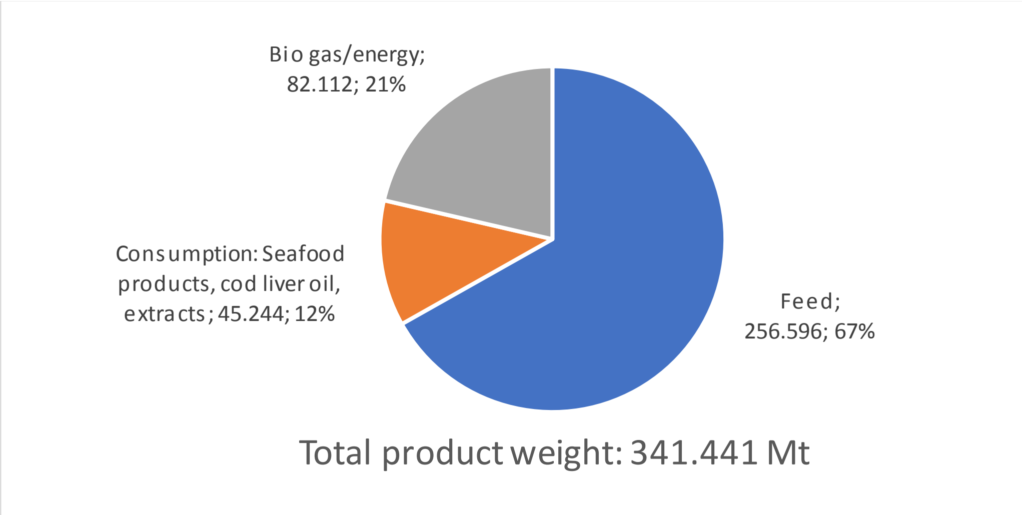
Products based on Norwegian marine residues are mainly for three main applications; i) for different feed markets, ii) for direct and indirect human consumption and ii) for energy/biogas. In addition, there is a certain production of what can be defined as bio-chemicals, but their volume is small when compared with other uses.

The cod fishery sector generates most consumer products, and since there has been a good supply of cod for the last 3-4 years, the quantity of direct consumption has increased. Both the pelagic sector and the aquaculture industry generate most feed products.

In addition, the aquaculture industry produces energy in the form of fuel oil and biogas. This is due to a significant increase in the amount of 'dead fish' from the plants. A considerable amount of raw material for biogas is exported to Denmark, but there is now increased national capacity during construction, for example, Biogass's plant under construction in Skogn.

Figure 35 shows the distribution between feed uses and consumption in terms of product weight. The energy / biogas market is estimated at about 82,000 raw materials for 2016, but it is more complicated to calculate 'product weight' of such production. This is mainly "Category II" silage from 'dead fish' salmon used for combustion plants or biogas. This application has increased over the last two years, both relatively and absolutely. This is due to the fact that the mortality of large fish in sal mon farming has increased significantly due to extra handling of the fish associated with lice treatment. 'Category II' silage has strong restrictions for use for other purposes. The alternative is as feed for 'non-food producing animals' - primarily pet food.

Figure 35: Main markets uses for RRM in Norway in 2016 (product weight, in MT, and %).



Source: Company interviews, export statistics, SINTEF

Consumables consist of well-known products such as liver (cod liver oil), cod tongue, heads, belly flaps, milt, etc. Consumer products also include flavouring in foods (extracts) and ingredients for functional food. Other products consist, for example, of dietary supplements and pharmaceutical products, but so far these have been produced to a very small extent from Norwegian-based residues. If one singles out traditional consumer products and cod liver oil, the other product categories constitute dietary supplements, extracts, and so on in the order of 1,300 tonnes (product weight) of the 45,000 tonnes in total.

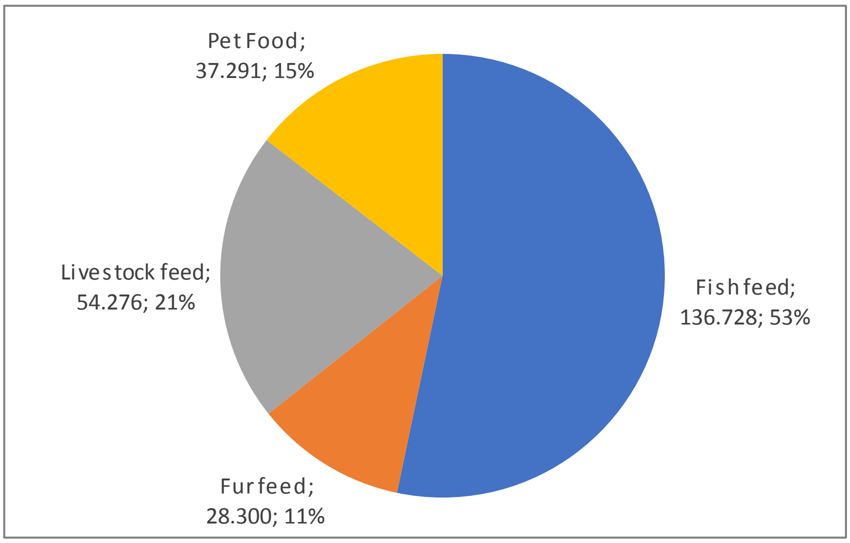
Feed markets – fish, livestock, and fur animals – are by far the most important uses in terms of removing large volumes. A total of 256,000 tonnes of feed products were produced in 2016. The total volume to feed has been fairly stable, but fresh residue hydrolysis has continually increased its use to the pet-food market, which is often better paid than feed for the agricultural sector.

Feed use consists of several submarkets with different product requirements and specifications. Proteins from residues from salmon cannot be included in salmon feed, but are sold to other marine species, for example, to seabass and seabream farming in Europe. Meal and silage (FPC) from residues of pelagic species and cod fish are important ingredients in Norwegian fish feed production for salmon farming. Marine residual raw materials thus constitute an important component of the feed of fish that is eventually used for human consumption.

Figure 36 below shows that the fish feed market is the largest in terms of volume. Then comes animal feed (pig, chicken, etc.). In total, feed for the production of fish and livestock feed accounts for 74% of total feed, of which feed for aquaculture is the clearest application.

The share of marine feed for the pet food industry globally has increased significantly in recent years, accounting for 15% of total feed. At the opposite end of the spectrum, fish feed for fur farming in Scandinavia has fallen in volume – in line with the general trend of the industry.

Figure 36: Distribution of products to the feed market (2016)



Source: Company interviews, export statistics, SINTEF

The feed market has changed in recent years. Interest for marine oils and proteins as the main components of fish feed for marine species is more sought after than ever; particularly marine oils, which have their main use for fish feed. However, hydrolysed proteins, either via controlled enzymatic degradation based on fresh raw material, or as silage fish protein concentrate, have attracted increasing interest from both the feed industry in general, and some players in the market of functional food for human consumption. Several Norwegian companies invest serious resources in R&D and documentation of the health effects of marine proteins. If they succeed, new market opportunities for the marine ingredient industry will open up.

Both the dry matter content and the protein content of the various protein products vary a lot, and it is in principle the protein share what the feed companies pay for. It should therefore be emphasised that in this study, protein products are not adjusted for different solids and protein proportions. The oil is more standardised with regard to content. When it comes to fish oils, a challenge might be that oils based on residues from farmed fish will contain less of omega-3 fatty acids in the future, since fish will be fed with less omega-3.

In terms of volume, most of the products are interesting because of their protein and fat content, and the products compete in a global market for marine oils and protein-controlled by the price of traditional fishmeal and fish oil. An interesting segment is the development of specialty ingredients for different types of feed. Example is weaning feed for pig and pet food with some particular feature. Several companies that rely on Norwegian raw materials supply these markets, but currently with modest volume. However, pet food ingredients are a very interesting market for marine remedies, where there is also some scientific evidence of positive health effects when using marine proteins.

Marealis AS is an example of a Norwegian marine biotechnology company focusing on the development and commercialisation of natural health products from marine peptides.

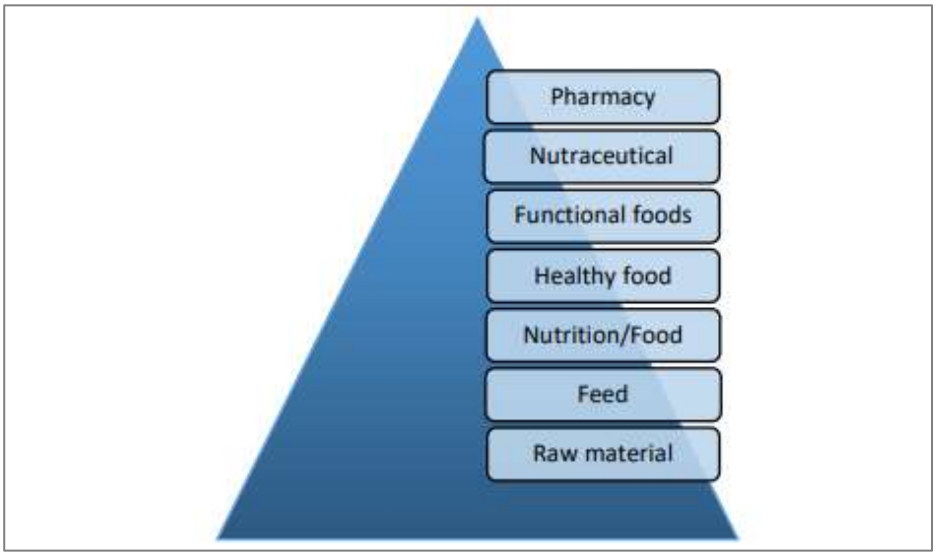
Processed residues can also be used as growth medium for bacteria and moulds. Then other bacteria and moulds are added that "eat" the residues to make new products. This method can be used to produce, for example, proteins, carbohydrates, polyunsaturated fatty acids or bioplastics. Such fermentation processes are monitored by specially developed spectroscopic methods in order to map which bacterial and mould types do what and optimise the residue selection to get the best possible products.

8.1.2 Iceland

According to a 2016 report[251] by Jónsson and Vidarson, the Icelandic seafood industry has focused on increasing the value of each kilogram caught since the quota system was implemented more than three decades ago. It has been a goal to utilise as much of each fish as possible into as valuable products as possible. The policy referred to in the report is part of a larger international (Nordic) project "Everything ashore: A feasibility study"[252]

From initially utilizsng RRM for production of low value products such as mince, fishmeal and silage, the by-raw materials of Iceland fisheries have been transformed to highly valuable products, in some cases even higher in value than the fillets, meaning that Iceland has been moving up on the value-pyramid (Figure 37) towards high value products such as pharmaceuticals, cosmetics and functional foods.

Figure 37 – The value-pyramid for by-products



Source: Jónsson, Viðarsson (2016)

It is clearly stated in the report that with better controlled value chains it is possible to optimise the processes, so that utilisation can be focused on creating products that return the highest value addition. At the top of the value pyramid is the pharmaceutical sector, but valuable components such as fish oil, proteins, collagen and gelatine, enzymes and minerals can also be classified as high-value products. Where to focus in the value chain depends for example on the availability and quality of the raw materials, the investments needed to produce the end products and market conditions where a processor wants to situate her/himself in the value pyramid.

Cod represents 30-40 % of the total export value from seafood products in Iceland (Statistics Iceland, 2016), and both the landing and export value of cod products have increased since 2000, despite the same catch volumes.

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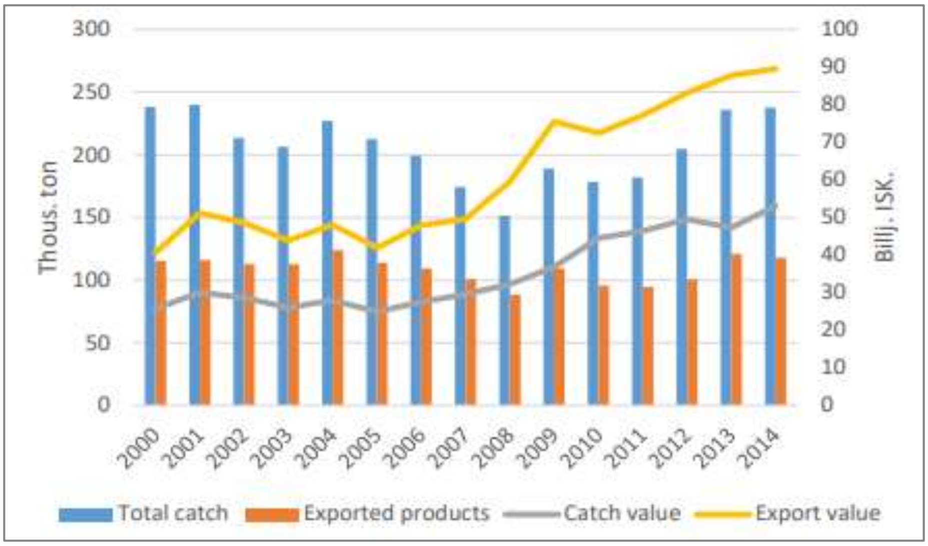
[251] Jonsson A. and Vidarsson J.R., Matis (2016) By-products from whitefish processing http://www.matis.is/media/matis/utgafa/08-16-By-products-from-whitefish.pdf.

[252] Laksá et al., Syntesa (2016) Everything ashore: A feasibility study http://www.fvg.fo/Files/FVG/F%C3%ADlur/Alt%20%C3%AD%20land/Alt%20i%20land_FINAL.pdf.

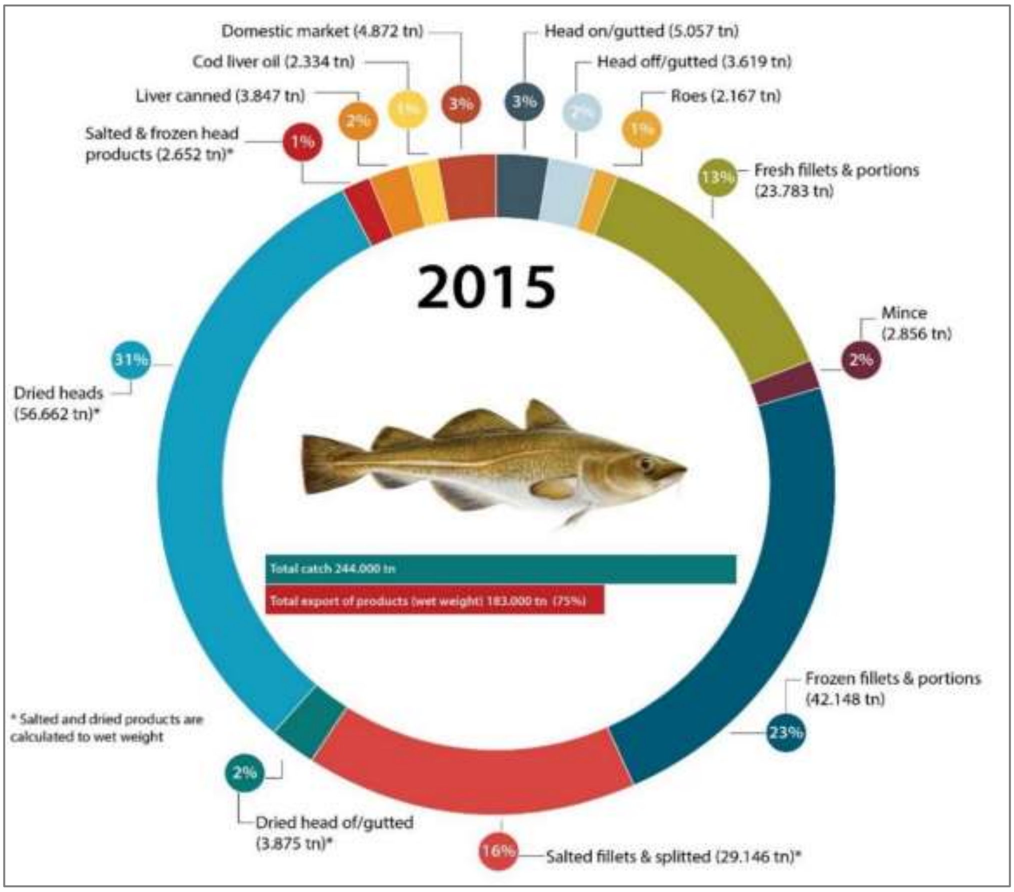
Figure 38 - Total Icelandic cod catches and exported cod products in quantity and value (FOB) 2000-2014



Source: Jónsson, Viðarsson (2016)

Most of the RRM which come from cod processing ashore in Iceland is utilised. These materials include, cut-offs, head, frame, skin, liver, roe and milt, skin and viscera.

Figure 39: Use of Atlantic cod in Iceland



Source: Matis ohf (2016)

Iceland could make further use of the cod resource; however, the set-up for the fishery limits utilisation since, for example, factory trawlers have problems with freezing RRM and vessels landing fresh gutted fish are not equipped to store viscera.

The report by Jónsson and Vidarson discusses in detail the different RRM outcomes from Icelandic cod fisheries as seen in Figure 39 above and more, i.e. the development, market etc., and we refer to the report for further detailed insight.

The report concludes that the catch limitation has contributed to research and product development leading to new processes and products, and to new sectors emerging where high technology has been applied to make added value products from RRM. However, the bulk of RRM is and will still be used for the more conventional routes with a long history, such as fish oil, dried heads and canned liver.

