Supply chain process mapping for the SUPREME project

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Report summary

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Title	**Supply chain process mapping for the SUPREME project**		
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Summary	The Norwegian seafood industry places emphasis on maximising utilisation of its catches and has through strategic improvements significantly increased utilisation in recent years by implementing improvements throughout the entire value chain. There are nevertheless still opportunities for improvements. The Norwegian research institute SINTEF estimates that approximately 120,000 tons of whitefish rest raw materials were discarded or wasted in some other form in 2019. Overwhelming majority of these are contributed to the sea-going fleet, which consists of large freezer trawlers, processing vessels, longliners and wetfish trawlers. These vessels travel long distances to their fishing grounds and challenge to increase utilisation of rest raw materials due to limited freezing capacities, lack of storage space, low value of the rest raw materials and limited human resources. The SUPREME project was initiated in order to address these challenges. The primary objective of the SUPREME project is to increase the resource utilisation and value creation from whitefish rest raw materials from the Norwegian sea-going fleet into valuable ingredients. This report provides an overview of the main findings of task 1.1 in of the project, which focuses on mapping and logistics management of rest raw materials for the Norwegian fishing industry. This report gives a summary of Norwegian fisheries industry, its current use of rest raw materials and identifies potential alternatives for improved utilization. The report also provides benchmarking with the Icelandic seafood industry and presents case studies where concreate examples for improvements are shown. This report is only a first step of many in the SUPREME project, and will feed into other tasks. For further information on the project and its outcome, please visit https://www.sintef.no/projectweb/supreme/		
Keywords:	*Norwegian fisheries industry, sea-going fleet, rest raw materials, utilisation, alternatives, onboard processing*		

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SUPREME

Forskningsrådet

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1 Introduction

The Norwegian fisheries industry produces around 300,000 tons of whitefish rest raw materials (RRM) each year. Marine RRM is a high value raw material rich in proteins, lipids and other important components (calcium, phosphorus etc.) and can be used to produce ingredients for food and feed. However, in 2019 approximately 120,000 tons of whitefish RRM was discarded and not utilized. A total of 84% of the RRM is generated at sea or upon landing, resulting in significant loss in potential value creation from already harvested resources.

AS example of the wasted opportunities, 120 000 tons of whitefish RRM can generate approximately 314 MNOK worth of fishmeal and fish oil; or it can be used to produce more added value products for pet-food and human consumption. One can assume that the potential value creation from RRM if used for pet-food could be around 455 MNOK or 600 MNOK if used for human consumption.

From 2006 to 2013 the total allowable catches (TAC) of cod in the Barents Sea doubled, resulting in less incentive to increase the value of each catch. In recent years however, the quota has decreased and become more stable, which has led to more focus on increasing value. Almost everything that is brought to land is utilized and the main focus is to reduce the discards of RRM at sea and specifically within the sea-going fleet, which only utilized 25,000 tons from 104,000 tons RRM generated in 2019.

The Norwegian fishing fleet can be categorized into coastal fleet (small and large) and sea-going fleet. Higher proportions of available RRM are utilized by the coastal fleet, since these vessels deliver fresh raw material (often round fish) to the land-based industry. The sea-going fleet consists of large freezer trawlers and/or combined fresh frozen trawlers which deliver headed and gutted frozen products, generating RRM fractions onboard. Due to economic and technological difficulties such as limited storage space and freezing capacities, the vessels are not able to store and treat the RRM properly resulting in low quality RRM with limited applications.

The primary objective of **SUPREME** is to ***increase the resource utilization and value creation from whitefish rest raw materials from the Norwegian sea-going fleet into valuable ingredients.*** To utilize the whitefish RRM into value added products, efficient logistics is crucial for maintaining the RRM quality, as well as improving the supply chain efficiency. This document reports on the main findings of task 1.1 in the **SUPREME** project, focusing on ***mapping and logistics management of RRM for the Norwegian fishing industry.*** The task had the following specific objectives:

1. Mapping of available RRM and current uses for the Norwegian fisheries industry.
2. Analyse what are the alternatives for using RRM with focus on onboard solutions for the seagoing fleet?
3. Provide case specific examples of RRM utilisation, with industry partners based on suitable alternatives.

To provide comparison and possible knowledge- or technological transfer, the work also included analyses of Icelandic fisheries and utilisation of RRM, due to similarities between the two countries and the fact that Iceland is by many considered a leader in “full utilisation” of RRM.

2 Background

2.1 Norwegian fishing industry

2.1.1 Fishing fleet

Total registered Norwegian vessels in 2019 were 5,980 vessels with more than half that are less than 10 m long (3,163) and 257 vessels in the length group 28 m and above (FIDIR, Ølmheim, 2020). The Norwegian fishing vessels can be categorized into two fleets, coastal and sea-going fleet. The coastal fleet consists of a closed group with quota rights, and an open group, in which all fishers who fulfill the requirements for fishing can participate. The coastal vessels have a cargo hold of up to 500 m^3. Previously the definition of a coastal fleet vessel was one of less than 28 meter long. With the new structure we can find coastal vessels up to 55 m long. The coastal vessels have shorter trips and usually without equipment for processing or freezing the catch. The main products resulting from coastal vessels are fresh, whole gutted fish.

The sea-going fleet consists of larger vessels with trawl or auto-line, as well as pelagic vessels with more than 500 m^3 cargo hold (NSC, n.d.). Freezer trawlers and autoline vessels freeze the catch on board and the main products are headed and gutted (HG) frozen products. Norwegian cod catches are generally landed fresh from coastal vessels or frozen from cod trawlers and conventional off-shore vessels (auto-liners), in a ratio of about 40% frozen and 60% fresh (Isaksen, 2018). The allocation of the cod quota to these groups is shown in figure 1 under the assumption that the Norwegian cod quota is above 330,000 tons. The total cod catch has decreased in past years from 473,000 tons in 2014 to 328,000 tons in 2019 (FIDIR). By the allocation rule the trawlers and autoliners lose about 1% of the cod quota each to the coastal fleet vessels.

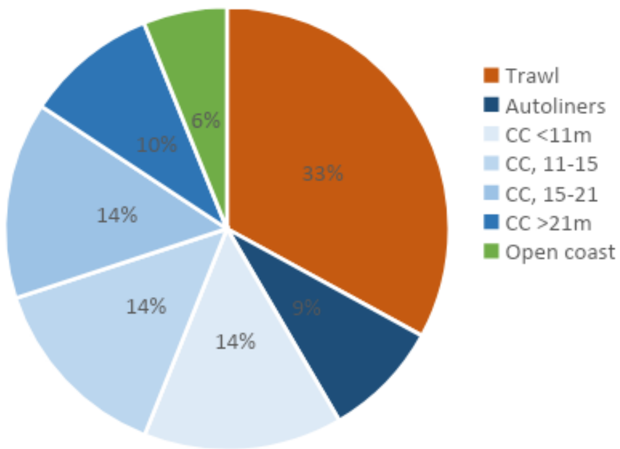


Figure 1: Allocation of the Norwegian cod quota on vessel groups above 330,000 tons (CC = closed coastal group) (PRIMEfish D3.4)

Over the past few decades, the fresh fish trawlers have virtually disappeared from the Norwegian fishing fleet. Also, a reduction in the number of on-board processing trawlers has taken place. Both have been substituted with either freezer trawlers or combined fresh/frozen trawlers. As a result, only 11% of the cod volume from trawlers was landed fresh in 2016 (Isaksen, 2018).

According to the Norwegian seafood council, in a typical year the Norwegian Cod catch is made up of about 30% trawling, 30% gill net, 15% longline, 15% Danish seine and 10% hand line. The fishing takes place year-round with focus on the first half of the year in the Barents Sea and coastal areas and later moves to the polar front separating the Atlantic and Arctic ocean.

In 2019 the catching of cod, haddock and saithe was made up of about 35% trawling, 20% Danish seine, 19% gillnet, 13% autoline, 8% hand line and 5% purse seines (FIDIR).

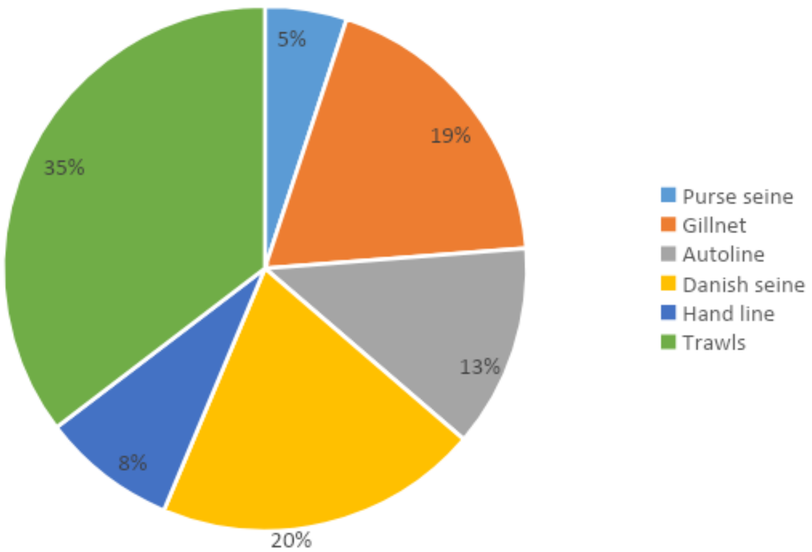


Figure 2: Norwegian catch of cod and cod like species by fishing gear in 2019 (FIDIR).

2.1.2 Available rest raw material and utilisation

In Norway, the RRM is considered an important biomass for value creation and most of it is utilized. Nevertheless, there is room for improvement, especially in the whitefish sector. SINTEF Ocean made an analysis of Norwegian marine RRM in 2019. The starting point for an assessment of RRM was a raw material base of 3.55 million tons live weight of which 964,000 tons are considered RRM. In 2019, 84% (812,000 tons) of the RRM was utilized which is the highest rate measured so far (Myhre et al., 2020).

Table 1: Rest raw material by sector (measured in tons). (Myhre et al., 2020)

	Whitefish	**Pelagic fish**	**Aquaculture**	**Shellfish**	**Sum**
Raw material base	683,000	1,268,000	1,543,100	52,100	3,546,200
Available RRM	297,400	194,000	458,200	14,800	964,400
Available RRM (%)	44%	15%	29%	28%	27%
RRM utilized	181,000	194,000	429,000	7,600	812,000
RRM utilized (%)	61%	100%	93%	51%	84%

In 2019, the pelagic sector represented about 1,27 million tons of raw material, with approximately 194,000 tons as RRM. In the pelagic sector the species that produce RRM are herring, mackerel, blue whiting and capelin. The other species such as sand lance and Norway pout enters the fishmeal/oil industry as whole, where 100% of the raw material base is utilized. While a relatively large proportion of herring landed is filleted, resulting in RRM, mackerel is essentially sold as round frozen. However, the small percentage of filleted mackerel has been increasing in the recent years. All RRM resulting from filleting of pelagic fish enter the fishmeal and oil factory, securing 100 % utilization of the RRM for the sector.

The aquaculture sector represented about 1.54 million tons of raw material in 2019, with approximately 458,000 tons of RRM. Salmon and trout constitute the aquaculture raw material base, of which 93% was utilized. It was only free flowing blood from the processing stage which was not utilized.

It is mainly the RRM from the whitefish sector that is not utilized. The whitefish sector represented about 814,000 tons raw material in 2019 with approximately 683,000 tons landed from Norwegian vessels. RRM from this sector was 297,000 tons with 84% of the generated RRM occurs at sea or upon landing. There has been an increase in the utilization of RRM from the whitefish sector, especially the heads that increased from 52% to 66% between the years 2017 and 2019. It is estimated around 120,000 tons of RRM were not utilized of the total RRM. From 2006 to 2013 the total allowable catches (TAC) of cod in the Barents Sea has doubled and for that reason the incentive to increase the value of each catch is lost. In recent years however, the quota has decreased which makes the industry focus more on increasing the value from each catch. Almost everything that is brought to land is utilized and the main focus is to reduce the discards of RRM at sea and specifically the sea-going fleet which only utilized about 24% of their RRM compared to the small and large coastal fleet that utilized about 88% and 60%, respectively, of the RRM in 2019. The main RRM from whitefish included heads (36%), viscera (18%) and liver (16%). Investment in technological solutions to handle and preserve the RRM have resulted in an increased utilization for the sea-going fleet in the last couple of years, from around 10 % to above 20% utilization in 2019.

Table 2: Rest raw material by fleet, whitefish sector (measured in tons). (Myhre et al., 2020).

	Small coastal fleet	**Large coastal fleet**	**Sea-going fleet**	**Total**
RRM	129,000	64,000	104,000	297,000
Not utilized	16,000	25,000	79,000	120,000
Utilized	113,000	39,000	25,000	177,000

There are three regions that have more than 93% of the total landed catch of whitefish and therefore most of the available RRM in the whitefish sector. Those regions are Møre og Romsdal, Nordland, and Troms and Finnmark. They also control more than half of the total registered vessels and buy raw material from other regions as well.

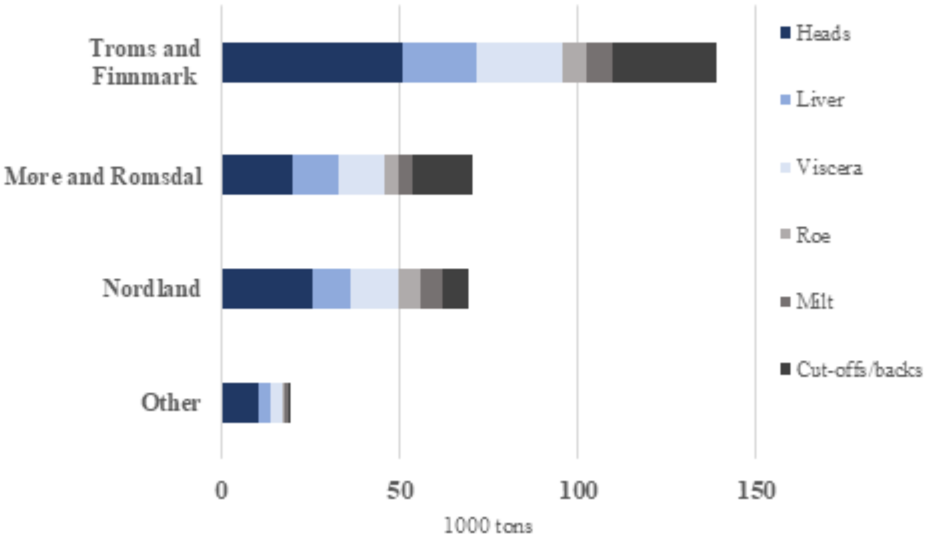


Figure 3: Available RRM by regions (Myhre et al., 2020).

Figure 4 shows the amount of RRM not utilized by type and sector. The highest amount of RRM that is discarded comes from foreign vessels. The available RRM from these foreign vessels was not included in the RRM analysis because the RRM was neither landed in Norway nor originated in Norwegian quotas. However, since the main product of these vessels was landed in Norway the RRM could have the potential of being utilised if it had been landed.

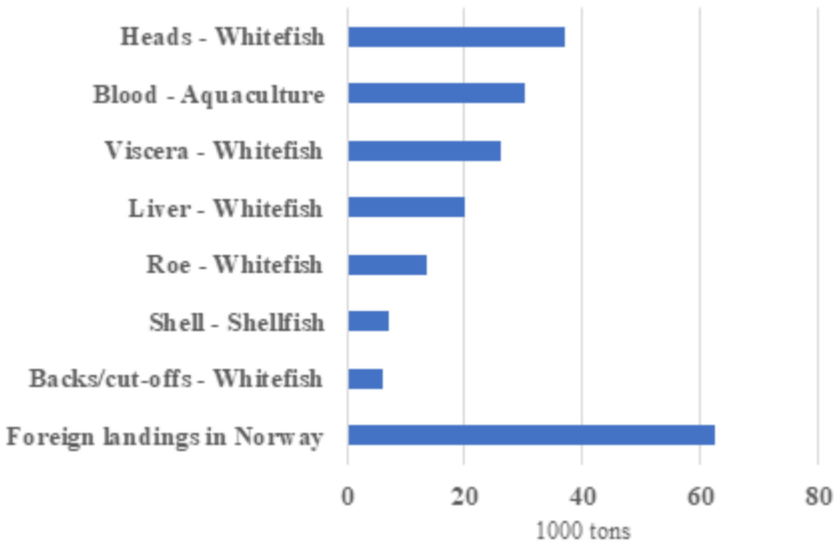


Figure 4: RRM not utilized by type/sector ranked by volume. (Myhre et al., 2020).

2.1.3 Processes, products and volumes

It's important to be able to conserve large quantities of material in an economically inexpensive way and therefore the 'classical processes' such as fish silage and fishmeal and oil process dominates the processing of RRM in Norway with 65% of the utilized RRM. Processing of RRM into silage is by far the largest use of RRM with 44% of the RRM in 2019, increasing from 41% in 2018. From the silage process, fish protein concentrate, and oil are separated, and used as ingredients in various types of feed for fish and pets together with other less expensive ingredients to get the right amount of fat and protein content along with omega 3 and a variety of vitamins.

The large and stable RRM from the aquaculture industry is more suitable for fresh use of raw material for production of oil and protein with higher quality by enzymatic hydrolysis, which is sought after in the pet-food industry and for marine fish feed. The oil- and protein production from fresh RRM was 20% of the utilized RRM in 2019.

With processing, 812,000 tons of RRM was converted into approximately 443,000 tons of products and semi-finished products as listed below:

1. Marine oils 110,000 tons (25%).
2. Fish protein hydrolysate (FPH) and fish protein concentrates (FPC) 116,000 tons (26%).
3. Energy 75,900 tons (17%).
4. Meal 47,000 tons (11%).
5. Consumer products in the form of seafood products, cod liver oil or extracts, 58 200 tons (13%).
6. Production of feed for fur animals 35,700 tons (8%)

Thus far, little of the Norwegian RRM is utilized into high value-added products such as in the nutraceutical, cosmetic and pharmaceutical markets. However, in the last years there has been several new products introduced and approved in various markets. With an increased investment in R&D, volumes from RRM as ingredients in different pharmaceuticals and nutrition products is likely to increase in the years to come.

