# Roadmap for the value chain of cod, salmon and char

*Cooperation between Matís- Iceland and*

*The Ministry of Economic Affairs and Employment of Finland*

**The objective** of this work is to discuss Iceland's fishing and fish farming industries and approach the challenges there are and report on what has been done to meet those challenges. The main focus of this work will be on creating roadmaps for the supply chain of cod and the supply chain of salmon and arctic char and identify the obstacles these industries have faced. From fishing/farming to the consumer. This roadmap will show how and where increased value can be made using real examples from Iceland, shed light on critical factors affecting the quality and highlight the obstacles hindering further growth and development.

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# Abbreviations

PUFA: Polyunsaturated fatty acids

RDC: research and development community

RM: Raw material

RRM: Rest raw material

# 1. The motivation and background for the roadmap: Current status of the Icelandic fish and aquaculture industry and the obstacles in its transition

The motivation for this roadmap is to summarise the current status of the cod and aquaculture industry and go through the value chain to report on what is important and point out challenges and obstacles that the industries may be facing. Cod is the best-known whitefish species in Iceland and has been the main base for the Icelandic fish industry for decades. It is a developed industry that has undergone changes and development. While the aquaculture industry is younger and still not fully developed and may be facing similar difficulties as the cod industry once did.

These industries are very important export industries that have a huge effect on the economy in Iceland, both the GDP and employment. These industries also support other industries, companies, small sectors and communities all around Iceland. The development of these industries and the value created by them and other servicing companies are very important for the nation. The research and development community (RDC) needs to be up to date on the current needs of the industries and be able to support on the matters that are important each time. This work is intended to support the RDC and to help them understand the needs for further research planning and policymaking.

The Icelandic cod industry has managed to increase utilization of both the whole fish and rest raw materials (RRM) that fall by during the processing. It took the industry some time to fully develop into this, but with more automation, throughput increased, and the production cost was lowered. The industry focused on fresh products and increased tourism gave access to frequent flight to valuable markets for fresh cod. The landscape is however always changing and competition against other countries gets stronger year by year as the quality of fish products goes up worldwide.

The aquaculture industry is rapidly expanding in Iceland and has become one of the big export industries. The salmon industry stands behind the largest part of the production and is likely to further grow in the future. The industry has faced some difficulties relating the farming, such as cold sea temperature during the winter months which affect growth, health, disease outbreaks and mortality. The industry perhaps needs some time to develop further, but according to data from the statistic of Iceland 2018, minimum processing is carried out in Iceland and the fish is mostly exported whole, with head and tail. One of the reasons for this might be the country's position, long transport time and tradition for processing salmon post rigour Mortis.

# 2. The value chain of cod

There is a long tradition for fishing cod in Iceland and it has been the main base for the Icelandic fish industry for decades. The stock size has fluctuated in the past due to overfishing and biological and environmental factors. The cod around Iceland spends most of its time on the depth between 50-200 meters. However, they can go as far down as 500 meters. Cod is considered a demersal species but is however known to chase food far up and spend time close to the surface. In the north Atlantic few strains of cod can be found such as the Greenland cod, Newfoundland cod, Icelandic cod and other smaller strains. The Icelandic cod spawns during the late winter months and until mid-summer depending on location. Most of the cod is caught in the period between January and May (Muus, 1968).

**FIGURE 1 ATLANTIC COD (HLÍÐBERG, 2020)**


The fishing practices have changed considerably in the last decades and handling has gained increased importance amongst the industry. The fishermen are now much more aware of the importance of adequate bleeding and cooling of the fish and general handling. The processing of cod, especially on land, has changed towards more automation and computer-controlled operations. This has also led to a rise of large technology companies offering holistic processing solutions for fish processors. These companies have now expanded their operations abroad to salmon-, poultry- and meat processing. On board the fishing vessels, new production decks have been developed with adequate handling in mind and which has led to a rise of many companies offering technical solutions for the industry in Iceland and abroad. These are one of the sides effects of the closed cooperation between the R&D community, entrepreneurs and the fish industry.

## 2.1. Fishing: external and internal factors affecting fishing

**Challenges & Drivers**

**Challenges:**

- Worms and pesticides
- Weather conditions
- Preserving quality in difficult sea conditions
- Perform adequate bleeding and gutting
- Maintain hygiene
- Process the catch before it dies
- Limit stress and pressure in the trawl

**Drivers:**

- The knowledge is there in terms of how handling should be carried out
- The external and internal factors affecting quality are known and documented
- There is a desire among most companies to do better

- There is limited space on board for adequate handling
- Communicate the importance of good handling and point out what can be improved
- Take smaller hauls to reduce pressure on fish and promote better quality

## External

External and internal factors can greatly affect the quality and value of any fish product. Factors such as the location of the fishing ground, time of year, depth of catch, sea temperature, wind and weather conditions can all influence quality, value and production cost. These internal and external factors have been documented in Sveinn Margerisson PhD study in 2007 where he had a look at the interaction between quality factors such as filleting efficiency, worm count, colour, water holding capacity, drip, types of fillet produced, pH and water content in relation to these internal and external factors. His finding indicated that both internal and external factors greatly affect the quality of the fish and that these factors can be controlled and optimized to give off more value. He developed optimization software for the fisheries to optimize their operations. Direct links were found between the time the fish was caught, the age of the fish and muscle gaping. Link was also found between the fishing ground, the length of each fish and the number of worms found in the fish. More worms are found in certain fishing areas, but worms have a huge effect on processing efficiency, product value and the time it takes to process the catch.

## Internal

The fishing practices, the type of fishing gear, the towing time, the amount of fish in each haul, weather conditions and the type of landing and storing equipment can also greatly affect the quality. Essentially, fish is a very sensitive species and is easily damaged by stress and pressure. To explain that, most of the microorganisms and enzymes are found in the fish viscera and in the blood. When fish is under pressure and friction, bruises and wounds can easily form on the fish creating access for enzymes and microorganisms to areas where they are not found in the same numbers, such as in fillets which are relatively free of bacteria and microorganism. If the fishing practices do not take into consideration the pressure and stress the fish undergoes, these enzymes may have better access for breaking down the raw material (RM) which will eventually promote microbial growth and deterioration of quality. In this regard, it is important not to haul too large quantities at the same time onboard, hauling for too long or too fast to limit stress and prevent fish from getting as squashed at the net when hauling on board deck. Bad weather conditions and big waves can also affect the raw material due to more stress and pressure on the fish in the trawl. The waves hit the trawl pushing it up against the vessel crushing the fish inside. In practice, it's easier to preach these things than to follow them, since a lot of external unavoidable things can play in as well as increased cost and sometimes more work.

The type of vessel and the design can also affect the quality of the fish. Smaller vessels are not large enough to use trawls and mainly rely on lines with hooks or nets which are known to cause less stress on the fish compered to big trawls. These smaller vessels do not have access to fishing grounds that reach out to the open sea, due to their size, sailing capability and space for catch and people. These vessels need to rely on fishing grounds that are closer to shore which is often areas known for more worms in the fish. Smaller vessels deliver newer fish as they are often landing the catch within the same day it is caught. However, that does not mean that they deliver a better product since they often lack equipment for bleeding and cooling due to limited space onboard. The procedure on board is most often bleeding and gutting but, in some cases, when targeting cod for salt fish it is better to leave the fish un-gutted due to poor gutting procedure and lack of hygiene on board. When the fish is not gutted, all rest raw materials (RRM) are brought ashore relatively easily, attached to the fish. It is difficult to collect RRM such as the liver standing outside on the deck of a small vessel.

Groundfish trawlers have become more and more advanced in the past decade. Many older freezer trawlers also called processing trawlers were changed to target wet fish and land whole fish on ice rather than frozen. In the context of the large freezer trawlers, wet fish trawlers bring almost everything onshore while freezer trawlers are often forced to discard a large portion of the fish and the RRM due to limited space for storing these secondary material streams such as backbone, skin, head and more. However, bringing everything onshore creates more value for the fisheries operating wet fish vessels because fresh fish fillets and all the RM are more valuable than only frozen fillets. Wet fish vessels normally don't stay at sea longer than ten to seven days as they are dealing with fresh RM that needs to go to the filleting factory as soon as possible. Wet fish trawlers have a good sailing capability and they can reach fishing ground further than smaller vessels which makes it easier to avoid areas with worms.

The number of freezer trawlers has decreased in the past decade, many reasons can explain that such as high labour and fuel cost as these vessels are staying for up to a month on the sea and all the processing is powered by oil. The contracts to the fishermen are moreover connected to the value of the catch landed which is considerable when you have fillets ready in packaging, this makes the labour cost higher compared to other fleet segments and is one of the reasons for the reduction in these vessels according to the fisheries. There has not been a lot of investment in new freezer trawlers in Iceland in the past years, however, the new vessels that have been built have had built-in fishmeal factories to process RRM such as viscera, bones and more. These small factories produce fishmeal and fish oil which is stored in special storage chambers in the ship.

## 2.2. Handling in the fishing vessel

**<u>Challenges & Drivers</u>**

**Challenges:**

- Process the catch before it dies
- Let the fish bleed in seawater
- Pre-cool the catch down to -1°C
- Maintain cold temperatures in the storage hold
- Maintain hygiene
- Maintain quality of RM

**Drivers:**

- Better quality means higher revenue for the firm
- More utilisation of RM means higher revenue for the crewmembers and the firm
- Rules have been set and abolished to compel companies to land RM

All groundfish catches need to go through the same onboard handling to maximize quality and extend shelf life. Whether it is on board a small fishing vessel or big trawler. The main steps in the on-board handling of groundfish are bleeding, gutting, cleaning, chilling, grading, storing and ensuring adequate traceability. The following figure gives an example of Icelandic wet fish trawler and how the deck layout may look like. The numbers represent different components which should give a better overview of the processes onboard. This discussion covers the main principles in on-board handling of groundfish which can be applied to all demersal fleet categories.

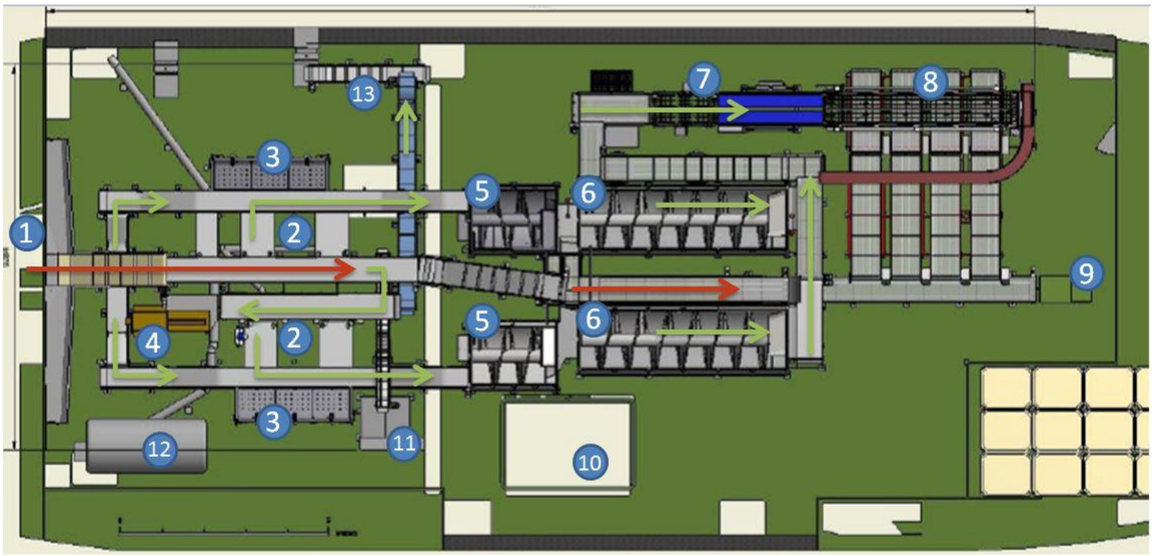


FIGURE 2 PROCESSING LAYOUT ONBOARD GROUNDFISH TRAWLER (1. RECEPTION UNIT - 2. BLEEDING/GUTTING/SORTING STATION -3. COLLECTION BOXES FOR BY-CATCHES – 4. GUTTING MACHINE - 5. BLEEDING IN FRESH SEAWATER - 6. PRE-COOLING IN RSW- 7. MEASURING & MONITORING - 8. SORTING – 9. HATCH DOWN TO HOLD – 10. ACCESS PANEL TO THE HOLD FOR LANDING THE CATCHES - 11. STORAGE FOR LIVER AND ROE – 12. RSW RESERVOIR TANK 13. DISCARD CHUTE.