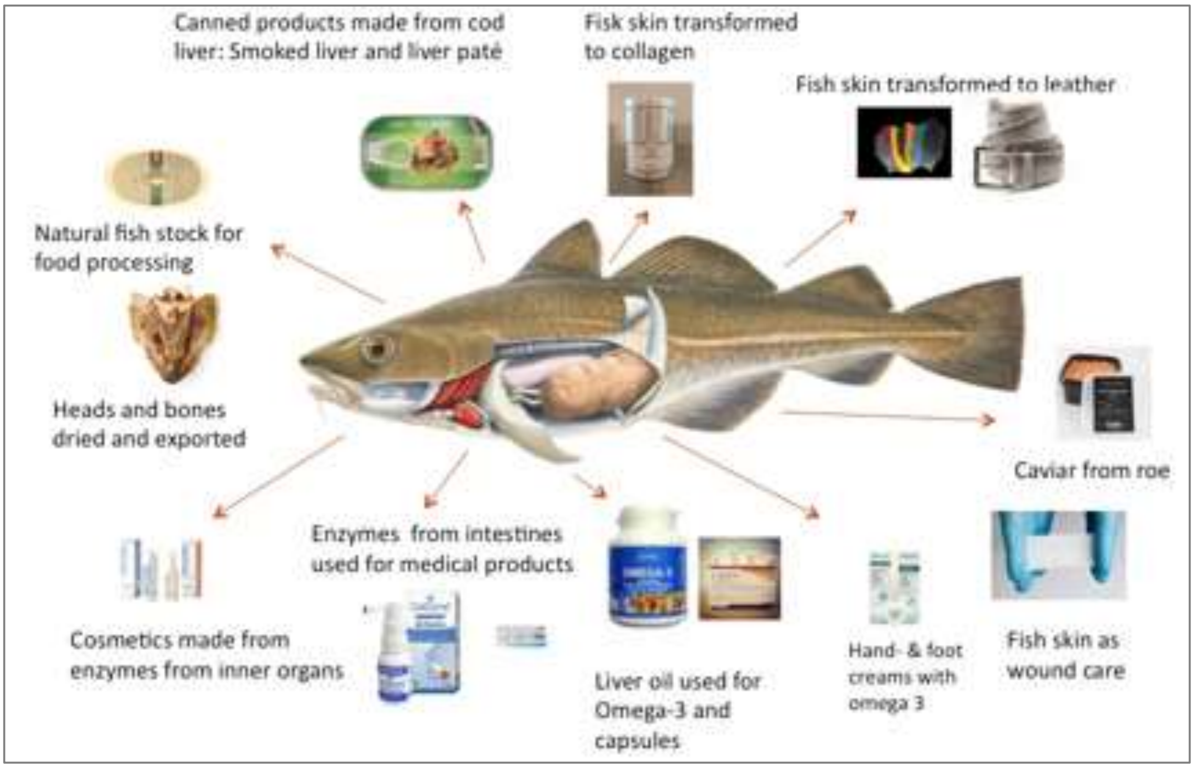
8.1.2.1 The Iceland ocean cluster

There has been a massive number of seafood start-ups created in Iceland, and the Iceland Ocean Cluster has played a significant role in this respect by, among others, bringing more investors into this field and also investing in start-ups in their own capacity, once again underpinning the need for funding resources as discussed in the EC workshop in 2016.

A basis for making value out of the RRM base from fisheries is to set up the vessels to take care of the resources, according to Thor Sigfusson[253]. On board the newest Icelandic ships, they have four product streams where the fish, liver, roes and intestines are separated from the beginning, making all these products available for further processing into high value products. The products are richer sources of vitamins and minerals than the fillets, and they have great potential for various new health markets. The figure below shows some of the products now coming from the Icelandic cod fisheries.

Studies by the Iceland Ocean Cluster have indicated that Iceland is using over 80% of each fish while most fisheries nations use around 50%. However, it is believed that this will change drastically for more nations as the price of quality raw material of the other products increases.

Figure 40: Cod products from the whole fish (fillets excluded)



Source: Sigfusson, Innovations for Optimal Utilization of GroundFish

253 Sigfusson T. (2017) Innovations for optimal utilization of groundfish, International Groundfish Forum.

At the Iceland Ocean Cluster there is a large group of entrepreneurs starting new companies in the field of making use of RRM. Sigfusson reports that women seem to be ahead starting many of the companies sometimes making a 5- to 10-fold value from it, compared to the fillet. For example, fish skin is used as a quality raw material in design products such as clothes, shoes and accessories, see figure below.

Figure 41 – Belt made from fish skin

Source: Sigfusson, Innovations for Optimal Utilization of GroundFish

Leather made from cod skin is an unusual mixture of fine and coarse texture and has a cross-fiber structure, unlike cattle leather. This cross-fiber pattern makes fish leather stronger than the ordinary leather used today. The belt in the picture is an Icelandic design, sold for 325 DKK (about 44 EUR at the time of writing).

Fish skin can also be used to isolate collagen which is a protein that has benefits for skin and joints. One kg of fish collagen is worth USD 15 in bulk. A new fish collagen plant which is being designed in Iceland is owned by four of the large fisheries companies in Iceland.

Figure 42 – Collagen from fish skin

Source: Sigfusson, Innovations for Optimal Utilization of GroundFish

Finally, products from fish skin can be used to create dressings for human wounds. The product acts as a structure around which healthy cells can grow. The company Kerecis in Iceland are already global leaders in this field. This product has been shown to have some superior qualities for wound care and is being used successfully where traditional methods of wound care have not been effective.

Figure 43 – Dressings for human wounds from fish skin

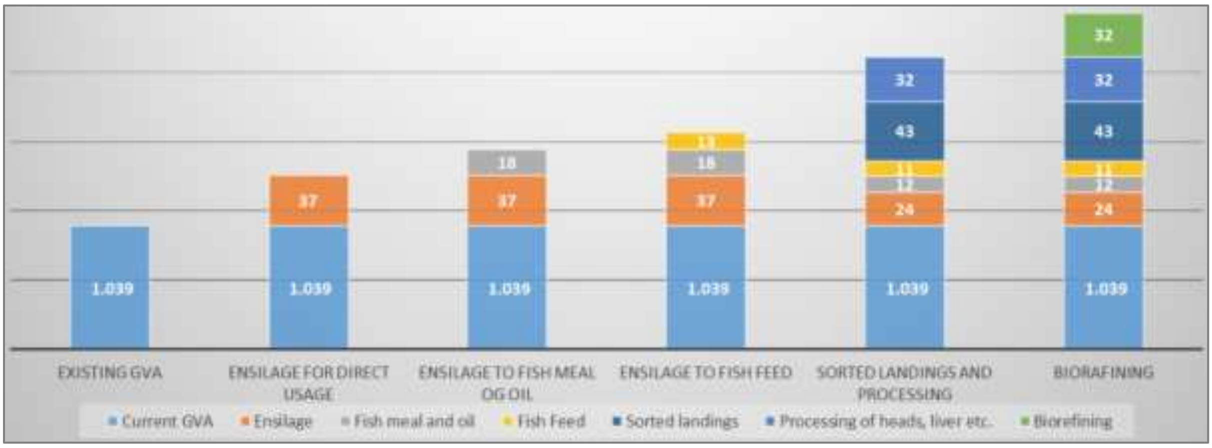
Source: Sigfusson, Innovations for Optimal Utilization of GroundFish

8.1.3 Other cases/countries with forefront activities

8.1.3.1 Faroes

In a report from Syntesa[254] it is estimated that the potential added value in the demersal fisheries in the Faroe Islands spans from 37 million DKK (about 5 million EUR at the time of writing) in silage for direct usage to 154 million DKK (about 21 million EUR at the time of writing) in a fully integrated bio refinery scenario, see figure below. The report was part of a larger international (Nordic) project, called "Everything ashore", led by the Faroese company Syntesa, and being a part of the Faroese chairmanship program at the Nordic Council of Ministers.

Figure 44: Potential GVA in the demersal fisheries in the Faroe Islands



Source: Laksá et al., Everything ashore: A feasibility Study (2016)

In the same report the performed analysis indicates that the potential increase in GVA (gross value added) for the various cases would range from 4 - 27 percent if all the biomass from fisheries were brought to shore and used (See Table 31 below). The total increase in the GVA combined for all of the case studies considered here would be 14% if all the additional biomass were landed as silage and 20% if the biomass were sorted. This would result in an increase in annual GVA of 833 - 1,142 million DKK (about 153 million EUR at the time of writing) for the fisheries in the case studies analysed.

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[254] Laksá et al., Syntesa (2016) Everything ashore: A feasibility study
http://www.fvg.fo/Files/FVG/F%C3%ADlur/Alt%20%C3%AD%20land/Alt%20i%20land_FINAL.pdf.

Table 31 - Overview of change in GVA for all case studies if everything came to shore

Overview of increase in GVA	mill. DKR Current GVA	Increase in GVA mill. DKR Silage solution	 Sorted landings	Percentage increase in GVA Silage solution	 Sorted landings
Greenland					
Greenlandic fisheries in the Barents Sea	94	17	25	18%	27%
Demersal fisheries in Greenlandic Waters	727	116	166	16%	23%
Iceland					
Icelandic fisheries in the Barents Sea	245	33	45	13%	18%
Faroe Islands					
Faroese fisheries in the Barents Sea	290	58	69	20%	24%
Demersal fisheries in Faroese Waters	1,039	46	105	4%	10%
Norway					
Norwegian offshore fisheries	3,396	563	732	17%	22%
Total	**5,791**	**833**	**1,142**	**14%**	**20%**

Source: Laksá et al., Everything ashore: A feasibility Study (2016)

8.1.3.2 Denmark

Denmark hosts[255] two of the largest fish meal companies in Europe, and has a role as an intermediate stop for final processing of Norwegian Aquaculture on the way to other parts of Europe. However, Denmark is not usually known to manufacture byproducts from aquaculture products. There are other processors in Denmark, such as Lumino for ensilage and composting manufacture and supplying a broad range of fields, mainly poultry and pig farms, with produced by-products from fisheries wastes. While Denmark focuses on producing fish meal – hence the use of fish oil – it has recently become leading the biogas and biodiesel producer from fish oil and is paving the way for its wide distribution throughout Europe. In addition, Denmark is in competition with Norway for protein enriched fish meal and protein hydrolysate production with its newly funded foundations for waste treatment.

Further, Fiskerforum claims from Fiskviden.dk that in 2014/2015 there were about 90,000 tonnes of cuts from herring, mackerel, trout and salmon in Denmark, and one recently established network "*…is expected to come up with at least five ideas for concrete projects on value cut-off, which will be able to utilize 10% of the approx. 90,000 tonnes of by-products produced annually in Denmark from fish species such as herring, mackerel, trout and salmon. These projects have the potential to achieve a value of 38 million DKK* [about 6 million EUR at the time of writing] *annually in 2018*". Furthermore, on fiskeviden.dk another project – Trash2Cash – is referred to and a report can be downloaded[256] covering different subprojects like "Whitefish – use of waste", "Use of viscera" and "Processing pelagic raw material" is described. The report also covers another subproject "Business incubators" based on observation from the early 1980's, that such tools can facilitate and even be necessary for new ideas to become a reality.

Thus also in Denmark there are many initiatives in accordance with the ones described above. However, currently the products from Danish seafood rest raw material is estimated to distribute with

[255] Se-Kwon K. (2014) Seafood processing By-products: Trends and Applications, Springer.
[256] Trash2Cash 2011-2015, Teknologisk institute, Aarhus, http://fiskeviden.dk/wp-content/uploads/2016/03/Trash2Cash-Faglig_Slutrapport.pdf.

about 60% for fishmeal and fish oil, fur feed about 35%, ingredients going into pet food 3% and human protein and oil about 2%[257].

8.1.3.3 France

For France the estimated amount of fish by-products is 150,000 tonnes, where about 90% of fish by-products are used for animal feed. The main companies are COPALIS (Boulogne), which specialise in protein hydrolysates for fish feed + several other ingredients for niche/high-value industries (flavours, emulsifiers, nutraceuticals, etc.) and BIOCEVAL processing mostly fish meal and fish oil[258].

Concerning shellfish by-products, there are interesting projects (Brittany, Normandy) to uses shells limestone mostly as fertilizers, but also for animal feed (e.g. Ovive), water treatment, etc. The potential of the French Atlantic seaboard is estimated to reach 30,000 tonnes of shells.

8.1.3.4 UK

In a paper by Stevens et al. (in the pipeline)[259] it is reported that in UK/Scotland there has been a primary concern about the fish in-fish out ratio when using wild fish for raising farmed fish, while less focus has been placed on the sustainability of downstream processing, including how by-products are managed. The findings from studying the Scottish Atlantic salmon industry show that there is considerable potential to increase the sustainability through maximising human edible yield by strategically managing by-products. Through exploratory scenarios based on a case study, it is estimated that Scotland could increase food production from fish farming by over 60 %, increase by-product revenue by 803%, and increase the industry bottom-line by over 5%, all without having to put any new cages in the water, or use any more marine resources. As the aquaculture industry moves into a new era of production and processing, where a diverse range of products can be produced from a single species, sustainability will be sought throughout the value chain.

8.2 Non-food uses of algae

8.2.1 Current industrial uses

In the EU seaweeds are primarily used for the commercial production of additives for food and non-food applications. The European seaweed processing industry is traditionally divided into two main categories: those producing alginic acid (alginate) and those producing products for agriculture (fertiliser, animal feed). The production of alginate and the production of cattle food require large quantities of raw material. In order to limit transport costs of wet material and to remain competitive with the importation of dried material, industries often decide to settle close to seaweed harvesting areas.

In **France**, for example, the two main companies are located in North-West Brittany, where is the most important kelp forest of the country.

In **Ireland**, the company processing the species *A. nodosum* is located on the west coast of the country where seaweed is gathered. Other small companies are located in the same area.

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257 Melgaard P., Danish Seafood Associaton, Personal communication.

258 Penven-Turpault A. et al. (2017) Utilisation des sous-produits de la peche et de l'aquaculture pour l'alimentation en aquaculture, Chapter in: Durabilite des aliments pour le poisson en aquaculture https://www.researchgate.net/publication/317689212_Utiisation_des_sous-produits_de_la_peche_et_de_l%27aquaculture_pour_l%27alimentation_en_aquaculture.

259 Stevens J. R. et al. (2018) The rise of aquaculture by-products: Increasing food production, value, and sustainability through strategic utilisation, Marine Policy.

However there has recently been a reduction of the size of the seaweed processing industry. Different reasons can explain this trend, such as the decrease in seaweed stocks, the high cost of European labour and the environmental constraints.

Nowadays, the European seaweed industry can supply several markets (human consumption, cosmetics, pharmacology, etc.) but seaweed is mainly used to produce hydrocolloids:

- **Alginate**: extracted from brown algae, used in the pharmaceutical industry, and in the production of textiles as well as in many other applications, for their very good gelling and bio-active properties.
- **Agar-agar**: extracted from red algae, it is a good gelling agent used as a substrate for culturing media and for the food-processing industry.
- **Carrageenan**: extracted from red algae, especially used in the manufacturing of dairy products and meat reconstruction for their thickening, gelling and stabilizing properties. It is used for example in fish finger processing industry.

Table 32: Hydrocolloids and their different uses

	Agri-food	Pharmaceutic	Cosmetic	Agricultural	Textile
Alginate	✓	✓	✓		✓
Agar-Agar	✓				
Carrageenan	✓		✓		

Source: own elaboration

Algae are integrated into what is called the "functional market", which is represented by high-value products (at the sanitary, social, ecological and economical level) (Hafting *et al*, 2012). This market implies the creation of partnerships between large industries, SMEs and specialised ingredient suppliers (Hafting *et al*, 2012). Three principal seaweed (unfit for human consumption) consumers/users/producers in Europe are identified[260]:

Table 33: Consumption and trade flows of seaweeds for the main producers in Europe (volumes given in fresh equivalent)

	Consumption	Imports	Exports	Species
France	180,000 tonnes[261]	125,000 tonnes	71,000 tonnes	*Laminar* and *Fucale*
Ireland	13,000 tonnes	51,000 tonnes	161,000 tonnes[262]	*Ascophyllum* and *Laminar*
Norway	…	56,000 tonnes	7,500 tonnes	*Laminar*, *ascophyllum* and *ulva lactuca*[263].

Source: Bretagne Developpement Innovation (2012)

However, some species are exploited and used for human consumption, particularly in France, Spain (Galicia) and Ireland, where several companies harvest edible seaweed. These new types of industry have been developed recently following the increasing demand from European consumers. All the edible algae are harvested manually and dried in an artisanal way.

[260] Bretagne Developpement Innovation (2012) Etude de marché et d'opportunité économique relative au secteur de l'algue alimentaire en France, en Europe et à l'international.
[261] These data are from 2011.
[262] In 2009.
[263] Netalgae "The Norwegian seaweed industry" (2012) http://www.netalgae.eu/uploadedfiles/Norwegian_seaweed_industry_WP12.pdf.

8.2.2 New uses and innovations

In the EU new uses are in development especially from cultivated algae. For instance, in France the largest producer of cultivated seaweed is Algolesko, who began harvesting in May 2014. All their products are certified organic. Interestingly, two of their partners are oyster growers which, apart from their obvious expertise in aquaculture, also demonstrates the complementary nature of seaweed culture with other types of aquaculture. Future aquaculture production will see more Integrated Multi-trophic Aquaculture practises, which optimise interaction between species while reducing environmental impact, leading to sustainable production systems that will supply healthy sustainable seafood for future generations[264].

More broadly, the new and potential uses of algae encompass a wide range of products and sectors:

- **Nutrition**: Omega 3 and Omega 6 for human consumption and fish meals (aquaculture).
- **Bioplastics**: renewable plastics based on cultivated algae.
- **Methanation**: especially based on green algae blooms causing coastal pollution.
- **Pharma**:
  - Cancer treatment. (Seaweeds contain a large variety of phytochemical constituents that can be used in the prevention and treatment of health diseases (Holdt and Kraan, 2011));
  - Obesity and type-2 diabetes treatment. (Carotenoid pigments from brown algae are recognized for their antioxidant activity as well as positive health effects).

Moreover, the recent interest from bio-fuel producers and bio-tech industries in the macroalgae sector will probably generate further perspectives. It may also lead to the development of macroalgae farming in Europe, for which several projects, aiming high added-value products, are currently in development but have to face strong constraints.

8.3 Algae industry in France, Ireland and Norway

8.3.1 France

Most of the French algae activity (90%) is in Brittany (colloid industry). The two main industries are situated in Northern Finistere[265]:

- Algaia (located in Lannilis) have recently bought the industrial site previously occupied by Cargill.
- Danisco (located in Landerneau).

In total, 85 SMEs are into harvesting, cultivating and processing brown and red algae. In the table below, the main SMEs are presented, with a brief description of their size, activity, the type of seaweed they are processing and the type of products they are producing.

