Utilization of Fish Byproducts in Iceland

Sigurjon Arason
Icelandic Fisheries Laboratories, and University of Iceland, Department of Food Science, Reykjavik, Iceland

Abstract
Fisheries are the single most important industry in Iceland, and will continue to play an important role in the economy of Iceland for a long time to come. In 2001 the total catch was around 2 million tons, accounting for 62% of the country’s merchandise exports. The living marine resources are, however, limited and it is important to utilize these resources in a sustainable way. It is also important to maximize their value by producing high-priced products from the raw material, which is currently being used for fish meal or simply discarded. For example, today all cod heads from land-based processing plants are being utilized and lately the freezing trawlers have begun freezing them onboard for processing on shore. Fortunately, most of the byproducts are no longer regarded as waste but are used as raw material for fish processing like roe, liver, mince, viscera, etc.

The byproducts from salting, freezing, and canning fresh fish and other processes have different qualities and potentials. Therefore, quality management is important and new technologies are emerging that will allow a new range of products to be made from byproducts which will, for example, benefit the pharmaceutical, cosmetics, and food industries worldwide.

Introduction
The living marine resources in Icelandic waters are the most important natural resources in the country. In 2001, the total catch was around 2 million tons, (Fig. 1), accounting for 62% of the value of exported products and around 48% of the foreign currency earnings that year. The most important fish species in Icelandic waters belong to the gadoids: cod, haddock, pollock, and blue whiting. Other important species are ocean perch, Greenland halibut, herring, capelin, and shellfish like shrimp, lobster, and scallop (Fig. 2).
Figure 1. Fish catch on Icelandic catching grounds, 1992-2001.

Figure 2. Catch of Icelandic vessels by fish species fishing in 2001; the total catch was 1,941,905 tons.
Fish meal and oil constitute the bulk of the volume of products from fisheries in Iceland or 63% of total, but their value is far less or only about 14% of the total value of exported seafood products (Fig. 3).

The Icelandic fishing fleet and the processing plants are highly mechanized as can be seen by the fact that only about 10% of the workforce is employed in fishing and fish processing. Icelanders, like many other nations, have realized that their fish resources are limited and that a collapse of any of the major stocks would be economically disastrous. In 1984 fixed quotas for each vessel were introduced in order to control exploitation of the fish stocks (Valdimarsson 1990). The main objective of the quota legislation was to prevent overfishing and to encourage responsible handling of all catches and exploitation of under-utilized marine life. There is no doubt that the quota system has had a major effect on changing the attitude toward full utilization of the catches. The fishermen and the processing industries are becoming more aware of the possibilities of making marketable products from raw materials that currently are either used for fish meal or simply discarded. Through research and development, publicly funded institutions assist the industry to increase utilization of seafoods.

During the last decade, the annual fish catch has stabilized at about 1.5-2 million tons, and according to fish biologists, no further growth is expected in the near future. Hence, optimal utilization of fishery byproducts is becoming increasingly important to provide more marine fish raw material for various industrial purposes.

The various fish processes give different byproducts and the production yield varies greatly. Calculation of yield in the fish processing industry is generally based on gutted fish with head. Some species, like ocean perch, herring, and other pelagic fish, will reach the factory ungutted and evaluation of processing yield for these species will be based on ungathered fish. Utilization of byproducts is highly dependent on the processing method. Cod can be frozen at sea or on shore and salted cod may be filleted or butterfly split, which will influence the utilization of the fish (Table 1) (Arason 2001b). The "by-raw materials" are better controlled in an onshore operation than at-sea processing. The utilization of the "by-raw materials" from freezing trawlers has increased, however, during the last five years. In 2001 byproducts brought to shore by Icelandic freezing trawlers were:

- Fish cut-offs 1,946 tons
- Fish heads 3,161 tons
- Roe 87 tons
Figure 3. The main Icelandic fishery products area, 2001. A = export value, B = quantity of export.
Utilization of fish byproducts

The discussion on byproducts from groundfish will be divided into three categories. In the first we will look at utilizing the viscera, in the second we will look closely at frames, cut-offs, etc., and we will give an overview of the utilization of heads, which represent the main volume and value of byproduct export from Icelandic fisheries (Fig. 4).