## Bleeding and gutting

Bleeding and gutting are essential to rid the fish of contamination bacteria which reduce the quality of the RM (Aðalbjörnsson & Viðarsson, 2013). These bacteria start to grow at accelerated rates post rigour Mortis after death and especially where blood is and inside the viscera. Blood and viscera must be removed to slow the deterioration process of the fish muscles during storage and to get rid of the bacteria and parasites. The blood contains iron which can acts as an oxidation agent when exposed to oxygen and therefore it can have a severe impact on the quality of the fish fillets, most noticeably in colour and taste. The viscera contain enzymes, bacteria, microorganisms and parasites which are not wanted int contact with the muscles. There is an uncertainty whether it is best to carry the bleeding and gutting procedure all in the same step or if it is better to bleed first and gut later. The reason that it has become more common to bleed the whole catch first and gut later is that the crew can that way bleed the catch sooner. There is a need for technological solutions in this area which could help the crew to bleed and gut the whole catch faster than done today, especially on bigger vessels. Such solutions could give off higher quality as the catch is processed sooner and make the work on board much easier. For most lean whitefish species such as cod and hake, given adequate cooling and proper bleeding and gutting, the shelf life is sixteen days at most if everything is carried out well.

**FIGURE 3 GUTTING OF COD AT SEA (BALDURSSON, 2014)**

## Cleaning and washing

Washing should be done in seawater. Simply immersing the fish for a few seconds is not enough time for the blood to completely drain the blood. For best results, the heart should still be beating when the fish is bled, and the fish should be given time in the bleeding tank. The cut should be made in front of the heart and it is also good to rupture the dorsal vein as well. The blood pressure in fish is not high and the fish relies on movements for the blood to circulate through the body. It is, therefore, best if the fish is on movement during the bleeding process to help with blood removal with a constant inflow of seawater running through. Special bleeding tanks or conveyors are advised for these applications.

## Chilling

Chilling and maintaining of unbroken chill-chain are extremely important, as it is a deciding factor on the quality and shelf life of the catch. Cooling is generally either done with ice or slurry in boxes/tubs in the hold of the vessels; or with pre-chilling in purpose-build cooling tanks on the processing deck. It is vital that the chilling process does not take a too long time and ideally the muscle should be close to the initial freezing point of water from the time it enters storage in the hold. The cooling in pre-chilling tanks can take up to an hour should it be done sufficiently, depending on the size of the fish, throughput and cooling media. The temperature in fish that is only chilled with ice in the hold can take many hours to reach the desired 0°C depending on the quality of the icing. Amongst the risks associated with inefficient cooling is that if the catch is not chilled properly from the beginning, it will have the effects that the fish will go earlier and faster through rigour Mortis, which will result in muscle gaping and shortening of shelf life. The effects of fish going fast through rigour Mortis are intermuscular loosening and the fish becomes slimy and undesirable.

Fishermen need to understand the difference between cooling and maintaining cold temperatures. Maintaining cold temperatures of fresh-caught fish is carried out in the storage hold where ice is used to eliminate thermal fluctuations of the fish but should ideally not be used for specifically cooling the products. Vessels that use ice to cool down their products before storing are simply not cooling their fish as efficiently as possible. When fish at sea temperature enters a fishing tub or box full of ice, the ice starts to melt, leading to the fish being stored in water. Another factor to consider is that storage holds are not designed to cool products down but to maintain even temperatures. If these things are misunderstood, the temperature will rise in the storage hold. Research has shown that by pre-cooling products before going into temperature-controlled storage, their shelf life can be extended by 1-4 days (Martinsdóttir, et al., 2010).

FIGURE 4 COD STORED WITH ICE CUBES

## Grading

Grading the catch according to species and size is an important part of on-board handling. In many fisheries, it is a matter of legislation to keep species separate, but it is also important with regards to the processing to grade according to species and size. The correct species and sizes can then be transferred directly to the desired processing and production can be better planned. The grading is in most cases manual and can either be done by personnel on the processing deck during gutting or by the personnel in the hold during storing preparations. On-board larger vessels it is common to send only the target species directly to the hold and store by-catches in purpose-built boxes on the processing deck until all target catch from the haul has been handled.

## Storing

Most fisheries in Iceland, if not all, use large plastic fish tubs to store fish. In the past, the industry manly used smaller boxes but moved into big 660L fish tubs. Today the industry mainly relies on 340L tubs since they are smaller which puts less pressure on the fish. When big tubs are used, the fish that is at the bottom is under too much pressure, which creates bruises in the fish muscle and affects the texture. In addition, when ice is put on the fish and between, ice cubes are pressured into the fish. How the fish is arranged in the boxes or tubs is also important with regards to maintaining quality. Each fish should be arranged with the head facing the tub-wall and with the belly down. That will allow for fluids to drain out of the cavity and through the drainage holes on the bottom of the boxes/tubs. Adequate amounts of ice should also be placed between each layer of fish to cool down the fish and maintain temperature around 0°C.

## Labelling, registration, and traceability

Labelling, registration and ensuring basic traceability is an essential part of on-board handling. How that is handled differs depending on requirements and availability of equipment/technology. The most basic way of addressing that is to put stickers on each box with the species name, size and date of capture. This will allow for better-informed decision-making during production planning and selling of the catch. There are also numerous requirements for reporting of catches that depend on good traceability and registration.

## Handling of by-products and materials for non-human consumption

Most by-products and materials for non-human consumption need to go through similar steps as the main product materials. There are though exceptions, as for example liver, roes, milt, and other viscera, as well as materials that are classified as unsuitable for human consumption. These are to be kept separate from other catches to avoid cross-contamination. There are different alternatives for on-board handling of such materials, including chilling, freezing, fishmeal production, silage production and more.

Iceland is known for its full utilization of the RM but in some cases, it can prove difficult to keep and preserve these RM streams upon landing. In the case of vessels landing iced fish, they usually cut the fish. The guts are removed and the liver and in some cases milt and roe are separated. The rest of the guts usually go off-board, while the liver is stored in tubs. The liver is not chilled in some cases since it can cause worms that are often present on the outside of the liver to start going further into the liver to flee the cold and damage the liver and making it not fit for canning. This film and worms are later removed during processing. In other cases, the liver is placed in airtight plastic bags in a fish tub and ice put under and on top of the plastic bag. This gives the liver a maximum 5-day shelf life for canning for human consumption.

FIGURE 5 LIVER IS GATHERED ON BOARD AND PUT INTO PLASTIC BAGS IN A FISH TUB, WHICH THEN GOES TO THE BUYER (AKRABORG, 2020)

## 2.3. Processing

**Challenges & Drivers**

**Challenges:**

- Maintain cold temperatures throughout the processing
- Maintain hygiene
- Worm and defect detection and removal
- Traceability
- Follow the buyer requirements
- Decrease production cost and increase throughput
- Still room for more automation (bleeding & gutting, quality inspections, trimming, worm removal, feed-in procedures and more)

**Drivers:**

- Lower production cost and increased revenue and profit
- Reputation
- Relationship with customers

After the initial handling and landing of the fish, it goes through processing depending on what is being produced. The fish is filleted, the fillets are trimmed and cut into pieces. This section covers the most common processing and the development that has taken place.

## Filleting and trimming

In this part of the production hygiene and cold temperature is not of less importance. The temperature control should be maintained throughout the production and especially on the production line where it may have to wait due to bottlenecks. The temperature control on this stage is most difficult to deal with and may require advanced technical solutions to keep the fish/fillets cold on the line. If no measures are taken, the risk is that during the production, the RM may warm up. It may also warm up during coffee breaks or shift

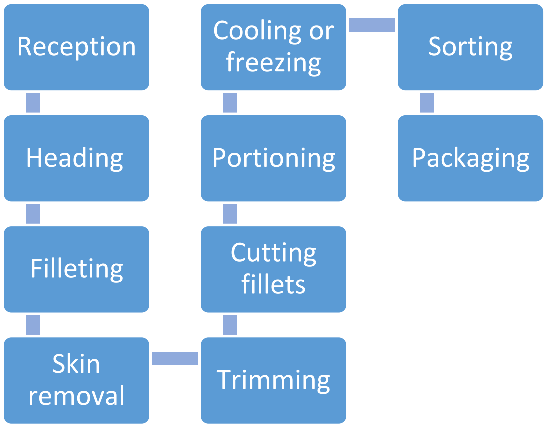


**FIGURE 6 STAGES IN ONLAND FISH PROCESSING FACILITY**

changes where the RM will have to wait on the line exposed to warm air and warm surfaces. Few alternatives are available, such as keeping the production room very cold or close to 0°C, have chilled conveyor belts, use slurry ice, or close the conveyor belt and blow refrigerated air over the product to name a few. It is very important to promote hygiene as the fillets are very open and sensitive to bacterial contamination.

From the reception, the fish is in most cases sent to a mechanical heading and filleting machines or it is done by hand Figure 6. The fillets are separated from the cod leaving whole fillets with skin, the head and the backbone. Straight after filleting comes to the skin removal machine which takes in the fillets and removes the skin. The fillets sometimes go into slurry ice baths between operations to maintain cold temperatures. When the skin has been removed the fillets need to be trimmed to remove bits that are not appealing such as bones, worms, blood spots or other defects. Bones cause trouble and can be harmful to consumers. Most fish products have a description that specifies whether it contains bones or not. If it says that no bones are in the product, that means that no bones should be found, not even the smallest peace for some quality standards. Worms and other parasites can be a big issue as well. If the consumer finds worm in the product it is unlikely, he will buy it again and it can have a huge effect on the reputation of the company or product. Worms are generally found inside the gut of the fish but can also go into muscles. This usually happens after the fish is caught where these worms travel from the guts and start moving into muscles. Worms are generally not harmful to the consumer unless it is consumed alive which is rarely the case after cooking and all the undergone processing. Worms are killed within a minute at 60°C, when salted, frozen or dried. However, other parasites can cause disease if they are consumed alive. Another aspect of the worm issue is that it becomes the bottleneck of the production and reduces the throughput and increases the time it takes to process each fish. This can easily be converted into increased labour cost and cost of production. The trimming operation often lacks mechanical solutions and its most often carried out by hand under light to detect these defects, which explains the decreased throughput and increased production cost.

## Cutting the fillets

The fillets can be cut into many different shapes and sizes from large fillets where very little is cut off to very specific neck or mid pieces. The buyer's preference determines what cuts are made and they choose what they want to buy. The production then plans the processing to fulfil its customer's needs.

### Whole fillets

When producing whole fillets, whether they are with or without bones and skin, the belly flap is almost always removed. This is done to cut away the peace where the original cut was taken during gutting.

The following figures show how whole fillets can be cut. E1-cut is a whole fillet where the lowest part of the belly flap is removed, while bones remain in the middle of the filet. E2-cut removes more of the belly flap while V-cut removes only the bone part of the fillet. J-cut removes both the bones and large part of the belly flap. As mentioned, the belly flap is removed in most cases, but Figure 11 shows how the belly flap can be cut in a few different ways.

FIGURE 7 (E1-CUT) LOWEST PART OF THE BELLY FLAP CUT OFF

FIGURE 8 (E2-CUT) LARGE PART OF THE BELLY FLAP CUT OFF

FIGURE 9 (V-CUT) ONLY BONES ARE REMOVED, HOWEVER, THE BELLY FLAP IS OFTEN REMOVED AS WELL (E1-CUT)

FIGURE 10 (J-CUT) BONES ARE REMOVED AND MOST IF NOT ALL THE BELLY FLAP

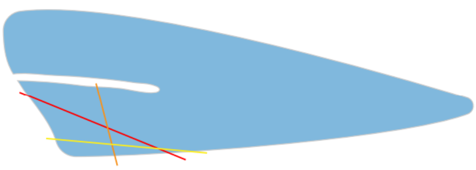

FIGURE 11 THE BELLY FLAP CAN BE CUT OFF IN MANY WAYS

### Portioning

When it comes to portioning the fillets into smaller pieces, the most common method is to start with fillets where bones and the belly flap have already been removed. Subsequently, it is attempted to obtain the most accurate cut of the neck which is the most valuable part of the fish. The customers very often have very precise demands of the size of these neckpieces. It is obvious that when the catch may vary in size it becomes challenging to deliver all these pieces in the same sizes and dimensions. Therefore, it's important to categorise the fish into different size categories upon arrival which facilitates work for those who are cutting and makes the production more uniform.

It has become more common to try to get the neckpiece if possible due to its high value. The following figures show how fillets can be cut into different pieces.