[264] https://www.bordbia.ie/industry/manufacturers/insight/alerts/pages/europeanseaweedsectorcontinuestogrow.aspx

[265] Ouest France (2014) La Bretagne, un vaste champ d'algues à cultiver https://www.ouest-france.fr/bretagne/la-bretagne-un-vaste-champ-dalgues-cultiver-3025766.

Table 34 – Main algae aquaculture SMEs active in France

Company name	Location	Function(s)	Turnover	Seaweed(s) type(s)	Uses (traditional and future)
Algaia	Industrial site: Lannilis RTD: Saint-Lô.	Production/ Processing.	670,000 euros in 2015.	Alginates. More than 60,000 tonnes collected per year.	Extraction of algae molecules for the **pharmaceutical**, **cosmetic**, **textile** and **food** industry. ->Additives such as thickening, gelling and moisture retention agents.
Danisco	Landerneau	Processing.	21 million euros in 2016.	Alginates. More than 35,000 tonnes collected per year.	Algae Processing for **food**, **cosmetic** and **pharmaceutical** application.
Olmix	Bréhan	Processing/ Value-creation.	160 million of euros in 2017.	Green, brown and red algae.	Improving **plant**, **animal** and **human care**: ->Natural fertilizers, pet food and dietary supplement.
Ulvans[266]	Future installation in Saint Pol de Léon.	Value-creation/ Development/ Processing.		Green algae. 15,000 of tonnes collected per year.	Create a new algae value-creation pathway in Brittany for the **animal** and **human nutrition** sectors.
Algopack	Saint-Malo	Processing.	111,855 euros in 2016.	Brown algae.	Transforming brown algae from industrial waste into **biodegradable plastics**.
C-weed Aquaculture	Saint-Méloir-des-Ondes	Cultivation/ Harvest/ Value-creation.	203,700 euros in 2013.	Wakame, Royal Kombu, Atlantic Wakame.	Increasing biologic algae values for the **food-processing** and **cosmetic industry**.
Algues et Mer	Kernigou	Cultivation/ Production/ Value-creation.	907,600 euros in 2015.	Brown and Red algae.	Extracting bioactive-molecules for the **cosmetic**, **nutrition** and the **pharmaceutic** industry.
Agrimer	Plouguernea u.	Cultivation/ Harvest/ Research/ Development/ Formulation/ Production/ Packaging.	7 million euros in 2016.	Ascophyllum , Fucus and Laminar.	Supplying the **agricultural**, **cosmetic**, **nutrition** and **pharmaceutical** sectors.
Bretagne Cosmétiques Marins	Plouguernea u.	Harvest/ Value-creation.	7.5 million euros.	Laminars. 30 tonnes of algae treated per day.	Increasing biologic algae values for the **agricultural**, **nutrition** and **cosmetic** sectors.

[266] Partnership between Olmix, 4 Breton SMEs (PRP, Melspring, Amadéite, Agrival) and two academic laboratories (Université de Bretagne Sud, CNRS de Mulhouse).

Company name	Location	Function(s)	Turnover	Seaweed(s) type(s)	Uses (traditional and future)
Ocealys	Plouzane.	Harvest/ Processing/ Value-creation/ Packaging.	946,500 euros in 2016.		Increasing biological algae values for the **agricultural**, **nutrition** and **cosmetic** sectors.
Lessonia	Saint Thonan.	Processing/ Value-creation.	13 million euros in 2017.	Fucus, Laminars, Lichen, Nori, Spirulina, Ulva, Wakame.	Increasing biological algae values for the **cosmetic sector**.

8.3.2 Ireland

In Ireland, **agriculture** and **horticulture products** (94.7%)[267] are the **most important seaweed market outputs**[268]. 1500 dry tonnes of alginates are used as a soil conditioner and to produce liquid seaweed extracts. Unlike France, most Irish processing industries have a semi-private status. In the table below, the main SMEs are presented, with a brief description of their size, activity, the type of seaweed they are processing and the type of products they are producing.

Table 35 - Main algae aquaculture SMEs active in Ireland

Company name	Location	Function(s)	Turnover	Seaweed(s) type(s)	Uses (traditional and future)
Brandon Bioscience	Kerry	Research and Development/ Production.		Ascophyllum nodosum.	Producing high performance natural plant biostimulants for improving **yield** and **quality of crops**.
OGT Amenity	Kilcar	Production/ Value-creation/ Manufacturing.		Ascophyllum nodosum.	Developing products and solutions to support **strong** and **healthy crops**.
Ocean Harvest Technology	Milltown + network of harvesters across South-East Asia.	Research and development/ Production/ Value-creation.		Ascophyllum nodosum, green and red macroalgae.	Producing seaweed feed **ingredients for animals**.
Algaran	Malinmore + Glencolmcille + Donegal.	Harvest/ Value-creation/ Production/ Manufacturing.		Carragheen, Dulse, Kombu, sea Spirulina, sweet Kombu, Wakame, sea Spaghetti.	Producing **organic cosmetic** and **food products**.

[267] http://www.netalgae.eu/uploadedfiles/WALSH_M_(EN).pdf.
[268] The seaweed site: information on marine algae http://www.seaweed.ie/uses_ireland/index.php.

Company name	Location	Function(s)	Turnover	Seaweed(s) type(s)	Uses (traditional and future)
Wildirish Seaweed	Caherush.	Harvest/ Value-creation/ Production/ Manufacturing.	Anticipate 1 million of euros in 2018.	Carrageen, Dillisk.	Developing products across 3 ranges: **edible**, **skincare** and **pet** and **land care**.
Sea vite	Galway	Research and development/ Production/ Value-creation/			Developing **cosmetic products**.
CyberColloids	Cork	Research and development/ Production/ Manufacturing.		Hydrocolloid.	Supplying the **agricultural**, **cosmetic** and **nutrition** sectors.
Arramara Teoranta	Connemara	Harvest/ Production.	94 million of euros.	Ascophyllum Nodosum.	Supplying the **alginate**, **agriculture**, **horticulture** and **aquaculture** industries.

8.3.3 Norway

The Norwegian seaweed industry relies on natural beds of Ascophyllum Nodosum and Laminaria Hyperborea (90% of the national harvest). The alginate industry is the most important sector in Norway. The rest is used directly as food, fodder, biostimulants, cosmetics, aquaculture and in health sectors[269].

The company that leads the alginate production in Norway is FMC BioPolymer.

In the table below, the main SMEs are presented, along with a brief description of their size, activity, the type of seaweed they are processing and the type of products they are producing.

Table 36 - Main algae aquaculture SMEs active in Norway

Company name	Location	Function(s)	Turnover	Seaweed(s) type(s)	Uses (traditional and future)
Algea- The Arctic Company.	Omagata	Harvest/ Production/ Value-Creation	6,206.70 euros in 2011.	*Ascophyllum Nodosum.*	Making extracts and phytocomplexes for use in **agriculture** and **animal feed**.
FMC Biopolymer/ Novamatrix.	Sandvika	Production/ Value-creation/ manufacturing	72,411.50 euros in 2011.	*Laminaria Hyperborea.*	Producing ad providing bio-compatible and bio-absorbable alginates for use in the **pharmaceutical**, **biotechnology** and **biomedical** industries.
Seaweed Energy Solutions	Trondheim	R&D/ Production.		*Saccharina Latissima, Alaria Esculenta, Laminaria Hyperborea, Palmaria Palmat.*	Cultivating seaweed for producing **food**, **feed**, **biochemicals** and **energy**.
Hortimare	Bergen	Cultivation/ R&D/ Production			Cultivating seaweed to respond to salmon farmers demands such as: -The **phosphorous** and **nitrogen reduction**. -Additives for **salmon feed**.
Ocean Forest (association of Leroy Seafood Group and the Bellona foundation)	Oslo	R&D/ Production.			Developing solutions for a sustainable aquaculture, and developing products for **food**, **feed**, **energy** and **raw materials** for **industry** and **agriculture**.

[269] Netalgae, The Norwegian seaweed industry http://www.netalgae.eu/uploadedfiles/Norwegian_seaweed_industry_WP12.pdf.

Section 4 - Understanding the investment trends

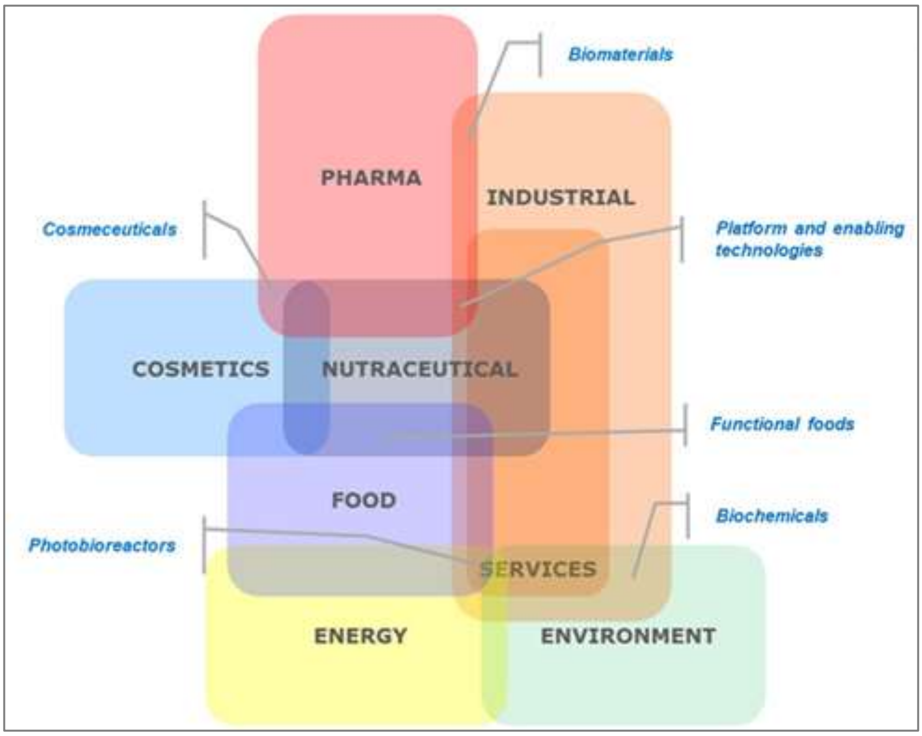
9 Introduction

The blue bioeconomy has climbed up the global, regional and national agendas in recent years, and there is increasing expectation as to its growth potential. A number of countries have launched programmes to support bioeconomy, sometimes also "Green Growth, "Green economy" or just "Industrial Biotechnology".

By dynamically supporting an integrated approach, the new stream of the blue bioeconomy can foster and sustain the valuable contribution of oceans, seas and coasts to food security, nutrition, cosmetics and pharmaceuticals and decent employment for future generations. Blue bioeconomy initiatives contribute significantly to the responsible and sustainable use of marine ecosystems, thus ensuring that countries can obtain the highest possible level of economic growth while conserving the natural resource base upon which that very growth depends.

Despite the generally positive outlook, investors need reliable information in order to evaluate the new investment opportunities in this fast-growing field, and so there should be a comprehensive way to approach the blue bioeconomy and facilitate decision making.

Figure 45 - Blue biotech sector map



Source: Blue Forward Fund presentation (2017), BioMarine - Rimouski

10 Conditions for Investment: Green lights

The main driver for investments is to be found in a series of conditions that may cause a shift towards a more optimistic perception of the sector by stakeholders, the main factors being:

- Investors have an appetite for risks if Return on Investment (ROI) is promising. Blue Biotech is being gradually perceived as a potential good high-return investment, which is overtaking some sectors such as oil and gas and mining which have been struggling in recent years. Biotech remains the only sector where one can have x10 and x100 returns.

- Governments are launching positive signs by increasing support (e.g. tax incentives) and creating a favourable regulative framework.

The paragraphs below offer examples of favourable regulative frameworks and other signals that are contributing to the aforementioned shift.

10.1 France

Nouvelle Aquitaine

- Launch of the blue cluster in February 2018
- The cluster includes an accelerator for existing companies and a financial support from the region through a private / public vehicle of 20 M€
- There is a strong synergy between the green and blue sectors. “Aquitaine croissance verte” is a regional initiative to promote through different public vehicle the synergies between the two sectors.
- The region is also supporting universities / SMEs partnerships to foster the technology transfers

Provence Alpes Côte d'Azur

- The region has developed a framework based on the Mediterranean sea basin
- There are many initiatives involving private and public funding to support projects, SMEs and NGOs.
- The main actor of the blue economy is the “Pole Mer PACA” which receives public and private funding. The Pole has established a fund (ATAYALA) to support the development of SMEs. This fund is financed by large corporations, and investors. Public funding is also very important coming from 3 main sources: FUI (Fond Unique d’Investissement), les Investissements d’avenir (35B€), and the region.
    - 356 projects have been financed for a total amount of 893.17 M€
    - 271 projects were co-financed for a total amount of 299.74 M€
    - 22 cooperative projects involving corporations, public actors and investors for a total amount of 807M€

Brittany Region

- Their strategy is based on public support. Through different actors including the pole Mer Bretagne, CapBiotek, the region is financing more than 837 M€ (at least 133 different projects).

10.2 Portugal

Portugal is definitively an interesting case as, despite the change of government, the blue strategy has been reinforced and new tools have been provided to support entrepreneurship.

- Several funds and financial vehicles will support the Blue Growth initiative: Fundo Azul, Portugal 2020, Mar2020, Atlantic Action Plan, ITImar.
- The new Blue Fund (Fundo Azul) which will have its final closing at around 80 million EUR, offers 12 million EUR in loans for blue biotech, and several other sectors including ports, ocean robotics, circular economy and ocean literacy.
- 1,2 million EUR in grants for Marine scientific and technological research.

- Iceland, Norway and Lichtenstein Grants will also contribute to the Portuguese Blue Growth up to 45 million EUR.
- In addition to these initiatives, Portugal has developed an important Business Angel network.

The national cluster Oceano XXI regroups the main stakeholders of the blue economy including the Blue Bio Alliance, which is a sub group bringing the blue bio key actors together. The national strategy, as it is described in Chapter 15 of this document, contributes directly to the economic development by financing infrastructure and allowing corporations and SMEs to deduct most of the innovation expenses.

A4F, a private company, has established an industrial park dedicated to micro algae research and development on an industrial site owned by Solvay. Solvay has invested up to 20 million EUR in the depollution of the site and the re-organisation of the structure so it could become the industrial park. The Portuguese government is supporting directly the project with 15 million EUR coming from different vehicles including the Azul fund.

10.3 Québec

In Québec, Canada, the regional government has established several vehicles to support innovation in marine research. The most popular are described in the table below:

Table 37 - Vehicles to support innovation in marine research (Quebec)

Financial support / Project type							
	Eligible projects						
	Applied research	Proof of concept	IP and regulatory	Experimentation	Pilot Project	Scientific documentation	Commercialisation
Initial capital (minimum)	10%	10%	10%	10%	20%	20%	30%
Program support (maximum)	80%	80%	80%	60%	50%	50%	35%
Gov. aids (total)	90%	90%	90%	90%	80%	80%	70%
Max amount per phase	200,000 $	50,000 $	50,000 $	200,000 $	150,000$	100,000$	350,000 $
Max period of support (years)	3			2	2	1	2

Source: Secretariaux affaires maritimes, Quebec, Final Report (2016)

There are several other vehicles dedicated to SMEs in the blue bioeconomy sector, especially for those which are producing biomass and marine compounds. Here is a sample of what could be found:

Fiscal rules:

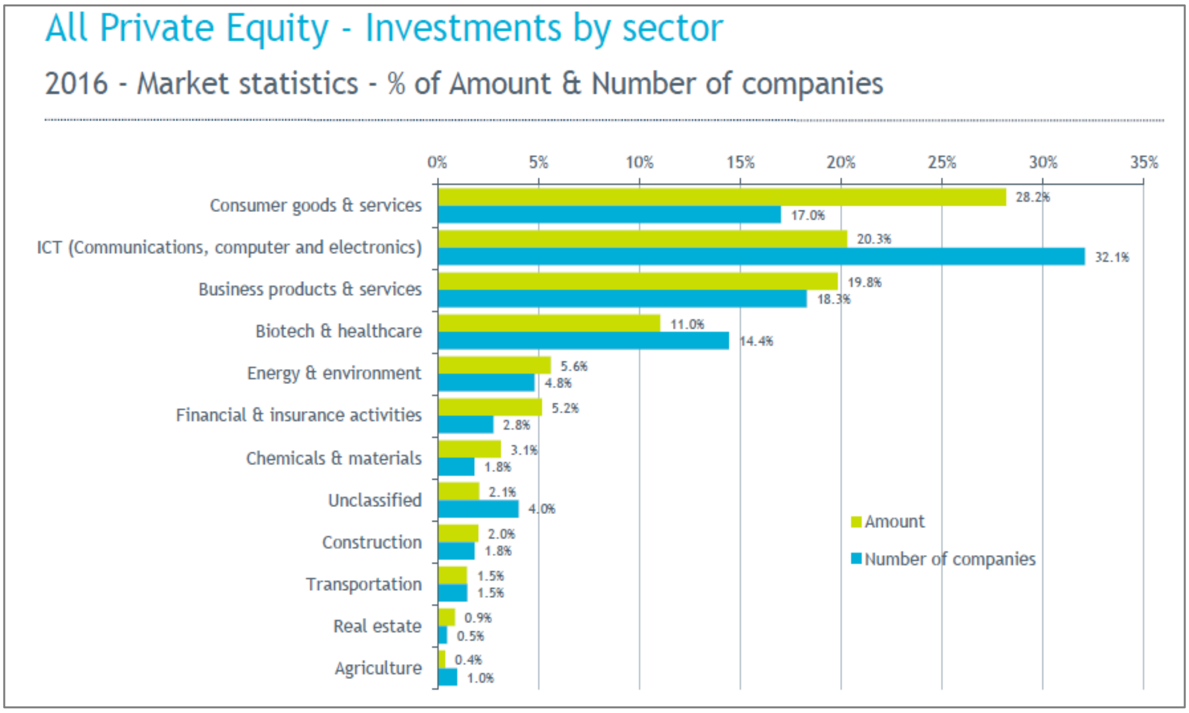
- Tax credit for R&D and Innovation. It is the most utilised by SMEs. Unfortunately, the first 50,000 $ are not included into the final calculation which is a severe blow for SMEs applying.
- The Innovation Passport Programme is a grant from the Ministry of Economy, Science and Innovation. It is easy, simple and flexible, but SMEs cannot apply more than once.