2.2 Icelandic fishing industry

2.2.1 Fishing fleet

The Icelandic fleet consists of 1,621 registered vessels in 2017. They are categorized into three groups: open boats, trawlers and non-conventional vessels (auto-liners). Non-conventional vessels were 735 and trawlers were 43. Unlike in Norwegian fisheries where fresh fish trawlers are almost out of the fleet there are only 11 freezer trawlers with a mean age of 31 years in the Icelandic fleet out of the 43 trawlers (Ólafsson, 2019).

Total catch of the year 2019 was just under 1.1 million tons with demersal catches of 481,000 tons, pelagic catches of 534,000 tons and shellfish and crabs catches of 10,000 tons. Cod catches were approximately 273,000 tons (Fiskistofa).

The main demersal species caught in Iceland are cod, haddock, saithe and redfish. Figure 5 shows the total catch of these species by fishing gear for the fishing year 2019. Trawling is by far the most used fishing gear for these species with 66% of the quota. Auto-liners come in next with about 21%. Hand line, nets and Danish seine each have about 3-5% of the quota. When considering cod specifically the trawls are about 54% and autoliners about 29% (fiskistofa).

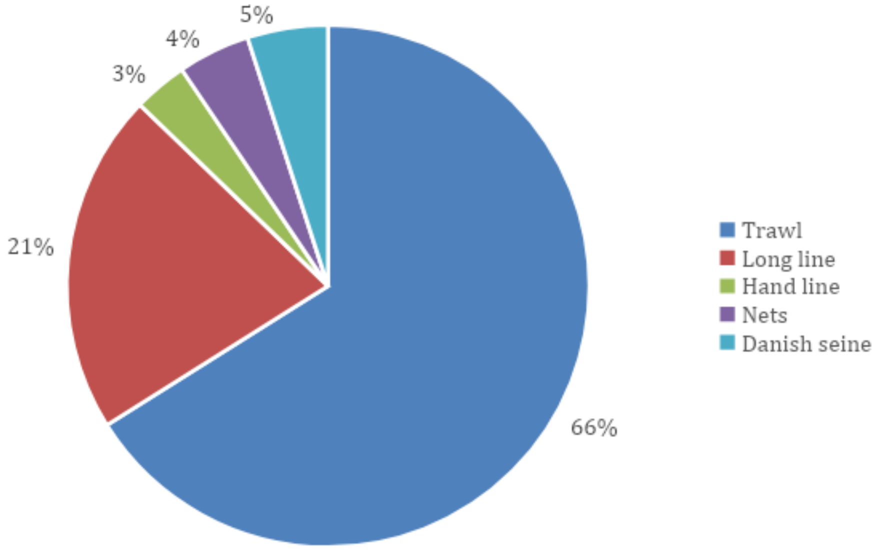


Figure 5: Icelandic catch of cod, haddock, saithe and redfish by fishing gear for the fishing year 2019 (Fiskistofa).

Products landed by the trawlers in Iceland are either frozen or fresh products in a ratio of about 28% frozen and 72% fresh. From the total catch of cod, about 13% is landed as frozen products while in Norway about 40% of the products are frozen at sea. Commercial value of fresh cod products have gone up substantially for the past 10 years while the commercial value of frozen products have been relatively stable (Ólafsson, 2019).

The quotas in Iceland are mainly owned by vertically integrated companies with interest in both processing plants and fishing vessels. By this structure, the fishermen are more incentivized to bring everything ashore. However, the Icelandic fleet is old and storage space and freezing capacity is low which results in discards of lower value material such as viscera, cut-offs, heads and other RRM. Large factory trawlers are obligated to land 40% of the cod heads and medium sized trawlers are obligated to land 30% of the cod heads. In Iceland there is more focus on value adding rather than exporting raw materials to low-cost production countries.

Theoretically it is possible to utilize the entire cod as it comes on-board the fishing vessels, however with the current setup of the fishery it is not realistic to expect 100% utilization. Factory trawlers have for example difficulties with freezing and storing RRM and vessels that land gutted fresh fish are not equipped to store viscera (Jónsson & Viðarsson, 2016).

The utilization rate of RRM from total cod catches was estimated at 72% in 2017. The Icelandic Ocean Cluster estimated the utilization rate of RRM of 80% from the whitefish sector in 2019 (Laksá et al., 2016). The current factory fleet is not built with capacity to process everything caught, with a lack of space to process RRM and capacity in the freezing hold to store lower value products. The catch from the Barents Sea in 2014 was approximately 21,500 tons of wet white fish caught by nine trawlers. Estimates show that around half of the biomass was landed (54%) while the rest was discarded at sea (Þórðarson et al., 2018). The factory trawlers have though been utilizing more of the catch for the last decade, though in the past RRM such as the liver or viscera was discarded at sea. The fleet is undergoing renewal with new ships coming in that will include fishmeal and oil factory on board. For example, the new freezer trawler Solberg OF-1 that started fishing in July 2017 is equipped with a fish-meal and oil factory that is fully automatic and environmentally friendly. Solberg has full utilization with only a small fraction of the catch being discarded.

2.2.2 Current utilization of RRM

As in Norway, almost everything is utilized from the pelagic sector in Iceland, even the processing liquid (blood etc.) is screened and evaporated before being processed into fishmeal. Most of the mackerel and herring is headed and gutted before being frozen for human consumption but the rest is processed as meal and oil.

The utilization of cod was approximately 72% in 2017. Total volume of 252,000 tons of cod was converted into about 182,000 tons of products (live-weight). The main products are demonstrated in figure 6 in terms of wet weight of raw material. The figure is missing information about products such as fur animal feed from viscera, skin and products from skin and health related products, however their proportions are not high.

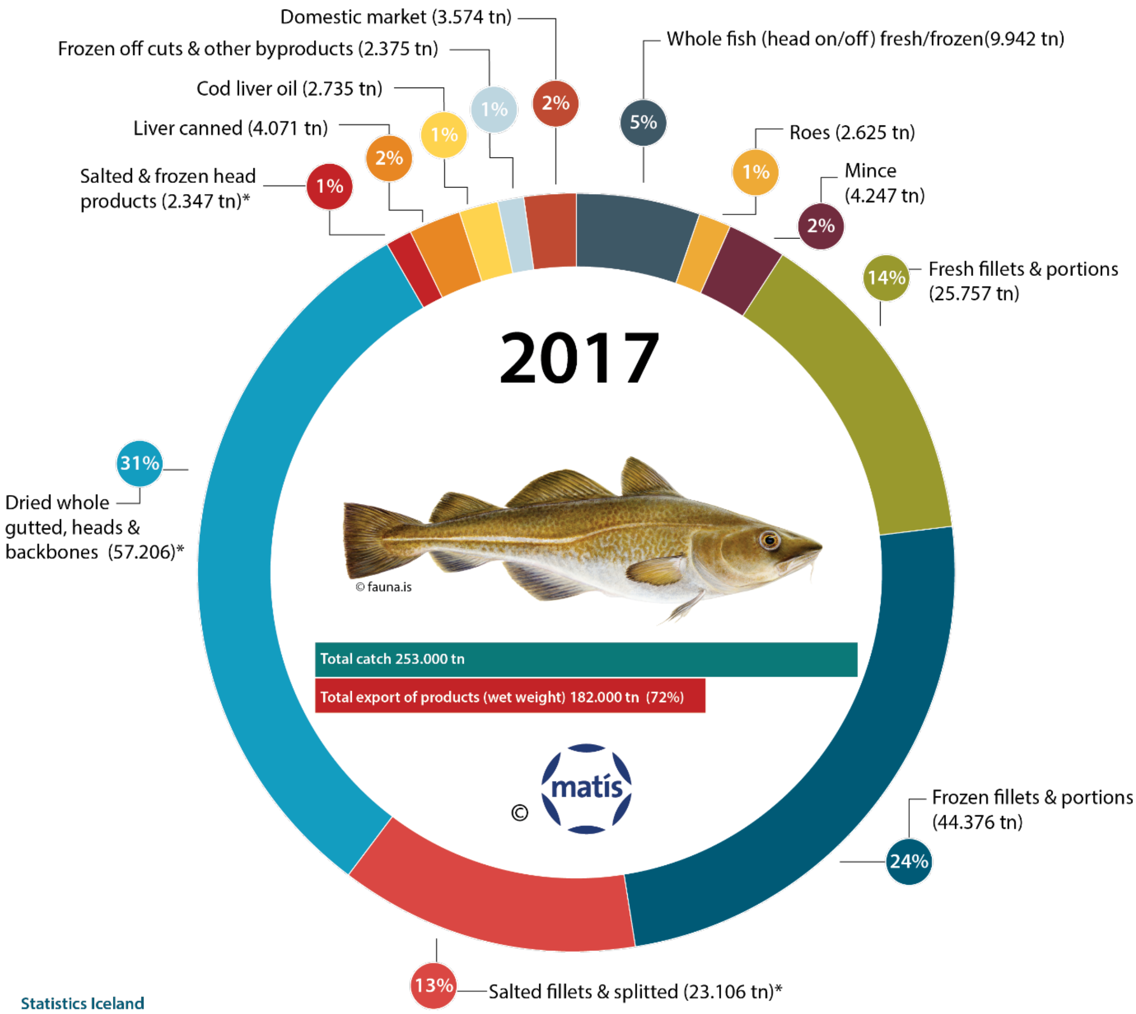


Figure 6: Utilisation of cod (Páll Gunnar Pálsson, 2018).

The aquaculture sector in Iceland is not as comprehensive as in Norway with approximately 34,000 tons of raw material produced in 2019, of which salmon was 27,000 and arctic char 6,300 tons. Salmon and arctic char are mostly exported whole, gutted with head on from Iceland. Viscera is mostly processed for animal feed as fish- meal or oil. The blood is discharged with quite some cost since strict regulation are set for this process for environmental purpose.

Crustaceans: mainly shrimps, lobsters and crabs generate up to 60% waste of the total raw material which was approximately 10,000 tons in 2019 and 12,000 tons in 2018. Icelandic companies are currently utilizing a good share of the RRM for chitosan production for nutritional, cosmetic and biomedical applications, as well as producing health promoting products for local Icelandic markets. Meal based on shrimp waste has become more desirable for animal feed production blended with other protein rich fish-meal or vegetable meal.

Production of fish silage in Iceland has been almost none-existent, but this could change since producers are becoming more aware of the potential value creation of low value raw material into silage and further processing for higher value products.

2.2.3 Products derived from cod in Iceland

Figure 7 demonstrates the products derived from cod in Iceland. It demonstrates how different parts are used for medical, cosmetic or nutraceutical products. For example, fish skin is utilized into plasters to heal chronic wounds or as leather. The liver is used for omega 3 and cod liver oil or as canned goods and paté. The heads and backs are typically dried and exported but could be used for higher value-added products such as fish protein concentrates or hydrolysates (FPC and FPH).

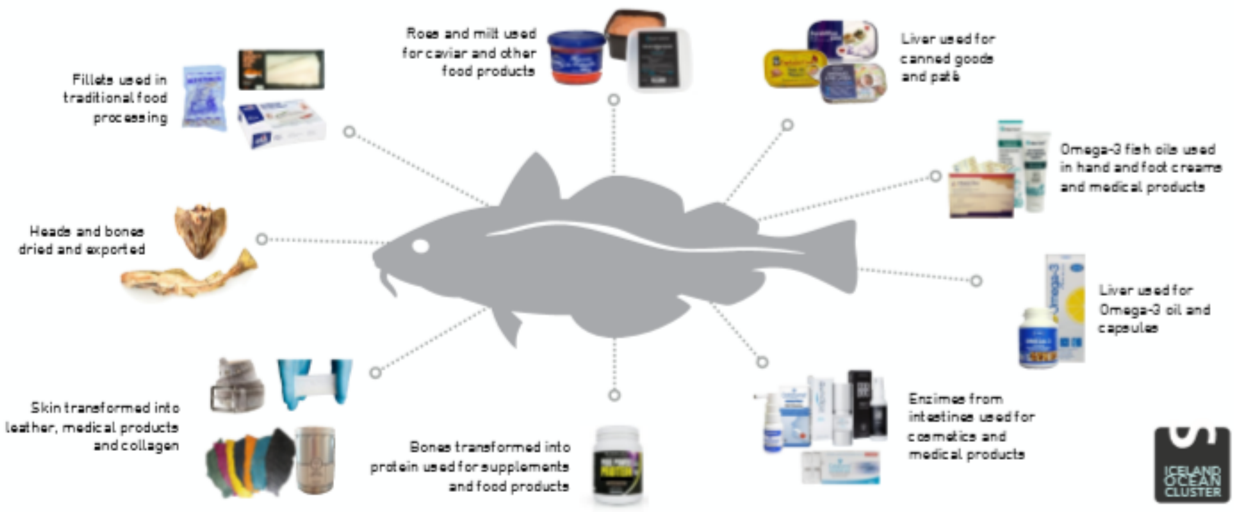


Figure 7: Products derived from Cod in Iceland © Iceland Ocean Cluster

According to a summary from the Iceland Ocean Cluster roughly 40 companies are processing rest raw material into products. As best can be seen by the Iceland Ocean Cluster, no other country in our region comes close to Iceland in specialization in this field, number of companies and utilization of fish.

2.3 Regulation regarding uses of RRM categorized by industry uses

Regulations regarding handling equipment, processing and transportation of fish raw materials for food applications are in place within the European Union (EU) and should be the same in all countries within the EU. By these regulations, the EU achieves a regulatory framework with rules that are applied directly in the individual EU countries as they are written. Since Norway is not a member of the EU, the rules must be transported into Norwegian law before they become applicable in Norway.

The EU's food hygiene legislation regulates the use of marine RRM for human consumption, and thus controls the greatest potential for value creation. RRM that is going to be used for food application, must follow the requirements listed in the regulations on the quality of fish and fishery products. No requirements have been set regarding the quality of RRM for food applications beyond what is stated in the regulations. Therefore, producers of food products must consider which criteria in terms of raw materials will be necessary to be applied to RRM so that the end-product will be of food-grade quality. RRM does not fall under a special category and the regulations for unprocessed fishery products must be followed. Some of the requirements are given below (Mozuraityte et al., 2020)

- TVBN 25-35 mg of nitrogen/100g flesh.
- Fishery products from fish species associated with large quantities of histidine should not exceed histamine levels of 100-200 mg/kg.
- Microbiological criteria – see table below for fresh and frozen fish (Fernandes, 2009 adopted from ICMSF 1986). For L. monocytogenes there is a limit of 100 cfu/g or absence in 25g.

Test	**Limit per gram**	**Limit per cm^2**
Aerobic plate count	$5x10^5$	107
E.coli	11	500
	Additional tests can be carried out when appropriated	
Salmonella	0	-
V. parahaemolyticus	102	103
Staph. Aureus	103	104

Norwegian regulation on quality of fish and fish products states that all fish and fishery products can be used for the production of fishmeal, fish protein hydrolysate, fish oil and other marine ingredients for human consumption. This includes whole fish and raw materials that arise during processing, if they are still suitable for human consumption. Raw materials contaminated as described in section 14 in the regulation on quality of fish and fishery products in Norway (see below) can however be used as raw material for the production of fishmeal, fish protein hydrolysate, fish oil and other marine ingredients for human consumption if it is documented that these substances will not be present in the final product (Mozuraityte et al., 2020).

Regulations on the quality of fish and fish products in force in Norway, section 14. ***Fish and fish products that cannot be traded for human consumption*** (*Regulations on the Quality of Fish and Fish Products*, 2013)**.**

Fish and fish products should not be traded for human consumption if they:

a) are self-dead: fish that are dead in the sea or in fresh water, but not fish that die as a direct consequence of the method of capture.
b) is rancid
c) that have freeze or drying burns, i.e. fish and fish products that have irreparable marks after freezing or drying,
d) "buktært" fish where decomposition activity in the gastrointestinal tract has been going on for so long after death that fish muscle/fillet has been damaged or have significant liver and/or bile spots,
e) is farmed and where errors mentioned in section 17, first paragraph (wounds, malformations, gross treatment errors or internal quality defects), cannot be corrected,
f) is farmed and has a distinctive sex suit,
g) is bloodshot or dissolved in the fish meat or has a different odor,
h) have detectable red mites, black mites or brown mites or are significantly grounded,
i) contaminated by substances in concentrations that give fish and fish commodity abnormal sensory properties,
j) has higher values of trimethylamine nitrogen than indicated in section 11, first paragraph (100 grams of fish meat should contain no more than 10 milligrams of trimethylamine nitrogen and no single sample over 15 milligrams). Except are finished goods that have undergone a maturation process (are fermented), are fully salted or dried (raked fish, saltfish, salt herring, clipfish and stockfish etc.),
k) have internal organs with clear signs of disease changes that can be seen with the naked eye, including internal bleeding, granulomas (outgrowth/scarring as a result of immune disease/infection) or wounds,
l) has extensive external disease changes, including large wounds.

Procedures for by-product regulation in EU

If the rest raw material is processed, handled or transported with regards to the hygiene regulations listed above it is called rest raw material. If the RRM is processed with regards to by-product processing (silage, transported without cooling to fish meal factory etc.) it is termed by-product. By-products are divided into three categories regarding their potential risk towards human health, animal health and the environment.

Category 3 are materials with no risk for health, including parts not intended for human consumption but whose hygienic quality could allow them to be used for human consumption. Examples are bones and skin. The material comprises animals or parts of animals suitable for human consumption, but which, for commercial reasons, should not be used for human consumption.

Category 2 material is high risk; it includes fallen stock, manure and digestive tract content. Category 2 is also the default status of any animal by-product not defined as either category 1 or category 3 material.

Category 1 material is the highest risk material and consists principally of material that is considered a Transmissible Spongiform Encephalopathies (TSE) risk. Such as Specified Risk Material (SRM) – those parts of an animal considered most likely to harbour a disease such as Bovine spongiform encephalopathy (BSE). For example, bovine spinal cord.

2.4 Potential uses of RRM categorized by industry uses

The available alternatives for utilization of rest raw materials (RRM) can be broken down into six main categories, which are shown in figure 8. Table 3 shows a list of available alternatives of rest raw material with external links to their fact sheets. The table also shows their feasibility in terms of process yield, technology maturity, value of the product, potential market, production cost and competing companies.

