Biorefining and Biotechnology Opportunities in the West Nordic Region

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Report summary

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Titill / Title	Tækifæri tengd fullvinnslu lífmassa og líftækni á Vestnorræna svæðinu / **Biorefining and Biotechnology Opportunities in the West Nordic Region**
Höfundar / Authors	Bryndís Björnsdóttir[1], Margrét Geirsdóttir[1], Elísabet Eik Guðmundsdóttir[1], Guðjón Þorkelsson[12], Rósa Jónsdóttir[1], Gunnar Þórðarson[1], René Groben[1], Stephen Knobloch[1], Aviaja Lyberth Hauptmann[3], Janus Vang[4], Ingunn Gunnarsdóttir[5], Ragnar Jóhannsson[1], Lisbeth Due Schönemann-Paul[6], Sigrún Elsa Smáradóttir[1] [1]Matís, [2]University of Iceland, [3]Ilisimatusarfik – The University of Greenland, [4]Research Park iNOVA – Faroe Islands, [5]The Environment Agency of Iceland, [6]Royal Greenland A/S
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Verknr. / Project no.	4005-2355
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Ágrip á íslensku:	Vestnorræna svæðið býr yfir miklum tækifærum til bættrar nýtingar, sjálfbærni og aukins virði lífrænna auðlinda. Þessi skýrsla ber kennsl á helstu lífrænu auðlindir svæðisins sem henta til fullvinnslu (e. biorefining) og notkunar líftæknilegra tóla. Skýrslan greinir frá verðmætum innihaldsefnum helstu lífauðlinda svæðisins, ásamt þeim vinnsluaðferðum sem beitt er eða hægt er að beita á þær og telur upp ýmsar lokaafurðir sem hægt er að framleiða með frekari fullvinnslu. Í skýrslunni er yfirlit yfir þá starfsemi sem nú er í gangi og þær afurðir sem framleiddar eru á svæðinu með fullvinnslu og líftækni. Lífrænum auðlindum er skipt upp eftir því hvort þær teljast hliðarafurðir, upprunnar í vatni eða á landi, eða vannýttar auðlindir. Athygli er beint að sérstökum tækifærum og hindrunum tengdum Vestnorræna svæðinu.
Lykilorð á íslensku:	*Vestnorræna svæðið, líftækni, fullvinnsla lífmassa, verðmætasköpun, hliðarafurðir, vannýttar auðlindir*
Summary in English:	The West Nordic region holds promising opportunities to improve utilisation, sustainability and value from its biological resources. The region's major bioresources available for biorefining and biotechnological applications are the focus of this report. It identifies valuable ingredients in the different resources, processing technologies which are or may be applied, and possible end products obtained from further processing the raw material. An overview of the current operations and products which are being produced within the region is given. The report divides the available bioresources into biodegradable residues of aquatic or land origin and underutilised biomass. High-north specific opportunities and obstacles are highlighted.
English keywords:	*West Nordic region, biotechnology, biorefining, value creation, sidestreams, underutilised resources*

Summary in English

The West Nordic region holds promising opportunities to improve utilisation, sustainability and value from its biological resources. The region's major bioresources available for biorefining and biotechnological applications are the focus of this report. It identifies valuable ingredients in the different resources, processing technologies which are or may be applied, and possible end products obtained from further processing the raw material. An overview of the current operations and products which are being produced within the region is given. The report divides the available bioresources into biodegradable residues of aquatic or land origin and underutilised biomass. High-north specific opportunities and obstacles are highlighted.

Summary in Danish

Den Vestnordiske region har mange muligheder for forøget udnyttelse, bæredygtighed og værdi af biologiske ressourcer. Denne rapport identificerer områdets vigtigste organiske ressourcer, der er egnet til biorefining og bioteknologiske anvendelser. Den identificerer værdifulde ingredienser i de forskellige ressourcer, forarbejdningsteknologier, som anvendes eller kan anvendes, og mulige slutprodukter, der opnås ved yderligere behandling af råmaterialet. Der gives en oversigt over de aktuelle operationer og produkter, der produceres i regionen via biorefining og bioteknologi. I rapporten opdeles de tilgængelige bioresources efter om de betragtes som biprodukter der stammer fra vand eller på land, eller udnyttede ressourcer. Der lægges vægt på særlige muligheder og hindringer i forbindelse med den Vestnordiske region.

Contents

1 Introduction

Sustainability is a key issue for the West Nordic region, consisting of Iceland, the Faroe Islands and Greenland. The bioeconomy of the West Nordic countries is a large part of the gross domestic product (GDP) value and further developments of sustainable bioresource-based industries and responsible utilisation will strengthen the economies of the three countries. An important focus for the region is the creation of multiple value streams from bioresources, to improve processes and to develop and apply new technologies, alongside minimising waste and maximising value. For this, technological knowhow and transfer, as well as cross-national collaboration between research, industries and governments is important. The blue bioeconomy, utilising aquatic biomass, is very important for the West Nordic region as marine resources play a central role for the economy of all three countries and this calls for a close cooperation within the region. This has led to the establishment of the West Nordic Bioeconomy panel (www.wnbioeconomy.com), a platform for promoting common policies and for setting common strategies for the region.