- Financial support to Fisheries and aquaculture from the Ministry of Agriculture, Fisheries and Food is also a very accessible programme. Unfortunately, only human nutrition final products could be eligible.
- There are also several federal credit loans that are available. Export Development Canada (EDC) is the main provider of these loans. Unfortunately, most SMEs are not in a situation to reimburse the credits at the development stage. Commercial banks are not an option, as they ask for guarantees on the owner assets.

Specific sectors, like biorefinery, human nutrition, nutraceuticals, biomaterials and cancer therapies, are attracting a lot of attention due to their very innovative potential – new products and drugs tend to be 'better' from an earlier stage. They are also considered to be safer and cleaner.

11 The share of the blue bioeconomy on total investments

Figure 46 - Percentage of investment and number of companies by sector



Source: Invest Europe / EDC

If one considers the chart above, it is difficult to figure out what is the real value of the blue bioeconomy. Despite having an annual turnover exceeding $216 billion (€185 billion, estimate for the blue bioeconomy – sources: L'économie de la mer en 2030, OECD, 2017), the inadequate attention devoted to marine activities has hampered the development within the various industries. Still, the BioMarine Organisation, which has been working on this topic since 2007, estimates that the blue part accounts for:

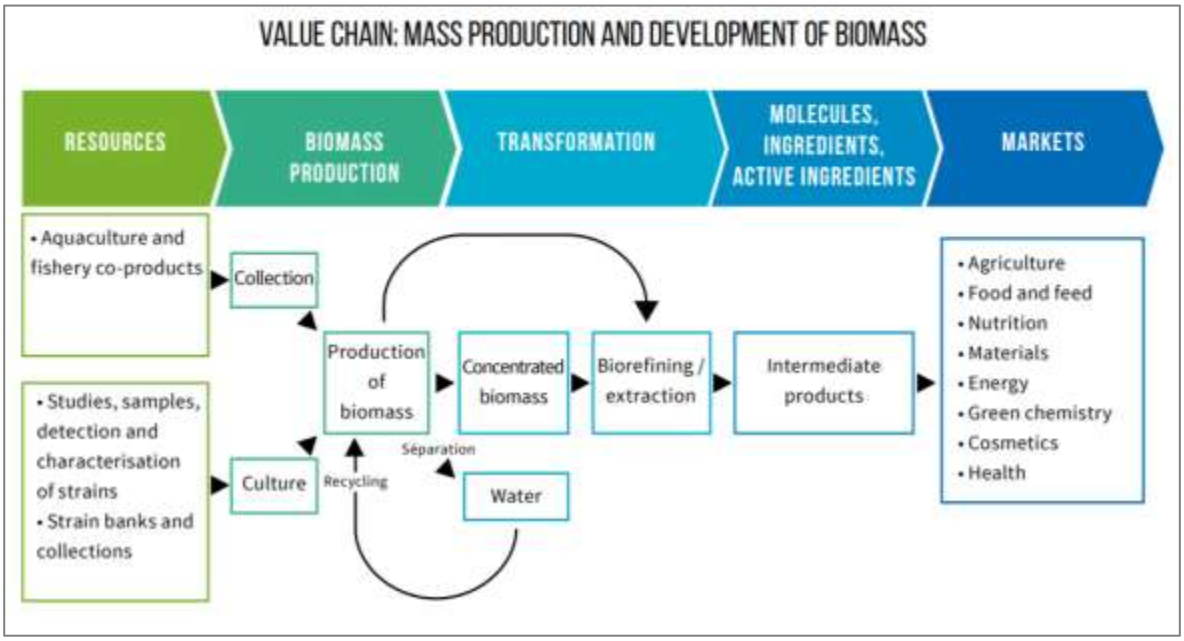
- 8% of the total biotech market
- Less than 1% of the total bio-materials market
- Marine bio energies represent 2% of the energy market (H2 from bacteria, and biogas)
- 11% of the global animal protein (fish aquaculture and seaweeds)
- 6% of the chemicals market

- 13% of the cosmetics market
- 32 % of the nutraceuticals market
- 38% of natural compounds market.

12 Investment trends analysis of the blue bioeconomy segments

Disclaimer: This information is based on the pre-study done by the Biomarine Organisation in preparation of the Blue Forward fund, and the compilation of data provided by two significant investment funds which include significant blue investments in the sector of human nutrition, microbiome and pharmaceuticals. The two funds collected many data, but they remain confidential as most of the investments are still currently part of their portfolios. The trends and analysis are based on the pre-study done in partnership with Biomarine Organization and a French private Equity fund which manages over 600 million € in total assets.

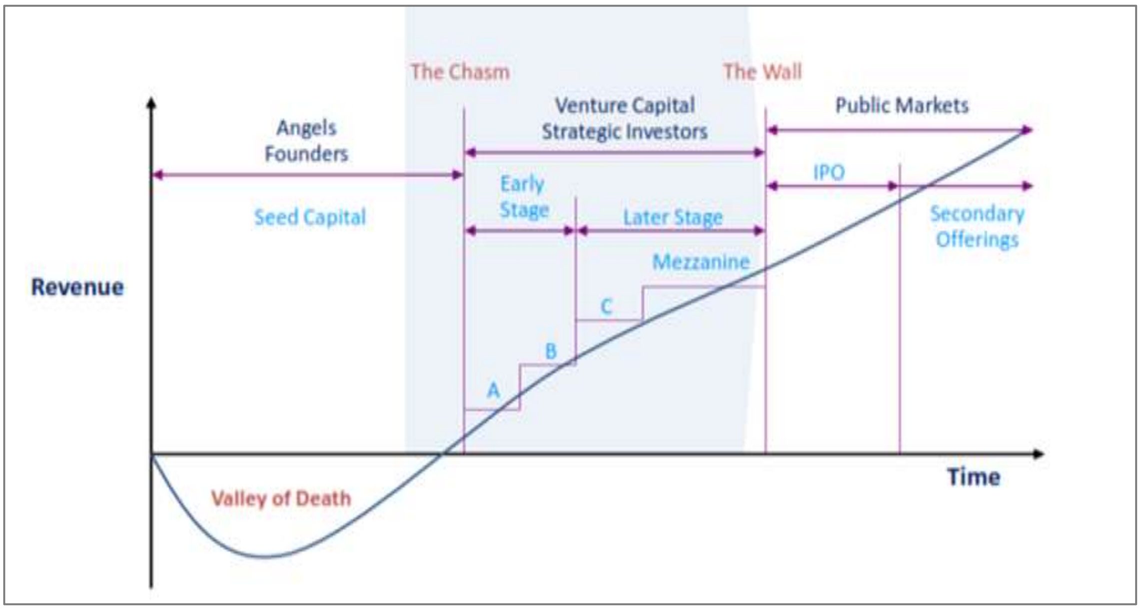
Figure 47 - Blue bioeconomy market value chain



Source: Eurôpole Mer

The picture above describes the different stages and processes of the blue bioeconomy. The investments that are needed depend on the stage where the business is positioned. The Blue Forward fund's portfolio analysis includes most stages and describes what type of investment is needed. It is important to note that when a start-up reaches the point of pre-commercialisation, the need for capital increases dramatically, and most projects (62%) will fail during the so-called death valley stage to the chasm.

Figure 48 - Revenue and funding sources



Source: Blue Forward Fund (2018)

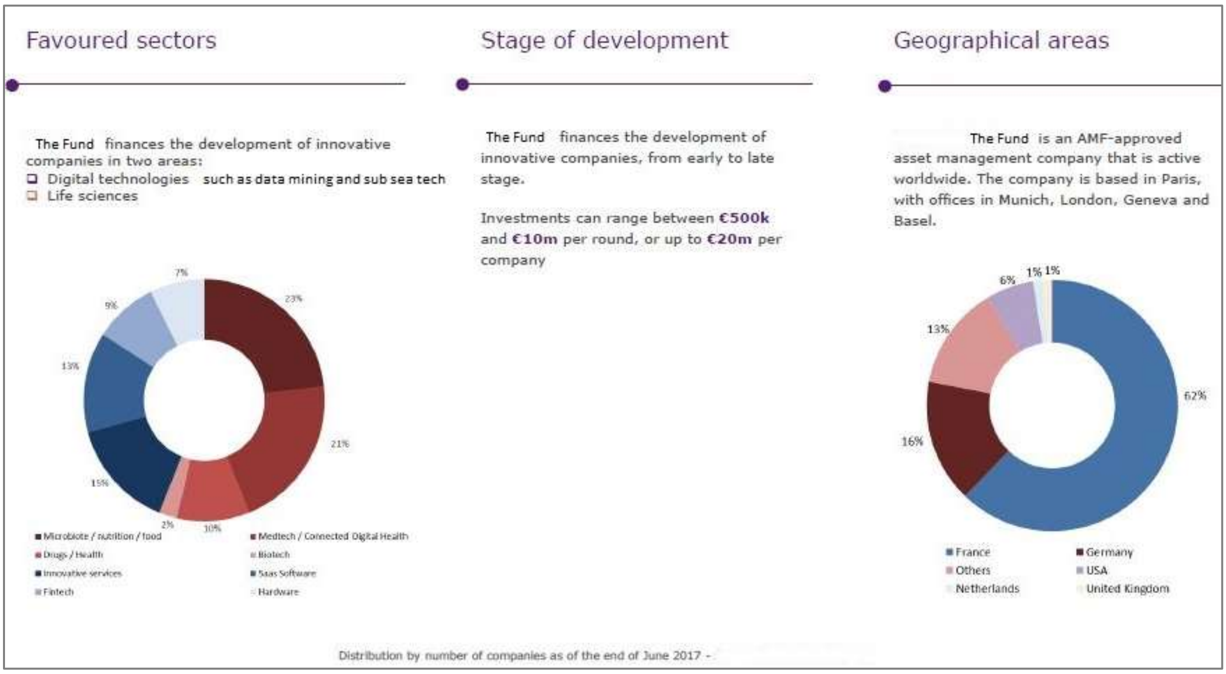
Figure 49 - Overview of the funds

Size	Name	Stage	Field	Geographical areas	Specificity
€56,1 m	Fund 1 (last closing 12/2015)	Seed fund	Digital technologies Life sciences	France	Acces to 1/3 of the French academic research (UPMC, Sorbonne, UTC...)
€160 m	Fund 2 (last closing 04/2015)	Venture & growth	Life sciences (and especially nutrition/ health, microbiome & connected health)	Worldwide	First investment vehicle that finances innovation in the microbiome field

Source: Private equity funds. N.B. Fund's name and partners are confidential

Fund 2 is specialised in life sciences with predominance of human nutrition and contains at least 46% of blue biotech-related technologies. It is the first fund dedicated to the microbiome, which represents one of the fastest-growing segment in the blue bioeconomy. It is directly linked to the utilisation of marine bacteria and guts bacteria coming from fishes, molluscs and worms. These bacteria could be associated with novel ingredients such as micro algae and cyanobacteria to facilitate the absorption of macro molecules such as chemotherapies or nutraceuticals.

Investment scope:



Source: Blue Forward Fund (2018)

Below is a sample of the companies checked by the fund and directly linked to the blue bioeconomy:

NB: the company listed in this document may not have been selected for an investment round. They are part of the deal flow that is currently being considered

Company	Activity
5 Degres Ouest	NUTRITION: develop frozen, raw and decorticated seashells based on innovative high-pressure process. BtoB. Revenues 2015: 5.8M ?
ACS Biotech	Injectable chitosan to repair cartilage.
AF Protein	Skin microbiome: cosmetics range based on a proprietary fish and insect protein mix from extremophile animal with cell preservation properties. Active sales channels at large retail outlets.
Agriloops	FOODTECH: develop salted water aquaponics farms. BtoB / BtoC. No revenue.
Alg&You	NUTRITION: an innovation based on the potential of microalgae as a super-food, by bringing adapted and easy to use production devices closer to consumers. BtoB. BtoC.
Algae Natural Food	NUTRITION: manufacture and sell organic micro algae products including organic spirulina. BtoC for dietary supplement, aquaculture, food and feed.
Algae West Store 2	FOOD: develop and sell B2C food products (cookies, salted snacks?) using spirulina as an ingredient. Revenue 2016: 55k?.
AlgaeGreen	INDUSTRIAL BIOTECH: Use of micro algae, for production as well as sale of biofertilizers, biopesticides and biostimulants destined for agriculture. 1 m? revenues.
Algaeon	FOOD INGREDIENT: developed and produced an algae-derived, highly concentrated beta-1,3-glucan, an immune health promoter with applications in Human Nutraceuticals, Functional Foods, Cosmetics, and Animal Feed. BtoB.
Alganelle	Cleantech: production and commercialization of biopolymers developed from micro-algae optimized by genetic engineering. BtoC.
algisys 2	NUTRITION: biotechnology company focused on producing high-value omega-3 fatty acid nutrition ingredients from microalgae. BtoB. No revenue.
Algobiotech	COSMETICS: algae production for cosmetics.

Company	Activity
Alver Golden Chlorella	NUTRITION: develop micro-algae protein based food with a neutral taste and colour that is 100% natural, 100% vegan, gluten free, lactose free, GMO free. BtoC.
aqua-cote	Marine anti-fouling coating.
Aromacelt&-Projet Merlin	Nutrition: alimentary supplements. Funded in 2010, the company is developing essential oils in powder form based alimentary supplements. 26 marine products. B to C - 700 k? revenues in 2014.
Bianchi	FOOD MANUFACTURING: a leading wholesaler for the delivery of fresh and frozen food to the Swiss market want to establish an ultramodern on-shore fish farm complex with main focus on production of the percid fish species. BtoB.
Biolistic	NUTRITION: Alimentary supplements, composed from non-esterified long-chain fatty acids, plant polyphenols, edible mushroom and edible algae polysaccharides. Very low revenues, no differentiation.
chinowa	NUTRITION: chitosan based customizable anti-bacterial solutions for variety of food and beverage applications (based on target anti-bacterial profile, a cocktail of various length chain chitosan is developed). Specificity of the customization remains to be seen, how better than just chitosan. For labelling, in particular in US, chitosan might be not the preferred preservative ? allergenic. CEO is very young, no commercial expertise.
cyano biotech	Isolation and characterisation of novel bioactive compounds from cyanobacterial extracts primarily for the pharmaceutical industry. Cyanobacteria, formerly called "blue-green algae" are relatively simple, primitive life forms closely related to bacteria. Cyanobacteria produce oxygen during photosynthesis.
Cysal	INDUSTRIAL BIOTECH: Production of di-peptides as ingredients for various industries including in the first instance cosmetics and fish feed.
Ennesys 3	CLEANTECH: develop and commercialize an innovative system of organic waste and water waste management using micro-algae. BtoB.
Entomo farm 2	Food nutrition : Insect manufacturer for fish farm.
Eranova ex-projet Blast	INDUSTRIAL BIOTECH: manufacture of bioplastics from stranded green algae. BtoB.
GEPS Techno 2	CLEANTECH: design and development of systems that produce autonomously electric power from the swell sea. BtoB.
HIECO	FOODTECH: The Company is developing High Impedance Electroporation (HIE) in place of thermal pasteurization. The focus is liquid-food industry with also applications in the water and wastewater treatment industry, as well as potential applications in the nutraceuticals (yeast or algae extract), medical, and pharmaceutical (high volume transfection) industries.
Inalve 2	ANIMAL FEED: Industrial biotechnology company specialised in the production of products from microalgae. They claim 10-fold increased productivity with their technology and less energy consumption. BtoB.
inbiose 2	Nutrition & Industrial Biotech: industrial white biotechnology company focused on the manufacturing of specialty carbohydrates, and they are a supplier of novel carbohydrates (human milk oligosaccharides, chitosan?) Level of Interest: medium.
Kepley Biosystems	NUTRITION: Synthetic bait for crustacean fishing, offering a cost-effective and sustainable alternative to the diminishing supplies and ecologically harmful depletion of natural fish bait.
Kimoko	FOOD: operating in preparation of Sushi and other Japanese food distributed on site through takeaway inside hypermarket. BtoBtoC. Turnover 2016: 6.5 m?.
kiomed	Pharmaceuticals. Development of cutting edge injection solutions made of gel vegetable-based chitosan to treat joint disorders/osteoarthritis then the dermal filter. Exclusive license on the exploitation of KitoZyme?s patent.
KitoZyme	Nutrition: Chitosan and chitin-glucan manufactured from non-animal and non-GMO sources. Both the performance and safety of all of these technologies are scientifically and clinically proven. BtoB.
Les chaises hautes 2	Nutrition: baby food - founded in 2012. The company proposes individual bags including frozen organic vegetables as well as meat or fish that can be used with baby-cook to prepare meals to babies. B to C - No revenues in 2014.
Metabolium	Nutrition: enrichment process of microalgae for antioxidant ingredients production. BtoB.
Microbloom	Foodtech: cultivates and harvests microalgae to extract valuable natural an organic extracts on a commercial scale.