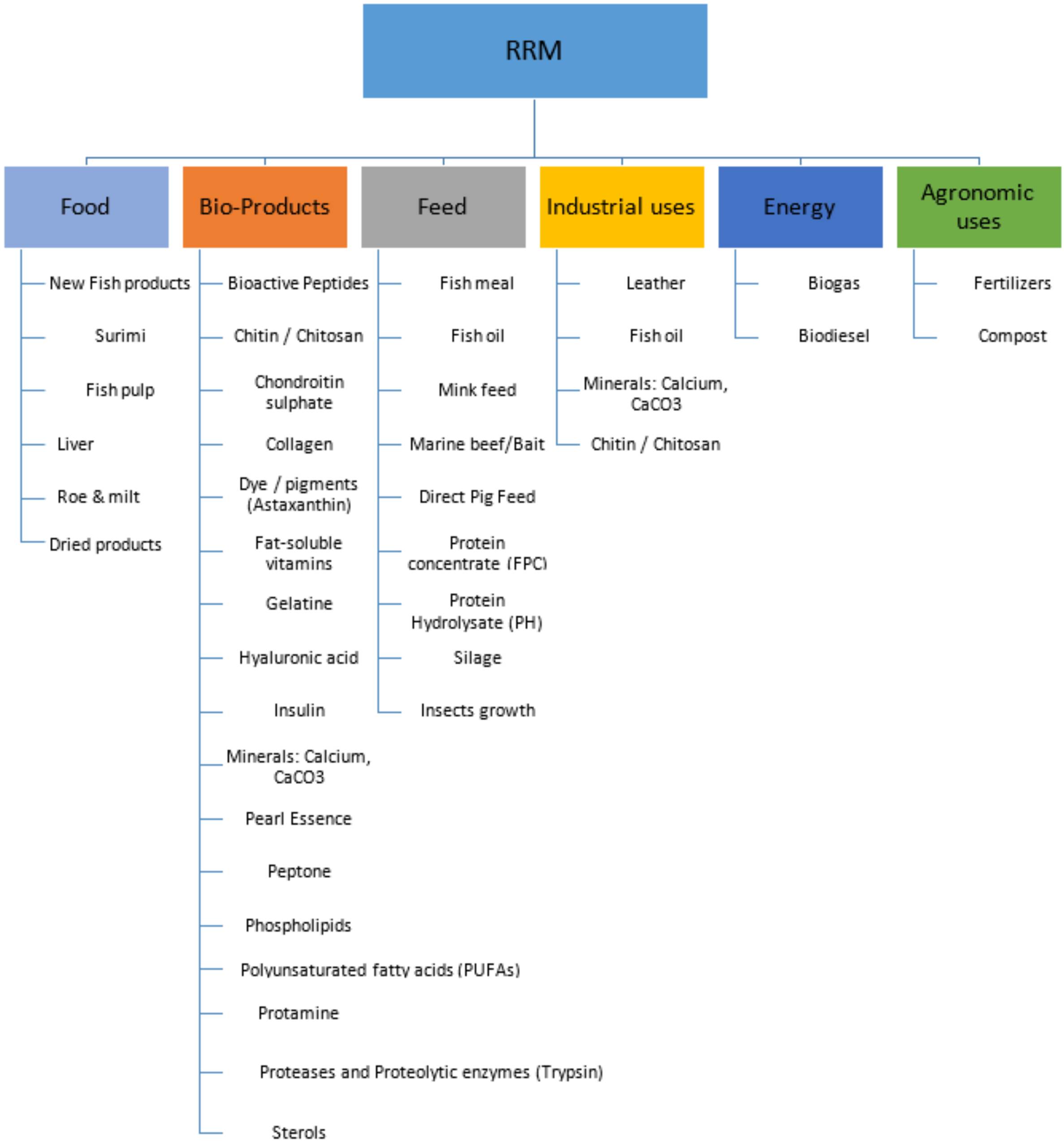


Figure 8: Marine products produced out of RRM and UUC (DiscardLess)

Food

Minced fish products: Fish balls and burgers are easy to make and give reasonable revenue. They often consist of a mixture of fish mince and wheat, potatoes or other ingredients. Minced fish can also be used to produce surimi or dried fish products.

Liver, roe and milt: By-products made from cod liver, roe and milt such as canned products have become more valuable in recent years. The freshest materials become high-value premium products and the rest is sold in bulk or used in lesser valued products such as liver oil.

Dried fish products: There have traditionally been good markets for dried cod heads and fish frames in Africa, particularly in Nigeria, where these products are mostly boiled to make soup. The markets have though been difficult in recent years, because of financial difficulties in Nigeria. Heads, frames and cut-offs left-overs from the processing of lean fish species are suitable, but heads and frames from fatty fish are not applicable for drying.

Bio-products

Fishes contain a large number of biomolecules that are valuable and can be used in food, pharmaceuticals and cosmetics, as well as in the feed industry.

Bioactive peptides: come from extensive hydrolysis of fish protein and contains mainly free amino acids di-, tri- and oligopeptides. These peptides have biological activities that make them valuable for the pharmaceuticals, cosmetics, food- and feed products.

Figure 9: Collagen and gelatine made from cod skin

Polyunsaturated fatty acids (PUFAs): come from purification of fish oil which can be obtained from viscera or from fatty fishes. PUFAs are fats with more than one unsaturation's (double bonds) present in the chain. PUFAs includes important compounds such as essential fatty acids that are correlated with the cardiovascular health of humans.

Proteases and Proteolytic enzymes: Extracted from by-products, especially viscera, that contain large proportion of digestive enzymes such as collagenase, trypsin, pepsin, chymotrypsin, elastase and carboxypeptidase. Proteolytic enzymes catalyse the degradation of peptide bonds of proteins. They have specificity of action and in the case of those from fish they have activity at low temperature and pH. They play a key role in a wide variety of physiological processes, biotechnology, food processing and other industries.

Chondroitin sulphate: obtained by an enzymatic or chemical hydrolysis process to deproteinize the cartilage and successive purification phases from the skeleton of cartilaginous fish, sharks and rays. Chondroitin sulphate provides cartilage with its mechanical and elastic properties and gives this tissue a large part of its resistance to compression. It is used as a dietary supplement with anti-inflammatory properties, as an aid against arthritis.

Fat-soluble vitamins: are obtained by solvent extraction of vitamins from fish oil. Fish liver oil is rich in vitamins A and D that are used in pharmaceutical, cosmetic and food applications.

Minerals (Calcium, $CaCO_3$): is obtained from spines, flakes and fins of fish and shells of bivalve molluscs (mussels, clams etc.). It can be used in the nutraceutical market (for human or animals), as a food ingredient.

Dye / pigments (Astaxanthin): is extracted mainly from crustacean shells. It is used as pigment in aquaculture, in fish and crustaceans feeding. One kilogram of astaxanthin is worth between 8.000-10.000 USD.

Collagen: is obtained by an acid or basic treatment of spines, scales and skin. Collagen has high content of proline and hydroxyproline and differs in their amino acid content from other proteins. Collagen is widely used in pharmaceuticals, cosmetics and also as food supplement.

Figure 10: Collagen is used as ingredient in variety of products and is particularly popular in food supplements, pharmaceuticals and cosmetics.

Gelatine: is obtained by the irreversible hydrolysis of collagen. There are two main types of gelatine, type A which is achieved through acid hydrolysis and type B which is achieved by alkaline hydrolysis. Gelatines are used as a gelling agent in pharmaceuticals, cosmetics and food. Fish gelatines are preferred for low temperature gelling needs.

Figure 11: Example of products that contain gelatine.

Sterols: steroids found in plants and animals can be obtained by extraction. Phytosterols have received much attention in the last decade because of their cholesterol-lowering properties and can be found in marine organisms in small quantities, as a dietary origin from phytoplankton. The major presence of phytosterols is observed in bivalves, due to phytoplankton food sources. Phytosterols are largely used in the food and beverage industry.

Insulin: extracted from various fish viscera. Insulin is a peptide hormone produced by beta cells of the pancreatic islets, and by the Brockmann body in some teleost fish. Insulin regulates the amount of glucose (sugar) in the blood and is required for the body to function normally and is used for treating diabetes.

Protamine: a purified mixture of simple proteins obtained from wild salmon sperm Protamine is a protein (Molecular weight around 4,000-5,000), which works to maintain and protects DNA from being damaged. It is used in pharma as a drug that reverses the anticoagulant effects of heparin by binding to it.

Hyaluronic acid: obtained by successive extraction and purification steps, it is a glycosaminoglycan present in skin, bones and joints. Its function is to give elasticity to these parts of the body. It is used in regenerative cosmetics of the skin and in injections in cosmetic surgery or in the recovery of injuries of joints.

Chitin / Chitosan: Chitin is obtained by deproteinization, discolouration of the exoskeleton of arthropods. Chitosan is obtained by further deacetylation of chitin by chemical-enzymatic processes. It has used such as chelating agent in the Water treatment, clarifier, thickener, fibre, film, chromatography column matrix, gas selective membrane, hypocholesterolemic agent, plant disease resistance promoter, anticancer agent, wound healing promoter and antimicrobial agent. It is used as a technological adjunct and is being tested for applications such as fruit preservation, wound dressings, cosmetics, artificial organs and pharmaceuticals. Chitosan made from the shells of prawns and lobsters is being used for pharmaceuticals and food supplements. All the shells available in Iceland are as an example used by the company Primex for making pharmaceutical and food supplement products, shown in Figure 12.

Figure 12: Example of the products Primex produces from chitin/chitosan.

Pearl Essence: is extracted from fish scales. Guanine is an iridescent substance that is found in the epidermal layer and scales. The suspension of guanine in a solvent is called "essence of pearls". It was used in cosmetics and paints.

Phospholipids: are extracted from fish oil by different procedures. Marine omega-3 phospholipids (n-3 PLs) are defined as PLs containing n-3 long-chain polyunsaturated fatty acids (PUFAs) derived from marine organisms. This makes them different from PLs derived from vegetable sources, since they do not contain long-chain n-3 PUFAs. Phospholipids are used as emulsifiers in the food industry, emollient in cosmetic, antibacterial or drug delivery system in pharma.

Squalene: extracted mainly from shark liver. Hydrocarbon compound, isoprenoid, intermediate in the synthesis of cholesterol, hormones and vitamin D. Used in cosmetics in moisturizers and in pharmacy or dietary supplements as an immune stimulator.

Peptones: produced by controlled enzymatic hydrolysis of proteins. Peptones are polypeptides formed during the enzymatic degradation of proteins. They are the main source of nitrogen in the organic medium for bacterial culture. They are used in the manufacture of culture media for microbiology and biotechnology (industrial fermentations).

Feed

Fish meal: obtained from any fish or fish by-products, after a thermal process to coagulate the protein and separate the oil, fish meal is a brown powder rich in protein. The colour is affected by fish species, particle size, fat and moisture content. Fish meal is mainly used in animal feed. Aquaculture account for > 60 %, pigs 25 %, and poultry 8 %.

Fish oil: obtained in the same process as fish meal, fish oil is a liquid product composed mainly by fatty acids, high in unsaturated fatty acid, with variable amounts of phospholipids, glycerol ethers and wax esters. Fish oil has different uses that can vary in function of its composition. ~80 % of fish oil is used in aquaculture and ~13 % destined to human consumption.

Mink feed: any fish of fish by-product can be used to feed mink for the fur industry (food regulation does not apply). This alternative is often used for products that cannot be used for anything else as food safety regulations do not have to be taken into consideration i.e. mink is not used for human consumption or for ingredients that become animal feed. Viscera, which contains digestive trace elements can, therefore, be used as mink feed.

Marine Bait: discard species can be used as effective pot bait when targeting crabs and lobsters. The condition of the material is generally not important, which makes this a good alternative for low-value materials that are difficult to preserve. Fish that are high in fat are usually considered good bait.

Fish Protein Concentrate (FPC): Dehydrated and ground products, with variable protein content, which may or may not taste and smell fish, depending on the method of production used. This technology aims to achieve a stable product, with a protein concentration higher than that of fish muscle. The manufacture of this type of products allows the use of species that are not accepted for direct consumption, and of the waste from the fish processing industries. Used for animal feed but due to their high nutritional value, they can also be used for human consumption or as a protein source in the elaboration of different foods.

Fish Protein Hydrolysate (FPH): Stable product with good functional properties and high nutritional value, prepared from the protein fraction of whole fish, by-products or processing waters thereof, by chemical or enzymatic hydrolysis. A product consisting of mixtures of amino acids and peptides of different sizes are obtained depending on the degree of hydrolysis carried out. It is used mainly in animal feed but can also be used in the food industry as a flavouring or RM for the elaboration of aromas.

Silage: Liquid protein hydrolysate made from whole fish or from processed residues. The hydrolysis is carried out by endogenous proteolytic enzymes, located in the viscera and in the meat of the fish, under acidic conditions. Acid conditions limit the growth of degradative bacteria. It is used mainly as a protein supplement in animal feed (cattle, poultry and aquaculture) and as a base for the production of fish sauce.

Insects meal and oil: obtained after the growing of insect over a fish substrate. Insect meal can be used for animal feed.

Industrial uses

When the previous options are not available, for example due to legal constrains, quality of the raw materials or of the products, other technical uses may be considered, which are often considered as industrial uses such as:

Leather: is the cured and tanned skins of fish. Fish leather can be used to make a wide variety of items such as jewellery, accessories, belts, wallets, bags and in shoes. It can also be used for a much larger variety of crafts.

Low quality Fish oil: obtained in the fishmeal production process can be used for industrial usage, such as solvent for painting, when it doesn’t meet feed quality standards.

Low quality Minerals: Calcium, $CaCO_3$: is obtained from spines, flakes and fins of fish and shells of bivalve molluscs (mussels, clams, etc) and can be used as soil improver or mineral fertiliser.

Low quality Chitin / Chitosan: when the product is obtained with low purity or quality the chitosan may be used in less demanding uses such as biological systems, agricultural use or as filtering agent in water treatment.

Energy

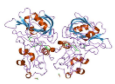
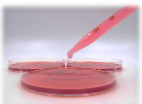
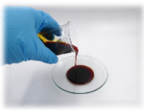
Biogas: is produced through the anaerobic digestion (AD) of organic matter. This is a complex biological process in which anaerobic bacteria decompose organic matter in environments with little or no oxygen. The process produces biogas (55-65 % methane, 35-45 % carbon dioxide, and other) which is used as energetic source for heating or producing electricity. Also, a digested substrate is produced that can be used as fertilizer in agriculture.

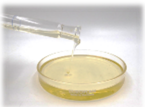
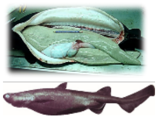
Biodiesel: is obtained by a transesterification process of the fish oil. Biodiesel is later used in diesel engines as an energy source.

Agronomic uses

Compost/Fertilizers: obtained by an aerobic decomposition process carried out by the own microorganisms of the organic matter. Compost from fish usually consists of fish waste, saw dust, wood bark ships and is covered with leaf compost to make a compost pile. The compost is used for soil amendment or fertilizer. Also, fish protein hydrolysates can be used as fertilizer.

Table 3: List of available factsheets (DiscardLess WP6)

Product	Application type	Species used	Process yield / Technology maturity / Value of Product / Potential Market / Production cost / Competing Companies
 Astaxanthin	Biomolecules	Algae, yeasts, salmon, trout, Antarctic krill, shrimp, crayfish and crustacean shells	
 Bioactive Peptides	Biomolecules	Fish processing waste and mollusks and crustaceans as well as those coming from fishery discards	
 Biogas	Other options	All species and fish fractions can be used.	
 Chitosan	Biomolecules	Crustacean shells	
 Chondroitin sulfate	Biomolecules	Cartilaginous fishes	
 Compost-Fertilizer	Other options	All species and all part.	
 Enzymes	Biomolecules	Fish, especially digestive organs	
 Fish meal and Oil	Animal feed	All fish and shellfish	
 Fish mince	Food	Wide range of species	
 Fish peptones	Biomolecules	Fish scales from species like sardine, carp or herring.	
 Fish Protein Concentrate (FPC)	Animal feed	All species	
 Fish Protein Hydrolysates (FPH)	Animal feed	All species	

Product	Application type	Species used	Process yield / Technology maturity / Value of Product / Potential Market / Production cost / Competing Companies
 Gelatine	Biomolecules	All species (skins, Tunas)	
 Hyaluronic acid	Biomolecules	Marine sources are shark cartilage and fish eyeballs.	
 Insect Meal	Animal feed	Marine sources are shark cartilage and fish eyeballs.	
 Insulin	Biomolecules	Teleost fishes	
 Leather	Other options	Carp, Salmon, Perch, Tilapia, Cod, Sea Bass, Eel or shark.	
 Mineral Supplements	Biomolecules	All Fish (Bones)	
 Pearl essence	Biomolecules	Fish scales from species like sardine, carp or herring.	
 Phospholipids	Biomolecules	Fish, Krill	
 Poly-Unsaturated Fatty Acids (PUFAs)	Biomolecules		
 Protamine / Protamine sulphate	Biomolecules	Sperm and roe of Salmonidae and Clupeidae	
 Silage	Animal feed	All fish and all part of fish	
 Squalene	Biomolecules	Shark:	

Product	Application type	Species used	Process yield / Technology maturity / Value of Product / Potential Market / Production cost / Competing Companies
 Sterols	Biomolecules	Fish and shellfish.	
 Surimi	Food	Allaska Pollock	
 Vitamins	Biomolecules	Cod and shark liver, Salmon, trout	

3 Methods

Research suggest that the highest potential for untapped resources lies in onboard processing of rest raw material that are for now discarded into the sea. There is considerable research available on utilization alternatives to increase the value of fish, but it is not utilized by fish processors or fishermen. In order to increase sustainability of the use of RRM the whole value chain must be examined since if there is no profit at the first stages of the value chain then it will unlikely have profit further down the value chain. To increase the utilization of RRM it must be either stored and landed or processed onboard. The industry must be incentivized to do so and one way to do so is helping them make an informed decision on what processes return profit.

3.1 Case studies cost-benefit analysis

A cost-benefit analysis is a method used for businesses to make informed decisions. For each case the sums of benefits of a process or action are listed and then the costs associated are subtracted. A lot of information must be gathered from the industry for each case. It is based on the volume of raw material available, volume of product obtained and value of the product to calculate the revenue and estimating costs associated with the action or process and then using mass balance to estimate the annual income for each case.