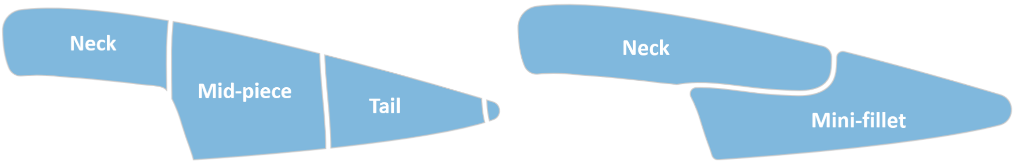


FIGURE 12 ON THE RIGHT, IS FILLET CUT INTO NECKPIECE, MIDPIECE AND TAILPIECE. ON LEFT, FILLET CUT INTO LONG NECKPIECE AND LONG MID-FILLET.

It is evident that a large amount of RRM fall by during these procedures and it's important to collect them and treat them as sensitive RM. When it comes to cut-offs, the most common method is to mince them in a special mincing machine which separates bones and minced muscle. The mince can, later, be utilised for a variety of products such as minced fish balls, surimi, dried fish products and more. On processing vessels, this RRM is often frozen onboard freezer trawlers and processed later.

## Technical development

A huge technical development has taken place in the last decades in Iceland. Strong technical companies that design and manufacture equipment for the fisheries industry have risen one by one and are now exporting knowledge and technological solutions and has created jobs for a variety of different expertise, from engineers, computer scientists to welders to name few. Some of these companies offer holistic solutions for fisheries from filleting-, trimming-, skin remover-, bone detectors machine and the advanced proportioning machine that can be used automatically detect fillets and make a cut accordingly taking in the customers' requirements, along with many other solutions. This new technology has transformed the way fish is processed and has reduced production cost and increased throughput.

The following Figure 13 shows an example of a semi-automatic fish processing facility. This specific facility has the flexibility to process different kinds of products from individually quick-frozen portions, fresh lions and packed fillets in block to be frozen. The fish is headed, and the fillets are removed from the backbone, the skin is then is most cases removed as well. The fillets go through the trimming station. After trimming, they go to through quality control inspection (QC) before going into FleXicut machine which cuts the fillets into portions with high-pressure water, the waste is used to make mince. The portions then either go to be sold fresh, quick-frozen or frozen into blocks. SensorX uses x-ray imaging to detect bones in fillets.

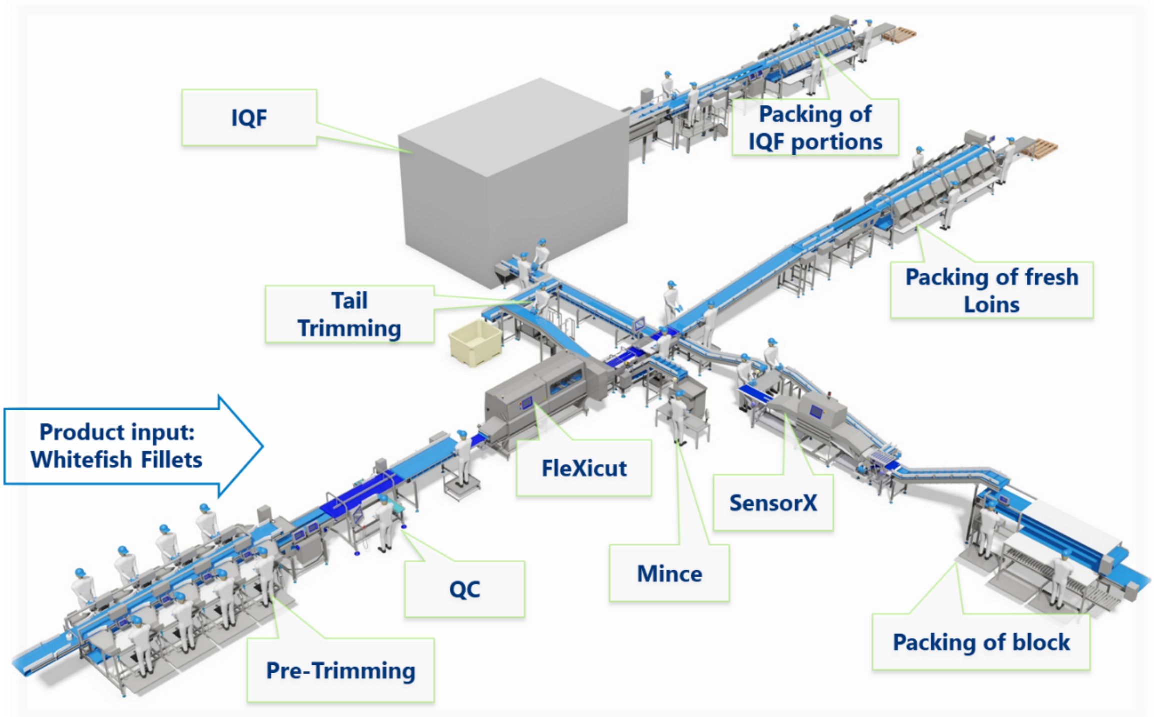


FIGURE 13 AUTOMATED WHITEFISH FILLET PROCESSING LINE FROM MAREL (ELÍASSON, 2016)

Producers are generally driven by the need for lower production cost and higher revenue. These systems promote to better quality products and increased utilisation efficiencies since these machines are much more accurate and efficient than the human hand. In comparison, the filleting, trimming and the portioning procedures used to require very skilled workers to get good products and still have high utilisation efficiencies, these procedures are now done by machines that use imaging technologies and even X-rays to make the best cut, this has also led to fewer defects. These previous jobs have now changed, and the workforce has moved to other stations in the production plant such as quality management which are not as demanding and difficult compared to the physical work that previously needed to be done. The jobs have also changed to become positions that require less expertise, for the companies this can reduce the effects of employee turnover since it is not as complicated to train new staff. The general feeling within the industry is that this development has not yet had a huge effect on the number of jobs, but rather that the jobs have changed. Facilities that have invested in such solutions have often kept the same number of people but increased the production throughput considerably. A producer that invest in these solutions is often in the position to be challenged to compete in the high-end market due to the high investment and ability to make good products. This has changed the mindset in many companies and made them more competitive.

**FIGURE 14 MAREL FLEXICUT MACHINE USES HIGH-PRESSURE WATER TO CUT FILLETS INTO PORTIONS OR REMOVE BONE AND BELLY FLAPS**

Despite this fast development and success in the past years, few challenges remain to be resolved in terms of technology. Many machines such as heading and gutting machines still rely on the human hand for feeding in the fish and this still applies to many other stations in these plants. For example, the trimming stations where worms and blood spots are detected and removed. Machinery for removing worms has not yet become commercially available. The quality control is also something that could become automatic but needs further development. Machinery for the onboard handling once the fish is caught such as automatic grading, bleeding, gutting equipment has not been fully developed. Machines are available for these procedures, but they require humans to feed into them. Gutting machines tend to damage the liver which is valuable RM, the machine does not consider the size of the fish and as a result, the neck part is often damaged, and hygiene is lacking and more. There is plenty of room for more research and development in this area to continue to improve the processes, reduce cost and increase revenue.

## Saltfish

There is a long history in Iceland for salted fish products, the production really caught on when trading in Iceland was made free in 1855 and it became easier to get salt. The fishing fleet got better, and the production grew to make saltfish products the biggest export product from Iceland. This changed around 1930 when sea transport with frozen fish became available. Iceland's still produces large volumes of salted fish products from cod to markets in European, in Spain, Portugal, Netherland and more.

Iceland has gone through a lot of technological development in the past decades to improve the quality of salted fish products. A key element in the salt fish process is to have the high-quality RM that has been handled and treated well. The fish must be properly bled and gutted because if not, the fillets can become red and undesirable. The salt itself is also important and that it is of good quality. The salt composition of the salt has a major influence on the changes that occur in the fish during processing such as deformation of proteins. Calcium (Ca) and magnesium (Mg) affect the colour, taste, texture and density of the fish. Calcium can improve the quality of the fish by making it whiter. However, if the concentration of these substances is too high, they have a negative effect, the surface of the fish can harden too much and even cause insufficient salting. Calcium and magnesium can also increase enzymatic activity in the muscle and have a negative effect on taste. Therefore, there have been certain limits to their levels in salt.

Yellow tints in salted fish are primarily due to oxidation. Metallic ions (copper, iron, etc.) and other contaminants can stimulate oxidation, these substances can enter the fish from the salt and/or from the processing equipment. It should also be kept in mind that poorly blooded fish contains a lot more iron which can lead to increased oxidation. For the Spanish market, which generally pays the highest price, it is a requirement that the fish is white with no yellow spots. Some additives are allowed in salted fish and can reduce oxidation and bind the metal ions, such as ascorbic acid, ascorbate, citric acid and citrates. Less oxidation means that the fish retains its original colour throughout the process and the final product becomes light coloured. When it comes to the use of phosphates, monophosphate and polyphosphate need to be distinguished, the former increases the water-binding while the latter function works as antioxidants. Phosphates are allowed today in specific concentrations. Their use has shown that the polyphosphates have a very positive effect on the colour of salted products showing less yellow colour due to less oxidation, these polyphosphates bind metal ions. However, monophosphates manly work as water-binding increasing the water holding capacity, which can cause problems for those wishing to dry the salt fish and make "old-fashioned" dried salt fish (Matís, 2012).

FIGURE 15 OXIDATION IN SALTED FILLETS

Saltfish production is divided into several different methods or processing stages. During the last decades, there has been considerable development in the processing of salted fish. Saltfish was earlier dry salted and the fish was re-folded several times before being spread outside to dry in the sun. Salting methods can have important effects on utilization and changes in the fish body. Later, pre-salting methods such as pickle salting, brining and injection salting were introduced.

FIGURE 16 DRY SALTING AND BRINE SALTING

Dry salting is when dry salt is distributed on the fish and between so that it is fully covered with salt. This is often done in containers with drainage, so the water can escape. Dry salting usually lasts for 12-14 days. When pickle salting, fish is put in a sealed container and liquid salt is spread on top of each layer as in dry salting but with no drainage in the container. The salt gradually draws water from the fish, thus forming saturated brine (26% salt). At the same time, salt enters the fish which causes certain changes in the fish in terms of texture, taste and smell. Nowadays it is common to inject the salt in the first step of the production and it has been found that the injection improves utilization considerably if properly applied. Salt immediately enters the thickest part of the fish and is a great advantage. Brine is either used alone as a salting method or as the next step after injection, as the brine is more closely submerged around fish. This method is most commonly practised today along with the injection of additives, Figure 17.

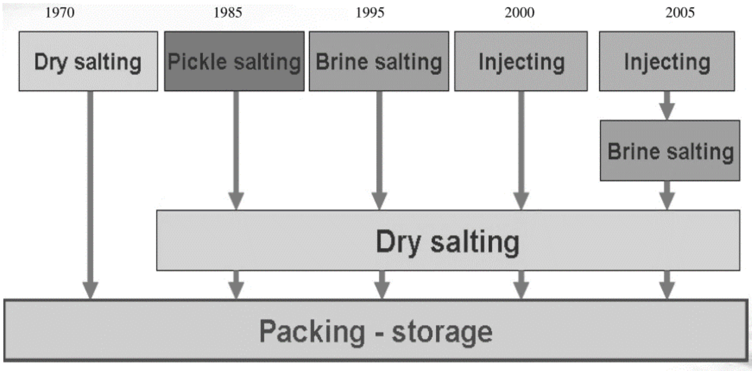


**FIGURE 17 HISTORIC DEVELOPMENT OF SALTING METHODS**

## 2.4. Transportation and quality

**Challenges & Drivers**

**Challenges:**

- Fresh fish products are very sensitive
- It is difficult to control temperature during transport
- Fresh fish products are not always pre-cooled before packaging
- Difficult to track temperature in real-time and identify mistakes during transport
- Transportation is a chain of many sectors
- Air transport is more expansive and more pollutant of greenhouse gashes
- Possible ban on single-use plastics (Styrofoam boxes)

**Drivers:**

- The need for higher quality is driven by the need for higher revenue and profit
- Temperature control affects the quality
- Packaging affects the quality
- Air transport allows newer products to markets
- Air transport allows newer products to markets
- Air transport creates an incentive to process in Iceland

### Temperature control

As in other parts of the value chain of cod is essential to emphasize temperature control, pre-cooling of the product and hygiene to promote better quality, shelf life and increased value. Before transportation, it is essential to pre-cool products before they are packaged. If the product is packed at warm temperature or a few degrees above zero it very unlikely that the product will go down to the optimal -1 to 1°C in the packaging through the transport. Also, if it goes warm into packaging on ice, the ice will melt right away rather than maintaining the temperature during transport, which is what it is intended for.