Company	Activity
Monsoon Bounty	Monsoon Bounty Foods manufacturing Pvt Ltd is an export-oriented fish, shrimp and vegetable processing unit into bulk-frozen, IQF, value-added products. Monsoon Bounty started in 2012 with 60 years of experience in shrimp farming and 4-year intensive research and collaboration with leading Indian Government research organization like CIFT Cochin and CFTRI Mysore.
Mosaic Sushi	FOOD: develops fish-free sushi with a combination of cereals and legumes, seaweed, spices and super foods. BtoC. No revenue.
Nutri Culture	NUTRITION: develop an algae texturing and offer trainings to healthcare staff to make texture modified food for patients suffering from dysphagia. BtoB. Revenue 2015: 120 k?
Odontella	NUTRITION: develops vegetal alternative food based on the marine microalgae Odontella aurita. BtoC.
Primex	NUTRITION: Icelandic marine biotech company commercializing high premium standard chitosan, self-affirmed GRAS product. It is used in food supplements, nutritional, biomedical and cosmetic products.
Projet Blast	BIOTECH: manufacture of bioplastics from stranded green algae. BtoB.
smartfish 2	Nutrition: revenue stage, clinical nutrition, lead product, based on proprietary emulsification technology is in clinical trials for cachexia, ?1m revenues.
springwave 2	Nutrition: a quadrink b2c Beverage integrating spirulina (no revenues, exists since 2012) - developed a new yogurt, and a mayonnaise based on algae.
Subitec GmbH	NUTRITION: The Company targets high value proteins, fatty acids and other valuable ingredients contained in Microalgae (Omega-3 fatty acids, carotenoids, Algal biomass for aquaculture, etc.). 2.9 m? revenues in 2015.
TAM	NUTRITION: specialises in large-scale industrial production organic-certified microalgae and molecules of interest mainly for the food supplements. BtoB. Revenue 2016: 137 k?.
Technophage 2	biotech: drug discovery organization using three different platforms in parallel : bacteriophage therapeutics, single-domain antibodies, zebrafish screening.
Tradapharma	Nutrition: Development, production and marketing of products aimed at men and their sexuality (Patented natural compound formed by eckloniabicyclisalgae, tribulusterrestris and glucosamine). BtoC.
Yorso	DIGITAL FOOD SERVICE: Web-service to automate sales, purchases and logistics processes for b2b wholesale fish and seafood market.
Your Superfoods	NUTRITION: Develops natural, organic and sustainable superfood mixes (fruits, vegetables, seeds, grasses, algae, and leaves).
AlgiPharma AS	PHARMA: biopharmaceutical company with a primary focus on developing its first drug candidate for patients with Cystic Fibrosis. Technology is based on highly purified and defined oligomer saccharide structures processed and isolated from the alginate polysaccharide (Inhibition of bacterial adherence to surfaces, Disruption of established biofilm matrix). Completed Phase 2 clinical trials in Cystic Fibrosis.

Below is the portfolio analysis of Bio Based – Food and Pharma companies:

Company	Activity
AIDP	Nutrition: B2B - 6M EUR turnover with vegetal protein, and XOS (booster of bifodobacteria), 4 double blind studies versus placebo.
Algae Natural Food	NUTRITION: manufacture and sell organic micro algae products including organic spirulina. BtoC. for dietary supplement, aquaculture, food and feed.
Algae West Store 2	FOOD: develop and sell B2C food products (cookies, salted snacks?) using spirulina as an ingredient. Revenue 2016: 55k?.
Algaeon	FOOD INGREDIENT: developed and produced an algae-derived, highly concentrated beta-1,3-glucan, an immune health promoter with applications in Human Nutraceuticals, Functional Foods, Cosmetics, and Animal Feed. BtoB.
algisys 2	NUTRITION: biotechnology company focusing on producing high-value omega-3 fatty acid nutrition ingredients from microalgae. BtoB. No revenue.

Company	Activity
Alver Golden Chlorella	NUTRITION: develops micro-algae protein-based food with a neutral taste and colour that is 100% natural, 100% vegan, gluten free, lactose free, GMO free. BtoC.
Amylgen	CRO offering validated in vivo models of neurodegenerative and psychiatry diseases for drugs and nutraceuticals developing a new plant extract for brain protection.
auranta	Range of natural plant extracts with biocidal properties. Enhancing yield and reducing food waste, Auranta and its derivative products are natural broad-spectrum antimicrobial products that can complement and/or replace synthetic chemicals currently used in the food industry.
Biolie 2	Nutrition Cleantech: Enzymatic extraction of bio-sourced oils and actives from plants. This is an aqueous process (patented). No solvent / No chemicals. Low revenues.
Biolistic	NUTRITION: Alimentary supplements, composed from non-esterified long-chain fatty acids, plant polyphenols, edible mushroom and edible algae polysaccharides. Very low revenues, no differentiation.
Bionascent	Nutrition: humanised and animal free infant formula, mimicking breast milk (focusing on replacing cow proteins primarily, possibly an alternative to synthetic HMOs which are more and more believed now to be mere prebiotics).
bonumosebiochem	Nutrition: sweetener from whey (tagatose) as a prebiotic, which could be cheaper than other tagatose thanks to proprietary enzymes. A reminder has been set up for 09-01-2017.
DNA Gensee	NUTRITION: develops a genetic analyzer using plant and / or algal DNA to identify plant species in order to develop nutraceuticals. BtoB.
EKO GEA	MICROBIOME: An algal-derived prebiotics, already existing in food supplements but newly positioned with a trade secret extraction method and aiming for clinical trials in psoriasis after anecdotal evidence in sales to family and friends.
eviagenics 4	NUTRITION: The Company develops natural seaweed-based extracts and wants to valorise brown seaweed co-products on the market.
Fitoguru	NUTRITION: The Company is developing products made of the mix of wild-grown herb, flowers, roots extracts, bee products, berries and superfruits (clinical studies carried out by Altay State Medical University). Multi-products (Intellect, Immuno, Tonus, etc.). BtoC.
GreenOnyx 3	Nutrition: Compact agro-food device that produces at home a highly nutrition vegetable (Khai-Nam, lentille d'eau asiatique). The produced vegetable grows very fast, it is available year-round, and in any location, and has a neutral taste and smell.
GRUPO NATAC	Nutrition: BtoB extracts from olive tree and grape.
Inalve 2	ANIMAL FEED: Industrial biotechnology company specialised in the production of products from microalgae. They claim 10-fold increased productivity with their technology and less energy consumption. BtoB.
inbiose 2	Nutrition & Industrial Biotech: industrial white biotechnology company focusing on the manufacturing of specialty carbohydrates, and they are a supplier of novel carbohydrates (human milk oligosaccharides, chitosan?) Level of Interest: medium
isobionics 3	nutrition et white biotech : strains for production of nootkatone et valencene (orange/grapefruit fragrances on terpenes.
KitoZyme	Nutrition: Chitosan and chitin-glucan manufactured from non-animal and non-GMO sources. Both the performance and safety of all of these technologies are scientifically and clinically proven. BtoB.
meistereber	snuff shooting machine for snuff tobacco and powders containing dextrose or chocolate.
Metabolium	Nutrition: enrichment process of microalgae for antioxidant ingredients production. BtoB.
Microbloom	Foodtech: cultivates and harvests microalgae to extract valuable natural and organic extracts on a commercial scale.
Muufri	Animal-free dairy products, milk and dairy derivatives based on (GMO) yeast grown milk proteins. USP is its animal free but with the robustness of animal derived milk, i.e. ability to mimic the behaviour of cow's milk when it comes to enzymatic curding to prepare cheese and quarks.

Company	Activity
New Gluten World	Nutrition: Physico-chemical detoxification method (microwave treatment) of gluten proteins from wheat grain with the purpose to combine the nutritional and technological properties of wheat with safety for celiac patients.
Oatly	NUTRITION: develop oat-based products using a patented enzyme technology that keeps high fiber and betaglucan content. Revenue 2014: 28 M EUR.
Omniactive	NUTRITION: An Indian natural ingredients company which develops products with clinical trial evidence to support claims. Core products indude carotenoids, plant extracts and specialty functional ingredients. Latest is a new enzyme inhibitor-based therapeutic platform for age-related ophthalmic conditions.
prenexus health	Nutrition: Commercialszing a XOS prebiotic fiber, using proprietary water extraction technology (that enables organic certification) and proprietary varieties of sugar cane with low sugar and high fiber content properties and higher raw material content (that enables lower material cost).
Primex	NUTRITION: Icelandic marine biotech company commercialising high premium standard chitosan, self-affirmed GRAS product. It is used in food supplements, nutritional, biomedical and cosmetic products.
Prolupin	NUTRITION: A company with patented procedure for extracting a legume protein to develop and manufacture lactose-free milk substitutes and products containing them.
Silver Project	Specialised in the development and production of natural active ingredients from botanical extracts for use in pharmaceuticals as weels as dermo- and premium cosmetics.
springwave 2	Nutrition: a quadrink b2c Beverage integrating spirulina (no revenues, exists since 2012) - developed a new yogurt, and a mayonnaise based on algae.
Subitec GmbH	NUTRITION: The Company targets high value proteins, fatty acids and other valuable ingredients contained in Microalgae (Omega-3 fatty acids, carotenoids, Algal biomass for aquaculture, etc.). 2.9 m? revenues in 2015.
TAM	NUTRITION: specialises in large-scale industrial production organic-certified microalgae and molecules of interest mainly for the food supplements. Revenue 2016: 137 k?
tauderma	Swiss company developing a rigorous approach to plant extracts with anti-cytokine effects. Lead product in the cosmetics space (treatment of sunburns and anti-ageing of the skin), more pipeline products as natural supplements with anti-inflammatory effects.
Valbiotis 2	Nutrition: the company is developing 2 patented active products (vegetal peptide hydrolyzate and a mix of 4 plants) targeting the cardio-metabolism axis.
Vital Solutions	Nutrition: the Company develops specific ingredients (plant extracts) that focus on digestive health, brain health, anti-aging. Clinical data for each product.
Odontella	NUTRITION: develop vegetal alternative food based on the marine microalga Odontella aurita. BtoC.

Here is the portfolio analysis of Bio Based – industrial biotech and cleantech companies:

Company	Activity
3ragrocarbon	industrial biotech: innovative technology development and industrial engineering organisation, one of the leading international pyrolysis technology, biochar and carbon-refinery knowledge centres.
Aexa	CLEANTECH: develops a micro-biorefinery for plants and a biosourced power station. BtoB. No revenue.
AlgaeGreen	INDUSTRIAL BIOTECH: Use of micro algae, for production as well as sale of biofertilisers, biopesticides and biostimulants destined for agriculture. 1 m€ revenues.
alpha recyclage composites	Cleantech: The Company is developing Steam-Thermolysis to recycle carbon fibers from composites wastes. Their aim is to develop and implement a pre-industrial demonstrator of steam-thermolysis. BtoB.
Alternative Petroleum Technologies	Other: company that is focuses on commercialising its oxidative desulfurisation (ODS) patented technology, know-how, and trade secrets.

Company	Activity
American Green Technology	Industrial biotech: the company manufactures and markets safe lighting solutions. This combines an energy efficient light fixture with a UVC / air circulation system, clinically proven to destroy pathogens. BtoB. 6 m$ revenues in 2014.
Antofenol	Cleantech: the company developed 3 technologies (microwaves, ultrasounds, vacuum) to extract specific compounds of plant. 300 L capacity. No revenues.
Arbaflame	CLEANTEHC: biomass to produce advanced wood pellets that can be used in coal-fired power stations.
avantium 3	White biotech: spin-out from Royal Dutch Shell Avantium has developed a proprietary process and product platform for renewable plastics, the unit YXY develops and commercialises PEF, a novel &amp- 100% bio-based polyester. Raise funds to build a scale up pilot plant.
Aykow 2	CLEANTECH: development and conception of innovative technologies for the detection of gas and particles. BtoB and BtoC.
bfc	BIOTECH: Chemicals. Dihydroxyacetone phosphate (DHAP) production and other chemical derivatives via biotechnology.
Biopolis	MICROBIOME: Microbial technology company with business units offering services in R&D for industrial biotech, probiotic production, microbiome analytics and functional ingredients as well as novel enzymes.
BRAIN	INDUSTRIAL BIOTECH: A public company offering enzymes, bacterial strains and analytics to generate new product opportunities for its clients and, more recently, itself.
bsf blue	Industrial Chemistry. Development of a unique technology at an industrial scale based on the reconversion of CO_2 from industrial emissions into products that can be used in a wide range of applications.
calcitech 2	Cleantech : waste recycling.
Covertis 2	BIOTECH: Develops R&D activities and production activities in the sector of green chemistry for the valorisation of vegetal resources. BtoB.
Cysal	INDUSTRIAL BIOTECH: Production of di-peptides as ingredients for various industries including in the first instance cosmetics and fish feed.
Demio	WHITE BIOTECH: wants to build a factory to produce 2nd generation biofuel and organic fertilizer. BtoB. No revenue.
direvo 6	WHITE BIOTECH: The Company focuses on the emerging biomass conversion industry. They are developing and marketing biology-based products and processes utilising safe and sustainable resources. They are using optimised proteins and enzymes.
Diverchim	INDUSTRIAL BIOTECH: Founded in 2000, it is a French company for organic synthesis of original molecules. This is a Contract Research Organisation (CRO) in organic chemistry. BtoB.
DxC Technology	CLEANTECH: Converting carbon dioxide to the industrial raw material dimethyl carbonate (DMT).
Energy	INDUSTRIAL BIOTECH: biotech company active in research and development of new bio fuel, polymer solutions and olfactive bio fragrances. Pre-industrial stage.
Ennesys 3	CLEANTECH: develops and commercialisea an innovative system of organic waste and water waste management using micro-algae. BtoB.
Enobraq	INDUSTRIAL BIOTECH: The Company develops yeast capable of using CO_2 (atmospheric or of other origins) and transforming it into molecules of interest for the chemical industry.
Envolure	Other: the Company has developed a range of innovative analytical solutions coupling performance, analysis speed and low costs for wastewater analysis.
Eranova ex-projet Blast	INDUSTRIAL BIOTECH: manufacture of bioplastics from stranded green algae. BtoB.
ethera 3	Cleantech : develops diagnostic kits for indoor air quality, for professional or private use.
Evoxx Technologies	INDUSTRIAL BIOTECH: A German company formed from the merger of two previously known industrial enzyme companies, focussing on biocatalytic enzymes and their application to produce novel carbohydrate ingredients.
Food Freshness Technology	Foodtech: range of products that reduce waste, protect and increase food quality. B2C.
Freesense	BIOTECH: Danish technology company designing and producing wireless, online sensors for bio-production optimisation. BtoB.

Company	Activity
gec	The world's first reactor driven by hybrid fusion fast fission technology.
GEPS Techno 2	CLEANTECH: design and development of systems that produce autonomously electric power from the swell sea. BtoB.
Germitec 4	Cleantech: Disinfection of ultrasound probes between each patient by UV-C. 1.1 m€ revenues in 2014.
Gingko Bioworks	INDUSTRIAL BIOTECH: Engineering microbes for molecule production.
Glowee	Cleantech –bioluminescence.
Green Research	CLEANTECH: develop and sell cost effective renewable green energy in the form of a biofuel unit produced from wood processing green waste and used for domestic heating. BtoB. Revenue 2015: 174 k€.
Greenbox	Other: installation of methanization units for agricultural operations. 1 m€ revenues planned for 2015.
Greennrg AS	cleantech/biofuel : Developing a second-generation technology to produce biofuel from wood.
heline energies	CLEANTECH: chauffe-eau solaire.
hive energy systems	Develops, engineers, manufactures, markets and installs large-format energy storage systems for use in industrial, electric utility, smart grid and military applications.
Home power solution	Cleantech: clean home power solutions.
Icohup	CLEANTECH: Develops low-cost and high-performance pollution sensors.
ImmunRise Technologies	BIOTECH: biocontrol solutions from micro-algae – biopesticide.
inbiose 2	Nutrition & Industrial Biotech: industrial white biotechnology company focusing on the manufacturing of specialty carbohydrates, and they are a supplier of novel carbohydrates (human milk oligosaccharides, chitosan?) Level of Interest: medium.
isobionics 3	Nutrition et white biotech: strains for production of nootkatone and valencene (orange/grapefruit fragrances on terpenes).
Klearia	CLEANTECH: Lab-on-a-chip process of water testing (micropollutants: heavy metals, pesticides, drugs residues).
kravex	Development of aerosol based e-cigarette product.
MiniGreen Power	Combination of Solar & Gasification technology.
New Environmental System	CLEANTECH: The Company develops the pumice stone in order to give it the capacity to chelate and inert heavy metals by remineralizing them, but also the molecules of the pharmaceutical products, with regard to the sludge of wastewater treatment plants.
Newfoss	Industrial biotech: Converting biomass waste flows into valuable products. A technology, which converts 100% of the biomass residues into 3 products: a woody fiber, an organic fluid and a mineral fluid containing all nutrients previously present in the biomass.
NIS Materials	Industrial: development of new chemical photocatalytic materials for business applications opportunities in large industrial fields like polymers, medical equipment, clothing, etc.
Photanol 2	CLEANTECH: platform renewable chemical company that utilises proprietary engineered cyanobacteria to process carbon dioxide (CO_2) and sunlight into valuable chemical products.
project woodbrige 2	Industrial Biotech: The Company develops, manufactures and sells an extensive selection of inorganic, organometallic, metal and acid-based chemicals.
ProjetGaïa	INDUSTRIAL BIOTECH: The company is specialised in setting up biofuel supply chains (granulated or crude) for large-scale energy and industrial installations. BtoB.
Projet wre227cf	manufactures springs and wire parts for the white goods (major household appliances) and automotive industries
Renaissance BioScience Corp.	INDUSTRIAL BIOTECH: The Company is focuses on the development of patented, non-GMO yeast strains to solve industrial process or product challenges (efficiency gains, novel product flavours etc). preventing yeast strain to reduce Hydrogen sulfide.. BtoB.

Company	Activity
reverdir	Development of a water retainer for agricultural use, the first of its generation to be 100% bio-sourced. Its use by farmers and in-land reclamation and reforestation programmes.
Salveco	CLEANTECH: The Company proposes to its partners to supply professionals with the advantages delivered by plant-based chemistry: formulas of 100% natural origin, reduced toxicity, no eco-toxicity, 100% biodegradability, renewable resources, no synthesis ingredients? BtoB.
Saphium Biotechnology	Industrial Biotech &amp- Cleantech: Biodegradable plastics with a microbial component.
Swiss Water Power 2	CLEANTECH: designs, develops and operates solutions for the production and distribution of drinking water and energy.
Syngulon	Industrial Bitotech: New selection technology designed for Industrial biotechnology: Innovative genetic firewall to boost fermentation.
The Pure Water Tech	CLEANTECH: The company has its expertise in the extraction of atmospheric water from moisture in the air. BtoB. BtoC.
unguis medical	Gas treatment for fungal nail infections.
unitair	Medtech: Designer and builder of cleanrooms and a wide variety of cleanroom components, workstations and air-handling equipment.
UpOwa	CLEANTECH: The Company is developing solar energy materials and solar cells for African countries. BtoC.
Waliag	ENVIRONMENT: develops a new way to treat household waste.
whitefox	Industrial Biotech – membrane-based tech to reduce energy and water consumption in industrial processes.
YNSECT 3	Nutrition: the company uses insects to bioconvert organic substrates, such as cereal byproducts, and transform those insects into sustainable nutrient resource for agro-industries and bioactive compounds for green chemistry. BtoB - 185 k? revenues planned in 2014.
Zasso	AGTECH: A system based on electrical pulses to provide a non-chemical alternative for weed control being developed for both agricultural and retail settings.