The benefits might include the following:

- Revenue and sales increases from increased production or new product.
- Intangible benefits, such as improved employee safety and morale, as well as customer satisfaction due to enhanced product offerings or faster delivery.
- Competitive advantage or market share gained as a result of the decision.

The main cost factors to be estimated for the case studies might include the following:

- Investment cost. Includes equipment needed for the process/action and setup of the equipment.
- Variable costs such as
    - Fuel cost (oil, electricity or excess heat)
    - Labour cost (supervisor, number of employees, percentage of revenue)
    - Chemicals (nitrogen, acids, bases)
    - Packaging (boxes, barrels, containers, cans)
    - Landing cost
    - Transportation
    - Other variable costs
- Fixed costs regarding the equipment such as
    - Depreciation of equipment
    - Insurance
    - Repairs and maintenance

3.2 SWOT analysis of case studies

Internal and external analysis was made for each case study using SWOT analysis. SWOT is used to identify *Strengths, Weaknesses, Opportunities* and *Threats* for each process or action. The internal factors, strengths and weaknesses, are identified for each case to understand which of its resources and capabilities are likely to be sources of competitive advantage and which are less likely. The external factors identify the critical threats and opportunities in its competitive environment. It also examines how competition in this environment is likely to evolve and implications that evolution has for the threats and opportunities of the process or action (Gürel, 2017).

3.3 Valorisation of prioritization options for use of RRM

Another method to make informed decision on steps to increase utilization of rest raw material is a valorisation of prioritization options method used in the DiscardLess project.

For the selection of a valorisation solution in a concrete scenario such as case studies in the DiscardLess project, there is a large number of parameters that must be taken into account. In each scenario, the combination of parameters may lead to different solutions even when the basic statements are the same.

In a first approach, a common prioritization scheme for the valorisation of food by-products may be applied, following the hierarchy of valorisation options for any food waste or by-product established by the waste framework Directive of the EU parliament (2008), as shown in figure 13.

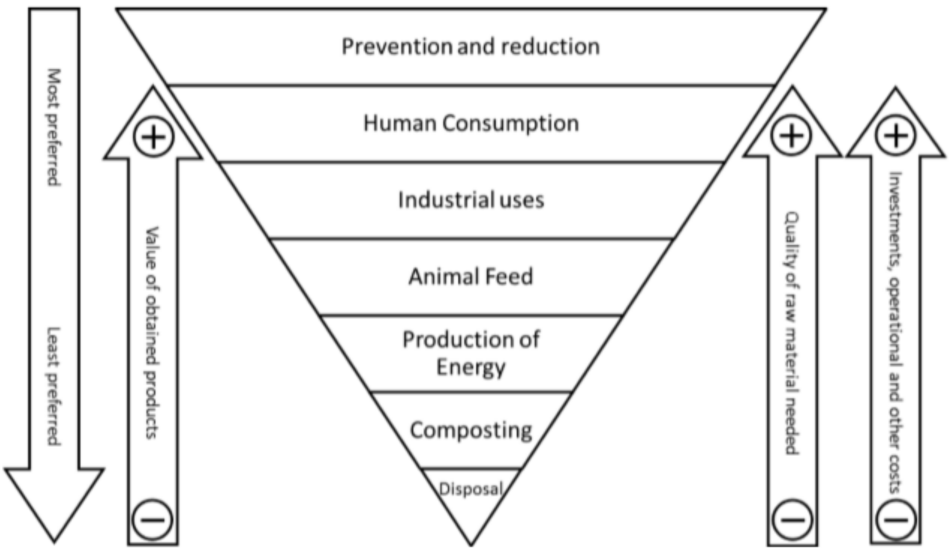


Figure 13: Standard prioritizations for the valorisation of food products

To be able to select the best and most feasible option in a concrete scenario the study must deal with all critical aspects that can influence the technical or economic feasibility. These aspects can be grouped in 3 main categories: Technical parameters, market aspects and economic aspects.

Technical parameters are those related to the technical feasibility of a solution, such as:

- Variability, dispersion of landings
- Characteristics of landed catches
- Maturity of the process
- Ratio, quality and purity of product obtained
- Availability of technology and equipment at industrial scale
- Feasibility of modifications on boat
- Availability of storage, preservation and other facilities, equipment, logistics, etc. in port and region

Market aspects, are the parameters related to:

- Compliance with health, environmental and other specific regulations for each use
- Existence of potential clients interested
- Market demand for the product produced, actual availability of acceptance
- Enough quality and volumes of product to satisfy the demand

Economic aspects are the factors that affect the economic feasibility of the solution such as:

- Minimum volume of raw material for sustainable production
- Final value / price of product
- Expected cost / benefit
- Feasibility of making use of current infrastructure to reduce investment cost

The selection of the most suitable option may need the evaluation of more than 15 parameters. Obtaining of all collecting data needed and the subsequent studies can be very time consuming and expensive and for that reason, a simplified methodology for the selection of most suitable uses of by-products in different scenarios was made.

Simplified methodology for the selection of potential uses

The methodology for the selection of the potential uses for RRM in a specific scenario is based on a Multi- Criteria Decision Analysis (MCDA) using an Analytic Hierarchy Process (AHP) method. Principles applied for the criteria selection to evaluate the main parameters involved in the process are:

- Systemic principle: criteria system should reflect the essential characteristic and the whole performance system.
- Measurability principle: Criteria should be measurable in a quantitative, or qualitative criteria should be transformed into numbers.
- Comparability principle: criteria have to be comparable or normalized.

This methodology has four main steps:

1. Data gathering for each valorisation option (include new options when identified)
2. Evaluate the available facilities for each option
3. Evaluate the amount of UUC available for each option
4. Complete the evaluation and prioritization table.

Data gathering for each valorisation option

An exhaustive list of valorisation options provided, according to the end-product obtained. Any further available option can be added to the list to be weighed. A detailed data sheet can be constructed with all the information for assessing the selected evaluation criteria. However, if a faster and preliminary evaluation needs to be performed it can be sufficient to complete the quantitative basic criteria indicated in table 4.

Table 4: Categories and criteria MCDA

Category	Criteria	units
CS dependent	Available Raw Material (A)	Tn/Year
	Available facilities (B)	Nº. Facilities
Technical factors	Yield (C)	%
	Technology maturity (D)	
Economic factors	Value of the product (E)	€/Kg
	Potential Market (F)	Kg/year
	Production Costs (G)	€/Kg
	Competing companies (H)	Kg/year

Evaluate the available facilities

Evaluation of existing and available facilities must be carefully performed for each case study. The selection of an option that is already industrialized has a great advantage and can be the straightforward solution for a short-term solution.

Evaluate the amount of raw material available for each option

The amount of raw material available for each option must be evaluated according to historic RRM landing data. A preliminary table that link the species with their possible valorisation options can be constructed as figure 14 demonstrates. The selected options are based on the species composition. For all these valorisation options, information related to the products obtained were collected and structured into a standardized products sheets, that group information in 3 categories: product information, raw material information and process information.

	3 letter CODE	COD	POK	OCE	ANL	LIN	USK	AMR	HAD	GHL	PLE	ARU	LEM	WIT	HER	CAP	WHB	MAC	PRA
	Latin	Gadus morhua	Pollachius pollachius	Sebastian norvegicus	Anarhichas lupus	Molva molva	Brosme brosme	Amblyraja radiata	Melanogrammus aeglefinus	Reinhardtius hippoglossoid	Pleuronectes platessa	Argentina silus	Microstomus kitt	Glyptocephalus cynoglossu	Clupea harengus	Mallotus villosus	Micromesistius poutassou	Scomber scombrus	Pandalus borealis
	English	Atlantic cod	Saithe	Ocean perch	Catfish	Ling	Tusk	Starry ray	Haddock	Greenland halibut	European plaice	Greater silver sme	Lemon sole	Witch flounder	Herring	Capelin	Blue whiting	Mackerel	Deep water prawn
FOOD	New Fish Produts	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Surimi	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	
	Fish pulp	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
BIO-PRODUCTS	Bioactive Peptides	x							x										
	Polyunsaturated fatty acids (PUFAs)	x	x	x		x	x	x	x	x	x				x	x	x	x	
	Proteases and Proteolytic enzymes (Trypsin ...)	x							x										
	Chondroitin sulphate							x											
	Fat-soluble vitamins			x					x										
	Minerals: Calcium, CaCO3							x		x	x								
	Dye / pigments (Astaxantin)																		x
	Collagen	x	x						x										
	Gelatine	x	x						x	x									
	Sterols									x									
	Insulin																		
	Protamine																		
	Hyaluronic acid																		
	Chitin / Chitosan																		x
	Pearl Essence								x										
	Phospholipids																		
	Peptone																		
	Escualene																		
FEED	Fish meal	x	x	x	x	x	x	x	x	x	x				x	x	x	x	
	Fish oil	x	x		x	x	x	x	x	x	x				x	x	x	x	
	Mink feed	x	x	x	x	x	x	x	x	x	x				x	x	x	x	
	Marine beef/Bait	x	x		x	x	x	x			x								
	Direct Pig Feed	x	x	x	x	x	x	x	x	x	x				x	x	x	x	
	Protein concentrate (FPC)	x	x								x								
	Protein Hydrolysate (FPH)	x	x								x								
	Silage	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
	Insects growth	x	x	x	x	x	x	x	x	x	x				x	x	x	x	
INDUSTRIAL USES	Leather	x		x	x														
	Fish oil	x	x	x	x	x	x	x	x	x	x				x	x	x	x	
	Minerals: Calcium, CaCO3	x	x	x	x	x	x	x	x	x	x								
	Chitin / Chitosan																		x
ENERGY	Biogas	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AGRONOMIC USES	Compost	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Fertilizers					x	x	x		x	x	x	x	x	x	x	x	x	x

Figure 14: A preliminary table that link the species with their possible valorisation options

<u>Complete the evaluation and prioritization table</u>

The quantitative values of each evaluation criteria must be normalized and classified into standard ranges to allow performing the evaluation of each option (table 5). Then, each range must be assigned a score, the more favourable the higher the score (table 6).

Table 5: Normalization of range values of prioritization criteria

Category	Criteria	units	High	Medium	Low	Null
CS dependent	Available Raw Material (A)	Tn/Year	>500	50-500	<50	<1
	Available facilities (B)	Nº. Facilities	>3	2	1	0
Technical factors	Yield (C)	%	>50	10-50	<10	< 0.05
	Technology maturity (D)		High	Medium	Low	Experimental
Economic factors	Value of the product (E)	€/Kg	>100	10-100	1-10	<1
	Potential Market (F)	Kg/year	>1000	1000-100	5-100	<5
	Production Costs (G)	€/Kg	>100	10-100	<10	-
	Competing companies (H)	Kg/year	>500	10-500	<10	<1

Table 6: Assignment of numerical scores to each value range

Category	Criteria	5	3	1	0
CS dependent	Available Raw Material (A)	High	Medium	Low	Null
	Available facilities (B)	Many and/or nearby	Not many and/or faraway	Experimental	Null
Technical factors	Yield (C)	High	Medium	Low	Null
	Technology maturity (D)	High	Medium	Low	Experimental
Economic factors	Value of the product (E)	High	Medium	Low	Null
	Potential Market (F)	Big	Medium	Small	Null
	Production Costs (G)	Low	Medium	High	Very-High
	Competing companies (H)	Low	Medium	High	Saturated

A ponderation or weighting coefficient will be assigned to each prioritization criterion and to each valorisation option will obtain a score (a value between zero and one) based on the following equations:

$V_{CS} = (x_1 \bullet A + x_2 \bullet B) / (5 \bullet (x_1 + x_2))$

$V_{tech} = (x_3 \bullet C + x_4 \bullet D) / (5 \bullet (x_3 + x_4))$

$V_{eco} = (x_5 \bullet E + x_6 \bullet F + x_7 \bullet G + x_8 \bullet H) / (5 \bullet (x_5 + x_6 + x_7 + x_8))$

Where V_{CS} is the score obtained for the case study dependent criteria, V_{tech} is the score of the technical criteria and V_{eco} is the score of the economic criteria. x_1 to x_8 (cells in purple table 10) are the weighting coefficient values assigned to each criterion for the prioritization and A, B, C, D, E, F, G and H the value that corresponds the range where each criterion moves normalized from 0 to 5.

The weighting coefficient value x_1 to x_8 should highlight the importance of each criteria in the final decision and are usually values between 1 and 10, defined through consensus within the project team. As recommendation:

- Key/critical factor: 10 points
- Very important factor: 7 points
- Factor with some relevance: 3 points
- Factor with small relevance: 1 point

The final score or priority value (V_P) for each solution comes from the product of the technical and economical score.

$V_p = (y_1 \bullet V_{CS} + y_2 \bullet V_{tech} + y_3 \bullet V_{eco}) / (y_1 + y_2 + y_3)$

Where y_1 to y_3 are the weighting coefficient values assigned to each category.

Thus, the methodology allows not only the evaluation considering all the criteria at the same time but also the evaluation of each valorisation option from the technical and economical point of view separately, as well as evaluating the weight of the case study dependent criteria.

4 Results – Case studies

This chapter focuses on case studies made for the industry, specifically for onboard processing vessels. The case studies are chosen based on the most suitable options for processing RRM onboard vessels such as freezer trawlers and fresh fish trawlers. The chapter is structured in such a way that each case is independent, which allows the reader to choose which case study to read.

4.1 Norwegian fishing industry

4.1.1 Case 1 – Utilization of cod heads

The Norwegian white fish sector produces about 300,000 tons of RRM each year, depending on the quota availability. With rich amounts of protein, lipid and other valuable components like calcium and phosphor, RRM from white fish can be utilised in various types of food for human consumption as well as feed.

In 2019, available RRM from the Norwegian white fish sector were calculated to 298 000 tons. With about 36 % of the volume, fish heads represented the largest fraction group. With an increased degree of utilisation over the past years, at 65-70 %, fish heads have been a strong contributor to the increase in the total utilization of RRM from the Norwegian white fish sector. However, there were still 37,000 tons of fish heads from the white fish sector not utilised in 2019.

Traditionally, Norway has exported dried fish heads to Nigeria, but also various markets in Asia. As a resource demanding process in terms of manpower and time, as well as highly volatile markets, producers have experienced economic difficulties in the past years. One example is the heavy decrease in exports from 2014 to 2016, caused by unrest in the world economy, including Nigeria. Although the exported volumes and prices have yet again increased since 2016, the general unrest in the world economy has convinced many to look for new ways to utilise the raw material, and especially cod heads.

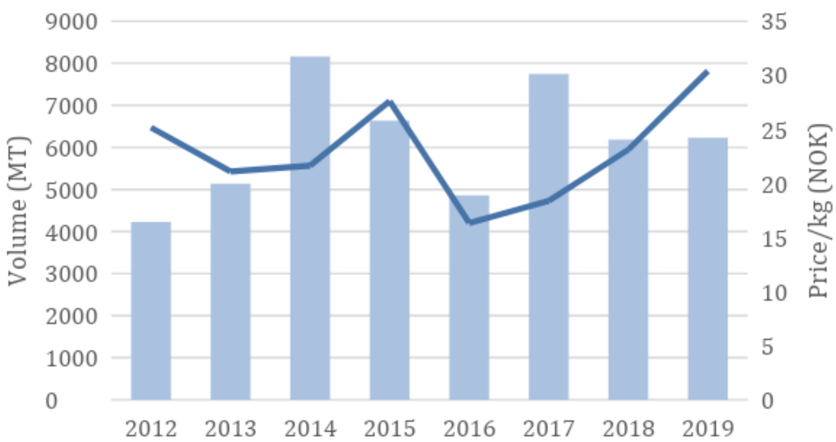


Figure 15: Norwegian export of dried fish heads to Nigeria.

New way to utilise cod heads

The RRM that are not sold for human consumption can be processed, either simple and affordable as silage, or more complex by enzymatic hydrolysis. Although, to satisfy the consumer market the protein content should be above 90 %, have a good flavour, nutritional quality, sufficient shelf life and competitive prices (Remme et al., 2018). The cod head, which represents about 17-20 % of the total weight of the fish, includes 15 % protein, a fair share of bones and small amounts of fat[1] and has the potential to fulfil these criteria.

Remme et al. (2018) studied the possibility of processing fresh cod heads with enzymatic hydrolysis by optimizing the processing conditions. In the study, each batch processed included about 400 kilos of fresh cod heads and the time ranged from 2 to 3 hours from the fish was landed to the process was complete. The study found that fresh high-quality raw material, as well as an optimized hydrolysis process, can result in high quality marine proteins, keeping all the essential amino acids. The protein powder achieved was bright and white coloured, with a neutral taste and smell. It contained more than 80 % protein and had a quality high above traditional fish meal.

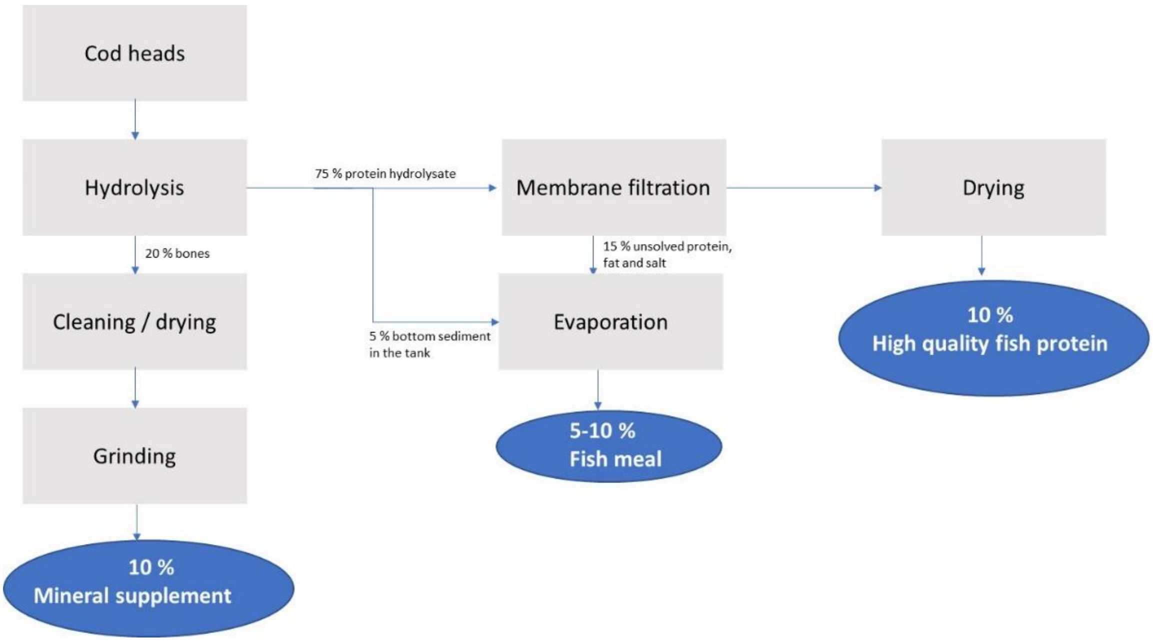


Figure 16: Potential products from cod heads (source: SINTEF Ocean)

While there is a vast number of studies on hydrolysis of fish and RRM from fish, there are only a few who are producing fish protein hydrolysate for the human consumption market today. To be willing to invest in production technology, the producer needs to be certain that the process is profitable compared to investment and production cost, and the products produced fulfils the current laws and regulations, as well as the market demands (Remme et al., 2018). In table 7, the estimated potential utilization and market price for protein hydrolysate, minerals and fish meal from cod heads are presented. The market prices are based on similar products from commercial actors in Norway, while

[1] Cod, http://www.fao.org

the estimated investment and yearly production cost is given through first-hand communication with the Norwegian industry.