What determines the storage temperature is the water content of fresh fish or fresh fillets. Ideally, it would be best to take the fish down below zero points to reduce the spoilage of the product. However, what happens when the temperature is reduced to low is that to a large portion of the fillet becomes frozen and large ice crystals start to form creating muscle gaping in the fillets, affecting its texture which makes them less appealing. The higher the water content, the more sensitive the fillets are to freezing temperatures, and the fattier they are they have less water and they can be cooled to lower temperatures without freezing. It is the percentage of water frozen in the fish which determines the storage temperature. For lean fish species, it is best to pre-cool the fillets down to about -1°C.

Studies conducted at Matís show the effects of cooling Figure 18. Styrofoam boxes were filled with 5kg of fillets, which were either chilled to -1°C and +1°C. After 10 hours at 15°C, the initial temperature had risen to 7°C in the boxes that were at +1°C in the beginning while the fillets that were chilled to -1°C had only risen to 0°C during the same period (Margeirsson, et al., 2010). The main reason for that is that more energy is stored in the ice that has formed at -1°C which takes longer to melt and warm up.

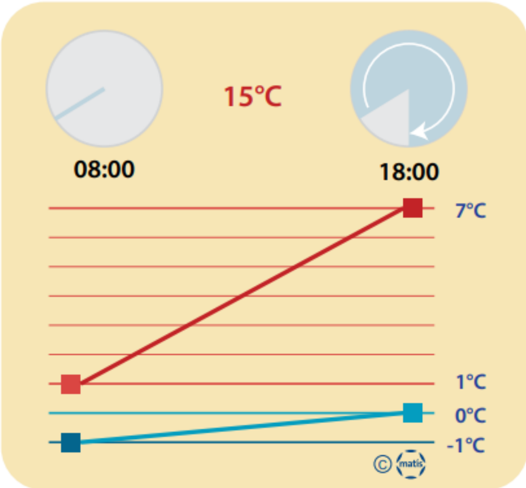


**FIGURE 18 STORAGE TEMPERATURE DEVELOPMENT IN PRECHILLED FILLET PRODUCTS VS NOT.**

Companies that are producing and exporting iced fish should be aware of the importance of stable temperature control through the supply chain. They should do regular tests where they send temperature loggers through transport to measure the ambient and initial temperature through transport. This will make sure that everyone involved in transport is doing the right thing and to guide them to do better. One mistake during transport can have a huge effect on the end quality. Companies should try to get a direct flight to avoid the risk of heating due to stops and plan the transport all the way to the destination.

## Packaging

The packing of the product it is kept in during transport greatly affects the temperature fluctuation of the product, especially in a warm environment. However, no matter how well insulated this packing is, if the fillets are not pre-chilled, they will most likely not do any good. In Iceland, cod products are mostly exported in styrofoam boxes with rounded corners to promote better insulation and big insulated fish tubs. The styrofoam boxes are mostly used for fillets while the fish tubs are often used for whole gutted fish that is exported to Europe for further processing. The styrofoam boxes are very good and affordable insulators, however, with more countries putting more restrictions on single-use plastics, these boxes may not be a good option.

FIGURE 19 STYROFOAM BOX FROM TEMPRA AND INSULATED FISH TUB WITH INSULATED LID FROM SÆPLAST

Frozen fish products do not need the same insulation since they should be transported in a cold environment such as reefer at -20°C. Frozen products are commonly packed in plastic bags and in waxed cardboard boxes.

### Air transport

A large portion of fresh fillets is exported by air. Tourism in Iceland has increased in the last years and flights between markets and Iceland as well, this has created opportunities for the fish processors to send fresh and new fish products all day of the week to markets. This is especially done for the more valuable parts such as neck peace and allows these products into markets much sooner than having to send it by sea. What this also creates, is an incentive to process the fish in Iceland. If the fish would be sent whole to Europe to be processed as sometimes is done and especially in the past, the final products would arrive in the markets much later. This contributes to more value creation in Iceland and increases employment.

### Sea transport

Sea transport has for a long time been the major line for Icelandic seafood products to their markets. Fishing vessels used to land their products abroad in the past. Nowadays most of the fish sent by sea is frozen products in a reefer and fresh whole fish stored on ice to be processed in Europe and some amount fillets and portions.

## 2.5. By-products

**Challenges & Drivers**

**Challenges:**

- The quality of the RM can be a limiting factor
- Independent companies utilising RM may experience an insecure flow of RM
- Many companies must rely on large volumes of RM to make a profit and keep production cost low due to general low prices of some products.

**Drivers:**

- Getting rid of RM in landfill costs money
- Energy such as hot water and steam can be very cheap in some areas in Iceland
- The value in RM is becoming more clear

- It is expensive to produce, develop and market high-end products and may require high investment cost

## Most popular products produced in Iceland

Regarding the current utilisation of RRM, the focus in Iceland has been more and more towards full utilization of all RRM's and production of valuable products for human consumption and biotechnical products. Despite this increased interest, the majority of all RRM is utilized into traditional products that have been produced over a longer time. Such as frozen block of trimmings or other cut-offs utilized for both feed and food, lightly salted products, dried cod heads and backbone for African markets, fishmeal and oil, silage making and canning of liver, milt and roe.

Today the production of innovative products for human consumption and high-value biotechnical ones is to a large extent limited to RRM from cod. An example of that are leather made from fish skins, pharmaceuticals and cosmetics made from bioactive compounds extracted from different parts of the cod (and other fish species), collagen made from fish skin, supplements and protein made from different by-products, mineral supplements made from fish bones, enzyme extracted from viscera, skin and tissue repair patches made from fish skin, extracts from RRMs made into powder or bouillon (i.e. for making soups and sauces), swim bladder and milt. Despite previous utilisation being mostly limited to cod products, the landscape is slowly changing towards utilisation of other fish species as the operators have started to realize the hidden value in RRMs. The RRM utilised into these innovative products, mentioned above, or bio-products, are still small part of the total RRM and many of the companies are still developing and investing in infrastructure. These biotechnical companies have not yet seen large profits margins but are never the less growing and returning small profits. It takes considerable time and work to market these products for foreign markets and building up a supply chain. The Icelandic market for these products is rather small so growth potential in Iceland is limited.

RRMs that are not readily applicable for added value production are commonly frozen for mink feed. It can be claimed that everything that is landed is utilized, there are however materials that are not landed, these are particularly viscera from fresh fish vessels and parts of the heads and frames from the processing vessels. This is though changing now, as vessels are being fitted with equipment that allows for better collection and storage of this RRM, new freezer trawlers are built with onboard fishmeal and fish oil factories to process RRM that fall by during processing. This development indicates that the utilisation of RRM may increase in Iceland, particularly on larger processing vessels. Smaller fishmeal plants have also been set-up around harbours in Iceland, they receive RRM from the aquaculture industry and from larger fish processing plants.. Silage production is another interesting alternative that can work well with fishmeal production. There is though some opposition amongst the fishing industry to try silage production, which is mostly contributed to some failed attempts in the '80s and '90s. The Icelandic company Lýsi exports roughly 10 thousand tons of wet silage annually from the fishing industry. The silage mostly consists of viscera and de-oiled liver from the largest oil processor Lýsi.ehf (Bjarnason, 2019).

With more utilisation of RRM, the industry has started to realise the hidden value in these secondary material streams which previously where thought to be waste and therefore often treated as such. Smaller companies that rely on RM from other companies are starting to experience more competition in the market place. For smaller companies and entrepreneurs that utilise these RRMs, the risk is always that bigger fisheries start seeing the profit they are making and start doing the same. This is especially sensitive when the production is as simple as freezing as the production heavily relies on access to RRMs.

## Drying

Dried heads and frames represent 27% of the total exports of cod products when converted into wet weight. Additional 3% are exported as dried whole fish, which is called stockfish. The heads and the frames have little meat on it and have traditionally been discarded or used for fishmeal in most fisheries, and the stockfish mainly consists of cod that is under the set size limits. Figure 20 shows these dried cod products.

**FIGURE 20: DRIED WHOLE FISH (STOCKFISH), DRIED FRAMES (BONES) AND DRIED FISH HEAD**

Heads and frames that are left after the processing of haddock, saithe, tusk and ling are also dried, but heads and frames from more fatty fish species like wolfish and redfish are not as applicable for drying. Utilizing heads and frames from fatty fish in an economically viable manner has therefore been a challenge that yet is to be solved. They are therefore usually either used for fishmeal or sold as bait.

Drying has traditionally been done outside on racks, but for the last few decades, the drying process has been moved inside; utilizing inexpensive energy, increased automation and better control over the entire production flow. Figure 21 shows the traditional drying method and the drying method most commonly used today in Iceland.

**FIGURE 21: TRADITIONAL WIND DRYING AND STATE OF ART INDOOR DRYING PLANT**

Fresh and frozen materials can be used alike for drying. All cod heads coming from land-based processing in Iceland are being dried and much of the frames and bones as well. A similar story can be told about most heads, frames and bones from land-based processing of other lean whitefish species. The same cannot be said about heads and frames derived from frozen-at-sea processing, as only a part of that RRMs are landed.

Handling of materials going to drying on-board the vessels needs to ensure that freshness is maintained. In most cases, the fish is landed fresh (whole with head-on), which means that all parts of the fish have been properly handled. The handling of heads coming from frozen-at-sea processing is trickier, as the most commonly used de-heading machines on-board the Icelandic fleet cuts the heads with the collar bone attached to the head and a part of the liver is then usually also attached. The liver parts that are attached to the head need to be removed before the heads are frozen, or the entire head will become spoiled because of rancidity.

Fish that are to be dried whole needs to be handled just like any other catch that is to be sold fresh or frozen. Fish that are below minimum conservation reference size need to be kept separate if the vessel owners want to count it 50% of the quota.

The main markets for dried whitefish products are in western Africa and particularly in Nigeria, where they are used for making soups. It is a big market that has been able to pay competitive prices for the products. In 2018 Icelandic producers exported 11 thousand tonnes of dried cod heads at an average price of 370 ISK/kg.

In Iceland, companies have had access to renewable energy sources such as warm water from geothermal power plants which are very affordable. This has, without doubt, help Iceland to build up this industry and made the production much more affordable compared to when using fuel or electricity.

### Liver, roe and milt

By-products made from cod liver, roe and milt have become increasingly 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. Figure 22 shows an example of premium products made from these RRMs.


**FIGURE 22: PREMIUM PRODUCTS MADE FROM COD LIVER, ROE AND MILT**

The on-board handling is of the utmost importance in order to be able to use the RRMs in these premium products. The liver does, for example, must be collected into plastic bags that can be sealed to minimise oxidation. The bags are then put on ice in plastic tubs and stored in the hold at the correct temperature. Roes and milt are not as vulnerable to oxidation but need to be properly chilled or frozen. Livers that are not of the right quality are used for making fish oils and roes and milt that are of lesser quality are exported in blocks, as shown in Figure 23.


**FIGURE 23: COD LIVER OIL AND BLOCK FROZEN ROES AND MILT**

The processing decks on most Icelandic vessels today are designed so that these by-products can be collected and stored properly. This includes a system of tubes on the processing board that collect the liver, roe and milt into the appropriate packaging.

There are healthy markets for all these products in Europe, as well as in other continents. Prices differ depending on quality, packaging, brands and markets.

Liver, roe and milt are only utilized from cod on a large scale. Liver from saithe is though used for making fish oil and livers from other species are sometimes mixed with the saithe liver.

### Trimmings, cut-offs and mince

Practically all trimmings and cut-offs from whitefish are utilized in the Icelandic fishery. Most of the trimmings and cut-offs are used to produce mince, which is then primarily sold block frozen and then used to produce fishcakes and fish balls. Some cut-offs are however utilized differently, for example, some processors salt the belly flap and sell them in niche markets in S-Europe. Figure 24 shows an example of these two products.

**FIGURE 24: BLOCK OF FROZEN MINCE AND SALTED BELLY FLAPS**

Products such as these are extremely vulnerable and need therefore to be handled properly. The RM is usually derived from processing on land. In the case of frozen-at-sea processing the trimmings, cut-offs and mince are block-frozen as soon as possible.