This report focuses on the bioresources of the West Nordic region, suitable for biorefineries and biotechnological applications. It focuses on sidestreams, underutilised biomass and unique conditions and resources within the region. It provides information on the major processes applied to different bioresources and highlights possible end products and opportunities. Suggestions on prioritisation of technology developments, value streams and valuable products are given.

Biorefining and biotechnology are central processes in improved utilisation and value creation of bioresources.

Biorefining is the sustainable processing of biomass into various biobased products; food, feed, bioactive compounds, chemicals and materials, and bioenergy; biofuels, power and heat.

Biotechnology refers to the use of living organisms or biological substances, such as enzymes, for manufacturing and/or processing purposes. The applications may produce a vast range of biological compounds such as platform chemicals, biofuels, pharmaceuticals, nutraceuticals and speciality foods.

This report is a part of the Arctic Bioeconomy II project. The project is an important addition to the previous mapping and opportunity analysis of bioresources and utilisation in the high north conducted within the previous project Arctic Bioeconomy; Future Opportunities in the West Nordic Countries (Jörundsdottir et al. 2015).

The report maps and analyses biorefining and biotechnology opportunities within the West Nordic region for increased sustainability and value creation. The outcome gives a basis for development of biotechnology strategy in the West Nordic countries and the report is intended as a supporting document for the ongoing strategy program development of the West Nordic Bioeconomy panel. Strategy on sustainable utilisation of resources in harmony with nature and society, at the same time as maximising their value, is very important and a well-grounded strategy will be essential for the establishment of a strong and competitive biotech industry within the region. The report may also benefit regional authorities, Nordic institutes and committees and biotech companies within the region. The end goal is to contribute to the growth of the Arctic bioeconomy through development of sustainable bioresource-based technology industries, for building stronger and more diverse communities within the West Nordic countries.

This work was funded within the Arctic Bioeconomy II project, supported by the Nordic Council of Ministers, Arctic Co-operation Programme and AG-fisk.

Partners within the project:

Iceland	Faroe Islands	Greenland
Matis The Environment Agency of Iceland	Syntesa Research Park iNOVA	Ministry of Fisheries and Hunting

2 Biodegradable residues

The term biodegradable waste refers to a large range of bio-resources, such as household and garden waste, agricultural and fisheries/aquaculture residues, manure, sewage sludge, forestry residues, natural textiles, paper, and processed wood. However, effort should be made to refrain from using the term waste in this context and to replace it with terms such as residues, rest raw materials, by-products and sidestreams, to emphasise that value can be made from utilisation of the biomass. The Environment Agency of Iceland (EAI) has published a report summarising the mapping and quantification of biodegradable residues in the West Nordic region, with emphasis on the fishing and meat industry (Kristinsdottir and Gunnarsdottir 2016). This mapping is hoped to support innovation and value creation from biodegradable residues within the region, as well as further promote the sustainable use of bioresources. In 2013, biodegradable residues in Iceland were estimated at 251.000 tons, of which around 155.000 tons were reused/recycled and 96.000 tons were put into landfill or incinerated. Further analysis based on information provided by waste receiving stations in Iceland from 2013, excluding mixed residues, timber, paper, cardboard and textiles, demonstrated that the largest quantity of biodegradable residues came from the meat industry, fish industry, as well as from gardens and canteens/kitchens (Kristinsdottir and Gunnarsdottir 2016). Data on biodegradable residues is not readily available from the Faroe Islands and Greenland. There, most biological sidestreams are currently incinerated, often for power generation. However, sidestreams from fishing industries and to some extent meat production are important contributors to the biodegradable residues in Faroe Islands and Greenland, in addition to household residues and sewage sludge (Kristinsdottir and Gunnarsdottir 2016). The EAI report (Kristinsdottir and Gunnarsdottir 2016) points out that there are ample opportunities for improved utilisation of biodegradable residue resources in the West Nordic region and for creation of new value streams from these resources, especially from the meat and fishing industries. However, the report concludes that in order to facilitate better utilisation and value creation, data collection and availability of the available bioresources (biodegradable residues) based on type, quality, location, time and quantity needs to be available for the region. Such a task has now been initiated by the EAI, where a web-based information and market place will be established, connecting biomass side-product providers and users, as well as collecting data on the availability of different biodegradable residue resources.