Cost-benefit analysis

From table 7, we assume a total volume utilisation of 27 % from the cod head when processed with enzymatic hydrolysis, based on the degree of utilization from the detailed overview for the different products. The average raw product price, as well as the production cost is estimated by the industry, while the market prices are based on similar products sold commercially in Norway today.

Table 7: Production overview: hydrolysis of cod heads (Source: Remme et al., 2018 and first-hands communication with the Norwegian industry)

General			
Investment cost	20 million NOK		
Production time	2-3 hours		
Production cost	3 500 NOK/tons		
Average raw product price	30 NOK/kg		
Volume utilization	27 %		
Application	Human consumption / animal feed		
Detailed			
	High quality fish protein	**Mineral supplement**	**Fish meal**
Application	Health food or as ingredients	Health food, ingredients, or animal feed	Animal feed
Volume utilization from raw weight (cod head)	10 %	10 %	5-10 %
Market price / kg (dried hydrolysate raw material)	85 – 200 NOK/kg	15-30 NOK/kg	15-20 NOK/kg

If a factory is to produce 300 tons of products it needs to purchase about 1,110 tons of fresh cod heads. With an average price for fresh cod heads at about 0.90 NOK/kg[2], this makes the total purchasing cost being 990,000 NOK. In addition, the production cost[3] (direct variable cost) at 3,500 NOK/tons needs to be covered, totalling 1,050,000 NOK with the given production volume at 300 tons.

[2] Average price for fresh cod heads so far in 2020 (Source: The Norwegian Fishermen's Sales Organization)

[3] Production cost includes mainly energy (drying), but also various equipment, enzymes, labour, and filtering (Source: Norwegian industry)

From the investment cost of 20,000,000 NOK, a 20-year linear depreciation is assumed, and a 5 % and 3 % maintenance and insurance cost, respectively.

In table 8, the net annual profit is calculated to 3,393,000 NOK, if the industry can achieve an average price of 30 NOK/kg. This means a yearly production of 300 tons of proteins, minerals and fish meal from cod heads processed with hydrolysis could repay the investment cost in about 6 years. However, realistically, 7 to 8 years is more reasonable with the necessity of a solid liquidity at all times for the industry if difficulties related to the processing technology or the business in general would occur. Remme et al. (2018) mentions grinding of cod heads, volumes of bones left in the tank and salt and fat reduction in the end-product as some of the main operating challenges still to face, which may increase the production cost or reduce the estimated market price before solved.

Table 8: Case example on yearly production with enzymatic hydrolysis

Volume products produced Weighted average product price per kilo	300 tons 30 NOK
Revenue	9 000 000 NOK
Expenses raw material (cod heads)	1 000 000 NOK
Production cost	1 050 000 NOK
Variable cost **Contribution margin** Insurance cost Maintenance/repairs Depreciation	**2 050 000 NOK** **6 950 000 NOK** 600 000 NOK 1 000 000 NOK 1 000 000 NOK
Fixed cost Tax (22 %)	**2 600 000 NOK** 957 000 NOK
Annual income	**3 393 000 NOK**
Investment cost *Annual return of investment*	*20 000 000 NOK* *17 %*

Today it is mainly looked at fresh raw material for enzymatic hydrolysis of cod heads, originating from the Norwegian coastal fleet. However, a few R&D-organisations are now looking at the potential for utilisation of frozen cod raw material as well. Frozen heads will probably demand more energy which increases the production cost, but at the same time contribute to an even stronger availability of raw material for the industry. If looking at the 37,000 tons of fish heads not taken care of in 2019, mainly originating from the sea-going fleet, there is a potential to produce about 10,000 tons of marine proteins, minerals and fish meal. With an average price of 30 NOK/kg, this will be worth 300,000,000 NOK. However, on board installation will likely be more costly, requiring limited space and adapted technical solutions for rough sea conditions.

A SWOT-analysis for hydrolysis of fish heads is presented below, compared to the conventional dried fish industry.

Table 9: A SWOT-analysis for hydrolysis of fish heads

STRENGTHS	WEAKNESSES
- Time efficient production - Market prices - Controlled production environment	- Conservative industry vs. new technology - Test phase stage
OPPORTUNITIES	**THREATS**
- Market stability - Increasing production volume - Increasing production locations	- Unestablished market - Costly investment - Undiscovered production challenges

4.2 Icelandic fishing industry

4.2.1 Case 1 – Collection of livers

In February 2012 a new regulation on utilization of the catch and rest raw material which included a landing obligation of livers. In the regulation ships other than processing ships (freezer trawlers) were obligated to land all livers from saithe, ling, tusk and anglerfish and the processing ships were obligated to land 50% of all cod livers. Because of difficulties with handling the liver on-board the regulation was changed in 2013 which excluded processing ships from landing livers. Difficulties were seen in preserving the liver, freezing e.g. can lead to cross-contamination into higher value products. Freezing is often insufficient which can cause the freezer plates to leak or even break due to load.

Annual revenue

Medium sized fresh fish trawler (processing ship) in Iceland has a yearly cod catch of approximately 2,400 tons and approximately 3,500 tons of cod, haddock and saithe. Given that the liver proportion is 5% of the fish, the amount of cod liver from a fresh fish trawler would be 120 tons of liver which could be landed. The liver would then either be sold to oil production or for canning. The value of liver to be processed into oil is 0.43 EUR/kg and 0.52 EUR/kg for canning.

Variable cost

The only cost in landing liver from fresh fish trawlers is manual labour. The salary management in Icelandic fisheries is not as simple as it may seem. It is for example statutory in collective fisheries agreements that proportion of the catch revenue is divided between the crewmembers instead of normal salary. According to Hjálmarsson (2017), fleet manager at HB-Grandi, the total overall labour cost as a percentage of revenue is 35% for fresh fish trawlers.

Income statement

Results show that there is profit in landing livers from fresh fish trawlers. If the livers are sold for processing of oil the profit would be just under 27,000 euros a year and just over 32,000 euros if the liver would be canned. Table 10 demonstrates the investment statement, when taken into account 35% labour cost and 20% tax. Collecting liver on fresh fish trawlers does not have other costs.

Table 10: Income statement for collection of livers onboard fresh fish trawlers

	Fresh fish trawler	
	Landing of cod liver for oil production	Landing of cod liver for canning
Liver (kg/year)	120,000	120,000
Value sold to Lýsi ehf. (€/kg)	0.43	0.52
Income	**51,240 €**	**62,220 €**
Labour cost (35% of income)	17,934 €	21,777 €
Profit before taxes	**33,306 €**	**40,443 €**
Tax (20%)	6,661 €	8,089 €
Profit after taxes	**26,645 €**	**32,354 €**

Collecting livers on freezer trawlers introduces many costs and problems. The livers would have to be frozen since the time at sea is often 20 days or more. This would take space from higher value products such as fillets. Frozen liver is sensitive to heat fluctuations and is easily damaged by external force such as pressure. The liver would have to be put on top of the freezer since it does not handle pressure well. It's important to freeze the liver in as low temperature as possible, usually between -25 to -30°C. The freezer would have to be cleaned more frequently and there is a possibility of cross contamination between the liver and higher value products such as fillets. Estimating the operating basis is difficult because there are many threats to the process and the market is quite unstable. Lýsi ehf. for example, has less interest in buying liver that has been frozen for some time (months) because the liver has been measured high in FFA content (Snorri 2013).

Processing equipment on-board freezer trawlers can cause damages to the liver but to get the highest value for the liver it needs to be whole. Because of difficulties in processing the liver on-board and store to get the highest market value, very little of the liver is landed from freezer trawlers. It is not profitable to bring the liver to land from freezer trawlers because the liver needs to be processed and the liver is fragile after freezing (Egill 2014).

Table 11: SWOT analyses for collection of livers for fresh fish trawlers

STRENGTHS	WEAKNESSES
Cod livers are very well-known products Stable demand for products Sustainable utilization of resources The raw material is so to say free No investment cost No production cost	Requires space on-board from higher value products A considerable share of the revenue goes directly to the crew
OPPORTUNITIES	**THREATS**
Be more sustainable Better image of the company More profit	Cross contamination between products Undiscovered challenges such as temperature fluctuations or seasonal quality changes of livers

4.2.2 Case 2 – Onboard fish oil production (processing vessels and freezer trawlers)

Case 2 covers oil production on-board medium sized freezer trawlers and fresh fish trawlers. Medium sized freezer trawler may be targeting around 1,500 tons of cod or around 3,000 tons of cod, haddock and saithe. Medium sized fresh fish trawlers may be targeting 2,400 tons of cod or 3,500 tons of cod, haddock and saithe. It is estimated that livers are 5% of the catch with 45% oil extraction yield and viscera 16% of the catch with 23% oil extraction yield (Einarsson, 2018).

Production of oil is twofold, one is production of crude oil from raw material, that takes place on-board and the other is purification of the oil to make it suitable for human consumption. Cod is gutted and the liver is separated from the viscera. When enough volume is reached the production of oil can take place. Oil production is similar to fishmeal production and they have the same processing steps in the beginning. First the raw material is minced, which is not necessary for livers, before being heated for better separation. After heating, the liver enters a decanter where the oil is separated from solid material and water.

Crude fish oil requires purification to achieve quality characteristics that are accepted for human or animal consumption. Pollutants such as PCB and dioxin can be found in livers and need to be removed. These processes include degumming, neutralization, bleaching and deodorization. After the purification process the oil can then be winterized to increase the EPA and DHA content of the oil. In this case study it is assumed that the buyer processes the crude fish oil further into the desired product.

Annual revenue

The most common method to determine the revenue of fish oils is to compare volumes with world prices. It is estimated that the value of crude fish oil from livers is 1,955 EUR per ton of oil and the value of crude fish oil from liver and viscera is a little lower or 1,530 EUR per ton of oil. These are world prices and can change between years.

Investment cost

Héðinn ehf. produces and sells fishmeal factories among other things and offers a production line, that is called HLOP-250 (figure 17). The production line takes approximately 8.5 square meters and can process 300 kg of raw material/liver per hour. Energy usage is 24 kW but the process is designed with regards to using excess heat from the main engine to heat up the raw material. The price of HLOP-250 is 430,000 USD or approximately 365,500 EUR and the setup cost is approximately 18% of the cost or 65,790 EUR. The total investment cost would then be 431,290 EUR.

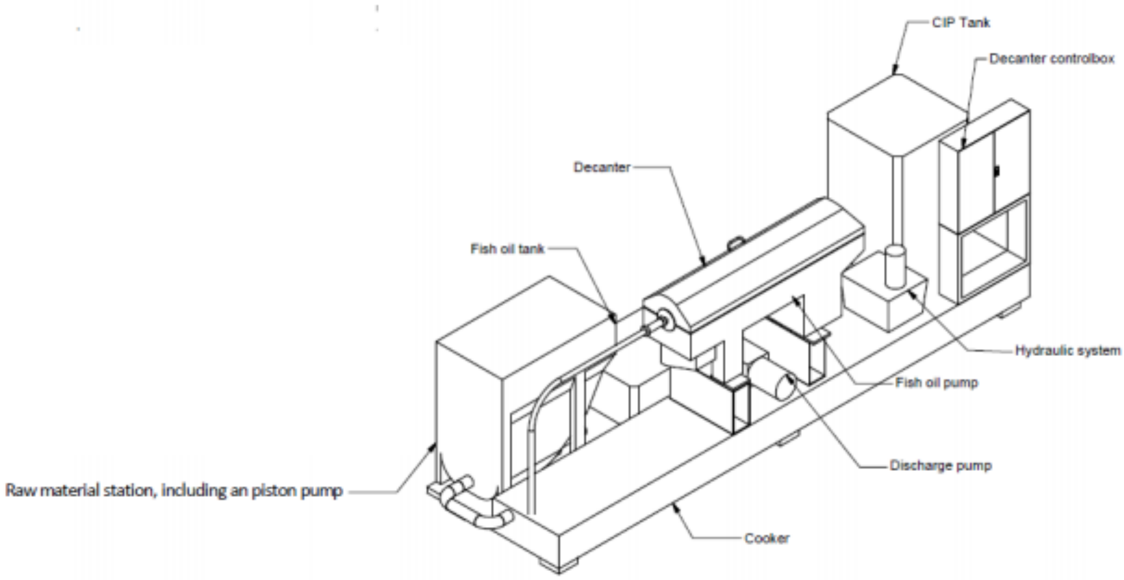


Figure 17: Oil production line (HLOP-250) from Héðinn ehf.

Variable cost

Fuel cost

It is assumed that excess heat from the main engine is used for heating and therefore no specific equipment or energy is needed to heat the material. HLOP-250 factory from Héðins is designed with regard to that. Fuel cost for the decanter, pumps and more is calculated from the power outage of the equipment which is 25 kW. The fuel cost is based on burned oil.

Packaging

Transporting high quantity of oil has three possibilities. IBC plastic tanks, flexitank bags into a container or steel barrels. Since the quantity for these vessels are not that high it is assumed that IBC tanks are used. IBC tank costs approximately 18 EUR each. Price of a flexitank is approximately 1,000 EUR, additionally a steel frame is needed so the bag does not move out when the door to the container is opened.

Figure 18: - IBC tank to the left and a flexitank bag in a transport container to the right (Einarsson, 2020).

Chemical cost

When the oil has been processed, nitrogen is pumped to the oil to remove oxygen. It is assumed that the cost for nitrogen is approximately 12 EUR per ton of oil.

Labour cost

The largest production cost is labour cost. It is statutory in collective fisheries agreements that proportion of the catch revenue is divided between the crewmembers instead of normal salary. According to Hjálmarsson (2017), fleet manager at HB-Grandi, the total overall labour cost as a percentage of revenue is 42% for freezer trawlers, compared to 27 crew members on board, and 35% for fresh fish trawlers.

Other costs

Many expenses can be overseen; therefore, it is assumed for variable expenses which count for 10% of the total variable cost.

Fixed cost

Under fixed cost falls depreciation of equipment. That is the yearly degradation of the equipment value. It is assumed that the equipment depreciates in 20 years.

Yearly maintenance cost is estimated at 2% of the investment cost. The equipment is expensive and specific, and the cost can increase quickly. Some years less maintenance can be assumed and some years more.

Income statement

The income statement (table 12) gathers all income and all costs for oil production on-board both medium sized freezer trawlers and fresh fish trawlers (processing trawlers). It shows three different raw material compositions, only cod liver, livers from cod, haddock and saithe and thirdly all viscera and livers from whitefish. The results show that more profit is gained from processing all viscera and livers from whitefish into oil for both medium sized trawlers and fresh fish trawlers (processing trawlers). The return of investment is the proportion between yearly profit and investment cost and can give an example on how fast the investment cost returns profit.

Results from this project indicate that production of oil on-board can be profitable for both freezer trawlers and fresh fish trawlers. However, little profit is in processing oil from cod liver on its own because of high investment cost and production volume low compared to production capacity. Results show that there is not enough operational basis for this kind of processing and more profit is in landing whole liver than producing crude fish oil on-board. The profit from traditional landing of cod liver from fresh fish trawlers with 120 tons of liver, would be 26,645 EUR a year if the liver would be sold to crude fish oil production and 32,354 EUR if the liver would be sold for canning. Same amount of cod liver which was processed into crude fish oil at sea would return 18,600 EUR a year.

If however, liver from cod along with liver from saithe and haddock were used, more volume of livers would result in better utilization of the equipment which would return more profit. Yearly profit turned out to be 28,400 EUR for medium sized trawlers and 35,550 EUR for fresh fish trawlers. The profit increase is however only about 4-12 thousand EUR for fresh fish trawlers considering if the liver would be landed.

The third option, processing all viscera from whitefish, including liver, turned out to be the most profitable option with 41,200 EUR for freezer trawlers and 51,500 EUR for fresh fish trawlers. The increase in profit for processing viscera is that there seems to be a small price difference between crude fish oil produced from viscera and livers compared to only liver and more fish oil is obtained from all viscera. This however can affect further processing since crude fish oil from viscera is not used for human consumption because of EU regulations.