### Freezing the "non-marketable" RRMs

There are always some RRMs coming from processing that does not have much value and cannot be used for direct human consumption. In Icelandic processing companies, these materials consist mostly of viscera that comprise largely of stomachs and what they contain. Many of the processing companies that specialise in producing from the catches of the small day-boats, which land their catch un-gutted, sell the RM to be block frozen. It is then sold as feed to mink farms. The freezing equipment is very basic vertical plate freezers and the blocks do not even require any packaging, as shown in Figure 25.

FIGURE 25: VISCERA AND OTHER RRM BLOCK FROZEN AS ANIMAL FEED

This production is operating with a narrow margin, but it saves the costs of having to dispose of it. Much of the products are sold domestically, but there are also some volumes exported abroad to mink farms.

These RRMs are usually not processed on-board fishing vessels and have until now mostly been discarded out at sea, except when fish is landed un-gutted. It is mainly the small coastal vessels that land their catches daily that land un-gutted catches. Alternatives for making products from these materials on larger vessels would most likely involve silage production.

## Silage production

Silage production has been tried in Iceland but has not really caught on. The main reason is probably that almost all parts of the catches can be used to produce more profitable products. It is basically only the viscera that is discarded on the larger whitefish boats, and as discussed, the viscera of the whole un-gutted fish that is landed by the smaller day-boats is frozen for mink feed or smelted into fish meal. The larger vessels could potentially utilize viscera for silage production. This was tried in the ’80s and ’90s, but that experiment failed because of several reasons, such as lack of storage space on-board vessels, difficulties to sell the product and low-profit margins.

## Fishmeal production

RRMs can be used for fishmeal production and there are factory vessels in Iceland that have fishmeal factories on-board. There are however not really any unwanted catches in Icelandic waters, which means that RRMs are solely used for the fishmeal production i.e. heads, frames and bones. Fishmeal’s factories that are to be placed on fishing vessels requires a relatively large vessel, which means that this solution is only an application for relatively few vessels.

There is however a new solution available now, called Hedinn protein plant that is a bit more compact and not as energy intense. It still requires a relatively large vessel but might be applicable for more vessels than a whole fishmeal plant, the entire protein plant is shown in Figure 26.

FIGURE 26: HEDINN PROTEIN PLANT

## Alternatives

A vast variety of products can be produced from all the RRM that fall by. To simplify and get a better overview of most of the products, these products have been classified into six industrial categories. The first one is Food which represents products produced to make food products ready for the consumer. Bio-products are products that can be classified into many different subcategories such as cosmetics, pharmaceuticals, supplements, etcetera. However, these are products could also be looked at as more high-end and innovative bio-products. The feed category consists of feeds or ingredients into feeds. Products in this category could in some cases fit into other categories. Products under Industrial uses are products that cannot be consumed. Fuels are under the Energy category, and Agronomic uses fertilizers and compost.

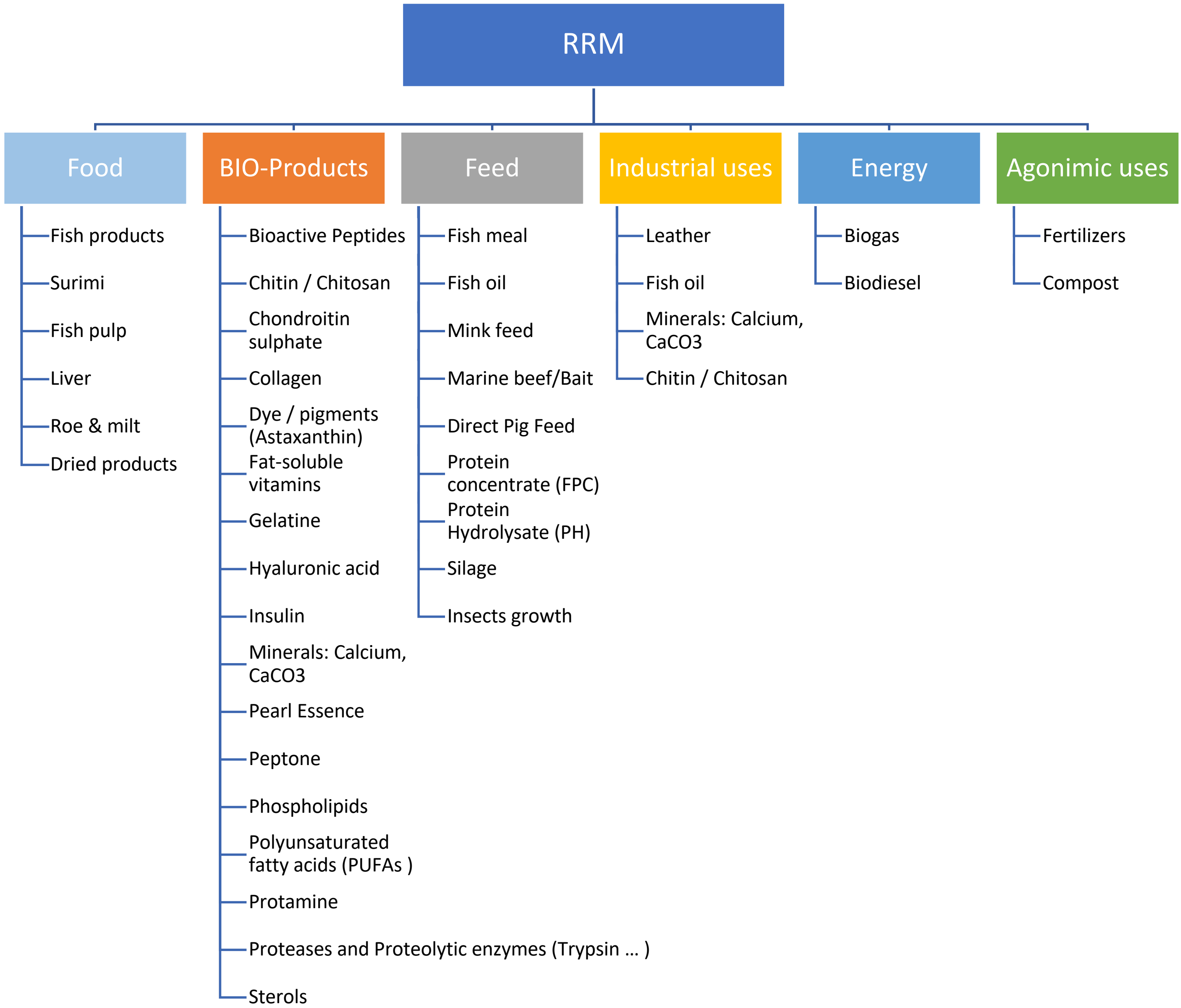


**FIGURE 27 ALTERNATIVE PROCESSING OF RRM FROM COD**

## Food

Minced fish products: Fish balls and burgers are known products. They consist of minced fish often in mixture with wheat, potatoes or other ingredients. Minced fish products are easy to make and give reasonable revenue. Minced fish can be used for a variety of other products such as surimi and dried fish products to name few.

Liver, roe & milt: Canned products made from cod liver, roe and milt have become increasingly 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.


**Figure 28: Liver, roe and milt**

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 boiled to make soup. Heads, frames cut-offs that are left after the processing of haddock, saithe, tusk and ling are also suitable, but heads and frames from more fatty fish species like wolfish and redfish are not as applicable for drying.

## BIO – Products

Fishes contain many biomolecules of high value that can be used in food, pharmaceuticals and cosmetics, as well as in the feed industry (pet-food, aquaculture and cattle).

Bioactive Peptides: come from the extensive hydrolysis of fish protein and contains mainly free amino acids di-, tri- and oligopeptides. These are peptides presents biological activities that make them valuable for pharmaceuticals, cosmetics, food- and feed products. Figure 29 shows peptide powder mate out of collagen from cod skin.

**Figure 29: Peptides made from cod skin collagen and gelatine from cod skin**

Polyunsaturated fatty acids (PUFAs): come from the purification of fish oil, obtained from viscera or from fatty fishes, and are fats with more than one unsaturation (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 a large proportion of digestive enzymes including collagenases, trypsin, pepsin, chymotrypsin, elastase, and carboxypeptidase. Proteolytic enzymes from fish catalyse the degradation of peptide bonds of proteins. They have a 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. Vitamins are classified as either fat-soluble (vitamins A, D, E and K) or water-soluble (vitamins B and C), a difference that determines how each vitamin acts within the body. Fish liver oil is rich in vitamins A and D that are used in pharma, 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 as a mineral supplement 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 a pigment in aquaculture, in fish and crustaceans feeding.

Collagen: is obtained by acid or basic treatment of spines, scales and skin. The amino acid content of collagen differs from other proteins because of their high content of proline and hydroxyproline. Collagen is widely used in pharmaceuticals, cosmetics and as a food supplement. Figure 30 shows some of the products made from collagen in Iceland.


**FIGURE 30: COLLAGEN IS USED AS AN INGREDIENT IN A VARIETY OF PRODUCTS AND IS PARTICULARLY POPULAR IN FOOD SUPPLEMENTS, PHARMACEUTICALS AND COSMETICS**

Gelatine: is obtained from the irreversible hydrolysis of the collagen. There are two main types of gelatines, Type A obtained from the acid hydrolysis procedure and Type B obtained from the alkaline hydrolysis procedure. Gelatines is used as a gelling agent in pharmaceuticals, cosmetics and food. Fish gelatines are preferred for low-temperature gelling needs. The world market for gelatine is extremely large, as it is used in a large variety of products, ranging from puddings to gummy bears; and face masks to capsules around pharmaceuticals, as shown in Figure 31.

**FIGURE 31: EXAMPLE OF PRODUCTS THAT CONTAIN GELATINE**

Most of the gelatine produced in the world are made from terrestrial animals, but with increasing numbers of consumers that do not want to eat farmed animals the market for fish, gelatine is becoming stronger. There are also large portions of consumers that do not want gelatine made from pigs (for religious reasons) or horses (for ethical reasons).

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 32.


FIGURE 32: EXAMPLE OF THE PRODUCTS PRIMES 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.

FIGURE 33 FISH PROTEIN HYDROLYSATE (FPH) POWDER

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 growth of insect over a fish substrate. Insect meal can be used for animal feed.

## Industrial uses

When previous options are not available, or due to legal constraints or quality of the RM or of the products, other technical uses may be considered, 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 shoes. It can also be used for a much larger variety of crafts.

Low-quality Fish oil: obtained in the fish meal production process can be used as a 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, ...) and can be used as a 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 a filtering agent in water treatment.

### Energy

Biogas: is produced through the anaerobic digestion 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 an 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 anaerobic decomposition process carried out by the own microorganisms of the organic matter. Compost from fish usually consists of fish waste, sawdust, 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.

## 2.6. Final products

**Challenges & Drivers**

**Challenges:**

- Increase production and value creation in Iceland
- Sustainability of fresh fish products from Iceland (Air transport)
- Increased competition on markets for frozen fish products
- Adjust to constantly changing market landscape

**Drivers:**

- Companies are driven by profit

Iceland produces a vast variety of different products from cod, ranging from fresh to frozen fillets, fillets with skin and bones or without, salted products for consumer and retail markets, dried or smoked products, coated and cured products and even ready meals to name some. In the early days, it was not uncommon to export large portions of the cod caught in Iceland whole for further processing in Europe. According to data from statistics of Iceland 2018, seen in Figure 34, based on customs clearance classes it can be seen that most cod is utilised and processed in Iceland. It is more difficult to determine whether these products are ready for the retail market or whether they need to be further packed and handled in Europe. The markets in Europe often rely on the date of packaging rather than the actual quality of the fish. This has the effect that some fish processors in Iceland rather choose to package the product into retail packaging in Europe rather than in Iceland to give the product a newer packing date and longer life on the markets. This applies to fresh fish products. This is believed to hinder further expansion of full processing and packaging in Iceland for retail markets in Europe.

The biggest cod export product in 2018 was “Land frozen interlaid or loose cod fillets “sometimes called individual quick frozen fillets with 16 thousand tons in 2018 and close to 20 billion ISK FOB. Nex biggest product is “Fresh skinless cod fillets in pieces” with almost 18 thousand tons and 11 billion ISK FOB. The third biggest export product is “Wet flat cod not in retail packaging“ or brined flat cod with 12 thousand tons and close to 11 billion ISK FOB. This is seen in Figure 34 which shows the export value FOB and the amount exported in 2018.