2.1 Biodegradable residues of aquatic origin

2.1.1 Fisheries and aquaculture

Marine bioresources are the most important biological resources in the West Nordic region (Jörundsdottir et al. 2015). Therefore, a substantial part of the biotechnology innovation opportunities for the region lie within the innovation and added value creation of marine biomass, especially fish. Innovation through biorefining and biotechnology applications, as well as technology, research and development investments are hugely important for increased value through creation of innovative and novel products. There should be considerable focus on marine bioresources, a clear strategy for R&D and commercialisation of products. A demonstration plant (and support/investors) is needed to bridge the gap between research and commercialisation.

Evaluating the amount of available raw materials is difficult. If cod catch in Iceland is taken as an example, the total cod catch in 2016 was around 249.000 tons (Hagstofa Íslands 2017). The ratios of the different parts of the cod when producing skinless and boneless fillets are as shown in Fig. 1. The expected amounts of the different parts from cod can then be calculated based on those values (Table 1).

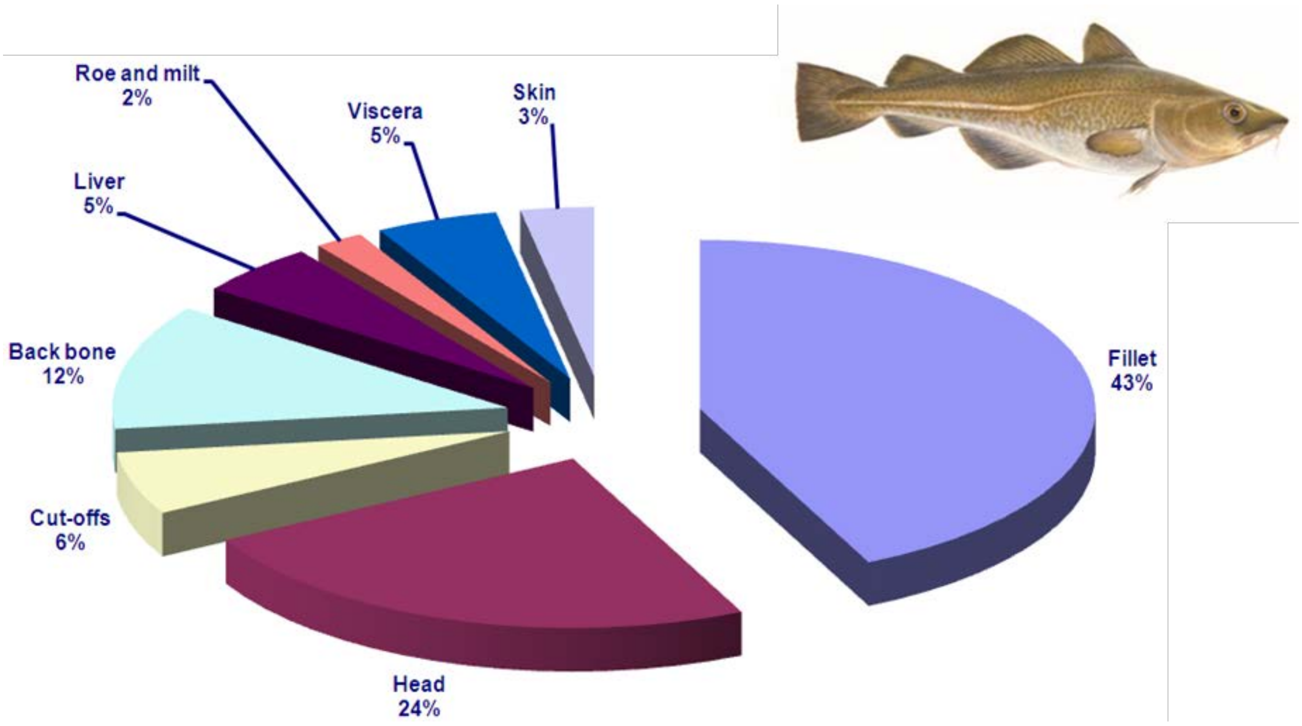

Figure 1. Ratio of raw materials in cod during production of skinless and boneless fillets (Arason et al. 2009).

Table 1. Quantity of raw materials from caught cod in Iceland 2015.

Product	Ratio of whole cod (%)	Quantity (tons)
Fillet	43	107.070
Cut-offs	6	14.940
Head	24	59.760
Backbone	12	29.880
Liver	5	12.450
Roe and milt	2	4.980
Skin	3	7.470
Viscera	5	12.450
Total raw material	**100**	**141.930**

The major resources of raw materials include cut-offs from fish processing, such as heads and backbones, guts, blood and fish skin. From those, enzymes, lipids and proteins can be isolated. Furthermore, fish contain many other nutrients like Vitamins A, D and B12 as well as trace elements such as Zinc, Calcium, Iron, Iodine and Selenium. Pelagic fish can also be used for extraction of the above mentioned ingredients and used into wider selection of products than the traditional fishmeal and oil productions. Thereby, wider grounds for their sustainable use can be established and for higher prices.