Table 12: Income statement for oil production onboard medium sized freezer trawlers and fresh fish trawlers

	Freezer trawler			Fresh fish trawler		
	Trawler 1: Cod liver	**Trawler 2: cod, haddock and saithe liver**	**Trawler 3: All viscera and livers of whitefish**	**Trawler 1: Cod liver**	**Trawler 2: Cod, haddock and saithe liver**	**Trawler 3: All viscera and livers of whitefish**
Catch for production (kg/year)	1,500,000	3,000,000	3,000,000	2,400,000	3,500,000	3,500,000
Raw material (kg/year)	75,000	150,000	480,000	120,000	175,000	560,000
Oil (kg/year)	33,750	67,500	110,400	54,000	78,750	128,800
Income	**65,981 €**	**131,963 €**	**168,912 €**	**105,570 €**	**153,956 €**	**197,064 €**
Energy cost	97 €	195 €	623 €	156 €	227 €	726 €
Packaging	616 €	1,231 €	2,014 €	985 €	1,436 €	2,349 €
Chemical treatment	410 €	821 €	1,342 €	657 €	958 €	1,566 €
Salary	27,712 €	55,424 €	70,943 €	44,339 €	64,662 €	82,767 €
Other cost	6,598 €	13,196 €	16,891 €	10,557 €	15,396 €	19,706 €
Variable cost	**35,434 €**	**70,867 €**	**91,813 €**	**56,694 €**	**82,678 €**	**107,115 €**
Margin	**30,548 €**	**61,095 €**	**77,099 €**	**48,876 €**	**71,278 €**	**89,949 €**
Maintenance	7,310 €	7,310 €	7,310 €	7,310 €	7,310 €	7,310 €
Depreciation	18,275 €	18,275 €	18,275 €	18,275 €	18,275 €	18,275 €
Fixed cost	**25,585 €**	**25,585 €**	**25,585 €**	**25,585 €**	**25,585 €**	**25,585 €**
Profit before tax	**4,963 €**	**35,510 €**	**51,514 €**	**23,291 €**	**45,693 €**	**64,364 €**
Tax (20%)	993 €	7,102 €	10,303 €	4,658 €	9,139 €	12,873 €
Profit	**3,970 €**	**28,408 €**	**41,211 €**	**18,633 €**	**36,554 €**	**51,491 €**
Investment cost	**431,290 €**	**431,290 €**	**431,290 €**	**431,290 €**	**431,290 €**	**431,290 €**
Return of investment	**1%**	**8%**	**11%**	**5%**	**10%**	**14%**

The main result from this case study is that investment in oil processing of all viscera, including livers on-board is economically feasible for both freezer and fresh fish trawlers. This solution only requires 9 m^3 and might be suitable for older boats where space is limited. Although, a storage space up to 20 m^3 must be included for freezer trawlers.

Table 13: SWOT analysis for onboard fish oil production of all viscera including livers

STRENGTHS	WEAKNESSES
• Fish oil is a well-known product • Stable demand for products • Sustainable utilization of resources • The raw material is so to say free • The investment can be sold and is not stationary as land-based facilities • Suitable for older vessels	• High investment cost • Requires a lot of space onboard • A considerable share of the revenue goes directly to the crew
OPPORTUNITIES	**THREATS**
• Process very fresh and new raw material • Be more sustainable • Better image of the company • More profit	• Undiscovered investment or production costs • Lipid hydrolysis or oxidation during storage

4.2.3 Case 3 - Processing vessel – Onboard canning

Case 3 covers on-board canning factory for medium sized trawlers and new generation of Icelandic freezer trawlers. The new generation freezer trawlers are larger. The medium sized trawlers may be targeting about 3,000 tons of whitefish while the new generation ones are targeting around 10,000 tons annually of mixed species. Livers as stated before accounts for approximately 5% of the fish. Before canning the livers must be processed to clean and remove unwanted quality factors and the utilization is approximately 70%, however it can vary by season. Canning factory on-board does not have to be big since the quantity to be canned is quite low daily. Canning factory on-board, however, must consist of the same equipment as a canning factory on land and does take up quite a lot of space.

The process for canned fish liver is shown in figure 19. The liver is processed before being canned. The hardest part of the process is removing ringworms from the liver which is done either by manual labour or by using hot water and drum. After that the liver goes to a dozing machine which puts the right amount into each can. The cans are then closed and rinsed before being boiled under pressure to 110°C. After that the cans are cooled and marked before being packed.

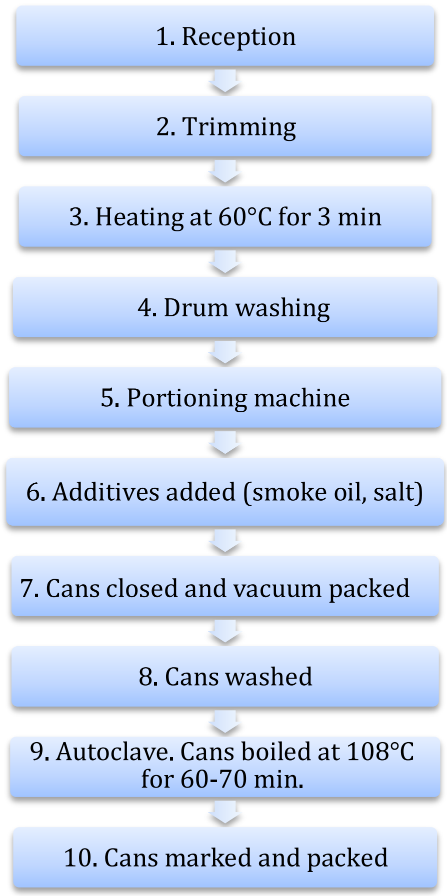


Figure 19: Production line for canned fish liver

Annual revenue

The value of canned fish liver is estimated from the export value of the total exported canned fish livers from Iceland in 2018. Figure 20 shows the main export countries of canned fish liver from Iceland in 2018.

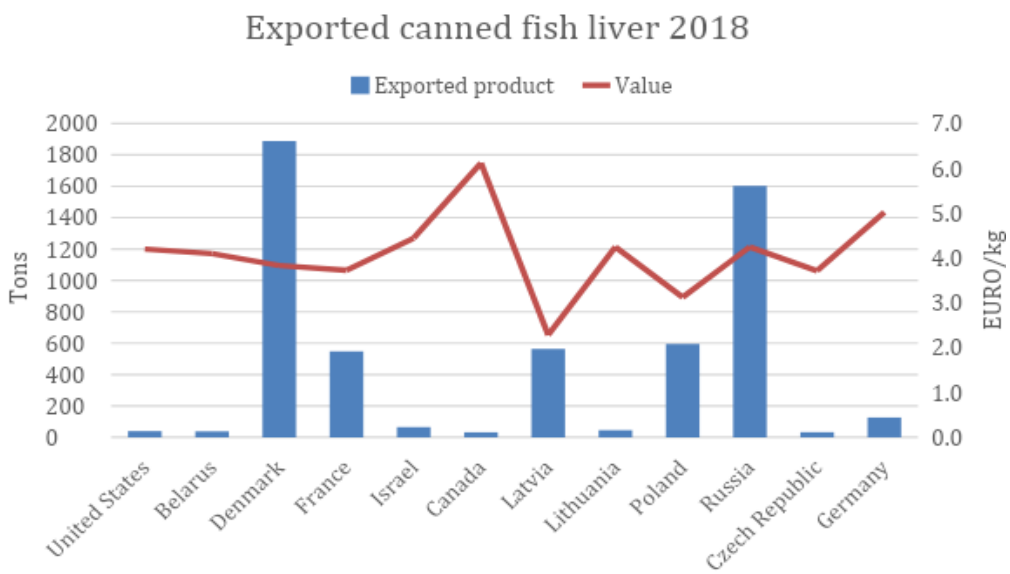


Figure 20: Main export countries of canned fish liver in 2018

It is estimated that the value of canned fish liver is 3,710 EUR per ton but may vary between years. The annual revenue is based on partners buying canned fish liver and selling it on the market, taking care of the costs of marketing and transportation and so the market value of canned fish liver is higher. For example, Fisherman ehf. sells canned fish liver for 2.9 EUR per 120 g canned cod liver which would be approximately 24,000 EUR per ton product. Estimated costs are based on already done work from Halldórsson in 2013 with minor adjustments.

Investment cost

Investment cost for such a factory was estimated at 282,500 EUR including setup cost.

Variable cost

Fuel cost

Fuel cost is estimated as 2,8% of the total revenue.

Packaging cost

The cost of cans and lids is estimated as 31% of the total revenue.

Labour cost

The largest production cost is labour cost. It is statutory in collective fisheries agreements that proportion of the catch revenue is divided between the crewmembers instead of normal salary. According to Hjálmarsson (2017), fleet manager at HB-Grandi, the total overall labour cost as a percentage of revenue is 42% for freezer trawlers, compared to 27 crew members on board.

Landing cost

The landing cost is assumed to be 3% of the revenue.

Other variable cost

Many expenses can be overseen; therefore, it is assumed for variable expenses which count for 10% of the total variable cost.

Fixed cost

Depreciation

Under fixed cost falls depreciation of equipment. That is the yearly degradation of the equipment value. It is assumed that the equipment depreciates in 10 years.

Insurance

The annual cost of insurance is 2% of the investment cost which is a value used by FAO in one of their cost estimations for canning factories (FAO, 1985).

Repairs and maintenance

Repairs and maintenance are a standard factor in the operation of a canning factory. This factor is expected to count for 4% of the total investment cost annually (FAO, 1985)

Income statement

The income statement for one year can be seen in table 14. For medium sized trawlers it's not economically feasible to produce canned liver on-board. For the new generation freezer trawlers, the annual income is high but also the cost is high. The production of canned livers on-board has many risk factors such as the utilization of livers can vary from as low as 40% and up to 85%. The market for canned fish liver is also unstable, for example in 2015 the market value of canned cod liver was 4,100 EUR per ton. This investment calls for a significant change in the processing on-board and the profit might be over-estimated. The investment has higher risk than other solutions and requires restructuring of the ships and the on-board processing but does increase profit substantially.

Table 14: Income statement for production of canned fish livers onboard medium sized freezer trawlers and new generation freezer trawlers

	Medium sized freezer trawler		**New generation freezer trawler**	
	Trawler 1: Cod liver	**Trawler 2: cod, haddock and saithe liver**	**Trawler 1: Cod liver**	**Trawler 2: cod, haddock and saithe liver**
Catch for production (kg/year)	1,500,000	3,000,000	5,000,000	10,000,000
Raw material (kg/year)	75,000	150,000	250,000	500,000
Amount of product	52,500	105,000	175,000	350,000
Income	**194,775 €**	**389,550 €**	**649,250 €**	**1,298,500 €**
Energy cost	5,454 €	10,907 €	18,179 €	36,358 €
Packaging	60,380 €	120,761 €	201,268 €	402,535 €
Labour	81,806 €	163,611 €	272,685 €	545,370 €
Landing	5,843 €	11,687 €	19,478 €	38,955 €
Other cost	14,764 €	29,528 €	49,213 €	98,426 €
Variable cost	**168,247 €**	**336,493 €**	**560,822 €**	**1,121,644 €**
Margin	**26,528 €**	**53,057 €**	**88,428 €**	**176,856 €**
Maintenance	11,300 €	11,300 €	11,300 €	11,300 €
Depreciation (10 years)	28,250 €	28,250 €	28,250 €	28,250 €
Insurance	5,650 €	5,650 €	5,650 €	5,650 €
Fixed cost	**45,200 €**	**45,200 €**	**45,200 €**	**45,200 €**
Tax (20%)	-	1,571 €	8,646 €	26,331 €
Annual income	**-18,672 €**	**6,285 €**	**34,582 €**	**105,325 €**
Investment	282,500 €	282,500 €	282,500 €	282,500 €
Annual return of investment	-7%	2%	12%	47%

SWOT analyses

Table 15: SWOT analysis for onboard canning

STRENGTHS	WEAKNESSES
• Sustainable utilization of resources • The raw material is so to say free • The investment can be sold and is not stationary as land-based facilities • High profit for larger vessels	• High investment and production cost • Can't process other rest raw material • Requires a lot of space onboard • Unsustainable energy production • A considerable share of the revenue goes directly to the crew • Hardly an option for older vessels
OPPORTUNITIES	**THREATS**
• Process very fresh and new raw material • Be more sustainable • Better image of the company • More profit	• The production is very dependent on utilization yield of livers • Utilization yield may vary by season • Unexpected production problems can reduce profit substantially since the livers can hardly be frozen

4.2.4 Case 4 – Processing vessel – Fishmeal and fish oil production on sea

Case 4 covers fishmeal production onboard the new generation of Icelandic freezer trawlers. Which are larger in comparison to older trawlers and better equipped. They are equipped with onboard fishmeal and oil factories that can produce fishmeal and oil from by-products with a capacity of up to 50 tons a day. They have special storage hold for fishmeal with space for up to 250 tons of fishmeal. They have special oil tanks constructed in the sides of the ships to hold up to 180 cubic meters of oil.

These vessels may be targeting around 10,000 tons annually of mixed species and go on 10 fishing trips over the year where each may be as long as 30 days. On a processing vessel, this may account for up to 40% of rest raw material or 4,000 tons annually (Einarsson, 2017). This ratio may vary between species and different vessels. Some species are processed down to fillets onboard while others may be frozen whole. The way the processing is carried thus affects the chemical composition and volume of raw material.

Using the catch combination from Einarsson, 2017, the following chemical composition is established. This includes heads, backbone, cut-offs and viscera from many different species.

	Protein	Fat	Water	Minerals
Byproducts	17%	7%	71%	5%

Figure 21: Average chemical composition of by-products that fall by during onboard processing

Fishmeal plant designs

Offshore production of fishmeal has been around in Iceland in some form for more than half a century (The Herring Era Museum, n.d.). The development has however been slow towards full utilization of all material streams, energy efficiency and quality aspects. These plants are commonly named compact fishmeal plants since components have been compressed to take up as little space as possible. Many older plants are so compact that the press cake becomes an absolute priority and press liquor is often discarded to the sea with all the oils and protein within. Thus, it can only produce fishmeal out of the press cake discarding the oils and excess protein source into the ocean. The press liquor contains valuable compounds such as proteins, oils, minerals and vitamins that can weigh up to 20-40% of the total fishmeal produced, depending on the raw material (FAO, 1986).

Nowadays these plants are more capable and have higher processing efficiency. Some plants can produce fishmeal, oil and have built-in evaporators to utilize stickwater and increase fishmeal yield. Others produce fishmeal and oil but discard this valuable source to the ocean but on the other hand demand much less fuel for energy. These fishmeal plans can be divided into the following three categories.

Fishmeal plant - Low degree processing

The Low degree processing design is simply a conventional fishmeal plant commonly used in the past decade onboard trawlers. It's a compact solution which is relatively simple to operate and maintain. However, it has one major disadvantage, the press liquor containing valuable sources of protein and oil is discarded directly into the ocean.

This design is not covered in this case since it is not economical to operate such a plant that has so low utilisation efficiencies. More than 20% of potential weight of the fishmeal is lost along with all of the oil.

Fishmeal plant - High Degree processing

This design is made to correspond to the idea of High degree, state of the art fishmeal and oil processing to retrieve material at its best possible quality and high utilisation efficiency. It is influenced by onshore processing plants and could be considered a conventional onshore plant. It is equipped with all the essential components, centrifuges, presses, dryers and evaporators to retrieve proteins from the stickwater. The main components of the High degree processing plant can be seen in Figure 22.

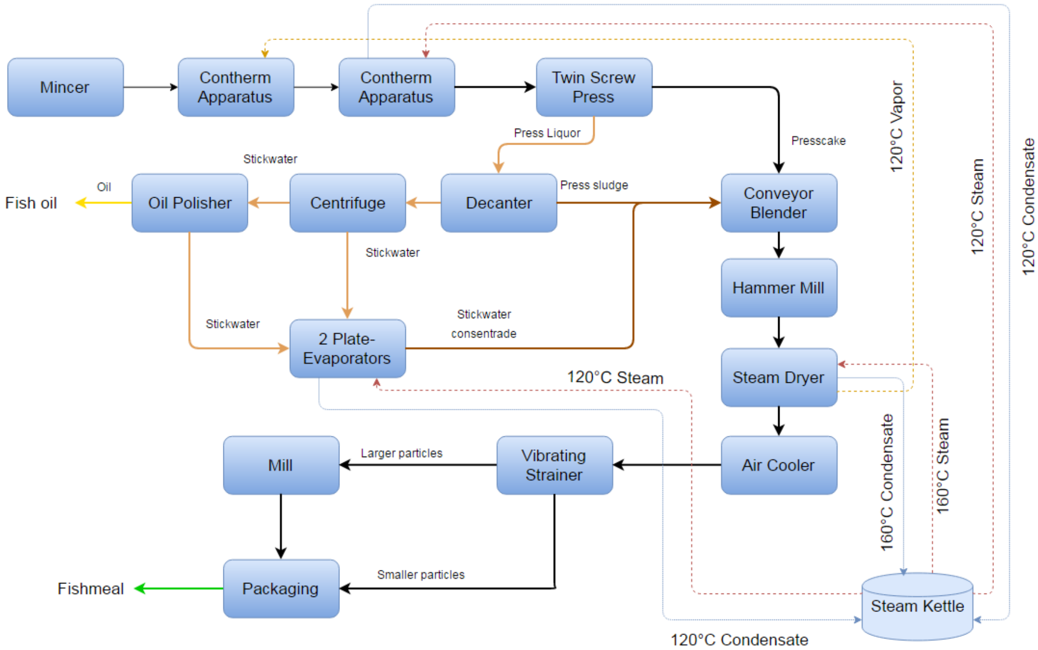


Figure 22: Flowchart for high degree processing of both fishmeal and oil

Mass balance calculations are used along with few assumptions to establish the final weight of fishmeal and oil. The first assumption is that fishmeal contains 9% fat and 10% water. This is enough to establish the fat free dry-matter (e.FFDM) in the meal and calculate the final weight of fishmeal. The space needed on board to store all this fishmeal and oil is close to 200 cubics and even more considering that space is not fully utilised when fishmeal is stored in bags.

Table 16: Chemical composition and volumes of different production streams in high degree processing plant. Based on mass balance calculation and Einarsson,2017

	Amount ton	Cubics	Cubics per tour	Protein	Fat	Water	Minerals	FFDM
Raw material	4000			17%	7%	71%	5%	22%
Vapor	2719					100%		0%
Oil	192	226	23		100%			0%
Fishemeal	1089	1675	167	63%	9%	10%	18%	81%

Fishmeal plant - Hybrid processing

The Hybrid design is the idea of a compact system that can fully process fish oil without an evaporation system. Oils are separated from the press liquor and the excess stickwater is simply discarded. This plant is equipped with a two-stage dryer that is constructed with a pre-and secondary unit to promote better energy efficiency.

The basic setup of components can be seen in Figure 23, the plant is the same as the High degree design beside the evaporation system and the two-stage drying setup.