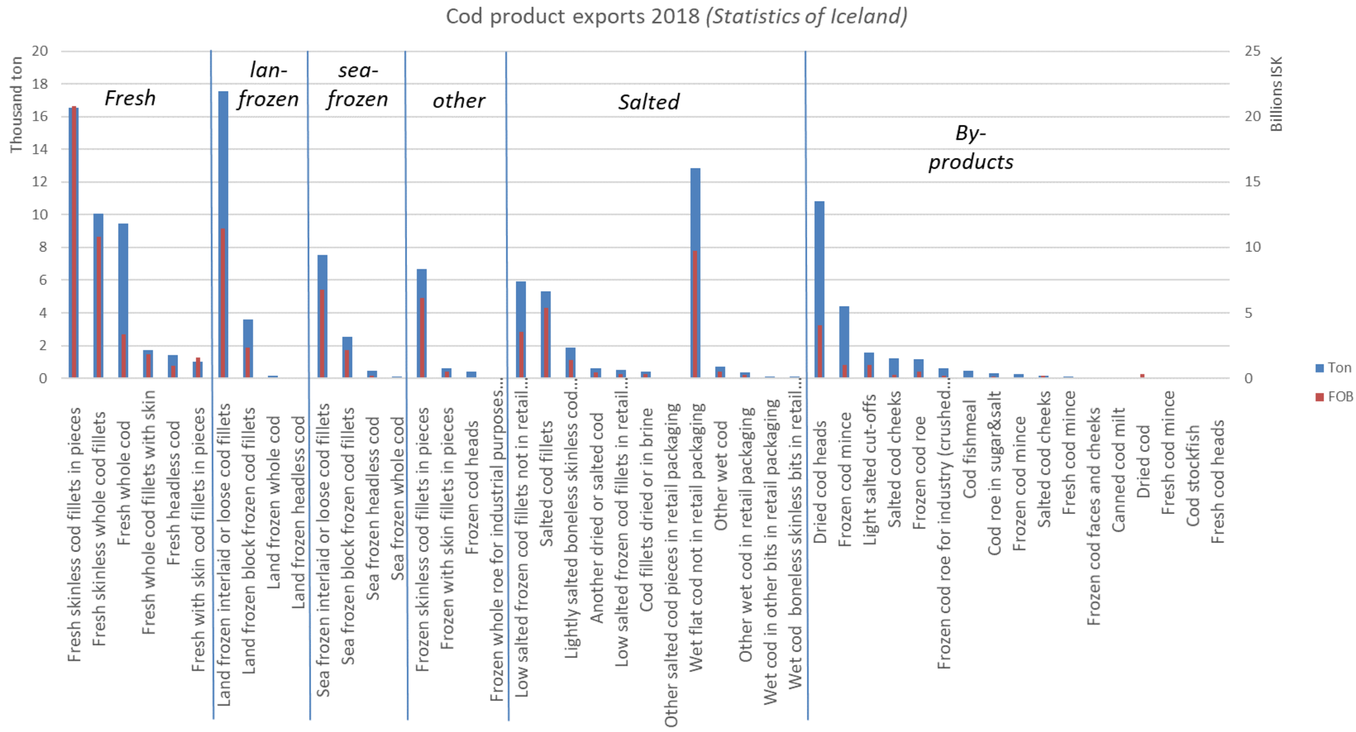


**FIGURE 34 COD PRODUCT EXPORT IN 2018. LEFT AXES SHOW THE VOLUME EXPORTED AND RIGHT AXES THE FOB EXPORT VALUE (STATISTIC ICELAND, 2020)**

While Figure 34 shows us the distribution of products exported, Figure 35 goes into more detail showing the export value per kg of product, indicating which products are the most valuable. The far most expensive products are “Dried cod” but with very little annual export. The second most expensive product is “Fresh with skin cod fillets in pieces“ with close to 1600 ISK FOB per kg. The third most valuable product is the “Fresh skinless cod fillets in pieces” 1260 ISK FOB per kg.

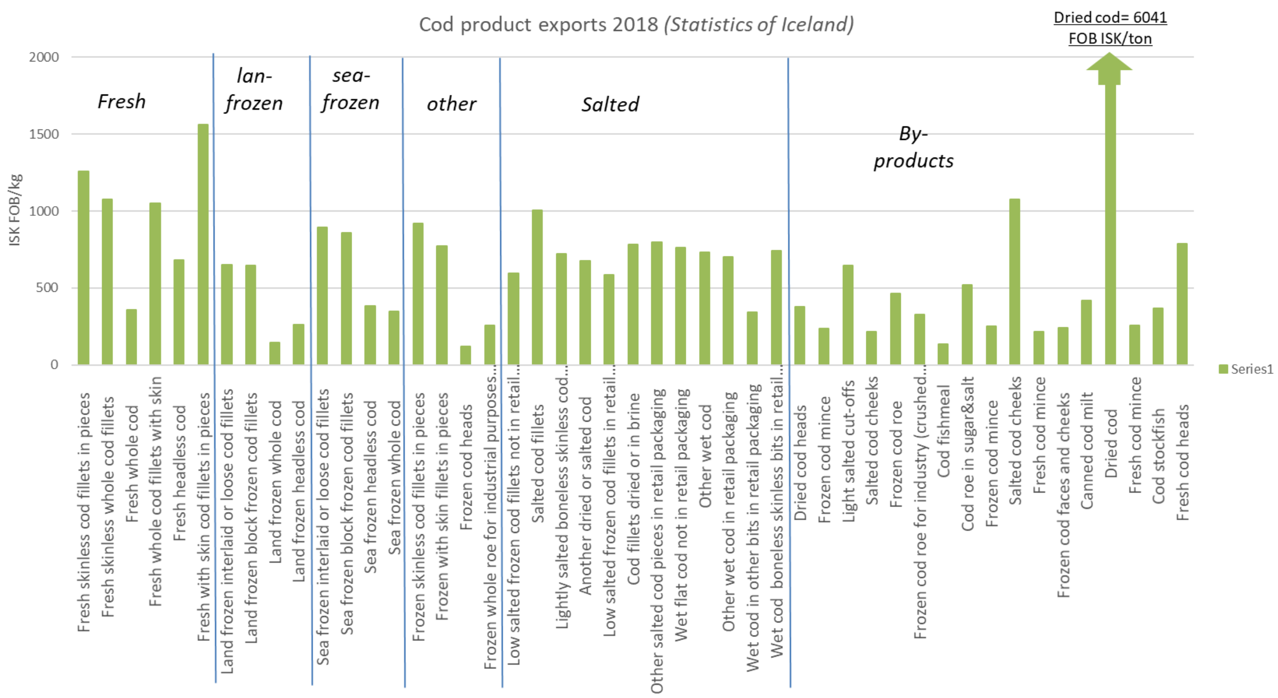


**FIGURE 35 COD PRODUCT EXPORT IN 2018, THE LEFT AXIS SHOWS THE EXPORT VALUE PER KG (FOB/KG) (STATISTIC ICELAND, 2020)**

The landscape on the markets is always changing and companies must be flexible and alert on the current status. Iceland has increased the production of fresh fish products in the past years and export by air transportation. This gave fisheries access to valuable markets and high revenue. As a result, many Icelandic companies got rid of their freezer trawlers for so-called wet fish trawlers to land fresh RM and make more value out of the fish. However, this landscape is constantly changing. Companies in Europe have increasingly started to de-freeze frozen fillets and package them as fresh which may reduce the need for fresh fish. Countries such as France are planning to ban the use of single-use plastics such as the styrofoam boxes used under fresh fish, this is due to environmental issues and sustainability of these packaging. This will make it difficult to deliver fresh fillet products from Iceland. Air transportation is also not the most sustainable, but the fisheries manly rely on passenger flights for their products, utilising space that would not necessarily be utilised. Also, air transportation with passenger flights can be insecure if flights are reduced due to external reasons. Other aquaculture whitefish species such as pangasius and tilapia are becoming more common in the markets and are competing with wild whitefish products. The complexity of the supply and -value chain is such that there is no one way to do things. Companies must be alert for what is happening in the marketplace.

## 2.7. Summary

The importance of, minimizing stress and pressure on fish, adequate handling, proper bleeding, gutting, washing and cooling cannot be emphasized too often. This is the key to producing good quality and valuable products and is controlled by those who fish the fish. Other factors are more difficult to control, but also affect the quality of the fish such as the location of the fishing ground, time of year, depth of catch, sea temperature, wind and weather conditions.

In the past, it was not uncommon to export a large portion of the cod caught whole to Europe for further processing. This development then took a turn when the number of freezer trawlers increased, they could process the fish pre-rigour Mortis onboard into products moving the processing facility out on the sea. However, in the last decade, production of fresh fillets and portions increased and is today the biggest export category Figure 40, moving the production on land. Export of fresh fish product relies to a large extent on air transportation and styrofoam insulated plastic boxes. The landscape is always changing but increased restriction on the use of single-use plastics and sustainability of the product might affect these products in the future.

Iceland is known for its emphasis on full utilisation of the RRM and production of valuable products for human consumption and biotechnical products. However, the majority of all RRM is utilized into fairly traditional products that have been produced over a longer time. Such as frozen block of trimmings or other cut-offs utilized for both feed and food, lightly salted products, dried cod heads and backbone for African markets, refined fish oil for humans, fishmeal and oil, silage and canned liver, milt and roe. There are however strong innovation and research companies growing year by year and are likely to expand further, but they won't necessarily require a large amount of RRMs but may have a considerable profit margin.

A huge technical development has taken place in the last decades and companies have risen that manufacture equipment for the fisheries industry and are now exporting knowledge and holistic technological solutions abroad, creating jobs for a variety of different expertise. This new technology has transformed the way fish is processed and has reduced production cost and increased throughput. Despite this fast development and success in the past years, there is plenty of room for more development and improvement. Few challenges remain to be resolved in terms of technology. Many machines and processes still rely on the human hand such as trimming stations, the quality control, onboard handling once the fish is caught such as automatic grading, bleeding, gutting equipment to name few.

# 3. The value chain of farmed salmon and Arctic char

Aquaculture in Iceland dates to the late 1800s when Icelanders began to transfer live freshwater fish into fishless lakes or streams. In 1884, salmon and trout hatchery first came into action, but aquaculture mainly involved hatching of salmonids and restocking of rivers. It wasn't until 1950 that the production of food-fish in aquaculture came into beginning in Iceland (Gunnarsson V. I., Staða bleikjueldis á Íslandi, samkeppnishæfni og stefnumótun rannsókna og þróunarstarfs, 2006).

In the mid-1980s, interest in salmon aquaculture grew rapidly and between 1984 and 1986 the number of aquaculture farms increased from 40 to 102. The total production increased as well during that time, from 150 tons in 1985 to 3.000 tons in 1990. Production mainly featured salmon and rainbow trout. However, the aquaculture business was not thriving well in Iceland during that time and many farms went out of business. Stagnation occurred in production around the turn of the century, but trout farming was the only production growing, from 70 tons in 1990 to 900 tons in 1999. Interest in aquaculture grew again at the beginning of a new century when large seafood companies took the lead in research and development of aquaculture. In 2006, the total production in Iceland reached a high, with 10.000 tons produced from aquaculture. Production decreased in the following years due to companies leaving salmon farming due to several reasons, holding under 5.000 tons in total in 2008, of which the majority came from char farming (Landssamband fiskeldisstöðva, 2009).

## Atlantic salmon

Salmon is one of the most popular aquaculture species worldwide. The demand for salmon has grown the past years and the future market landscape looks bright. Salmon farming has grown considerably in the past years in Iceland and has been pursued intermittently since before 1980. The increased production that has taken place in the past six years has been driven by the growing infrastructure in the West and East part of Iceland. The total production in 2018 was close to 14 thousand ton of salmon which was at least three times more than produced in 2015 Figure 36. The Icelandic salmon strain which is used today originally came from Norway three decades ago but have been breed and improved since then and have never been genetically modified. Roes from this strain are today popular amongst many farmers and are exported from Iceland to Scotland, Ireland, Faroe Islands, Norway, Chile, China and more (Landsamband fiskeldisstöðva, 2020). Despite the growing salmon farming industry in Iceland and the fact that salmon farming is becoming one of the large export industries, the production is still very little on a global scale. Iceland is still just taking the first steps and is not very well-developed industry yet.