Fish viscera

Viscera (including liver and roe or milt) constitute between 10 and 25% of the net weight of fish. In Iceland, most of the intestines are discarded at sea. It is well known that the intestines, the stomach, and the pyloric caecum contain large quantities of digestive enzymes. For a number of years the University of Iceland, the Icelandic Fisheries Laboratories (IFL), and others have worked toward producing crude enzyme mixtures, containing high concentrations of cod enzymes. At the university further work is being carried out by purifying the specific enzyme mixtures, especially trypsin and chymotrypsin (Asgeirsson et al. 1989).

Hydrolytic enzymes, especially proteinases, have many uses and potential applications are in industry, medicine, and research. Among these applications are detergent production, leather processing, chemical modifications, and food processing. Enzymes, isolated from cold water marine organisms, may prove to be especially useful for these purposes. The cold-active or psychrophilic enzymes are frequently more active at low temperatures than their mammalian or bacterial counterparts, a characteristic that could be beneficial in many industrial processes, as

Table 1. Processing yield percent of cod at different production.

<table>
<thead>
<tr>
<th>Product</th>
<th>Filleting</th>
<th>Splitting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frozen on shore</td>
<td>Frozen at sea</td>
</tr>
<tr>
<td>Head</td>
<td>48</td>
<td>45</td>
</tr>
<tr>
<td>Backbone</td>
<td>30</td>
<td>34</td>
</tr>
<tr>
<td>Skin</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Cut</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Viscera</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>By-raw material total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1. Processing yield percent of cod at different production.
Figure 4. Export of byproducts from groundfish processing in Iceland, 2001. A. Quantity of export byproducts 2001 was 45,543 tons. B. Export value for 2001 was $73.5 million.
well as in medical, pharmaceutical, hygienic, and cosmetic applications (Bjarnason 2001).

Various food processing applications are also being considered, such as in the chill-proofing of beer, biscuit manufacture, tenderizing of meats, preparation of minimally treated fruit and vegetable beverages, and hydrolysis of various food proteins, such as gelatin, vegetable proteins, and collagens. Currently, cryotin is being prepared on a pilot plant scale for marketing trials and application tests, both in-house and in collaboration with external partners. Purification of the individual proteinases, trypsin, chymotrypsin, elastase, and collagenase is also being scaled up to allow large-scale tests to be conducted. Cryotin is now being used in a patented process to prepare high quality, all-natural flavorings for food processing and innovative cooking (Bjarnason 2001).

Penzyme, a pure, super-active proteinase from cod, is currently being sold in Iceland as an enzyme ointment called PENZIM gel or lotion. The PENZIM ointment is a soothing, moisturizing, cleansing, and nourishing skin healing treatment for dry or chapped skin. It also appears to have good qualities as an “age-specialist” product for facial skin, and rejuvenates whole body skin by removing the outermost layer of dead skin cells (Bjarnason 2001).

There is also a growing market for fish hydrolysates with defined qualities. This is one area where fish enzymes might become valuable in producing a variety of fish protein hydrolysates from scrap fish.

The “by-raw materials,” which have been utilized from viscera, include liver, roe, milt, and stomach. The best-known Icelandic fish byproducts are undoubtedly the cod liver oil and cod roe. From 1901 to 1950 the annual production of cod liver oil was about 5,000 tons per year and around 2,000 tons of salted cod roe.

**Roe**

There is a high demand for frozen and salted cod roe for smoking, canning, and the production of various kinds of spreads, such as “caviar” spread. The roe from cod, haddock, and pollock are only available for a period of three months each year. The ripening stage is very important in terms of product quality.