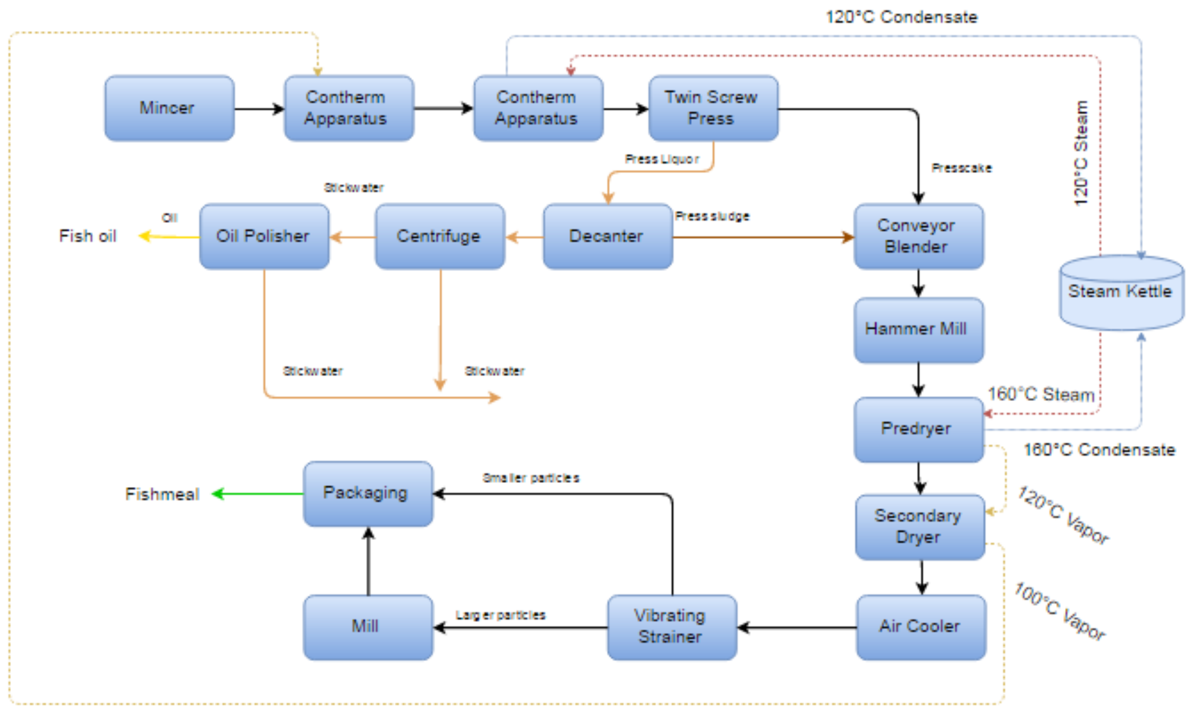


Figure 23: Flowchart for hybrid system design

Mass balance calculations are used along with few assumptions to establish the final weight of fishmeal and oil. The first assumption is that fishmeal contains 9% fat and 10% water and that stickwater contains 20% of the total FFDM (FAO, 1986). The following table shows different production streams and space requirements. The vessel needs a minimum of 160 cubic meters of space.

Table 17: Chemical composition and volumes of different production streams in the hybrid plant. Based on mass balance calculation and Einarsson,2017

	Amount ton	Cubics	Cubics per tour	Protein	Fat	Water	Minerals	FFDM
Raw material	4000			17%	7%	71%	5%	22%
Press liquid	576			24%	0%	69%	7%	31%
Vapor	2341					100%		0%
Oil	212	249	25		100%			0%
Fishemeal	871	1340	134	63%	9%	10%	18%	81%

Annual revenues

The most common method to determine the revenue of fishmeal and oil is to compare volumes with world prices. The world prices mostly follow availability for a given time and the production output from Peru which has been the largest supplier of fishmeal and oil in the world.

Fishmeal is normally priced by the chemical composition and the material quality. The most common way to evaluate fishmeal price for a given material is to compare the amount of protein with fishmeal prices (FAO, 1986). However, fishmeal prices are represented in tons of fishmeal but given that the fishmeal contains 65% protein. The world prices can thus be converted into USD per ton of protein, which is around 2,300 USD (CIF), given that fishmeal prices are around 1,500 (CIF) USD per ton (Figure 24). The world fish oil prices are close to 2,300 USD per ton. In this case study, the EUR is used, and the exchange rate is 0.85.

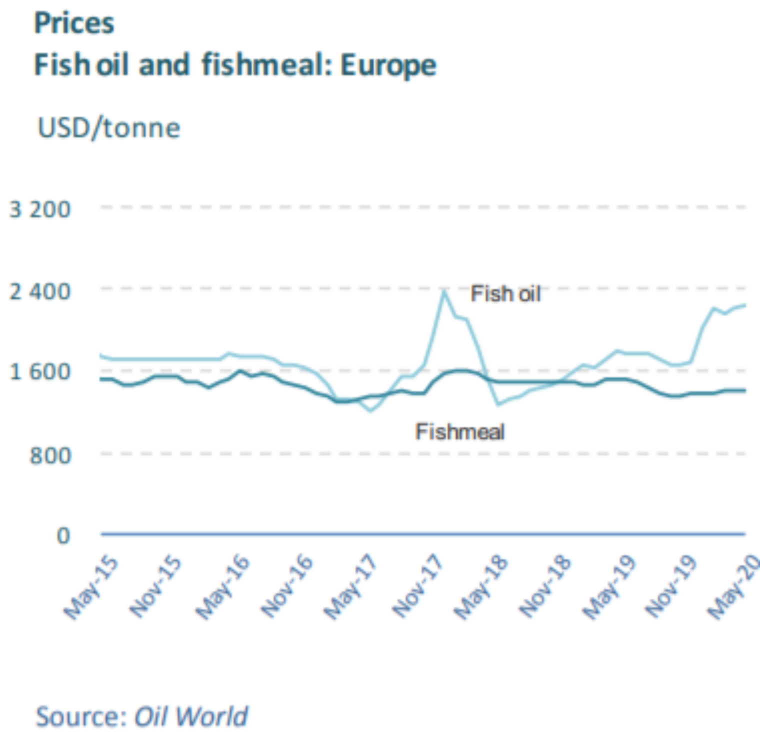


Figure 24: European fish oil and fishmeal prices represented in USD (FAO,2020)

The revenues assessments for each design take into account the volume of fishmeal and oil obtained by each design and the chemical composition. The difference between the final accumulated revenue for the two designs can be explained by the degree of processing. The High degree design fully utilizes all material streams, such as press liquor and stickwater, producing fish oil and fishmeal which increases revenue significantly. Hybrid design produces fishmeal, oil but discards the stickwater.

Variable cost

Fuel cost

The energy comes from marine diesel oil (e.MDO), the world price is somewhere close to 500 USD per mt. The designs and the degree of processing greatly affect energy demand and fuel cost. The drying is particularly energy-intensive as well as evaporating the stickwater. According to Einarsson,2017, the high degree design requires 135 kg MDO per ton raw material put in and the hybrid design requires 62 kg MDO per ton of raw material in.

Labour cost

It is essential to have at least one extra employee with supervision over the plant. The salary management in Icelandic fisheries is not as simple as it may seem. It is for example statutory in collective fisheries agreements that proportion of the catch revenue is divided between the crewmembers instead of normal salary. According to Hjálmarsson (2017), fleet manager at HB-Grandi, the total overall labour cost as a percentage of revenue is 42% on freezer trawler, compared to 27 crew members on board. This percentage harmonizes with Magnason's findings in his master theses on this matter (2012). For newer trawlers, this value is considerably lower in the first seven years or around 34%.

The catch share is not drawn from net income, since the crew has only the right to receive a catch share based on the FOB prices, which is only the landed value. Fishmeal and oil prices are based on CIF, which is a term that requires the seller to arrange for carriage of goods oversea. To take into account this difference between FOB and CIF, it is assumed that FOB prices are 7% lower than CIF prices. This leads to labour cost being 31.77% of the (CIF) revenue for 7 years old or younger ships and 39.25% for older ones.

Chemical cost

Additions of antioxidant chemicals are essential to preserve reactive fishmeal and to prevent deterioration of the material. It also reduces the risk of fire, since fishmeal can be highly flammable due to oxidation. Due to the recent ban on ethoxyquin, many different antioxidants are being used, such as tocopherols and rosemary to name some. They are used in different proportions in different mixtures. It is common to use up to 1500 ppm maximum of antioxidants. According to a recent buyer, one kg costs 3,500 ISK, around 22 EUR.

Packaging cost

The fishmeal is packed in 1.2 square meter bulk bags and the oil is in 200-litre steel barrels. To determine the total volume and number of containers, densities for fishmeal and oil are used. The density for fishmeal is 0.59 ton per cubic meter and 0.92 for fish oil. Each bag costs 5 USD and the barrel costs 60 USD.

Transportation cost

Since the trawler examined in this case study will be operated from Iceland, it is appropriate to assume for transportation cost over-sea. If it is assumed that fishmeal and oil will be transported in 40 feet containers and that each container can hold around 40 bags and around 160 barrels, the number of containers can easily be calculated using the density of fishmeal and oil.

According to the Icelandic shipping company Eimskip, transportation of a 40 feet container from Reykjavík fishing harbour to Rotterdam costs 2,600 EUR (Ákason, 2017).

Landing cost

The landing cost is assumed to be 3% of the revenue.

Other variable costs

Many expenses can be overseen; therefore, it is assumed for variable expenses which count for 10% of the total variable cost.

Fixed cost

Depreciation

It is assumed that the equipment will depreciate down to 30% of its original value in 20 years which corresponds to an annual discount rate of 5.8%. Depreciation on investments in Icelandic fisheries may not exceed 8% annually according to regulations.

Insurance

The annual cost of insurance is 2% of the investment cost which is a value used by FAO in one of their cost estimations for fishmeal plants (FAO, 1986).

Repairs and maintenance

Repairs and maintenance are a standard factor in the operation of fishmeal plants. Spare parts are expensive as well as hourly wages by specialized experts. These factors are expected to count for 5% of the total investment cost annually (FAO, 1986).

Investment cost

Offshore fishmeal production has been gaining increased interests by ship designers and engineers specialized in the marine industry. These parties work both as designers and consultants for the industry and receive regular offers for plants in diverse sizes. It can be hard to get a hand on reasonable offers on special designs as it matters who the manufacturer is dealing with. The experience has shown that ship designers and ship constructors tend to get lower prices than the fisheries themselves. After a discussion with a Sævarsson (2017), project manager of an Icelandic company that specializes in ship designing, the price of plant such as these three designs would most likely vary 2,200,000 EUR for the High degree design and 1,800,000 EUR for the Hybrid design.

Income statement

The main results of this case study are seen in the following table 18, which shows the income statement for one year. High degree refers to fishmeal and fish oil plant that fully utilises the raw material leaving nothing behind, while the hybrid facility produces fishmeal and fish oil but discards the so-called stickwater which contains valuable proteins.

The annual profit for both designs is between 370 - 400 thousand EUR a year. This translates into between 17-22% return of investment, or that it will take this freezer trawler about 5 to 6 years to pay up the investment. After that period the investment starts to return a profit.

Table 18: Income statement for the two fishmeal plants

	High degree (With evaporators and oil processing)	**Hybrid** (With oil processing)
Annual catches (ton)/year	10,000	10,000
By-products (ton)/year	4,000	4,000
Fishmeal (ton)/year	1,080	880
Fish oil (ton)/year	200	200
Revenue	**2,012,807 €**	**1,725,250 €**
Energy cost	229,500 €	105,400 €
Packaging cost	61,918 €	60,717 €
Chemical cost	35,640 €	29,040 €
Labor Cost	638,060 €	546,904 €
Transportation cost	116,816 €	98,454 €
Landing cost	60,384 €	51,758 €
Other costs	126,924 €	99,141 €
Variable cost	**1,269,242 €**	**991,415 €**
Contribution margin	**743,565 €**	**733,836 €**
Insurance	44,000 €	36,000 €
Repairs	110,000 €	90,000 €
Depreciation	128,480 €	105,120 €
Fixed cost	**282,480 €**	**231,120 €**
Tax (20%)	92,217 €	100,543 €
Annual income	**368,868 €**	**402,173 €**
Investment	*2,200,000 €*	*1,800,000 €*
Annual return of investment	*17%*	*22%*

The largest cost of production in Iceland is the labour cost. The crew shares the revenue with the fisheries which a considerable amount or more than 40% of the total production cost. The following figure 25 shows the costs in columns.

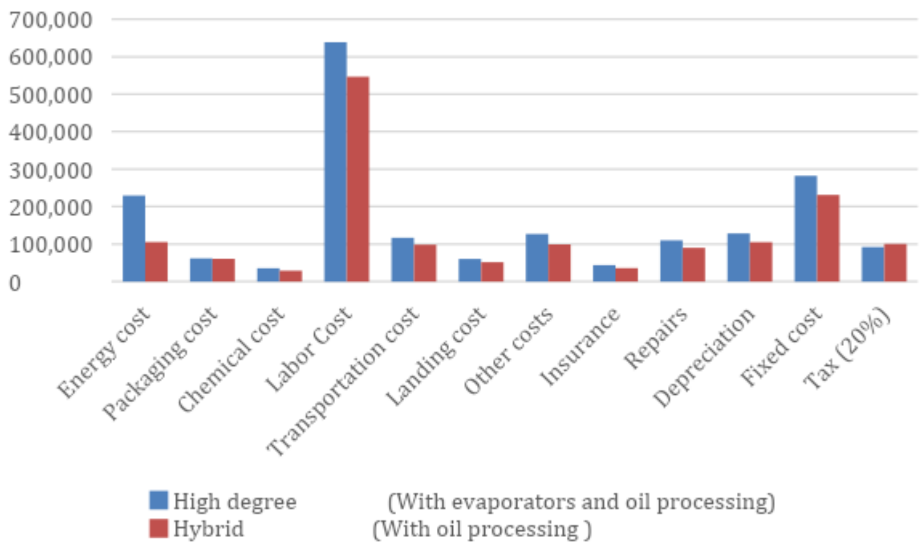


Figure 25: – Annual production costs in columns

Swot analyses

Table 19: SWOT analysis an onboard fishmeal and fish oil production

STRENGTHS	WEAKNESSES
• Fishmeal and oil are very well-known products • Stable demand for products • Sustainable utilisation of resources • The raw material is so to say free • The investment can be sold and is not stationary as land-based facilities	• High investment cost • High production cost • Requires a lot of space onboard • Unsustainable energy production • A considerable share of the revenue goes directly to the crew • Hardly an option for older vessels
OPPORTUNITIES	**THREATS**
• Process very fresh and new raw material • Be more sustainable • Better image of the company • More profit	• The production is very dependent on oil. • Fuel prices may rise with future potential environmental taxes • It can be challenging to store dried fishmeal in moist conditions at sea

4.2.5 Case 5 – Valorisation of prioritization options for use of RRM in Iceland

<u>Amount and type of fishes</u>

In 2019, a total of about 1,050,000 tons were landed in 62 harbours around Iceland. The ten main ports accounted for 70% of the landing volume, 91% of the pelagic species, 49% of the demersal species and 40% of flatfish species, as shown in table 20.

Table 20: Landings by harbour in 2019

Demersal species	Pelagic species	Flatfish	Shellfish	Total

Harbours	tn	%	tn	%	tn	%	tn	%	tn	%
Neskaupstaður	21,609	4%	132,175	25%	2,112	10%	464	5%	156,360	15%
Vestmannaeyjar	41,163	9%	63,564	12%	952	4%	47	0%	105,726	10%
Reykjavík	67,046	14%	3,167	1%	3,160	14%	5	0%	73,378	7%
Vopnafjörður	860	0%	88,713	17%	134	1%	0	0%	89,707	9%
Eskifjörður	3,474	1%	95,681	18%	418	2%	63	1%	99,636	10%
Hornafjörður	12,176	3%	27,305	5%	335	2%	84	1%	39,900	4%
Grindavík	42,217	9%	2,160	0%	804	4%	59	1%	45,240	4%
Fáskrúðsfjörður	5,058	1%	35,519	7%	11	0%	0	0%	40,588	4%
Seyðisfjörður	7,963	2%	36,803	7%	36	0%	8	0%	44,810	4%
Siglufjörður	32,380	7%	0	0%	894	4%	1,658	16%	34,932	3%
Other harbours	247,008	51%	49,285	9%	13,332	60%	7,663	76%	317,289	30%
Total	**480,954**	**100%**	**534,372**	**100%**	**22,188**	**100%**	**10,051**	**100%**	**1,047,568**	**100%**

Existing facilities

There are two main kind of harbours to be evaluated in Iceland:

- Harbours focusing on pelagic species, both for human consumption and for fishmeal- and oil production. Landed volumes going through these harbours can vary between 50 and 100 thousand tons a year. A total of 5 harbours would fall into this group.
- Large multi-purpose harbours that service all fleet types and contain large seafood companies that process most or all types of catches. Volumes going through these harbours can reach an excess of 200-300 thousand tons a year, depending on quotas in pelagic species. A total of 7 harbours would fall into this group.

Furthermore, there are a number of facilities available for utilizing RRMs in the Icelandic fishery, including smelting into fishmeal, making silage, freezing, canning or turning it into value added products using biotechnological solutions. Utilization of RRM even include making pet food, pharmaceuticals, flavouring, stock for making soups and sauces, skin care products, collagen and more. There is also a strong infrastructure, good logistics and a tight net of fish markets that efficiently brings together fishermen and processors. This combined has contributed to allowing processing of specialized products, as sourcing of raw materials is relatively simple and stable.

Selection of valorisation option

Following the standard methodology for valorisation option described in the method chapter, the resulting scores for Iceland are reflected in table 21. Interestingly, more or less all of the options receiving high scores are already being produced, which in a way confirms the methodology applied for the selection of valorisation options.