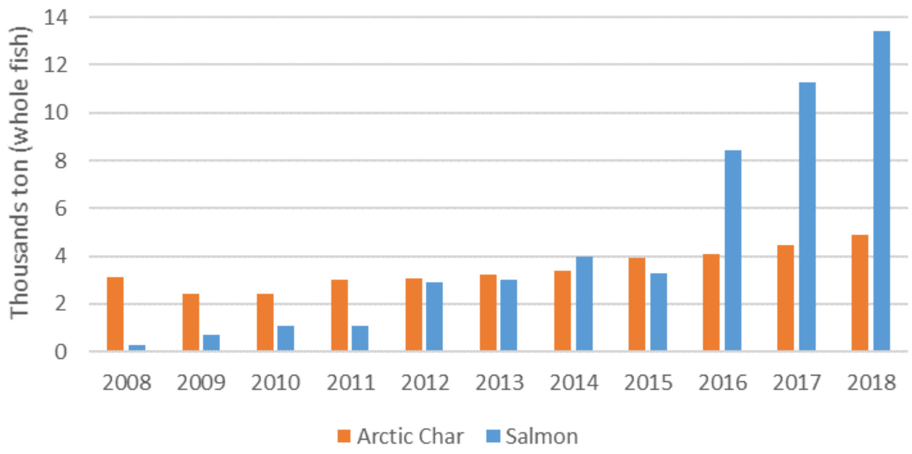


**FIGURE 36 ANNUAL PRODUCTION OF ARCTIC CHAR AND SALMON IN ICELAND (STATISTICS ICELAND, 2020)**

## Arctic char

Arctic char is not the best-known aquaculture species worldwide. The world production is rather small, and Iceland is the biggest producer. The biggest markets for arctic char are in the US, UK, Denmark, Germany and France. Arctic char is freshwater species but can adapt to salinity and is well adapted to the cold climate in the arctic. Total production was close to 5 thousand tons in 2018, Figure 36.

## 3.1. Internal and external factors affecting aquaculture farming

**Challenges & Drivers**

**Atlantic salmon**

**Challenges:**

- Sea lice
- Climate and sea temperature
- Wounds and mortality
- Kidney disease
- Genetic mixing with wild salmon stocks

**Drivers:**

- Iceland is rich in natural resources
- The ocean is relatively clean
- Available infrastructures and towns around the island
- Large sea area suitable for salmon farming

**Arctic Char**

**Challenges:**

- Arctic Char goes early into puberty which reduces growth and quality
- The world market for Arctic Char is rather small
- Kidney disease

**Drivers:**

- Iceland is rich in natural resources such as access to freshwater, geothermal hot water and clean underground seawater
- In some areas, these resources are very affordable
- Arctic Char does well in cold water
- Arctic Char prefers being raised in high densities
- Arctic Char has high fillet utilisation efficiency
- Appealing fish fillets

### Atlantic salmon

The conditions for aquaculture in Iceland are different from many other neighbouring countries. Iceland has excessive resources of fresh water, geothermal energy and access to clean seawater. These conditions make land-based facilities feasible and economical option. Salmon farming in Iceland is done both on land in freshwater and seawater facilities and in sea cages in the open sea. The hatchery is in all cases on land in freshwater and when the juvenile reach desired size and have been adjusted to salinity, they are moved to the sea. In the best farming areas abroad, juveniles are released into the sea during the biggest part of the year, but in Iceland, the sea temperature is a limiting factor when releasing the juveniles.

Adult salmons are mainly raised in sea cages at the moment in Iceland but it is technically feasible to do so on land in some areas in Iceland, there is one company that operates an on-land facility for 1500 tons of adult salmon per year and which is one of the biggest on-land facilities for salmon I the world. The main challenges that the salmon farming companies face in Iceland, in terms of fish farming in the sea, are the cold sea temperature during the winter months, sea lice during the summertime and general bad weather conditions. The sea temperatures during the winter months are generally lower compared to competing countries, except the east coast of Canada. Iceland is defined by some as the peripheral area for aquaculture. What can happen during the cold winter months, especially when the temperature goes down to around 2°C, is that the fish slows down and often moves to the bottom of the cages. When they all gather in the bottom and the weather is bad, as it sometimes is in Iceland, some fish are squeezed against the net creating bruises, most often it is due to the weaker and smaller fish that is forced to the outside. Bacteria and germs present in the environment then settle in these bruises creating wounds that often cause death within weeks It is difficult to avoid these circumstances since the weather is often very bad when this comes up making it difficult to act and for example slaughter the fish due to the difficult sea conditions, or the capacity to process all the fish at once (Steinarsson, 2020).This is more likely to occur when a high density of fish is kept in the cage as there is less space for each fish. The sea in Iceland can go below zero degrees which are challenging for the fish, especially weaker individuals. If they get wounds, they are much more vulnerable in the cold since the wounds tend to heal slower. The cold sea temperature not only affects mortality it also influences the growth. When temperatures are low the salmon spends more energy coping in the cold which results in slower growth (Gunnarsson V. , 1991).

FIGURE 37 SEA LICE ON FISH

FIGURE 38 LUMPISH USED TO GET RID OF SEA LICE IN CAGES

Sea lice are found in the ocean. These are natural parasitic species that are killed soon after wild fish that normally enters the freshwater in rivers. The sea lice stick to the fish and feed on the mucosa and blood of the fish. They can cause death, can carry other germs and decrease market value. They cause stress and open wounds start to form leading to other kinds of infections which can cause death. Sea lice are known to cause considerable damage in aquaculture where they can thrive in high densities. Fjords and locations with aquaculture can have little sea lice, to begin with, but the numbers increase as the stock of sea lice grow around the sea cages. This is said to be one of the biggest problems in Norway and is hindering further expansion in Norway. It was first believed that the sea around Iceland was too cold for the sea lice to thrive, but sea lice have never the less been found in most areas around Iceland where salmon is farmed. According to many, more research is needed in Iceland to monitor sea lice in farmed salmon as well as to monitor the impact on other wild species as wild small fish is very vulnerable to sea lice first after it goes into the sea (Ástþórsson & Guðfinnsson, 2019). Many are worried that the future growth in salmon farming around Iceland will increase the number of sea lice in Iceland creating problems for wild fish and farmed.

Over the past two decades, the measures taken to prevent sea lice in fish farming has been largely based on drug treatment. It is costly, and, in some cases, the lice have developed resistance to many of the drugs. The diminished efficacy of the drugs has led to an increased focus on the development and use of other methods. This includes treating salmon in warm water as well as freshwater and introduction of species that eat the lice. The Icelandic company Stofnfiskur and the Icelandic marine research institution have produced and sold millions of lumpfish last five years and sold to aquaculture companies in Faro Islands. The lumpish is released into the sea cage with salmon where their purpose is to eat the sea lice present in the water reducing their number.

Bacterial kidney disease is a harmful disease that occasionally appears in Icelandic farms. It was first detected in 1968 and was the first infectious disease confirmed in aquaculture in Iceland. The disease was found in salmon juveniles in a hatchery. Kidney disease is found in wild salmon fish stocks in Iceland and a considerable amount of time and resources has been spent on fighting the disease. Wild fish can have the disease but their immune system manages to hold down the symptoms. The disease has come up from time to time, primarily in salmon farming, but also in arctic char farms and occasional rainbow cases. Extensive work on hatcheries has been carried out since 1985 but the disease is extremely difficult to cope with and can have very negative consequences, it is not uncommon for farms to become bankrupt after infection. There is no cure nor vaccine available. The bacterium is found in wild fish and can thus easily be transmitted to a farm with fresh carriers.

Organized monitoring and screening for kidney disease have been practised in Iceland since 1985. The results of the screening last two decades indicate that latent transmission in wild salmonids is usually in the range of 0.5-3%, though varies from year to year. Years have passed where no infection is detected, but in between, there is a kind of waves where the rate of infection rises and can even become rather high. Farmers are required to have a sampling of salmonids to be used for breeding.

The disease can be transmitted through direct or indirect contact with fish, contaminated freshwater and seawater, with organic matter, e.g. blood, faeces, ureas, mucus and fish flesh, from the roe, people and utensils, transport equipment, net, tools and equipment. Cases are often seasonal and in line with the maturation of the fish. In freshwater, it is common for kidney disease to rise with rising heat in the spring, but in aquaculture, it is not uncommon for clinical symptoms to develop several weeks after the juveniles are smolted and been transported to sea cage. The disease period varies between fish and can sometimes be over two years from the time of infection until visible signs and symptoms appear. The disease is sometimes not visible, and the impact varies between spreads. Drugs do not work on the disease and despite extensive efforts and development work, there is no vaccine for the disease (Matvælastofnun, 2019)

Many other factors can affect farming and the health of the fish, such as wild animal getting into the cages and take up space and eat the feed, predators such as birds, seal, mink, jellyfish and harmful algae growth. The design of the net and equipment also can have a huge effect on fish health. The location of the sea cages is also something that needs to be considered. The location must be chosen so that waste, uneaten feed faeces do not pile up on the bottom and make sure that waves and streams are present to ensure good water quality. Too much stream or irritation can have negative consequences as it puts more stress on the fish and increases the risk of wound formation and death.

## Arctic char

The benefits followed by farming arctic char in Iceland are their ability to do well and grow fast in very cold water and in high densities meaning that they require little space. The species is rather tough, and handling does not affect them much, they are also relatively resistant to disease, have a very good feed utilization due to eating off the bottom and in darkness. Arctic char gives off beautiful orange fillets and good fillet processing efficiency. However, the fish also has some downsides as a farmed fish. For example, it tends to enter the puberty phase too soon, or on its second year of existence, which makes it a non-selling product. Farmers try to avoid this by bringing them to the market before entering the puberty phase, as when the fish is undergoing puberty, growth is considerably slower. The fish tends to go faster into this phase when it is raised too fast with excessive feeding. The fish size also tends to vary within groups, making it difficult to make plans for feeding and other operations (Thorarensen, Gústavsson, Karlsson, & Sigurgeirsson, 2011).

The time it takes to raise fish to market size varies a lot between companies and they type of equipment as seen in Figure 39. Icelandic companies, manly rely on an inland freshwater flow-through system with a partial circulation of the water and the costal facilities with a flow-through system where a mixture of seawater and fresh water is used, and the water is partially recirculated to save energy such as geothermal hot water which is used to warm up the water. The biggest facilities in Iceland are categorised in the latter coastal facilities which use a mixture of freshwater and seawater. In coastal facilities, the juvenile is generally first around 100 g but is raised to about 1,5kg roughly in one year. While costal facilities generally take in smaller juvenile close to 5-15g and it takes about 1 to 2 years to raise them to a market size below 1kg. The growth depends on a lot of factors such as the water temperature which is difficult to control and optimize for the fish in flow-through systems relying on cold freshwater (4-5°C) which fluctuate depending on the time of year. The result of too cold water is reduced growth.

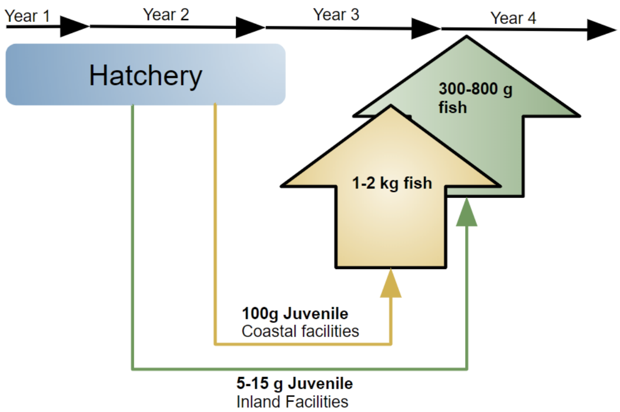


**FIGURE 39 SIMPLIFIED IMAGE SHOWING THE TIME IT TAKES TO GROW ARCTIC CHAR**

Iceland has various advantages in terms of ability to farm arctic char. Iceland is rich in natural resources such as access to fresh water supplies, geothermal hot water and clean underground seawater. These sources are used together to create optimal conditions for the arctic char and the abundant of these resources and relatively affordable price in many areas make it economically feasible to build up large facilities. In comparison to other countries, farming arctic char, these resources are not always in place which makes it difficult to maintain optimal conditions for the fish. They must rely on recirculating aquaculture systems with constant renewal of the water while in Iceland many facilities have flow-through or partially recirculating system. The costal flow-through systems in Iceland give the operators more stability as they can control the salinity, the temperature, they use very sterile seawater and geothermal water that does not cost much. Making it easier to optimize the conditions for the fish. Another alternative is to farm arctic char in sea cages, but it has however not caught on due to difficulties dealing with temperature fluctuations in the sea which has shown to lead to higher mortality (Gunnarsson & Rúnarsson, Bleikjueldi á Íslandi, 2006). There have been many improvements in Arctic char farming through the years, and trial and error have educated farmers to stabilize the production. With technical methods such as genetic selection and breeding (not genetic modification), it has been possible to reduce the frequency of early puberty within the second year and to increase the growth rate substantially (Thorarensen, Gústavsson, Karlsson, & Sigurgeirsson, 2011). The kidney disease is also found in arctic char and is known to cause considerable damage for farmers.