All bio-based industries value chains are facing several challenges and risks (Figure 2). The challenges that marine bio-based industries in the Arctic face are even greater than applies for other industries in the field. At all stages, the use of those raw materials face several risks and challenges:

Feedstock supply can be seasonal and unreliable due to weather conditions and seasonal changes in fish stock size.

The supply chain tends to be fragmented and insufficient infrastructure makes transport of raw materials hard, especially where fishing and landing is distributed over large areas with long distances in-between in the Arctic. Seafood, as growing in cold environment, is especially vulnerable to temperature changes and needs to be kept cold and be processed as soon as possible.

Biorefineries call up on **heavy investments**, there are **technological risks** in relation to them and **regulation constrains** can be a burden.

There are also challenges and risks on the product end, including product delivery risks, product development risks, consumer acceptation and product specification.

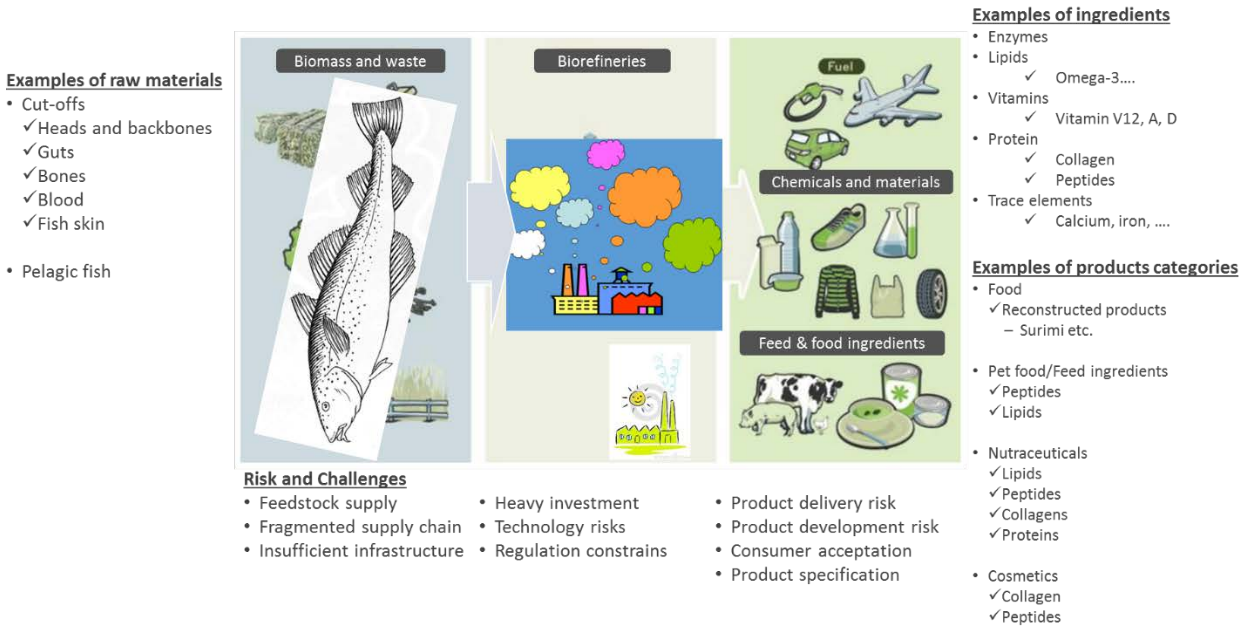

Figure 2. Fish rest raw material biorefinery value chains, challenges and risks. Figure adjusted from Iturralde (2016).

A short description of each of the rest raw materials from fish processing is listed below. A more detailed information can be found in the report By-products from whitefish processing (Jónsson and Viðarsson 2016).

Fish liver; mainly from cod, used for production of fish liver oil and for canning.

Roes; cod roes are sold frozen and salted. Same applies for roes from Lumpfish, capelin, salmon and other species.

Milt; currently milts are not used for production and are not brought to shore. Cod milt is a product that is a part of traditional Japanese cuisine. Some years ago, companies produced milt as a canning product but the global market was very difficult and no production is ongoing now.

Fish head; fish heads are sold dried. There is also a market for parts of the fish heads like fish faces, tongues and cheeks which are sold either salted or frozen. The market for dried fish heads has reduced in the past years.

Frames, backbones and collars; same applies for frames, backbones and collars as for the fish heads, they have been sold dried to Nigeria but the market has reduced. These materials are discarded from fishing vessels but collected and dried in land based production.

Bones, process water, blood, eyes, gall bladder and swimming bladder; those parts of the marine raw materials are not used at all today.

Fish viscera (offal); today fish silage is processed from fish viscera by some companies in Iceland but mainly sold to Norway for further processing. Viscera is also used to produce enzymes and used in products like Penzim, a skincare product, and PreCold, a mouth spray against common cold, both processed by Zymetech.

Combined fish offal used as fuel; fish offal could potentially be used for production of biofuel and methane.