Table 21: Prioritization evaluation of valorisation options for the Icelandic case study

	Option	CS dependent			Technical Parameters			Economical Parameters						
		Available Raw Material (A)	Existing facilities (C)		Yield (B)	Technology maturity (D)		Value of the product (E)	Potential Market (F)	Production Costs (G)	Competing companies (H)			Total Score (FACTOR)
Category	Valorisation option	10	7	5	7	5	7	10	10	7	2	7		
FOOD	New Fish Products	5	5	1,00	5	5	1,00	5	5	3	1	0,91		0,97
	Surimi	5	0	0,59	3	5	0,77	5	3	1	0	0,64		0,67
	Fish pulp	5	5	1,00	3	5	0,77	5	5	5	5	1,07		0,94
BIO-PRODUCTS	Bioactive Peptides	5	2	0,75	3	3	0,60	5	3	3	3	0,79		0,71
	Polyunsaturated fatty acids (PU	5	5	1,00	3	5	0,77	5	5	3	1	0,91		0,88
	Proteases and Proteolytic enzyr	5	1	0,67	1	3	0,37	1	0	3	1	0,24		0,40
	Chondroitin sulphate	5	3	0,84	1	5	0,53	5	1	1	1	0,51		0,60
	Fat-soluble vitamins	3	0	0,35	1	3	0,37	3	3	1	1	0,51		0,42
	Minerals: Calcium, CaCO3	5	1	0,67	3	5	0,77	3	3	3	3	0,64		0,70
	Dye / pigments (Astaxantin)	5	1	0,67	1	5	0,53	5	3	1	3	0,69		0,63
	Collagen	5	1	0,67	1	5	0,53	3	3	3	0	0,60		0,59
	Gelatine	5	0	0,59	1	5	0,53	3	3	3	0	0,60		0,57
	Sterols	1	1	0,20	1	5	0,53	1	3	1	1	0,36		0,38
	Insulin	1	0	0,12	3	1	0,43	3	1	1	0	0,35		0,32
	Protamine	1	0	0,12	1	3	0,37	1	1	1	0	0,20		0,24
	Hyaluronic acid	1	0	0,12	1	3	0,37	3	3	1	0	0,50		0,35
	Chitin / Chitosan	3	1	0,44	1	5	0,53	5	3	3	1	0,76		0,59
	Pearl Essence	3	0	0,35	1	5	0,53	1	0	3	3	0,27		0,39
	Phospholipids	3	0	0,35	1	3	0,37	3	3	1	3	0,54		0,43
	Peptone	5	1	0,67	3	5	0,77	1	1	5	1	0,42		0,61
	Escualene	0	0	0,00	1	3	0,37	5	3	1	0	0,64		0,37
FEED	Fish meal	5	5	1,00	5	5	1,00	1	5	5	1	0,72		0,90
	Fish oil	5	5	1,00	5	5	1,00	1	5	5	1	0,72		0,90
	Mink feed	5	5	1,00	5	5	1,00	1	1	3	3	0,35		0,76
	Marine beef/Bait	5	1	0,67	5	3	0,83	1	1	5	3	0,45		0,65
	Direct Pig Feed	5	1	0,67	5	3	0,83	1	3	5	3	0,60		0,70
	Protein concentrate (FPC)	5	3	0,84	5	5	1,00	3	5	5	3	0,90		0,92
	Protein Hydrolysate (PH)	5	3	0,84	5	5	1,00	3	5	5	3	0,90		0,92
	Silage	5	1	0,67	5	5	1,00	1	1	5	1	0,42		0,70
	Insects growth	5	0	0,59	3	3	0,60	1	1	5	3	0,45		0,54
INDUSTRIAL USES	Leather	3	1	0,44	1	5	0,53	3	1	3	5	0,53		0,50
	Fish oil	5	5	1,00	5	5	1,00	1	5	5	1	0,72		0,90
	Minerals: Calcium, CaCO3	5	1	0,67	3	5	0,77	1	3	3	0	0,45		0,63
	Chitin / Chitosan	3	1	0,44	1	5	0,53	5	3	3	1	0,76		0,59
ENERGY	Biogas	5	1	0,67	1	3	0,37	1	3	3	1	0,47		0,48
AGRONOMIC USES	Compost	5	1	0,67	3	3	0,60	1	3	5	1	0,57		0,61
	Fertilizers	5	0	0,59	3	5	0,49	1	3	5	1	0,57		0,55

5 Discussion and conclusion

This report provides an overview of the Norwegian fisheries industry, its current use of RRM and identifies potential alternatives for utilization of RRM. The starting point for the assessment was a raw material base of 3.55 million tons live weight of which 964,000 tons are considered RRM in 2019. In Norway, RRM are generally considered an important and valuable biomass, and most of it is utilized (84%). Nevertheless, there is room for improvement, especially in the whitefish sector.

The whitefish sector has approximately 300,000 tons of available RRM with 61% utilized. The seagoing fleet has 104,000 tons of available RRM but utilizes only 24%. The main available RRM from whitefish include heads (36%), viscera (18%), liver (16%) and backbones and cut-offs (18%). The fleet mainly consists of large freezer trawlers and/or combined fresh/frozen processing vessels. Fishing whitefish largely takes place during January and April, when it is easiest, with large quantities of available RRM coming onboard. Limited storage space or freezing capacity on these vessels are some of the reasons why most of the available RRM is discarded from the sea-going fleet. In recent years there have been considerable investments in technological solutions to handle and preserve the RRM which has resulted in an increase of utilization from around 10% up to 24%. 'Classical processes' such as fish silage and fishmeal and oil production dominate the processing of RRM in 2019 with 65% of the utilized RRM. Processing of RRM into silage is by far the largest with 44% of the utilized RRM in 2019. Since the fishing takes place in a short period with large quantities of raw material coming in between January and April, strong technological investments that can process or preserve high quantities of raw material are needed.

This document presents different alternatives for utilizing RRM, which are listed up with links to available fact sheets for each process (chapter 2.4). Cost-benefit analysis was done for the most suitable onboard solutions such as collection of livers, fishmeal and fish oil production and fish liver canning along with on land hydrolysis of cod heads. Each case has its strengths, weaknesses, opportunities and threats. Most onboard solutions require heavy equipment which has high investment and production costs but could increase both the revenue and utilization rate. Collection of livers is not feasible onboard these large vessels in the sea-going fleet since they need to frozen which can lead to damaged livers or cross contamination however production of fish oil onboard shows great promise. Onboard canning of livers can add value to the product and increase profit substantially however it has less impact on the utilization rate since livers are only 16% of the available RRM from this fleet and with even less storage space for other RRM would then mean more heads would probably be discarded. Onboard fishmeal and fish oil production requires major investment in technology, and the production cost is significant, but the returns can be well worth it, with annual return of investment between 17% and 22% as well as being able to process all RRM. However, if all the RRM is processed into meal and oil then higher value alternatives cannot be obtained such as collagen from fish skins or tongue, cheeks and eyes from heads which make excellent salted/frozen products with strong markets in S-Europe.

Comparison with the Icelandic fisheries industry was made regarding utilization of RRM. Norway and Iceland have similar utilization in the pelagic and aquaculture sectors however, they have taken different paths in utilizing their cod resources. The three main cod export products from Norway in 2019 were dried clipfish (28.9%), frozen whole (21.8%) and fresh whole (15.2%) while the main cod exports from Iceland were fresh portions (24.1 %), fresh fillets (15.5%) and frozen fillets and salted splitted with equal amount (11.6%) (Sea Data Center, 2020). This suggests that the Icelandic sector is more diverse and more orientated to added value domestic processing. The value chain for Icelandic fisheries is based on integration of fishing, processing and marketing. This ensures maximizing quality and value of products all year round to meet customers' demands. This way has the positive effect of providing job security for the whole year in Iceland with emphasis on profit for the whole economy of Iceland. In Norway there is more emphasis on keeping fishing and processing separate where the cod is caught when it is the easiest, this results in higher quantity for the period between January and April and processing is limited with most of the catch being exported headed and gutted whole, either fresh or frozen. It should be noted that the fisheries industry of Iceland is responsible for more than 40% of the total exports from Iceland while in Norway it is closer to 10%.

There are three regions in Norway (*Troms and Finnmark, Møre and Romsdal and Nordland*) that have approximately 93% of the total landed catch of whitefish and therefore most of the available RRM which has the greatest potential for value added processing. Technological investment in those regions could increase the value of the catch, utilization and create jobs. The fishing must be linked with the processes since the raw material must be preserved in such a way that the product meets with the regulations listed in chapter 2.4. For these large vessels in the sea-going fleet, freezing is most likely necessary if the material is to be processed on land later. The large vessels in the sea-going fleet bring to land high amounts of HG whole fish, either fresh or frozen. If the HG fish would be processed further on land then the RRM would have to be preserved by freezing, producing silage or processed into fishmeal and oil and then the RRM resulting from on land fillet production could easily be processed further, as has been done since most of the catch that is landed in Norway is utilized. Today it is mainly looked at fresh raw material for enzymatic hydrolysis of cod heads from the coastal fleet, however, a few R&D projects are looking at the potential for utilization of frozen cod heads. Frozen heads will probably demand more energy which increases the production cost, but at the same contribute to an even stronger availability of raw material.

The second deliverable in WP1 will focus in more detail on supply chain process mapping and improved logistics where information and physical flows linked to transportation of RRM for small and large companies in the whitefish SCN in Norway will be analysed to identify key logistic nodes (e.g. landing sites, processing facilities) and transportation routes.

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Appendix

Comparison on Norwegian and Icelandic cod export values

Sea Data Center (SDC) explored the topic of whether Icelandic or Norwegian producers are creating more value from cod resources. The topic is quite extensive but nevertheless an interesting one. As previously mentioned, Iceland and Norway have taken different paths in utilizing their cod resources.

For example, the comparison of Norwegian and Icelandic cod export products in 2019 is shown in figure 26. As can be seen in the figure the three main export products from Norway were dried clipfish (28.9%), frozen whole (21.8%) and fresh whole (15.2%) while the three main export products from Iceland were fresh portions (24.1%), fresh fillets (15.5%) and frozen fillets and salted splitted with equal amount (11.6%).

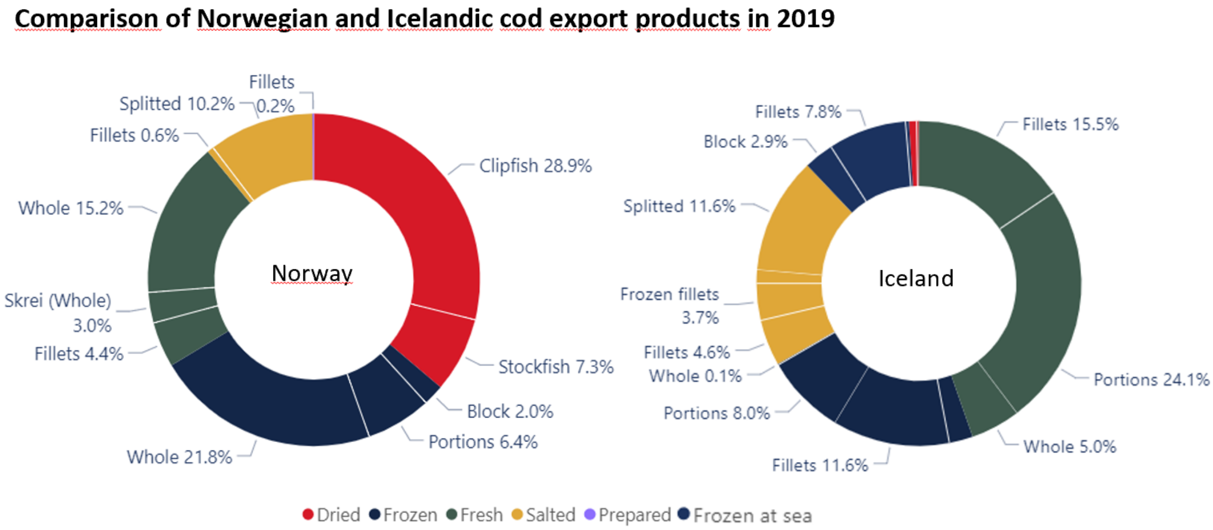

Figure 26: Comparison of export products between Norway and Iceland by Sea Data Center

The most important export product from Norway the first 7 months of 2020 was frozen whole cod, followed by dried clipfish and fresh whole cod. In the same period the three most important export products from Iceland were fresh portions, frozen fillets and frozen portions. The three largest products sum up to 61% of total export value for Norway while the three largest products were roughly 40% of the total Icelandic export value, showing a more diverse production in Iceland. For this period the total export value was 564 million EUR for Iceland, similar to the same period last year but 12% more than the average of last three years. The total export value for Norway was 651 million EUR, which is 10% less than for the same period last year and 9% less than the average of last three years. There is only a difference of 15% between Iceland and Norway in total export value for this period. The total volume exported for the first 7 months of this year from Iceland was 92 thousand tons and 138 thousand tons from Norway, which is approximately 50% higher. Export value per thousand-ton product from Iceland was 6.13 million EUR while the export value per thousand tons from Norway was 4.72 million EUR. The case is however not as clear cut since official live-weight coefficients are debatable and comparing them between countries can cause misunderstandings as a larger product portfolio will increase the discrepancies in the calculations. For example, with live-weight equivalent of exports, which essentially means the amount of resource that is behind the exports, for Iceland is

262 thousand tons in the first 7 months of this year and the same number for Norway is 271 thousand tons. The average export price per live-weight kg would then be 2.15 EUR/kg for Iceland and 2.40 EUR/kg for Norway.

Another method SDC used was comparing total volume landed and total export value. In 2019 the total landed volume in Norway of whole-round weight cod was 436 thousand tons while landings in Iceland were 284 thousand tons. Total exported value of cod products was 1,057 million EUR for Norway while export value for Iceland was 857 million EUR in the same period which suggest Norway getting on average 2.43 EUR/kg for each landed unit while Iceland gets 3.02 EUR/kg.

Comparing the total landings and export value is not a perfect way to answer the question whether Iceland or Norway is getting more value out of each catch. There is a time lag between catching period and export period which differs between production methods and which affects these numbers, landings differ between years, and there are other issues that have to be taken into account such as landings from foreign vessels and exports of by-products utilized from the production both domestically and for exports.

Figure 27 shows the export quantity and value of cod by the most common processing categories for the year 2019. The differences can clearly be seen in the figure where Iceland focuses on domestic processing and exporting of products while Norway exports whole headed cod to other countries for processing such as China.

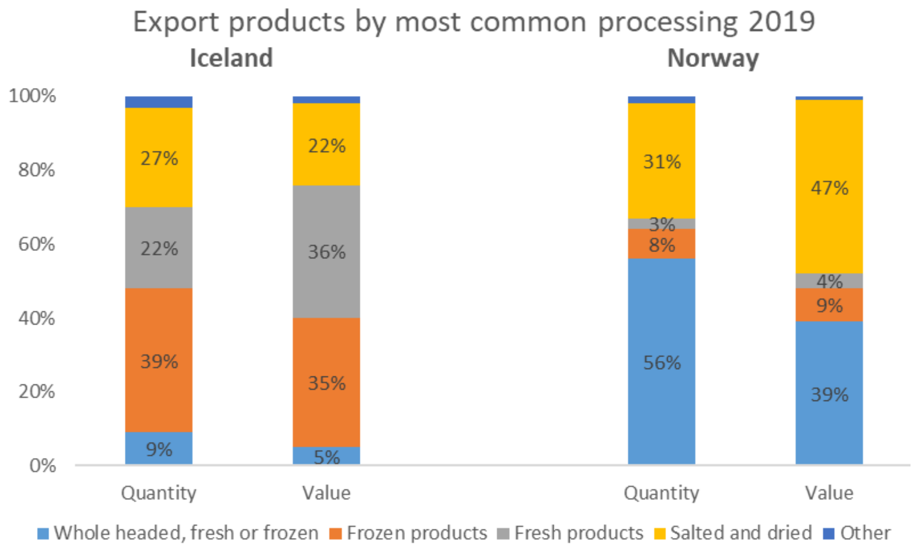

Figure 27: Comparison of exported cod products from Iceland and Norway

In Norway fishing takes place when it’s easiest to catch cod which results in high volumes of cod landed between January and April which makes it difficult to process it all. Fishing in Iceland however, takes place all year round with continuous processing.

Figure 28 shows the quantity and value of exported cod products from Iceland for the past 5 years based on data from Hagstofan and Seðlabanki Íslands. Calculations were made by Samtök fyrirtækja í sjávarútvegi (SFS) using fixed average rate of 2019. In the past 5 years the value per kg cod product has increased from 750 ISK/kg to almost 900 ISK/kg while the quantity has been relatively stable.

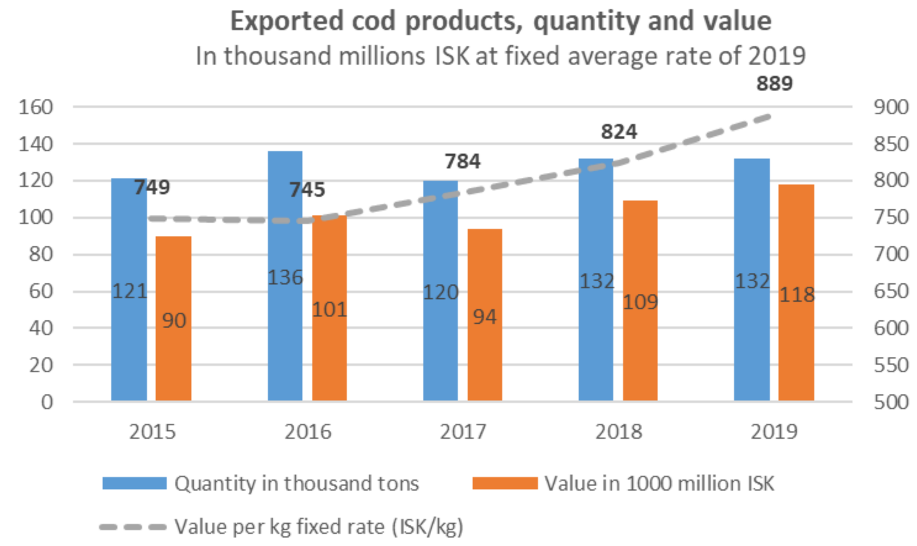

Figure 28: Development of export value and volume of cod products

One cannot assume from the above data that the Icelandic fishing industry returns more profit since complex value chains are of great importance. Iceland has a more emphasis on domestic value than Norway and processes higher proportions of raw material themselves while competitors of the Icelandic fishing industry use cheaper work force abroad for processing. Also, it should be noted that there is a significant difference in the importance of the fisheries sector economically in Iceland and Norway. Total export of seafood products from Norway was approximately 10-11% in 2019 while for Iceland it represents up to 45%. It is obvious that neither Iceland nor Norway can compete with the low-wage market in terms of wages and therefore technologicalization of fish processing in Iceland is probably one of the few ways to ensure continued processing in Iceland. The technology investment provides a simpler way to meet diverse demands and increased quality but requires considerable investment in equipment as mentioned in the following case studies.