In Iceland, all iced fish must be gutted if the individual fishing trip is longer than 24 hours. Traditionally, only roe from fish that has been brought to shore ungutted for salting or freezing have been utilized. Increased roe prices have changed this and today roes from most of the harvested groundfish are being utilized. Vessel workers, who are eviscerating the fish at sea, collect the roe in insulated plastic tubs, using salt for preservation; or the roes are frozen onboard the freezing trawlers. Table 2 shows the different categories of exported roe from gadoid species.

The lumpfish roe industry is now well established in Iceland, and most of the roe is packed as caviar under various foreign labels and sold
on the European market. The export value was $10.8 million in 2001 and the quantity was 1,184 tons.

Capelin roe has almost exclusively been sold in Japan, but some producers are now producing caviar or spreads for the European market. The export value was $10.4 million in 2001 and the quantity was 6,165 tons.

**Liver**

One part of cod liver is used for making medicinal liver oil. The University of Iceland, Lysi Ltd., the Icelandic Fisheries Laboratory (IFL), and others have been working on the product development. The main effort has been toward producing cod liver oil with a higher proportion of omega-3 fatty acids. Icelanders have long been loyal consumers of cod liver oil, and since the media started reporting on the alleged beneficial effects of the omega-3 fatty acids on human health the consumption has increased even more. Generally there is now more demand for cod liver than can be supplied from the uneviscerated catches alone.

Canned cod liver has always been in demand, but over the last few years only 220 tons have been produced annually. One reason for this is the short operating period. Table 3 summarizes the various categories produced from liver.

Although most of the emphasis has been placed on the health benefits of fish oil, it is known that fish oil and fish liver oil contain other interesting compounds. With improved separation techniques and more gentle processing methods, these oils might play an even more important role in the pharmaceutical and health food industry in the near future.

**Fish frames and collars**

Considerable quantities of fish flesh can be recovered from the remaining collars and the frames after filleting groundfish. Bone separator

<table>
<thead>
<tr>
<th>Roe Type</th>
<th>Quantity (tons)</th>
<th>Value (thousand $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry frozen roes</td>
<td>483.6</td>
<td>2,947</td>
</tr>
<tr>
<td>Special quality frozen roes</td>
<td>603.6</td>
<td>5,677</td>
</tr>
<tr>
<td>Salted roes</td>
<td>287.0</td>
<td>4,881</td>
</tr>
<tr>
<td>Sucker salted roes</td>
<td>1,181.7</td>
<td>387</td>
</tr>
<tr>
<td>Canned roes</td>
<td>27.9</td>
<td>8,742</td>
</tr>
<tr>
<td>Others</td>
<td>213.0</td>
<td>464</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2,796.8</td>
<td>23,099</td>
</tr>
</tbody>
</table>
technology is well known and widely used in many countries. In Iceland, practically no fish mince is produced except from the cut-offs rendered by the production of boneless fillets (Table 4). The mince from the collar and the frames is darker in color than the cut-off mince and therefore sells at lower prices.

From one ton of gutted cod some 100-180 kilograms of mince can be produced from the different parts of the fish. Following is the possible mince production out of various parts from the processing of cod fillets:

- Cut-off: 3-4%
- Collar: 4-5%
- Head: 3-4%
- Belly flap: 5-6%
- Frame: 4-5%
- Total mince: 15-18%

MESA is an Icelandic company that has developed machinery for scraping flesh and cutting sounds and belly flaps from the backbones after splitting or filleting of cod. These products have been exported and used as value-added products on the salted fish market.

**Fish skin**

Fish skin is collected and exported to Canada and Spain by an Icelandic fish processor. Research in Iceland indicates that fish skin can be stored refrigerated and frozen for a short period of time without negative effect on the functional properties of the gelatin (Gudmundsson and Hafsteinsson 1997). Fish skins are also being processed into leather (Table 5).

Fish offers new applications as a food ingredient, both because it has properties that are different from mammalian gelatin and also because it
Table 4. Production of minces from gadoid species in Iceland, 2001.