Fish skin; especially salmon skin can be used directly after processing, usually dried or fried. Some biotechnological products are already on the market. Cod skin is being processed by the Icelandic company Kerecis and sold as skin plasters for treatment of wounds and skin problems. The protein collagen can be extracted from fish skin and used as gelatine. It can be further processed to collagen hydrolysates and used as an ingredient in food products, supplements, cosmetics and nutraceuticals. The Icelandic company Codland is planning to start collagen extraction production in Iceland in the near future. Furthermore, fish skin is processed into leather for fashion items in Iceland.

A feasibility study, Everything Ashore (Laksá et al. 2016), outlines the economic possibilities of bringing the entire biomass from selected fisheries ashore. The study demonstrates the potential of increased value if the biomass discarded today is brought ashore as sorted landings. A reform of the Faroese fisheries management made in 2017 mandates the landing of heads and frames from demersal fisheries in Faroese waters, with a future goal of landing the entire biomass from demersal fisheries. The feasibility study (Laksá et al. 2016) identifies three main actions to stimulate actions of bringing the biomass ashore in the West Nordic region: removing regulatory obstacles to vertical integration, government incentives (tax cuts etc.) and government mandates.

Products

Several biotech products based on biomaterials from fisheries and aquaculture are already on the market or in development as previously mentioned. It is of interest that the success stories that we have in the field are mostly spin-offs from research units, such as Protis (spin-off from Matís, Icelandic food and biotech R&D company), and Zymetech (spin-off from the University of Iceland). While others like Codland, Lýsi, Dropi, Primex, Margildi and Genís have worked in close relation to research units and universities. Examples of products that are on the market can be seen in Figure 3.

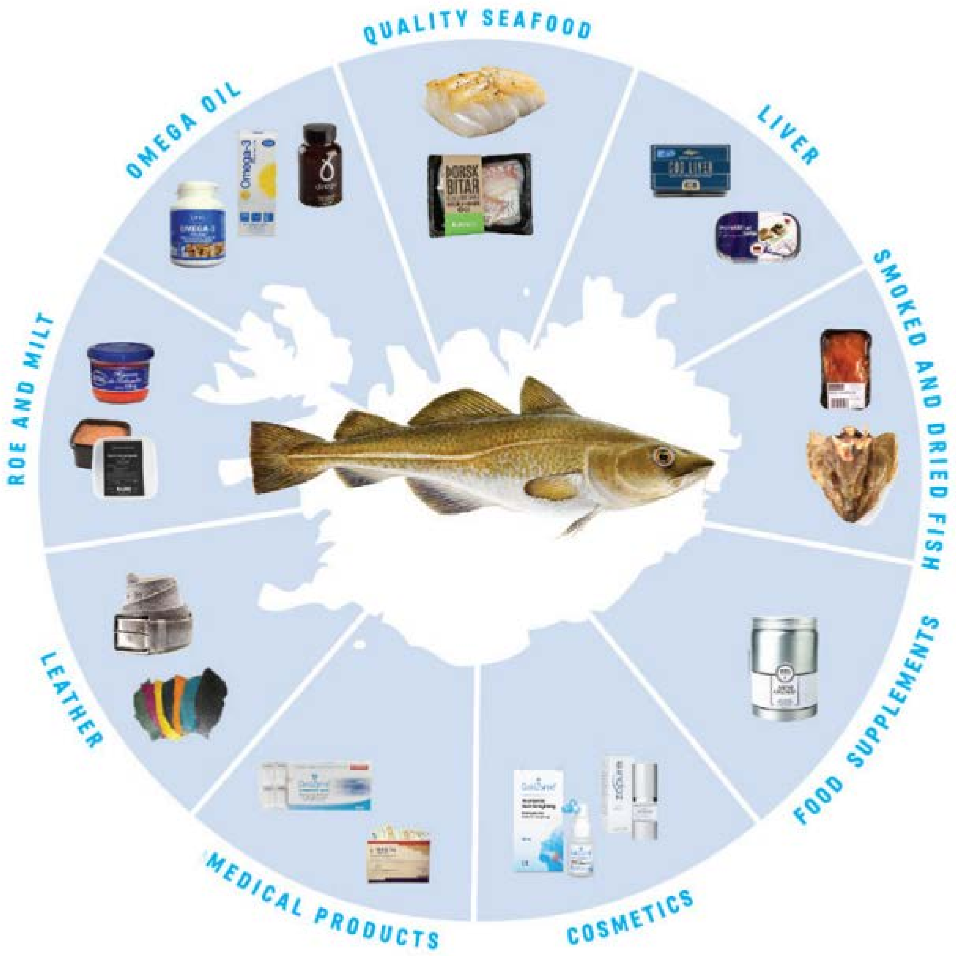

Figure 3. 100% Fish – Iceland Fish and Ships. Figure published with permission from the Iceland Ocean Cluster (2016).