13 Specific issues

Over the large spectrum of investments covered by the blue bioeconomy sector, some deserve special attention, in that they might emerge rapidly and become blockbusters.

13.1 The case of Micro algae

Pretty much everything has been said about micro algae and our purpose is not to depict the potential of the sector which is becoming a true reality. Spirulina, which is a photosynthetic bacteria, and Chlorella, a fresh water micro alga, are the most common strains produced in Europe.

Below are some examples of current investments in the sector.

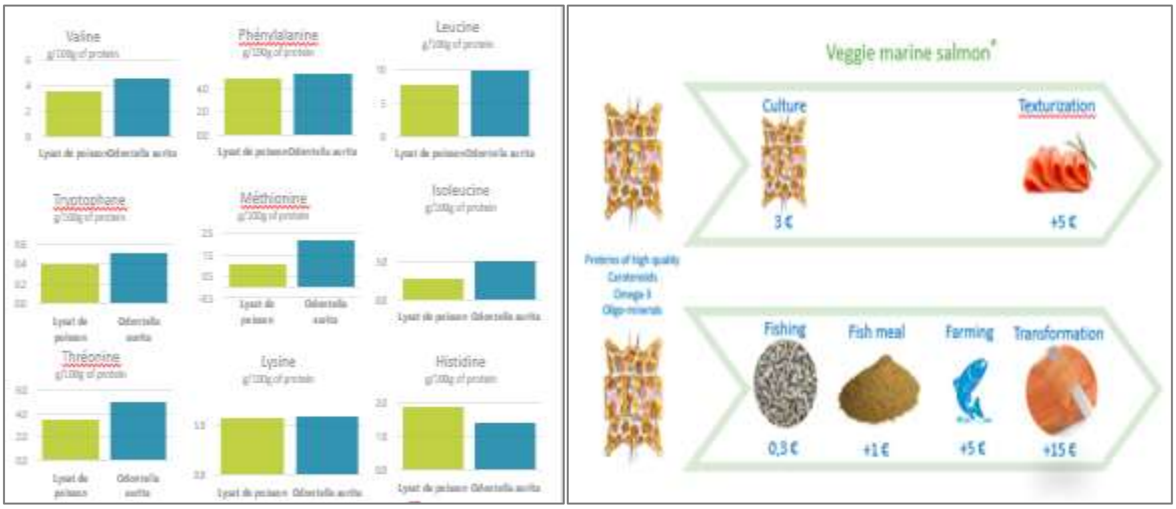
Odontella is a French start-up which is producing natural food products made out of this red marine micro algae. They have already produced the first vegetal salmon steak, which has the texture and taste of real salmon with no animal protein. Salmon aquaculture is becoming a real issue and consumers tend to fly away from this intensive and industrial production. The Omega 3 and 6 is becoming scarce in the flesh of the salmon which is fed more often on vegetal pellets associated with fish meal. Even if the salmon is fed on real fish meal, the conversion ratio is awfully low.

Figure 50 - Fish meal conversion rate for salmon

Source: Odontella

Using the odontella strain we could dramatically cut the production costs and reduce pollution of marine environment consequently. The vegetarian salmon steak brings more essential compounds to the human body than the farmed salmon steak itself.

Figure 51 - Benefits of "veggie salmon"



Source: Odontella

The main investors in the company are: crowd funders (600,000 €), Nouvelle Aquitaine (200,000 €), Olmix 600 000 €), a Japanese Venture Capitalist (1.2 million €).

Buggy power - http://www.buggypower.eu is a Portugal-based company producing micro algae for human food and cosmetics. They have developed a very high-quality product which is already used in the food industry (their products could be tasted in their restaurant in Lisbon), the nutraceuticals industry and the cosmetics. Their production site in Madeira can produce up to 30 tonnes a year, and their ambition is to multiply the production by four. To that extent, they are organising a round table in order to raise capital to finance their new plant in Gran Canaria and their pilot project in Iceland. The company could quickly become one of the European leaders in this field.

A4F: initially the company was contracted by Secil, a cement company, to develop a new way of carbon capture for their factories and produce green Biomass. The contract ended recently and A4F is now developing a new industrial park concept based on micro algae technology. In Partnership with Solvay and the government of Portugal they manage to raise 40 million EUR to install the park on the former site of the Solvay plant. This park will bring different actors working around micro algae: production, textile, biomaterials, pharmaceuticals, nutraceuticals, bioremediation etc. It is important to note that research and production have been largely subsidised and 80% of the micro algae companies work on research and development to get grants and tax breaks. It would be very important to place incentives on product development, so that the market could really take off. A4F is well positioned to foster the product developments that the consumer market needs.

Iceland: In 2016, the BioMarine organisation convinced the economic development agency to participate in the Oslo edition. One of the major stakes was to identify potential development in the biomarine sector using geothermal energy to produce biomass. After the 2016 convention a large study referenced the key European players for micro algae production. A selected panel was invited to Iceland and after 2 years of negotiation Iceland set up an ambitious plan to produce micro algae of different strains all year long. Stable conditions and low cost of energy are likely to turn the island into the largest producer of high value biomass from micro algae.

Other noteworthy investments are:

Empresa de Eletricidade da Madeira invested 10 million EUR to build a plant in Madeira and an annual fee of 2 million EUR is paid to support the production and the infrastructure.

United Arab Emirates is planning to invest 20 million EUR in a new facility in Dubai.

The Cabildo of Gran Canaria is also supporting the development of new facilities (5 M EUR).

13.2 The case of Shellfish by-products

Due to the huge waste produced each year by the shellfish processing industry and the absence of waste management, which represents an environmental hazard, the extraction of chitin from crustaceans' shells may be a solution to minimise waste and produce valuable compounds which possess biological properties with application in many fields. As a food waste, it is important to also be aware of the non-food uses of these wastes.

Chitin/chitosan is one of the most abundant bio-renewable resources. It is the major waste product of marine and fishery industry especially from the expansion of shrimp and crab industry of the world. One of the major wastes from these industries are chitinous materials such as shrimp and crab shells and squid pens. These wastes are normally discarded, used as fertiliser, or used for flavour and aroma extractions. However, there have been remarkable advances in the field of chitin/chitosan in the past decade and these materials can be of great value for the fishery industry. Furthermore, the production of such materials is not complicated and can be manufactured wherever there is a good source of chitinous materials. Among the possible applications of chitin/chitosan are:

Pharmaceutical and Medicine: Chitin/chitosan is the major source of amino sugar, N-acetyl-D-glucosamine and D-glucosamine found in nature. The United States FDA has approved only the hydrolysis product of chitin/chitosan to be the source of N-acetyl-D-glucosamine and D-glucosamine for human consumption. These simple amino sugars are used for the treatment of osteoarthritis in human as well as joints in animals. Chitin/chitosan is being studied and applied for drugs formulation as a mean of control release. It is applied as an adjuvant in vaccines with success. Chitosan coated wound dressing was also explored since chitosan has antimicrobial activity and can accelerate the healing process. Bio-matrix for tissue engineering using chitosan and composite of other inert material with chitosan was also constructed and has been shown to have great potentials for further development.

Agriculture: In Asia chitin/chitosan has been used as foliage spray to induce disease resistance and increase quality and production of orchid, and other ornamental plants. It has been researched and applied in crops such as rice, palm, corn, cassava and many tropical fruits with success. Chitin/chitosan has been incorporated into animal feed for fish and shrimps as feed coating as well as supplemented in the drinking water of poultry, cattle and porcine. The use of chitin-chitosan can elicit proper response when the proper molecular form, chain length and percent degree of deacetylation, and program are applied.

Polymer and Textile: Chitin-chitosan can also be applied and used in many other applications such as textile. Due to its antimicrobial property, chitin/chitosan when processed in to film or wet spin into fibers can be incorporated into both woven and non-woven fabric and can control the odour and prevent microbial growth.

Food and Nutraceutical Products: Food and nutraceuticals have been one of the major applications of chitin-chitosan, since it is the major source of amino sugar, N-acetyl-D-glucosamine and D-glucosamine. Chitosan can also act as a thickening agent, and recent studies have shown that chitosan can interact with proteins to change their interaction, resulting in improvement of texture of the product, as well as water retention of food products.

Some noteworthy investments have been made by **Ovensa** and **Lagosta**, two biotech companies developing tri-chitosan, a unique molecule used to protect the oral chemotherapy molecules when they pass the gastric barrier through digestion. Ovensa has been financed by Anges Quebec – two rounds of 600,000 $ and 1.8 million $. Lagosta has been financed by an industry capital venture fund (confidential) first with 500,000€ and then with 1.2 million €. Monaco has also been supporting their research lab for an amount of 600,000€.

13.3 The case of sea-cucumbers

Benthos Bioscience is a Chinese company which is developing its activities in the USA, Canada, and Europe with a focus on the French outermost territories and Portugal. They are one of the largest producers of sea cucumbers. Sea cucumbers are a class of echinoderms widely distributed in the marine environment. The high market value demand for sea cucumbers lies in the use of its muscle as a source of protein. The total production of sea cucumbers in China was 100,000 tonnes in 2010; 80% of the production is from aquaculture and enhancement. Beyond the direct consumption market, sea cucumber offers a wide range of new possibilities:

- Collagen: 80% of the by-products represents soluble collagen, which is in high demand from the cosmetic industry.
- Gut bacteria: analysis of intestinal bacteria has revealed some unique candidate bacteria that could lead to new innovative drugs. These bacteria have also proven that they can degrade oil residues in sediments.
- Neuropeptides: some species contain a small portion of neuropeptides, which are one of the best candidate to treat some of the most resistant metastasis cancers. Neuropeptide are sold at 312 million $/Kg (267 million €/Kg).

Mile stones developments:

- 2014: Possess Isostichopus fuscus genetic mapping, successful development of new technology in sea cucumber genetic engineering.
- 2008-2014: Successful Extraction/separation of highly active sea cucumber collagen, highly purified Frondoside A, STS-12A with uric acid reduction function, NP-14D - small molecule polypeptide that stimulates Gonadotropin-Releasing Hormone, and NP-82B neuropeptide with cell regeneration function etc.
- 2015: Benthos Laboratory, Tahiti was established to develop unique sea cucumber seedling technology-
- 2016: Gained permission for exclusive harvesting rights of ninety islands for 99 years in Tahiti
- 2018: Launched Benthos Institute, current plan:
  - Los Angeles (U.S): oil technology and daily R&D;
  - Mazatlan (Mexico): collagen extraction and separation;
  - Papeete (Tahiti): sea cucumber seedling and hatchery;
  - Shenzhen (China): R&D and product development;
  - Lisbon (Portugal): European headquarters.

Segmentation:

Phases	Technical term	Progress
1	Separation and extraction of high quality variable sea cucumber collagen	R&D completed, can be commercialised
2	Separation and extraction of high purity Frondoside A (raw material for anticancer drugs)	R&D completed, can be commercialised
3	Separation and extraction of STS-12A (lowering uric acid level)	R&D completed, can be commercialised
4	Separation and purification of polypeptides from sea cucumbers	R&D completed, can be produced
5	Separation and purification of NP-82B neuropeptide (immunomodulation and cellular regeneration)	R&D completed, can be commercialised
6	Separation and purification of NP-14D active peptide (improved sexual function)	R&D completed, can be commercialised
7	Separation and extraction of antithrombotic fucosylated chondritin sulfate	R&D completed
8	Preparation of lms-12a (HPV prevention and treatment)	Completion of research and development, preparation of preclinical and clinical trials
9	Preparation of 3D printed sea cucumber collagen wound dressing	R&D progress exceeds 85% and is expected to be completed within one year
10	Separation and extraction of triterpenoid saponins (bactericidal and anti-inflammatory functions) of sea cucumber	R&D progress exceeds 70% and is expected to be completed within six months
11	Separation and purification of sea cucumber small molecule polypeptide (analgesic function)	R&D progress exceeds 30% and is expected to be completed within four years
12	Separation and purification of sea cucumber small molecule polypeptide (enhanced myocardial systolic function)	R&D progress exceeds 55% and is expected to be completed within six months

Phases	Technical term	Progress
13	Separation and purification of the polypeptide (assisted with glycemic function and metabolic syndrome) of sea cucumber	R&D progress exceeds 40% and is expected to be completed within four and a half years
14	Preparation of 3D printed sea cucumber collagen based injectable hydrogel	R&D progress exceeds 85% and is expected to be completed within one year

Products developed

NP-14D Neuropeptide

► Protects against neurodegenerative diseases, neuronal damage and cognitive disorders as a result of its antioxidant effects.

► Stimulates directly over pituitary gland, increasing testosterone production plus libido levels and boosting sexual response and performance, in both men and women.

Tests for biocompatibility (genotoxicity, hemocompatibility, in vitro cytotoxicity, systemic toxicity, mutagenic activity, immunotoxicity) were completed by Tecnalia Research & Innovation Foundation in October 2016, Project number 055187.

NP-82B Neuropeptide

► A bioactive neuropeptide derived from marine collagen fibers.

►Regenerates skin, reaffirms tissues.

►Restructures damaged cells and superficial membrane, bringing a scar eraser effect.

Biocompatibility analysis with human skin cells in Tecnalia Research & Innovation Foundation from Spain done on December 2015 - project number 033145.

ISO 10993-3 for genotoxicity
ISO 10993-4 for hemocompatibility
ISO 10993-5 for in vitro cytotoxicity
ISO 10993-11 for systemic toxicity

Frondoside A (anti-cancer)

► A bioactive triterpenoid saponin and an immunostimulant.

► An extremely potent inducer of apoptosis in multiple cancer cells.

► 99.62% purity.

Anti-HPV gel

►Vioselective nanotechnology that inactivates a wide spectrum of microorganisms through DNA and RNA chain dislocation, leading to a loss of transmission of genetic information.

5 yeas development plan: (sales based on Chinese and US operations only).

Step1. Health Care (2018-2019)

Focusing on high-quality natural seafood and biological raw materials business, protecting consumers' food safety and life quality from the beginning of industry chain, also ensuring research institutions' material demand.

Step 2. Health Promotion (2020-2024)

Based on healthy sea food and biological materials, Benthos will vigorously promote the business of high-efficiency Health Care Products, linking the technology, capital and business, and improving human health and quality of lives all over the world.

Step 3. Health Reinvention (2025-)

After years of preparation, the medical and pharmaceutical business will become the priority, and the goal is to become a global leader in this field. Based on a strong R&D team, Benthos is contributing to the treatment of human diseases, prolonging life expectancies.

Figure 52 – Benthos' projected financial statements

	2018	2019	2020	2021	2022
	USD	USD	USD	USD	USD
Sales Income	62,460,000	124,920,000	249,840,000	287,316,000	330,413,400
Sales Cost	17,640,000	35,280,000	70,560,000	81,144,000	93,315,600
Gross profit	44,820,000	89,640,000	179,280,000	206,172,000	237,097,800
Sales expense	20,877,255	41,754,510	83,509,020	96,035,373	110,440,679
Operating expense	4,746,960	9,493,920	18,987,840	21,836,016	25,111,418
R&D expense	3,653,910	7,307,820	14,615,640	16,807,986	19,329,184
Total expenses	29,278,125	58,556,250	117,112,500	134,679,375	154,881,281
Profit before tax	15,541,875	31,083,750	62,167,500	71,492,625	82,216,519
Tax	2,331,281	4,662,563	9,325,125	10,723,894	12,332,478
Net revenue	13,210,594	26,421,188	52,842,375	60,768,731	69,884,041

Source: Benthos

Benthos has been funded by its main shareholder and two new corporate ventures funds will come soon in the capital. 50 million $ (43 million €) are expected to be raised in 2018 for a pre-IPO. They received support from the Chinese government and the Shenzhen district in return of R&D relocation from USA to china. The direct and indirect support is estimated to 6 million $ (about 5 million € at the time of writing).

13.4 The case of Seaweeds starch for bioplastics

Plastics are carbon-based polymers, mostly made from petroleum. Biomass-based plastics or bioplastics are a form of plastics derived from renewable biomass resources like vegetable oil or corn starch, whereas conventional plastics are made from petroleum. Their advantages are innumerable, and one is their capability to biodegrade naturally within a short period of time only. The bioplastic industry is currently developing a biomass-based plastic from the natural polysaccharides of seaweeds. The technology development for the seaweed-based bioplastics are still in the research phase and it is hoped that significant advancements will be made in the bioplastics industries in the coming months, so as to make seaweed bioplastics a reality in the near future. Fermentation and genetic engineering can take the lead in using novel techniques to make bioplastics from seaweeds which would make them as a viable alternative.

13.5 The case of Seaweeds cooperative in Quebec

The mandate of the Lower North Shore Bioproducts Solidarity Cooperative is to stimulate local economic diversification through the sustainable and added-value exploitation of indigenous natural resources in the Municipality of Bonne Esperance and the other communities of the Lower North Shore. The Coop aims to accomplish this while creating local business and employment opportunities through the development, harvesting, processing and marketing of raw and prepared products from ocean. Supported by investments from government development programmes (i.e.: MAMROT, DEC, etc.), community engagement and a joint venture business collaboration with Industry, the Coop will translate this 'solidarity' into a planned expansion of marine products into regional, provincial, national and international markets over a three-year period that will provide the basis for local employment opportunities, the creation of local infrastructure and skill base, as well as a return on investment that will fund future development initiatives in the cosmetic industry. Starting with a core team of 15 full-time employees and supported by 15-20 occasional and part-time employees (harvesters), the Coop plans to eventually create 50 full-time and at least 30-40 seasonal jobs over a three-year period.