<table>
<thead>
<tr>
<th></th>
<th>Quantity (tons)</th>
<th>Value (thousand $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod mince</td>
<td>3,526</td>
<td>5,990</td>
</tr>
<tr>
<td>Other groundfish mince</td>
<td>654</td>
<td>809</td>
</tr>
<tr>
<td>Total</td>
<td>4,180</td>
<td>6,798</td>
</tr>
</tbody>
</table>

Table 5. Icelandic exported products from skin, 2001.

<table>
<thead>
<tr>
<th></th>
<th>Quantity (tons)</th>
<th>Value (thousand $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frozen skin</td>
<td>425</td>
<td>65</td>
</tr>
<tr>
<td>Leather from fish skin</td>
<td>0.2</td>
<td>57</td>
</tr>
<tr>
<td>Total</td>
<td>425.2</td>
<td>122</td>
</tr>
</tbody>
</table>

can be used in food where mammalian gelatin is not desired (e.g., in kosher and halal food, because of the bovine spongiform encephalopathy [BSE] scare, etc.). Fish gelatin is soluble in cold water, which is an important quality in frozen products. There is also a market for non-gelling gelatin, such as in the cosmetic industry as an active ingredient (i.e., shampoo with protein).

**Fish heads**

In Iceland, as in many other countries, fish tongues and cheeks are considered delicacies, although some cheeks and tongues are also exported. Until recently an obstacle for processing these products was the relatively high manpower requirement, but now the Icelandic company MESA has a machine for this process. The machine uses fish heads and removes head cheeks and tongues. Another machine is used for splitting fish heads and tearing the gills out. The machine can process all sizes of heads, from the smallest to the largest, without special adjustments. As the product from one of the MESA machines is new on the market, time has to be allowed for further product development (Sigurdsson 1992, 1993). In Iceland the tongues and “double cheeks,” products from the head splitter, have mostly been salted and sold on the salt fish markets in Portugal and
Spain. Most of the cod heads from the Icelandic onshore processing line are utilized into different products (Table 6).

Fish heads contain relatively little meat. However, the meat from the fish head is considered a delicacy due to its taste and excellent texture. If cod heads are taken as an example it can be assumed that the tongue constitutes approximately 1-4% of the weight of the head, cheeks 5-15%, collar 15-20%, and upper head meat 5-15% (Fig. 5).

### Table 6. Products from cod heads in Iceland, 2001.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(tons)</td>
<td>(thousand $)</td>
</tr>
<tr>
<td>Dried heads</td>
<td>11,432</td>
</tr>
<tr>
<td>Salted head products</td>
<td>4,277</td>
</tr>
<tr>
<td>Frozen head products</td>
<td>186</td>
</tr>
<tr>
<td>Total</td>
<td>15,895</td>
</tr>
</tbody>
</table>

Drying cod heads indoors

In Iceland, indoor drying has been tested in regions where geothermal energy is found. The reason is that the cost of oil or electricity for heating during the drying process is considerably higher than the cost of hot water or geothermal steam. It is more profitable to locate the processing near inexpensive hot water and steam sources, and collect the raw material and transfer it to the processing plant.

The price of energy for heating varies much from one energy source to another and from one location to another. The price of oil has fluctuated; the price of hot water and electricity has changed less, although it tends to follow the price of oil (Fig. 6).

The energy cost of heating air for drying one kilogram of dried cod heads in Iceland is lowest using geothermal resources (Fig. 6). The prices are extrapolated using the price in March 2001. The main conclusions are that the energy required for evaporating one kilogram of water from a substance is 4,400 kJ (1,100 kcal), the efficiency of oil boilers is estimated at 90%, coefficient of performance of heat pumps 2.5, and it is assumed that the hot water is cooled from 80ºC to 30ºC (Arason 2001a).

Weather conditions limit outdoor drying in Iceland. Indoor drying of fish, such as cod heads, stockfish, or small fish, is done in such a way that hot air is blown over the fish and the moisture from the raw material subsequently removed.
Figure 5. Location of the muscle on a cod head.