The principal component in most of the raw materials mentioned above are proteins that can be broken down into smaller units, peptides, by use of enzymes. Many studies have reported that peptides can be used as antihypertensive, antioxidative, anticoagulant, and antimicrobial components in functional foods or nutraceuticals and pharmaceuticals in the treatment or prevention of diseases (Kim and Wijesekara 2010; Geirsdottir et al. 2011; Harnedy and FitzGerald 2012; Halldorsdottir et al. 2014). Peptides made from marine raw materials have shown to have those activities, in some instances higher activities than peptides made from other raw materials.

Isolating proteins from different raw materials and using enzymes to break down the protein structure into smaller units may yield a variety of products for different markets. Enzymes can also be used directly on some raw materials without prior protein isolation, for example on fish frames.

Possible applications of fish protein hydrolysates include:

- Flavour enhancer
- Salt and monosodium glutamate (MSG) replacer
- Milk replacer
- Protein enrichment (i.e. for sport drinks)
- Pet food
- Bioactive ingredients
    - Functional food ingredients
    - Antioxidant

The company Protis in Sauðárkrókur has recently started production and marketed a product from fish protein hydrolysates. Codland in Reykjavík is aiming at processing collagen hydrolysates from fish skin. Both Codland and Protis are owned by big fishing companies in Iceland, Fisk seafood and Visir/Thorfish, ensuring good raw material control for the production.

Another interesting product is to use fish bones for calcium production (Bubel et al. 2015). Research *in vivo* in pigs has shown good results indicating that calcium from fish bones can be used as a supplement (Malde et al. 2010).

A project at The University of Greenland, Ilisimatusarfik, is looking into the potential of using bacterial strains from locally and traditionally dried fish for prolonging shelf life of industrial fish products in collaboration with Royal Greenland. The project is also assessing the pre- and probiotic potential of traditional Greenlandic foods with particular focus on fish. While these are not side products of the fishing industry they represent research-based opportunities within the fisheries sector. In Greenland, efforts are being made to connect industry and research within the food sector through cluster development currently lead by Sermersooq Business Council, Nuuk.

Suggested actions

As stated above proteins are the most promising single component that should be aimed at in the next steps. Other important products are calcium production from bones and better use of silage as fertilizer.

Further developments in processing and value creation from fish rest raw materials are hindered by three factors; lack of access to good pilot plant facilities to test and develop products and ideas, need for good *in vivo* tests to verify product claims, and support product marketing.

Setting up a pilot plant unit is very costly, and financing of development and trials is difficult for small producers. An open access, publicly supported biorefinery for testing at pilot plant level is especially important for the Marine Biotechnology (MBT) Industry and other Arctic Bioeconomy projects. An MBT pilot plant should be equipped for raw material handling like cutting and mixing, reactors that can be heated and cooled, mixing containers for hydrolysation and fermentors. Furthermore, centrifuges for removing lipids and/or sediments, filtration units for fractionation and dryers. Also, cooling and freezing devises for raw materials and products. Location needs to be carefully chosen in relation to access to water, power, transport etc. and the possibility of a mobile biorefinery should be considered. The Bio Base Europe Pilot Plant located in Gent in Belgium is an example of a large and modern pilot plant unit (www.BBEU.org /).

2.1.2 Crustaceans

Sidestreams from fishing and farming of crustaceans, mainly shrimps, lobsters and crabs, can be valuable for biotechnological processing purposes and there is a substantial shrimp industry within the West Nordic region. In several of the major fish-producing countries, by-products are a problem for the fishing industry, meanwhile constituting an important source of proteins, lipids, enzymes and carotenoids. Shrimp processing generates considerable quantities of solid residues in the form of head and body carapace, up to around 60% of the total raw material. Sidestreams from processing of crustaceans were considered as waste but recently they are increasingly being considered as a side product material, valuable for biotechnological processing purposes. For an area like the West Nordic region, considerable amounts of shells are generated as side products from processing and wastewater from factories contains substantial amounts of biomaterials. With changes in waste legislation, shellfish residue management has become increasingly difficult and expensive. This has significantly affected the shellfish processing sector, particularly the crustacean sector as there is a lack of cost-effective outlets for their biological residues.

Icelandic companies are currently utilising a good share of by-products coming from shrimp processing factories and generating valuable products from it. Primex in Iceland produces chitosan from shrimp shells and sells in bulk for nutritional, cosmetic, food and biomedical applications. Primex has also developed and marketed specialised chitosan-based products for weight management, human and animal health, wound care and water treatment worldwide as well as for local Icelandic markets. Current trademarks are ChitoClear®, LipoSan Ultra®, ChitoCare® and SeaKlear®. Genis hf, also located in Iceland, produces short chain chitosan derived from shrimp shells and sells as an innovative, natural health supplement, called Benecta. In Greenland, large quantities of shrimp shells are discarded each year (Kristinsdottir and Gunnarsdottir 2016) where isolation from markets is a major hindrance of utilisation. Meal based on shrimp residues is becoming more desirable for the animal feed production than before and indicates that use of shrimp meal blended with other protein rich fish meal or vegetable meal can improve animal growth and the health of livestock as well as improve the colour of the product (Fanimo et al. 1996). This is important because these markets pay higher prices and are more reliable than fish feed markets, which have been the main markets for shrimp meal until now. The astaxanthin pigment in shrimp meal has been of interest to salmonid farmers but low protein content of the biomass has been a drawback.