The harvesting and processing of algae, star fishes and sea cucumbers on the Lower North Shore (LNS) will keep the revenue generated within the region creating tangible economic benefits (e.g. taxable income, job creation, economic spin offs for businesses, etc.) and stimulating community economic development. Given that the non-timber forestry sector on the Lower North Shore is largely undeveloped, the Coop aims to become the leader in this industry by creating viable business opportunities that will contribute to the sustainable development (economic, social and environmental) of the region.

The immediate objective of this proposal (Year 1) is to:

Initiate a line of five cosmetics and four nutraceutical products under an Arctic brand. This will be accomplished through the harvesting, processing and distribution of extracts from two algae varieties and birch sap to targeted markets in North America and China, using materials sourced from the communities on the Lower North Shore and neighbouring territories.

The medium-term objectives (Years 1-3) are to:

- Expand the cosmetic line, nutraceutical and food lines of the Coop to other communities along the LNS, and the products sold in targeted Chinese markets;
- Expand the range of bio products offered by the Coop to include additional seaweed and new natural resource products;
- Produce further recipes from the additional bio-products, as well as expand to other product families, such as natural health products (NHP);
- Install the sea cucumber hatchery and aquaculture operations, based on recommendations in study.

The long-term objective (Years 4+) is to:

- Expand the birch water and algae operations of the Coop and the products sold into targeted markets in the US and internationally with partners from other Arctic regions;
- Install the bio extraction facilities for the sea cucumber;
- In achieving these objectives, the Coop will be able to contribute to the economic stability of the region by aiding in job creation, creating local business opportunities, and improving revenue in the region.

Partner Network's contribution (5 years):

Local: 50,000 CAD
- Coasters Association Inc;
- MRC de Golfe St.Laurent;
- Municipality of Bonne Esperance.

Regional : 100,000 CAD
- Municipalité Régionale de Comté (MRC)du Golfe du Saint-Laurent;
- Commission Scolaire du Littoral.
- Centre d'expérimentation et de développement en forêt boréale);
- Biopterre;
- Coopérative de développement régional Bas-Saint-Laurent/Côte-Nord (CDR);
- Centre de Développement Bioalimentaire du Quebec (CDBQ).

Provincial : 2,000,000 CAD
- Ministère des Affaires municipales, des Régions et de l'Occupation du territoire (MAMROT)
- Emploi-Québec;
- Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ);
- Ministère du Développement économique, de l'Innovation et de l'Exportation (MDÉIE).

Federal: 1,500,000 CAD
- Canada Economic Development–Québec (DECQ);
- Young Canada Works (YCW);
- Agriculture and Agri-Food Canada (AAFC);
- Human Resources and Skills Development Canada – Services Canada (Canada Summer Jobs).

Companies: 5,000,000 CAD
- 101;
- L'Onvie;
- Benthos Bioscience;
- Qu'anglo Communications.

Other
- Université du Québec à Trois-Rivières (UQTR)
- Memorial University
- U Arctic.

14 How to foster investment in the blue bioeconomy?

It is always difficult to draw a clear picture of what should be done precisely. The market is evolving fast, consumers evolve towards more safety, more sustainability, but the industry is reacting slowly to these demands. The environmental impact is becoming a key driver for cleaner and safer innovation. Europe has established a very good framework to foster this innovation and accelerate the development of projects. We are on the right track, but we could accelerate the process if we:

1- Develop a communication towards the public, the financial community and investors. Making sure that the blue bioeconomy becomes a fully-recognised industry within the wider bioeconomy. We need to tear down the existing silos and present the potential of marine bioresources as a key stone for the final markets such as cosmetic, food, nutrition, material, chemistry.
2- Work and convince EU banks, EIB and EIF to accept lower entry tickets especially for funds of funds. The biomarine industry is still at a stage where most of the projects are emerging and the capital that is needed is not in the range of the other industry sectors such as space or shipping. The average ticket is from 0.5 to 2 million EUR.
3- Design a special financial vehicle accessible only to SMEs during their pre-commercialisation phase and proof concept. Product development is the key and all efforts should be redirected towards this primary goal and not research nor production which have enough financial support.
4- Organise mentoring for those SMEs 'CEOs who are often coming from research and may not be familiar with a business environment. A programme that supports them through the different steps towards commercialisation.
5- Support business communities and cross-fertilisation initiatives. This will foster international cooperation and commercialisation.

Section 5 - National strategies to support the blue bioeconomy

15 Public policies for academics and public initiatives

There is no global pan-European plan, strategy or policy specifically dedicated to marine biotechnology. However, marine genetic resources research has been supported through the MarBEF (Marine Biodiversity and Ecosystem Functioning, FP6 Network of Excellence), JPI Oceans (Joint Programming Initiative), or Marine Biotechnology ERA-NET. These initiatives mostly focus on academic research. An overview of key marine biotechnology science policy is available on Marine Biotech website (www.marinebiotech.eu), including major infrastructures coordination and support initiatives, science policy and coordination initiatives and research initiatives. This part of the document focuses on public policies and plans dedicated, or linked with private companies.

Furthermore, several European countries have adopted overarching science strategies, plans and policies. Most of them are not specific to the blue bioeconomy but include it to some extent.

15.1 Investment landscapes

Public investment strategies depend on the history and facilities of the concerned countries. Investments aim to mostly support the discovery and growth of:

Pharmaceutical molecules

SMEs develop their strategies with a hope for licensing-out or trade sales. They are usually financially supported by founders, seed capital and institutional investments. But the level in investments is not sufficient to reach their goals. Examples include companies such as Aquapharm or Nereus.

Some of them reach profitability by diversifying their portfolio, backed by bigger SMEs. In this scheme, no public funds are implicated. This is the case of Greensea, a subsidiary company of Greentech/Altinat group.

Another way for blue biotech SMEs to develop is to integrate consortia, financially supported by both public investments and major companies. An interesting example is the Algohub programme, led by the world leader Roquette Frères (France). This 29 million EUR programme backed by the French public OSEO Innovation fund (9.8 million EUR) brought together 14 partners, including SMEs. This programme also integrated food, feed, cosmetics, aquaculture, and thus can be considered as a pioneer blue-biotech programme supported by public policies.

An increasing number of major companies are investing by themselves through corporate venture funds. This is the case of Zeltia (Spain) who invested more than 500 million EUR in PharmaMar R&D. But some other major companies use local fiscal advantages. This is the case of some French pharma companies, whose research in marine resources benefits from a 30% tax credit on research expenses. In Belgium, Solvay has established an environmental fund dedicated to clean the old chemical plant and to finance new green ventures.

Enzymes for industrial and process use

Deinove has been strongly supported by Bpifrance and reached out to the financial markets.

Barentzymes, ArcticZyme, Ingenza benefit from Norway national programmes.

Sources for biofuel

The US Biorefinery Assistance Programme supported Sapphire Energy with a 454 million USD (about 388 million EUR at the time of writing) investment.

Bioprocess Algae (US): Monsanto decided to finance one of their major projects before taking full control.

EU funding FP7 also supported MIRACLES, BIOFAT, All-gas, InteSusAl, The MicroAlgae Biorefinery for 36 million EUR out of 53 million EUR.

15.2 Funding

Several countries have general research funding dedicated to biotechnologies, but not specifically dedicated to blue biotechnology. For example, Denmark has private funding such as a state investment fund: the Danish Growth Fund (Vaekstfonden). Innobooster is dedicated to small enterprises and entrepreneurs with sound development plans. Companies can also apply for co-financing to the Market Development Fund (Markedsmodningsfonden).

Nearly all countries with an access to the sea have public investment policies. These funding can be specific (Salmon Genome Project, Canada), or part of a general strategy (Oman M.A.F., Indian National Biotechnology Strategy). The following examples from all over the world highlight the diversity of public investments in marine biotechnologies:

Table 38 - Programmes that support marine biotechnologies

Country / Area	Programme
Germany	Via ScanBalt strategy
Ireland	Via Marine Institute
Portugal	Fundoazul
France	Via OSEO/Bpifrance
E.U.	FPs/H2020, ERA-MBT
Canada	Salmon Genome Project
U.S.A.	Parts of USDA Biorefinery program, CO_2 reduction program and DoE alternative energy support
India	Via National Biotechnology Strategy, throughout joint programs, with UK for example (biofuels, marine bio-prospecting, bioenergy)
Australia	Depend on individual states e.g. BlueBiotech Shoalhaven, NSW Aquatic Biotechnology Sector Strategy may 2014
New Zealand	Via Biotechnology Roadmap
South Africa	SANCOR (South Africa Network for Coastal and Oceanic Research)
Mozambique	Via National Biotechnology Program
Oman	Specific funds from Ministry of Agriculture and Fisheries
Japan	Marine Bio 21 Project
South Korea	Blue-Bio 2016
Brazil	BIOMAR, MCTI; Brazilian Development Bank
International	OECD Initiative, CIESM (Commission Internationale pour l'Exploration Scientifique de la Méditerranée), marine genomes

The following European countries have no specific marine biotechnology strategy or policy: Austria, Belgium, Bulgaria, Croatia, Estonia, Greece, Italy, Latvia, Lithuania, Malta, The Netherlands, Poland, Romania, Slovenia, Sweden, Switzerland, United Kingdom.

The Danish Ministry of Food, Agriculture and Fisheries published in 2010 a report, The Sea – an unexploited resource (Havet – en uudnyttet resource), reporting 6 identified themes: use of marine biomass, cultivation of commodities in and from the sea, health-promoting ingredients, discovery of new substances, materials and biological activities and principals, extraction of valuable biochemical substances, and biofilms.

Finland

Two programmes have been developed to support private initiatives in blue biotechnologies:

SymBio - Industrial Biotechnology: this programme had a budget of 80 million EUR and was funded by the Government (49%), private companies (48%) and research institutes (3%). The aims of the programme were to:

- create competitive industrial processes, new products and services using biotechnology;
- enhance the environmental friendliness of industrial processes;
- create new business opportunities in the fields of industrial production and environmental biotechnologies; and
- boost the transfer of research results into technology and new products.

BioRefine: 137 million EUR were earmarked for this program. It aimed to develop innovative technologies, products and services. The programme also looked to develop bio refineries.

France

There is a French science and technology policy ("National Program Law for Research and National Research Strategy), but there are no specific marine biotechnology strategies, plans or policies in France at the national level.

Two public governance structures exist, namely Pôle Mer Bretagne and Pôle Mer Méditerrannée, and 3 other clusters: CapBiotek, Blue Cluster and Europole Mer 3Blue Network".

There is no specific public fund for marine and biotechnological private development.

ADEME (French Environment and Energy Management Agency) can launch calls for some specific economic developments linked to climate change, microalgal biomass for biofuels…

BPI France is the public-sector institution dedicated to economic development, and a key source of financing and other supports to SMEs.

Germany

Blue biotechnology is not yet a priority in Germany. Most efforts consist in supporting public research and focus on durability and marine conservation.

Germany has a global strategy of protection and sustainable development of the seas (horizon 2030), throughout three federal programmes: SUBMARINER, MIMAS, and MicroB3, but these programmes mostly imply public research, in a descriptive work of marine populations and their genomic background.

Ireland

As soon as 2007, there was a marine biotechnology strategy: Sea Change – A Marine Knowledge, Research, and Innovation Strategy for Ireland 2007-2013, still influencing the strategic direction of Ireland. The Strategy on Marine Biotechnology is the national strategy on marine biotechnology. It is an important part of the Overall Marine Strategy (Sea Change), focusing on biodiscovery and functional food/nutraceuticals.

Enterprise Ireland provides in-company research and development for companies in most industry sectors, including the blue biotechnologies.

Lithuania

Lithuania has published a general biotechnology policy:

(www.bio-economy.net/bioeconomy/member_states/lithuania/files/report_lithuania_final01.pdf)

Iceland has no dedicated marine biotechnology policy, strategy or plan. The Science and Technology Policy Council is responsible for setting public policy. The Ministry of industries and innovation covers blue biotechnologies. All major initiatives come from private sector. A network of bio-marine companies and start-ups already exist: the Iceland Ocean Cluster. The Association for Biotech Industries is also defined by the Federation of Icelandic Industries.

Norway

Sea Food Cluster Bergen is the main pubic governance structure.

Three strategic documents exist: The Strategic Plan for Marine Bioprospecting (strategic document on how to implement the national strategy for Marine Bioprospecting), The Arctic and Northern Areas Initiative, and HAV21 (marine strategy for Norway).

Ten biotechnology platforms offer service in different high-tech niches to industry. Most important funding structures for the blue biotechnologies SMEs come from Innovation Norway (funds innovation projects) and the Research Council of Norway (BIOTEK2021, Aquaculture – An industry in growth, Sustainable Innovation in Food and Bio-based Industries), Pre-Industrial and Industrial Supports.

Portugal

The Blue economy is one of the main priorities for Portugal. Portugal has a national strategy for the Sea (ENM). The Direcção-Geral da Política do Mar (DGPM) develops, evaluates and updates the National Strategy for the Sea. It elaborates and proposes political measures and promotes the national and international cooperation in maritime affairs. There is an existing private / public governance structure called Blue Bio Alliance Portugal which is part of the larger organisation Ocean XXI which includes maritime and ports.

Portugal rolled out Fundo Azul, a national fund specifically dedicated to the promotion of economy, marine scientific and technological research, protection and monitoring of the marine environment, and maritime security and safety.

Spain

There is a global national strategy (Spanish Strategy for Science and Technology and Innovation) under the authority of the Ministry of Economy and Competitiveness (MINECO), with a specific section on marine and maritime topics.

Most of public efforts supports academic research and collaborative platforms. Private companies can apply and participate in the actions financed under the national plan. Small and medium-size enterprises (SMEs) are considered differently than public organisations and individual entrepreneurs.

The most famous private investment in the blue economy was a 500 million EUR made by the company Pharmamar.

Spain - Canary Islands

Both financial supports and logistics have been set up by the Canary Islands regional government.

- The Jeremie Canarias Fund (23M EUR€) is dedicated to SMEs. It includes specific lines of co-investment in technological and environmental SMEs.
- The Technological Fund (35M EUR) is composed of capital instruments for the consolidation of technological SMEs (5M EUR) and debt instruments for technological tractor companies (30M EUR). The fund acts in a public-private co-investment model.
- 100 M EUR are also invested in technology parks to facilitate implantation of firms and facilitate the links between companies and universities in an integrated network. Gran Canaria mainly focuses on marine science & technology, Tenerife on biomedicine, and Fuerteventura on renewable energies and water management.

Priorities include marine environment with the Canarian Oceanic Platform (PLOCAN) and experimental projects on renewable energies in offshore facilities. Biotech is also listed as a priority, with the Campus of Excellence, the Applied Algology Centre, and Canary Islands Technological Centre.

Canada

At the time of writing this information the federal government will release its super ocean cluster funding strategy (500 M CAD). It is a vehicle that will coordinate regional strategies based on smart specialization in order to avoid regional competition.

Canada - Québec

The government of Québec has made the development of marine biotechnologies a priority. A recent effort has been made to identify and organise the whole value chain.

Plans are under development, among which are:

- single government desk
- thin mapping of the links of the value chain
- support fundamental research
- ease public-private partnerships
- facilitate the transfer of discoveries and innovations from the lab to the factory, then to the final consumer
- training a highly skilled workforce
- create a public blue tech fund
- strengthen private investments, including sovereign funds for major investments

The strategy is currently being implemented. It was presented at BioMarine 2017 and pre-launched to the Québec industry during the course of 2016 – 2017. The collaboration between the government of Québec and BioMarine generated more than 58 M CAD in direct investment before, during and after the convention. Some major projects creating 250 jobs and preparing a master plan for farming low trophic species on the north shore of St Laurent river have been launched based on public and private investment.

Most countries do not have a specific marine biotechnology strategy or policy. When they have such strategies, they mostly focus on academic research. Private companies are rarely involved, and financial support is usually inexistent, except for specific innovative programmes. Countries with an access to the sea and a marine culture have the most important global blue economy-turned strategies, plans and policies: France, Ireland, Norway, Portugal, Sweden and United Kingdom.

The most advanced countries in terms of global strategy are Québec (Canada) and Portugal, who are building global strategies, from fundamental research to economically supported industrialization in an integrated chain.

16 Summary table

The following table summarises public policies at national level:

Table 39 - Public policies summary table

Country	Overarching science strategies, plans and policies
Austria	No specific Marine Biotechnology strategy, plan or policy, but if we look at the nutrition industry, especially energetic drinks, Austria has been one of the leading countries where most of the key products have emerged, thanks to the massive entrepreneurial programme they have initiated on that niche to counter Red Bull implantation.
Belgium	No specific Marine Biotechnology strategy, but the blue cluster is preparing a road map to be submitted to the national Parliament. It will encompass both a maritime and a marine dimension.
Bulgaria	No specific Marine Biotechnology strategy, plan or policy.
Croatia	No specific Marine Biotechnology strategy, plan or policy.
Denmark	National Whitepaper: "Research2020".
Estonia	Estonian biotechnology strategy 2008-2013.
Finland	Finnish Biotechnology policy.
France	There are no specific Marine Biotechnology strategies, plans or policies at the national level. The Overarching French Science & Technology Policy is described in the National Programming Law for Research and in the National Research Strategy (SNRI) In 2009, the "National strategy for the sea and the oceans" Blue Book laid out France's maritime policy. The Blue Book reaffirmed France's ambition to know in depth, protect and manage its vast maritime area; a source of economic and ecological wealth. Blue book / National strategy for the sea and the oceans. The marine research component of the overarching Science & Technology Policy is further elaborated in the strategic policy document of the French marine science organization Ifremer: Exploring the sea to understand the earth: contribution to a national research strategy for marine sciences for 2020.
Germany	There are no specific Marine Biotechnology strategies, plans or policies – Gesine Meissner from the European group is preparing a roadmap at national level that she will present when the new government is formed. At the federal level: - "National Research Strategy BioEconomy 2030: Our Route towards a Biobased Economy"(BMBF) and the "National Policy Strategy BioEconomy" (BMEL) - High-Tech-Strategy 2020; Technology Campaign (Innovationsstrategie); Nationaler Masterplan Maritime Technologien (NMMT) "Biotechnologie 2020+ - Strategy of the German Agricultural Research Alliance (dafa - Deutsche Agrarforschungsallianz) - Framework Program Research for Sustainable Development (FONA) At the regional level: - "Sea or Future" initiative of state Schleswig-Holstein; - Masterplan Marine Biotechnology Schleswig-Holstein.
Greece	*There are no specific Marine Biotechnology strategies, plans or policies.*
Iceland	The Science and Technology Policy Council is responsible for setting public policy in matters of science and technology. Iceland does not have a dedicated Marine Biotechnology policy, strategy or plan.