Figure 6. Comparison of prices for different types of energy for heating, ISK for drying one kilogram of dried cod head, based on cost in March 2001 ($1 US = 90 ISK). (OR = Reykjavik Energy, Rarik = Icelandic State Electricity, ISK = Iceland Kroner.)
There is an extensive advantage in drying fresh raw material year-round compared to being dependent on the weather conditions. The process is faster and the drying time is shortened from weeks to days. The main advantages of indoor drying are:

- Shorter drying time than outdoor drying.
- Drying year-round and more even export shipments.
- The product is more consistent in quality and water content.
- Flies and insects are prevented from contaminating the product.
- Utilization of local energy sources.

Traditionally, cod heads used to be dried by hanging them on outdoor stock racks, but about 20 years ago indoor drying was begun. In Iceland the production of dried cod heads increased from 1,000 tons to about 14,000 tons per year which equals about 70,000 tons of undried heads. This practice has grown and now there are several drying factories in Iceland. The largest drying factories are Laugafiskur, Samherji, Hnotskurn,
and Thorungavinnslan. The last one specializes in drying seaweed and kelp. In all, about twenty factories air-dry cod head products, all except three using geothermal energy. One drying plant is using oil and another is using a heat pump system. A third one uses a heat pump extracting the heat from coolants from the freezing machinery. One plant uses geothermal steam for drying but most companies use geothermal water. Most of the drying cabinets are constructed for batch drying where cod heads are arranged on trays. Only two cod-head drying plants, including Thorungavinnslan, use conveyor-belt dryers.

There are also about fifty small drying plants for producing dried fish snack, which is a very popular delicacy in Iceland. Most of the small dryers are using geothermal energy. Full drying of cod heads indoors has been successful and the drying is divided into two stages, primary drying and secondary drying (Fig. 8). The cod heads are treated in three different ways prior to the drying (Arason et al. 1992).

**Primary drying** is done in a rack cabinet or a conveyor-belt cabinet. The rack cabinet is the most common with cod heads arranged in one layer on the racks where about 25 kg of heads can be arranged per square meter. The water content of the heads at the end of this stage is about 50-55%.

**Secondary drying** of semidried cod heads is conducted in drying containers with hot air blown through it. The water content of the cod heads after drying is about 15%, or the water activity of the products must be lower than 0.6, which is achieved after about 3 days in the drying container.

The greatest advantage of dividing the drying process is that relatively large quantities of cod heads may be placed in the secondary drying facilities than in the primary drying cabinets. The initial and operational costs of secondary drying are much lower than for primary drying, so the production cost is lower in a divided process.

It is also possible to extract the heat from the drying air, which is either blown out or recycled. The recycling of the heat is important, in particular in locations outside the geothermal regions. Results from a preliminary study at IFL indicate that up to 35% energy savings can be achieved by using heat exchangers, and up to 70% savings through the use of heat pumps.

**Primary air-drying: batch dryer, rack type**

The most common equipment for indoor drying in Iceland is a rack cabinet, the cabinets most frequently consisting of two tunnels with a pyramid in the center. The pyramid can be moved in such a way that if the cabinet is only half full all the airflow is directed through one tunnel. Air valves are inserted in the inlet and recycling outlets, but the regulation of the valves is controlled by the air humidity, measured at the opening of the cabinet (Fig. 9). A regulating valve on the hot water inlet connected to a thermometer, which is located at the same place as the humidity sensor, controls the temperature in the drying cabinet.
Figure 8. The figure shows how the weight of cod heads changes with time in indoor drying (Arason and Arnason 1992).

Figure 9. The construction of the rack drying cabinet.
One rack cabinet dryer with heat pumping system is in use in Iceland. The air is heated in the condenser and then blown through the cabinet. In the evaporator, the chilled air and the moisture, which was absorbed in the cabinet, is condensed before the air is heated again in the condenser. About 40% of the energy needed for heating is supplied by electricity and the other 60% comes through reuse of the condensing heat, which is released in the evaporator. The heat pumping systems can be of much use in warming where geothermal energy is not available. On the other hand, the initial capital cost is high, and since there is not much experience from these types of cabinets people have been hesitant to experiment with them.