## 3.2. Slaughtering and processing

**Challenges & Drivers**

**Atlantic salmon**

**Challenges:**

- Increase processing of salmon products in Iceland
- Manage to fillet and process the salmon before rigour Mortis occurs
- Shorten the time products arrive on the market
- Increase employment in Iceland

**Drivers:**

- The Icelandic industry has tackled similar issues in the whitefish industry before and succeeded
- Increased production in Iceland will have a positive effect on exports value, increase employment in rural areas and create a greater consensus on salmon farming

**Arctic Char**

**Challenges:**

- Transportation of live animals
- Process the fillets and package before rigour Mortis occurs

**Drivers:**

- Having the fish live in the filleting facility allows them to be processed before rigour Mortis occurs. This allows the producer to deliver newer Rm to markets.
- Newer RM on markets gives higher prices

### Atlantic salmon

Majority of the salmon farmed in Iceland is not fully processed in Iceland. Upon slaughtering, the guts are removed, and the fish is prepared for export to markets. Most of the salmon is exported whole, with head and tail, fresh on ice. This means that very little processing is done, and less volume of RM falls by during the processing. Since Iceland is located far from the markets compared to many other competing countries, it takes more time to export by sea. In addition to the long transport time, extra days will add up if the fish is filleted post rigour Mortis, which is the traditional way of filleting and processing salmon. The fish then has to go through rigour Mortis when the fillets are still attached to the fish under cold temperatures. This may extend the process by 2-3 days as the processor has to wait for rigour Mortis to occur before he can start processing, he then has to bring older material on to the market which reduces the sale value. In this sense, it's reasonable to transport the fish whole as it will be given the time to go through rigour Mortis during the transport and will be fit for filleting upon arrival.

However, research has shown that farmed salmon fillets processed pre-rigour Mortis due not shrink nearly as much in comparison to wild cod fillets for example. The quality of salmon fillets processed before rigour Mortis has proven to be good and the result is less muscle gaping compared to the traditional post rigour filleting which may sound surprising (Skjervold, et al., 2001). Filleting before rigour is, therefore, a feasible option which perhaps needs to be looked further into since it can bring fresher and newer material onto them markets and has proven to be a preferable alternative to the traditional post-rigour filleting (Rosnes, et al., 2003). This could be the key to increasing the production in Iceland and make large scale processing feasible. A small share of the export volumes consists of frozen products such as fillets. Frozen products give off less revenue compared to fresh products but are not as limited to the shelf life and could be a feasible option for Iceland as well. One thing is for sure that many variables play in and affect the possible value creation, such as investment, production, labour and transportation -cost, the market landscape and prices to name few.

## Arctic char

Many operators farm arctic char in Iceland and the way they handle the fish varies between. The biggest producer transports the fish, often long distances alive to the fish processing facility which is located close to the main airport. There the fish is slaughtered and later processed into different products both frozen and fresh. Having the fish alive to the processing facility allows the producers to process the fish pre rigour Mortis. This is practised for both fresh and frozen fillets and has proven to have a positive effect on quality.

# 3.3. Products

**Challenges & Drivers**

**Atlantic salmon**

**Challenges:**

- Process more in Iceland to increase employment and export value

**Drivers:**

- Companies are driven by profit
- The whitefish industry has gone through the same in the past

**Arctic Char**

**Challenges:**

-

**Drivers:**

-

## Atlantic salmon

Salmon farming is still a relatively new industry and perhaps not yet fully developed. A major part of the salmon export is whole gutted salmon as can been seen on the export data from statistics of Iceland 2018 Figure 40. Thereafter comes fresh fillets and then other products along with frozen products. Whole gutted salmon is, however, the majority of the export. In 2018, most of the whole exported salmon were exported to markets in Denmark, Britain and Netherland Figure 41.

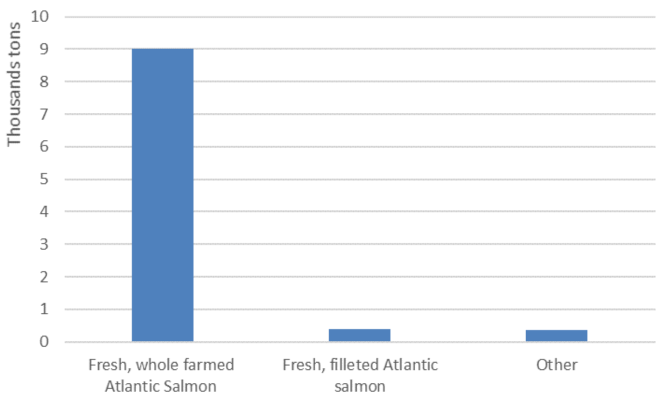


FIGURE 40 EXPORTED SALMON PRODUCTS IN 2018 ( (STATISTIC ICELAND, 2020))

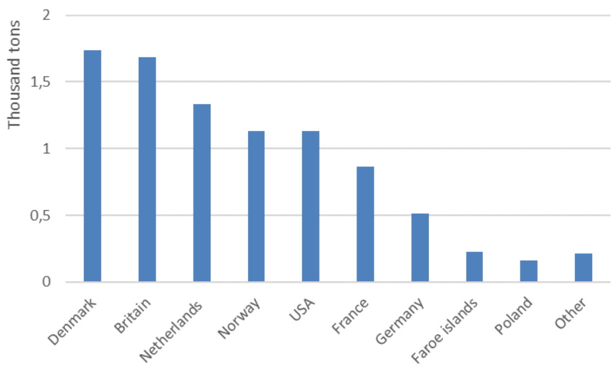


FIGURE 41 EXPORT VOLUMES 2018: FRESH WHOLE GUTTED FARMED ATLANTIC SALMON (STATISTIC ICELAND, 2020)

## Arctic char

The same data is not available for arctic char from statistics of Iceland as for salmon and the distribution of different products. However, it is well known that fillets and portions are the main export product both fresh and frozen. Frozen products can be vacuum packed or not. Whole fish is exported both fresh and frozen and by-products are exported frozen. As mentioned, the arctic char is exported alive to the processing facility to process the fish pre rigour Mortis which gives of good quality and brings a newer product to the market which greatly affects sales value.

**Figure 42 Frozen fillets and portions (Samherji, 220)**

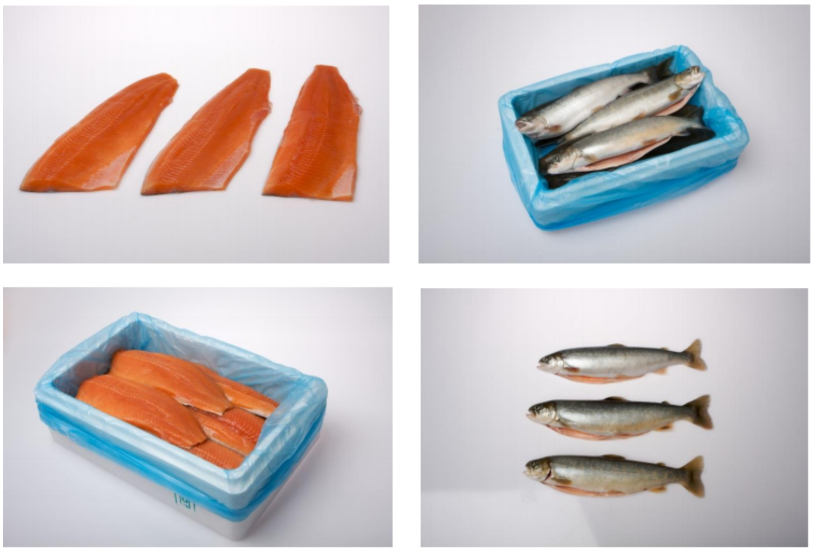

**Figure 43 Fresh fillets and whole fish (Samherji, 220)**

## 3.4. By-products

**Challenges & Drivers**

**Atlantic salmon**

**Challenges:**

- Utilise all RRMs
- Make the most out of all RRMs
- Preserve quality

**Drivers:**

- It has been shown that the utilization RRMs delivers greater value
- Throwing RRM away costs money

**Arctic Char**

**Challenges:**

- Utilise all RRMs and small volumes from all the small farmers and processors around the island

**Drivers:**

- Throwing RRM away costs money

As in the whitefish industry, there are many possible ways of processing RM from the main production. In Iceland, the salmon is still not fully processed into fillets and most of the salmon is exported whole gutted with the head attached to the fish. It is sold to market abroad for further processing. This reduces the amount of RM that fall by during processing in Iceland and the volumes are therefore not as great compared to whitefish industry. However, Arctic char is most often filleted leaving more RM from the production. Attempts have been made to utilise RM such as viscera to make fishmeal and oil intended for pet food or supplements for pets such as oils. This way of processing proved to be too costly as the volumes are not great enough to cover the cost of production and the production does not have stable enough access to RMs all year around. Today, most salmon farming companies utilise its RMs such as viscera and dead fish, into fish silage. Most of it is sold to Norwegian feed companies that produce pet food and feed for mink. For the farmers, this is a relatively inexpensive way of utilising the RM and requires very little infrastructure. Silage production is relatively simple where whole fish and fish parts can be used, including the viscera. Everything is simply ground, and acid, often the formic acid added to the mix. Enzymes from the fish break down fish proteins into smaller soluble units, and the acid helps to speed up their activity while preventing bacterial spoilage. The process takes place in a tank and it is important to mix the content thoroughly so that all the fish comes into contact with acid because pockets of untreated material will putrefy. The acidity of the mixture must be pH 4 or lower to prevent bacterial action. After the initial mixing, the silage process starts naturally, but occasional stirring helps to ensure uniformity. An example of equipment needed to produce silage are grinding and mixing machine, protected tank to store and pump acid and container to hold all the equipment needed to produce silage on-site Figure 44

FIGURE 44 DEAD FISH SILAGE UNIT, TANK FOR STORING ACID AND PUMPING AND CONTAINER FITTED WITH COMPACT SILAGE MAKING UNIT FROM (STEINSVIK, 2020)

Fish silage, in general, is mostly used as animal feed but can also be used as fertilizer or even RM for fishmeal factories. To reduce transportation volumes and increase the revenue of silage. The silage can be de-oiled to separate the oils from the rest, thus selling crude oil and wet silage. It can be taken even further, and the wet silage can be evaporated to get rid of water and reduce the transport volume and cost and increase the value. Wet silage is a good alternative for feed making and especially extrusion since it has a very positive effect on pellets when moist silage is mixed with other dry matter and extruded.

It is more common to fillet arctic char so the relative volume of RMs is bigger. Parts from the processing facilities such as backbone belly flaps and heads are frozen and exported. The greatest challenge is perhaps to utilise all the RRMs that fall by from small farmers and processors all around the island

## 3.5. Summary

### Arctic salmon

Salmon farming is a rapidly expanding industry. Even though salmon has been farmed in the Icelandic sea for years, many challenges remain to be resolved regarding the farming of the fish. The ocean is particularly cold during the winter months which can affect the health of the fish, mortality and growth. Sea lice can be found in Iceland but are not as big of a problem as in Norway yet. Another issue is a kidney disease which occasionally comes up with severe consequences. Solutions have not been found to cure the disease, but it is found in wild healthy fish and symptoms do not always show up.

According to data from the statistic of Iceland 2018, minimum processing is carried out in Iceland and the fish is mostly exported whole, with head and tail, and viscera have been removed. Some companies fillet and package fresh and frozen salmon, but the volume is little in the big picture. More research is needed on the processing of salmon pre-rigour Mortis as it could be the key to increased utilization and processing of salmon in Iceland. This is particularly due to the country's position and long transport time.

Most of the RRM, dead fish and viscera are utilized into silage and exported abroad.

### Arctic char

Iceland is one of the biggest if not the biggest producer of arctic char worldwide, but the market is relatively small. Iceland is rich in natural resources such as geothermal energy, fresh water and access to clean boreholes with sterile seawater. These resources are very inexpensive in comparison to electricity and fuels which makes it economical to scale up the production.

The arctic char is in many ways' good aquaculture species for the Icelandic conditions. They grow fast in cold water and in high densities meaning that they require little space. They have good feed utilization efficiency and fillet processing efficiency. The downside is that they enter puberty early which affects growth and quality. They need to be slaughtered before going into puberty. Arctic char is raised in freshwater flowthrough systems and in partially recirculating systems with seawater.

The biggest producer in Iceland processes all its fish pre-rigour Mortis, both frozen and fresh. The fish is transported, often long distances alive to be able to process as soon after death as possible. This has had a good effect on the quality and could be further investigated in the context of salmon.

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