Country	Overarching science strategies, plans and policies
Ireland	National research agenda is set-out in the Strategy for Science, Technology and Innovation. Ireland has a national strategy on marine biotechnology, as an element of an overall marine research strategy (Sea Change), focusing on biodiscovery and functional foods/nutraceuticals. A recent broader national research prioritization exercise includes marine functional food as part of a 'Food for Health' priority and opportunities marine biodiscovery research within the 'Therapeutics' priority. Other related policy and national strategies include: - Food Harvest 2020 (a plan for Ireland's food sector); -Food Research Ireland (strategic research agenda).
Italy	Italy does not have a dedicated Marine Biotechnology strategy, plan or policy. The overarching Italian Science and Technology Policy is described in "Programma Nazionale della Ricerca". The marine research component of this Strategy is further developed in the Italian Research for the Sea programme managed by Ministry of Education, University and Research. RITMARE is a national programme which promotes marine research, including Biotechnologies.
Latvia	*There are no specific Marine Biotechnology strategies, plans or policies.*
Lithuania	Lithuanian biotechnology policy.
Malta	There is currently no specific Marine Biotechnology strategy or policy in Malta. A National Strategy for Research and Innovation for the period 2011-2020 is being developed. National Strategic Plan for Research and Innovation: Building and Sustaining the R&I Enabling Framework Malta Council for Science and Technology (MCST).
The Netherlands	*There is no dedicated strategy or policy for Marine Biotechnology research.*
Norway	- National Whitepaper: "Climate for research" (overall government's research strategy). - National Whitepaper: "Marine Bioprospecting- a source of new and sustainable wealth growth" (Government's strategy for marine bioprospecting). - National Whitepaper: "National strategy for biotechnology" (government's strategy on biotechnology). - National White paper: "Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry" (government's strategy on aquaculture)
Poland	There are no specific Marine Biotechnology strategies, plans or policies

Country	Overarching science strategies, plans and policies
Portugal	Portugal has a National strategy for the Sea (ENM). This strategy is a public policy instrument that presents a new development model for the ocean (blue growth) that points to a long-term, intelligent, sustainable and inclusive growth path, and intends to prepare Portugal to tackle the challenges brought by the growth, promotion and competitiveness of the Sea Economy, at both European and International levels. This strategy lists a series of concrete measures and actions and one of the main intervention domains deals with the sustainable exploitation of living resources, where it is expected that biotechnology will be a major instrument for in sea food processing, including fisheries and aquaculture, valorisation of biomass and rest raw materials, leading to an impact in numerous industrial applications, such as food and feed, pharmaceutical, cosmeceutical, and others. "The Research & Innovation smart specialization strategy" (ENEI_PT) reinforces these intentions, and identifies the Sea economy as one of the main priorities for Portugal - Direcção geral da política do mar (DGPM) The DGPM's mission is to develop, evaluate and update the National Strategy for the Sea, to elaborate, and propose political measures, to plan and regulate the maritime space in his different uses and activities, to follow-up and participate in the Maritime policy integrated in the EU and promote the national and international cooperation in maritime affairs. - COTEC Portugal is a business association for innovation. It has the mission to «promote the competitiveness of companies established in Portugal". COTEC led the elaboration of a document "Blue Growth for Portugal" that analysis in detail the current state and perspectives for the six main maritime areas: 1.Food/feed from marine resources, 2.Offshore energy, 3.Equipment, repair and shipbuilding, 4. Leisure, tourism and recreation, 5.New uses and bioresources from the sea, 6. Ports and Maritime transport (see: Blue growth for Portugal).
Romania	*There is currently no national strategy or plan specifically for Marine Biotechnology research.*
Slovenia	*There are no specific Marine Biotechnology strategies, plans or policies.*
Spain	Strategy: Spanish Strategy for Science and Technology and Innovation. National Plan for Scientific and Technical Research and Innovation The Spanish National Plan focuses on research and innovation. It has been developed to implement the National Strategy.
Switzerland	*There are no specific Marine Biotechnology strategies, plans or policies.*
Sweden	There is currently no dedicated Marine Biotechnology policy or strategy. Overarching research priorities of the government are determined by the Swedish Research and Innovation Bill and the Swedish biotechnology policy.
Turkey	There is currently no national marine biotechnology policy or strategy Nevertheless, Marine Biotechnology is addressed as part of the overarching long-term science and technology vision and strategy (National Science, Technology and Innovation Strategy). The Strategy has fundamental objectives to develop cross-disciplinary and cross-sectoral research-technology and innovation which suits perfectly marine/maritime and biotechnology research.

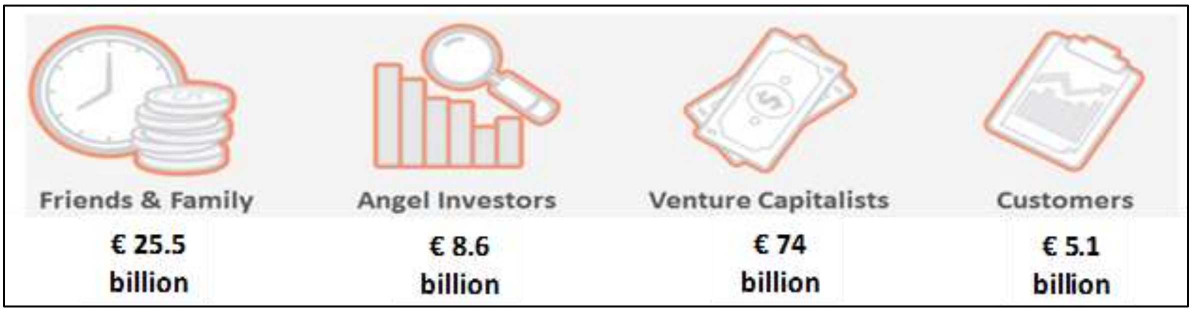
Country	Overarching science strategies, plans and policies
United Kingdom	There is currently no national strategy for marine biotechnology. Marine Biotechnology fits into the wider science and technology policy and supported via overarching marine and bioscience strategies. The marine research component of this Policy/Strategy is further developed in UK Marine Science Strategy (2010-2025) led by the UK Marine Science Co-ordination Committee.

In addition to these science strategies, plans and policies, several European countries have published general or specific strategic documents related to blue biotechnologies:

- Belgium has its Belgian Report on Science, Technology and Innovation.
- France published its Marine Programme, an inventory of French research on marine and coastal environments, their means of study and the technological developments they sustain, and identifies key issues in terms of knowledge and public policy.
- Germany has its Masterplan Marine Biotechnology Schleswig-Holstein - Marine Biotechnologie in Schleswig-Holstein – “Nationaler Maritimer” Masterplan.
- Italy has several general documents that can be linked to blue economy: BioinItaly report, Guideline for the development of biotechnologies in Italy, and Industial Biotechnology in Italy, initiative and policies.
- Norway has three, specific documents related to the marine economy: Strategy plan for Marine Bioprospecting: Strategy document on how to implement the national strategy for Marin Bioprospecting, The Arctic and Northern Areas Initiative (Forskning.nord.to): The Research Council of Norway’s research strategy for the high north, HAV21: The marine strategy for Norway.
- Sweden possess a State of art of Swedish biotech, and a report named Europabio report on Swedish Industrial Biotechnology.

Annex I - The typology of private investment in Europe

Figure 53 – Breakdown of investments in Europe by source



Source: www.fundable.com

Friends & Family

It may come as a surprise, but friends and family invest huge money in start-ups, with over 25.5 billion € per year overall. 38% of start-up founders report raising money from their friends and family. The average amount invested is 23,000 EUR.

Angel Investors

An angel is a high net worth individual who invests directly into promising entrepreneurial businesses in return for stock in the companies. Many angels are successful entrepreneurs themselves, as well as corporate leaders and business professionals. Angel groups are organisations formed by individual angels interested in joining together to evaluate and invest in entrepreneurial ventures. This scenario enables angels to pool their capital and make larger investments.

There are an estimated 303,650 active "angel" investors in Europe (258,354 in the US). They invest an estimated 8.6 billion EUR into 32,940 companies a year. On average, they invest 74,955 EUR into companies.

Table 40 - Angel investment by country

Country	No of Angel Networks	No of Angels	No of inv.	Total Angel inv. 2015 (M€)	% change on year before	Total Angel inv. 2014 (M€)	% change on year before	Total Angel inv. 2013 (M€)	Avg. inv. per Angel 2015 ('000 €)	Avg. inv. per Angel Network 2015 ('000 €)
UK	44	4738	567	96	10%	87	3%	84.4	20,262	2.18
Spain	52	2732	232	55	5%	52.63	-9%	57.6	20,132	1.06
Germany	32	1930	178	44	19%	37	5%	35.1	22,798	1.38
France	78	4621	292	42	%11	38	-8%	41.1	9,089	0.54
Finland	11	550	434	36.5	%6	34.5	31%	26.4	66,364	3.32
Turkey	15	850	154	31	%38	22.4	52%	14.7	36,471	2.07
Russia	15	290	54	29.2	%-4	30.36	-27%	41.8	100,690	1.95
Portugal	17	624	58	23.4	%-16	27.85	102%	13.8	37,500	1.38
Denmark	4	215	168	23	%16	19.8	68%	11.8	106,977	5.75
Sweden	12	809	91	21.8	%6	20.6	6%	19.4	26,947	1.82
Austria	5	325	32	16.3	%9	15	417%	2.9	50,154	3.26
Switzerland	10	462	44	14.9	%6	14.1	6%	13.3	32,251	1.49
Ireland	10	725	67	14.4	%15	12.5	-5%	13.2	19,862	1.44
Poland	5	411	32	12.35	%30	9.5	44%	6.6	60,049	2.47
Italy	13	821	74	12.25	%5	11.7	18%	9.9	14,921	0.94
Netherlands	16	1024	81	12.2	%4	11.7	19%	9.8	11,914	0.76
Belgium	5	345	66	11.5	%10	10.5	5%	10	33,333	2.30
Estonia	1	101	63	6.67	%39	4.8	2%	4.7	66,040	6.67
Norway	4	125	23	4.6	%48	3.1	-26%	4.2	36,800	1.15
Bulgaria	2	88	47	4.29	%30	3.3	14%	2.9	48,750	2.15
Greece	4	51	12	2.7	%50	1.8	-14%	2.1	52,941	0.68
Luxembourg	1	61	21	2.5	150%	1	-38%	1.6	40,984	2.50
Serbia	1	50	18	2.1	17%	1.8	157%	0.7	42,000	2.10
Slovenia	3	78	23	1.85	17%	1.58	%	n.a.	23,718	0.62
Slovakia	3	55	12	1.75	32%	1.33	%	n.a.	31,818	0.58
Lithuania	1	120	8	1.2	-43%	2.1	5%	2	10,000	1.20
Macedonia	2	28	7	1.1	38%	0.8	%	n.a.	39,286	0.55
Latvia	1	46	9	0.76	230%	0.23	%	n.a.	16,522	0.76
Kosovo	1	15	15	0.7		n.a.	%	n.a.	46,667	0.70
Cyprus	1	47	3	0.62	-13%	0.71	18%	0.6	13,191	0.62
Croatia	1	28	5	0.35	-13%	0.4	-50%	0.8	15,500	0.35
Others	100	8000	404	80	-20%	100	-18%	122.6	10,000	0.8

Source: European Trade Association for Business Angels,Seed Funds, and other Early Stage Market Players

Customers

In 2015, customers rallied behind their favourite companies through crowdfunding campaigns, and contributed an estimated 5.1 billion EUR in total — up from € 3.2 billion in 2012. The average amount of funding raised by these companies is approximately 7,000 EUR.

Generally speaking, the average crowdfund supporter is between the ages of 24-35, and is internet savvy. Men are much more likely to contribute to an unknown start-up, and individuals who earn more than € 100,000 each year are the most avid crowdfund supporters.

Venture Capital

Venture capital firms are in the business of reviewing, assessing, and investing in new and emerging businesses. As a result, VCs look at a very high volume of deals, and on average only invest in 1 out of every 100 deals they consider – compared to angels, who invest in 1 out of every 10 deals.

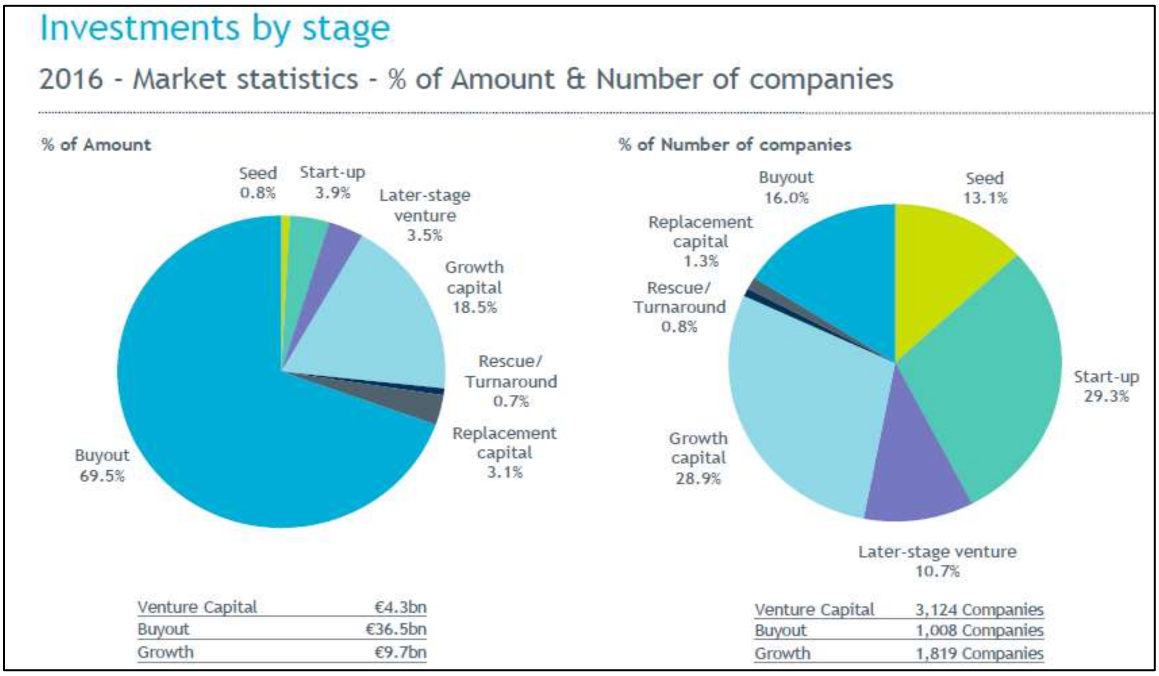
Furthermore, VCs conduct significantly more due diligence than angel investors, spending an average of 5 months on due diligence for each investment.

While angels occasionally act as mentors to the entrepreneurs they bankroll, venture capital is consistently an active, rather than passive, form of financing. These investors seek to add value, in addition to capital, to the companies in which they invest, both to help your company grow and to achieve a greater return on their investment. This means active involvement: virtually all VCs will want a seat on the Board of Directors.

There are approximatively 3,000 active venture capital firms in Europe managing more than 7,000 funds. The total equity amount invested in European companies remained stable in 2016 at 52.5 billion €. About a third of this amount was invested cross-border. The number of companies receiving investment decreased by 8% to just under 6,000 and 83% were SMEs. Buyout investment decreased by 3% year-on year to €36.5B into over 1,000 companies. By amount, mid-market transactions increased by 25%, small buyouts reduced by 10%, and large and mega buyouts fell by 17% and 34% respectively.

Annex II - The stages in venture capital investing

Figure 54 – Stages in venture capital investments



Source: Invest Europe / EDC

Seed: The first stage of venture capital financing. Seed-stage financings are often comparatively modest amounts of capital provided to inventors or entrepreneurs to finance the earl y development of a new product or service. These early financings may be directed toward product development, market research, building a management team and developing a business plan.

A genuine seed-stage company has usually not yet established commerci al operations - a cash infusion to fund continued research and product development is essential. These early companies are typically quite difficult business opportunities to finance, often requiring capital for pre -start-up R&D, product development and testing, or designing specialized equipment. An initial seed investment round made by a professional VC firm typically ranges from 250,000 to 1 million EUR.

Early Stage: For companies that are able to begin operations but are not yet at the stage of commercial manufacturing and sales, early stage financing supports a step-up in capabilities. At this point, new business can consume vast amounts of cash, while VC firms with a large number of early-stage companies in their portfolios can see costs quickly escal ate.

Start-up: Supports product development and initial marketing. Start-up financing provides funds to companies for product development and initial marketing. This type of financing is usually provided to companies just organised or to those that have been in business just a short time but have not yet sold their product in the marketplace. Generally, such firms have already assembled key management, prepared a business plan and made market studies. At this stage, the business is seeing its first revenues but has yet to show a profit. This is often where the enterprise brings in its first "outside" investors.

First Stage: Capital is provided to initiate commercial manufacturing and sales. Most first-stage companies have been in business less than three ye ars and have a product or service in testing or pilot production. In some cases, the product may be commercially available.

Formative Stage: Financing includes seed stage and early stage.

Later Stage: Capital provided after commercial manufacturing and sales but before any initial public offering. The product or service is in production and is commercially available. The company demonstrates significant revenue growth, but may or may not be showing a profit. It has usually been in business for more than three years.

Third Stage: Capital provided for major expansion such as physical plant expansion, product improvement and marketing.

Expansion Stage: Financing refers to the second and third stages.

Mezzanine (bridge): Finances the step of going public and represents the bridge between expanding the company and the IPO.

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KL-04-18-892-EN-N

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ISBN: 978-92-79-96713-9

doi: 10.2771/053734

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