**Secondary air-drying**

When a fish is dried in rack cabinets or in conveyor-belt cabinets, it is removed from the cabinet when the water content is about 50-55%. The fish is then placed in a drying container of 1-4 m$^3$ volume. The container is located on top of an air tunnel duct and the air is blown up through it. It is possible to pile 3-4 containers on top of each other (Fig. 10).

**Shrimp offal**

Shrimp offal constitutes about 50% of the shrimp. It contains protein, chitin, and the coloring agent astaxanthin, which is a necessary ingredient for salmon feeds. One company, Primex, produces chitin products from shrimp shell in Iceland. Chitosan is a biodegradable polysaccharide with a great application potential, ranging from flocculants in wastewater treatment and additives in foods and cosmetics to numerous technical and medical applications (Sikorski et al. 1995). Two companies produce shrimp meal in Iceland. Table 7 shows the different export categories from shrimp shell.

<table>
<thead>
<tr>
<th></th>
<th>Quantity (tons)</th>
<th>Value (thousand $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chitin</td>
<td>174</td>
<td>1,911</td>
</tr>
<tr>
<td>Shrimp meal</td>
<td>612</td>
<td>328</td>
</tr>
<tr>
<td>Total</td>
<td>787</td>
<td>2,239</td>
</tr>
</tbody>
</table>

The Icelandic AVS project
The Icelandic Ministry of Fisheries’ priority project on added-value for marine catch is called the AVS project. Although the government intends to play an important part in the AVS project of adding value to the catch, the industry will play the most important role and must lead the way. The most important areas of that growth are likely to be in the areas that are relatively small now. For potential growth in seafood value in 2007 and 2012, see Fig. 11.

The future
One thing that all agree on is that there is not an endless amount of fish in the sea and therefore we need to manage our fisheries better than in the past. There are many ways in which it is possible to optimize fisheries management. It is, however, unlikely that we can increase the catch of wild fish but we can increase fish farming. Furthermore, there are many ways to increase the value of our catches.

Annual discard from the world fisheries has been estimated to be approximately 25% of the total catch. Utilization is driven by economic factors. The conditions onboard the vessels are currently not optimized for a cost effective utilization. Therefore, the main challenge will be to build knowledge of (1) the market potential of the different byproducts and (2) which processes, for practical reasons as well as preservation, should be done onboard the vessel and which on shore.

Increasing the proportion of the catch intended for human consumption and other value added products (pharmaceuticals, feed ingredients, etc.) would increase the profitability and reduce the amount of “waste.” In order to achieve this it is necessary to:

- Develop systems to sort and handle the byproducts on board.
- Find safe and cost-effective preservation methods.
- Improve logistics to get the byproducts from the vessels to the processing plants.
In order to upgrade the byproducts, more knowledge is needed on the chemical composition, including seasonal variation, of the fishery stocks. This is necessary in order to find effective and safe preservation and storage procedures and to find biomolecules with possible application in the food, feed, and pharmaceutical industries (Fig. 12).

More knowledge is also needed on processing methods to extract the interesting fractions/biomolecules. Finally, there is a need to study the market for these compounds. Byproducts contain components with applications in food, healthcare products, pharmaceuticals, and cosmetics. Screening of the valuable components and an evaluation of the market situation for each component are needed.

The use of geothermal energy for drying of fish products is likely to increase in the future. The interest in Iceland is mainly focused on the use of geothermal energy in low-heat regions. The fish meal industry is likely to use geothermal steam in the processing within a few years. It can be expected that the price of oil will increase more than the local energy in the future, and therefore it is worth paying attention to the use of locally available energy sources for the fishing industry. New, feasible alternative uses of geothermal energy are within sight, such as in freeze drying of food. Equipment designed for drying fish can also be used for drying other industrial products.
**Figure 12.** There are many interesting possibilities for byproducts from fish.

### References