Shrimp processing by-products used to be an environmental problem in the Icelandic shrimp industry. In Ísafjörður in Northwest Iceland, the shrimp processing factory Kampi has set up a simple meal factory. The process is only a one-man operation with minimum cost. In a large shrimp factory owned by Royal Greenland at Ilulissat, this solution has also been used for some time, processing additives for human consumption (Nordic Council of Ministers 2017). The Kampi factory is profitable, generating value and saving substantial cost of disposal. The meal is graded into two products, shrimp meal and larger shell pieces. The shrimp meal is sold for animal feed production in Australia. It contains around 40% protein and astaxanthin levels have been measured from 3.5 to 8.5 mg/kg. Larger shell pieces are sold to Genis in Iceland, using it as raw material for their production.

Matís has researched the outflow of processing water from the Kampi shrimp factory (Thordarson et al. 2013). The outcome showed that in a 10-hour shift around four tons of material, mostly protein, was collected. This material was collected from enormous amounts of water but efficient and reliable equipment was not commercially available for this process.

If this protein would be collected and used for shrimp meal production, the protein content would increase and the product would be more valuable and desirable for animal feed production.

There are enormous opportunities for the West Nordic countries to improve environmental issues by preventing the discard of biological residues and for making valuable products at the same time. Biological materials discarded into the environment are harmful as they induce undesirable anaerobic bacterial growth that produces harmful waste products, as well as resulting in nutrient enrichment of the marine environment. New ideas and technological developments are needed to use less water in the processing of marine biomass and to prevent protein washout during production. This will lower production costs and reduce protein loss, hence increasing value. Collecting materials that are currently discharged and turning them into profitable products is beneficial, as well as potentially reducing the amount of disposed organic material by 34% (Valsdottir et al. 2005). For West Nordic countries, which are heavily relying on fisheries and fish production, new developments in filtering and processing technologies will be of importance in the future.

With protein being an important ingredient in processing of marine crustaceans, there are opportunities to make more value from shrimp factory side products in the future. Shrimp shells are rich in carbohydrates, where chitin is a major constituent. Other major components in crustacean shells are proteins and calcium carbonate (Kurita 2006). Chitin, the structural element in the exoskeleton of crustaceans, is found widely in nature and crustacean shells are among the most easily accessible sources of chitin. Chitin is a polysaccharide composed of N-acetylglucosamine units and chitosan is a deacetylated derivative of chitin. Chitin and chitosan are valuable for a range of biological, physiological, and pharmacological applications (Kurita 2006; Cheung et al. 2015). They are known to have antimicrobial, immune enhancing, and tissue regeneration activities (i.e. cartilage, bones and tendons) and can reduce inflammation. Chitin may also be hydrolysed to glucosamine and sold as a dietary supplement. Chitosan is an important ingredient in the pharmaceutical industry for instance; forming tablets, microspheres, micelles, vaccines, hydrogels, nanoparticles and conjugates. Its derivatives are used in the drug delivery business, both to be implemented by transplant and injectable system through oral, nasal or ocular routes. It is also one of the most efficient materials for treatment of contaminated water, but its amino and hydroxyl groups allow for adsorption of contaminants polluting water, like dyes, metals and organic compounds. These functional groups are also subject to modifications (cross-linking and grafting) that enhance the absorption efficiency and specificity (Kurita 2006).

Substantial research has been done on chitosan regarding tissue engineering, drug delivery, wound healing, and water treatment, antitumor and antimicrobial effects. Chitosan is also marketed as a dietary supplement or nutraceutical for cholesterol control and weight management, as a natural fibre it can enhance satiety feeling once in the stomach, bind to dietary fats to reduce their assimilation, without being digested in the gastrointestinal tract. Chitosan is a biodegradable and inexpensive polymer, valuable for the biomedical and pharmaceutical industries.

Chitin can be moulded into anatomical shapes biocompatible with biological fluids and tissues; as well as providing temporary mechanical support. These properties fit the special properties of a tissue engineering scaffold. Chitosan demonstrated antitumor activity in terms of a therapeutic agent and a drug carrier (reviewed by Cheung et al. 2015).

Chitin and its derivatives are processed by acid and alkali decomposition of the shrimp shell and protease treatment may be applied for protein removal. Chitosan is produced by chitin deacetylation using alkali solutions. End-products need to be highly purified if they are to be used for biomedical or pharmaceutical purposes.

Another important ingredient found in shells of marine crustaceans and which is commercially valuable is astaxanthin, a carotenoid pigment, used as a natural colourant in fish feed as well as for its antioxidant activities (Sila et al. 2015). Carotenoids are lipid soluble pigments found in the photosynthetic protein complex of phytoplankton and algae. They are important in animal metabolism, as well as being the chemicals responsible for giving fish and shellfish their red and pink colouring, taken up in the diet. Astaxanthin is the most commercially important pigment used in farmed fish, particularly salmon and pigments can account for up to 25% of feed costs. EU regulations limit the amount of synthetic colourant that can be added to fish food, creating a market for natural colourants.

Shrimp residues are one of the most important sources of natural carotenoids. The recovery of these valuable components from the residues would not only improve the economy for shrimp processors, but would also minimise the pollution potential of the residues. The major carotenoids found in crustaceans are astaxanthin and its esters. Astaxanthin has beneficial effects supporting human health and well-being and by preventing pathologies (Ambati et al. 2014). Significant antioxidant activity has been ascribed to astaxanthin, based primarily on experimental findings (Sila et al. 2015). Astaxanthin is present as an ester in crustacean residues at low levels 50 – 200 mg/kg. Pigments may be extracted from shellfish residues during chitin and chitosan production. Most sources of pigments are currently either chemically synthesised or obtained from none marine sources. Extraction of astaxanthin from shrimp sidestreams is a complex chemical process. Carotenoid pigments (astaxanthin) may be extracted with different processes, such as using non-polar solvents, pressure, supercritical carbon dioxide extraction and/or enzymes.

Crustacean shell by-products may furthermore be processed using heat, fermentation and enzymes for flavour component extractions, such as for soups and stocks.

2.2 Biodegradable residues from agriculture, industries, households and municipalities

Underutilised raw materials from agriculture, industries, households and municipalities can be looked upon as streams of valuable terrestrial resources for producing different types of products.

Just over 2 million cubic metres of hay and 4.700 tons of barley were harvested in Iceland in 2015. Three farms have started producing rape in usable amounts. Production of potatoes was 9.000 tons, turnips and carrots 1.750 tons and indoor production of cucumbers, tomatoes, mushrooms and paprika about 3.900 tons. Production of meat was 17.000 tons and about 135 million litres of milk were produced (http://www.statice.is/). There are about 60 farmers in the Faroe Islands producing 7.5 million litres of milk, beef and mutton. There are also 2-3.000 part time sheep farmers there. The Faroe Islands are self-sufficient with milk and produce about 60% of the demand for mutton (http://caa.lbhi.is/Faroe%20Island.aspx). In 2013 there were about 20.000 sheep, 3.000 tame reindeer, 125 cows, 132 horses and 191 fowl in Greenland (Statistics Greenland).

2.2.1 Biodegradable residues from primary production in agriculture

Biodegradable residues from primary production in agriculture include:

- Hay leftovers and residues from milling of barley and rape and oil pressing of rape seeds.
- Manure from animal husbandry; residues of compost in mushroom production.
- Horticultural harvests not utilised as food.

Agricultural University of Iceland in collaboration with Sorpa B.F; Metan hf (waste management) and the engineering firm Mannvit studied options for utilising organic residues from agriculture in Iceland.

The collaboration included:

- Construction of pilot fermentation and gas purification facilities.
- Mapping of available and suitable areas for integrating land reclaim and cultivation of plants for diesel and gas production.
- Production of methane from manure from animal husbandry in Eyjafjörður.
- Options in the utilisation of slaughter residues. Biogas, compost or landfill?
- Methane production at farm level. A study using four different farming systems as models.

The questions asked and answered in the study were:

Which raw materials are available? Where are they and how much of them is there? Could the production be environmentally, economically and energetically viable? How should the resources be used? It was concluded that:

- Small size of farms and long distances between them and low energy prices make practical biogas production impossible in most regions.
- In Eyjafjörður there is enough manure both in quantity and quality to support a centralised biogas plant.
- A pilot study on a farm with 700 sheep and poultry breeding with seven 2.700 birds cohorts/year showed that the residues from poultry breeding could support the heating of the poultry house.

- A dairy farm with 70 cows and 100 other cattle and 160 tons of barley harvested each year and a 25 kW hydroelectric power plant could provide enough energy either for drying the barley or substituting 17 tons of diesel oil.
- Pig farm with 160 sows and 1.000 piglets, 40 cows and 30 sheep and 400 tons of barley provides enough manure both for drying of the barley and substituting 46 tons of diesel oil. Including cow manure would produce surplus energy.
- Abandoned hayfields could provide more than all the fuel used at a farm with 250 sheep.

Stepwise adoption to biogas production was proposed and is shown in Figure 4.

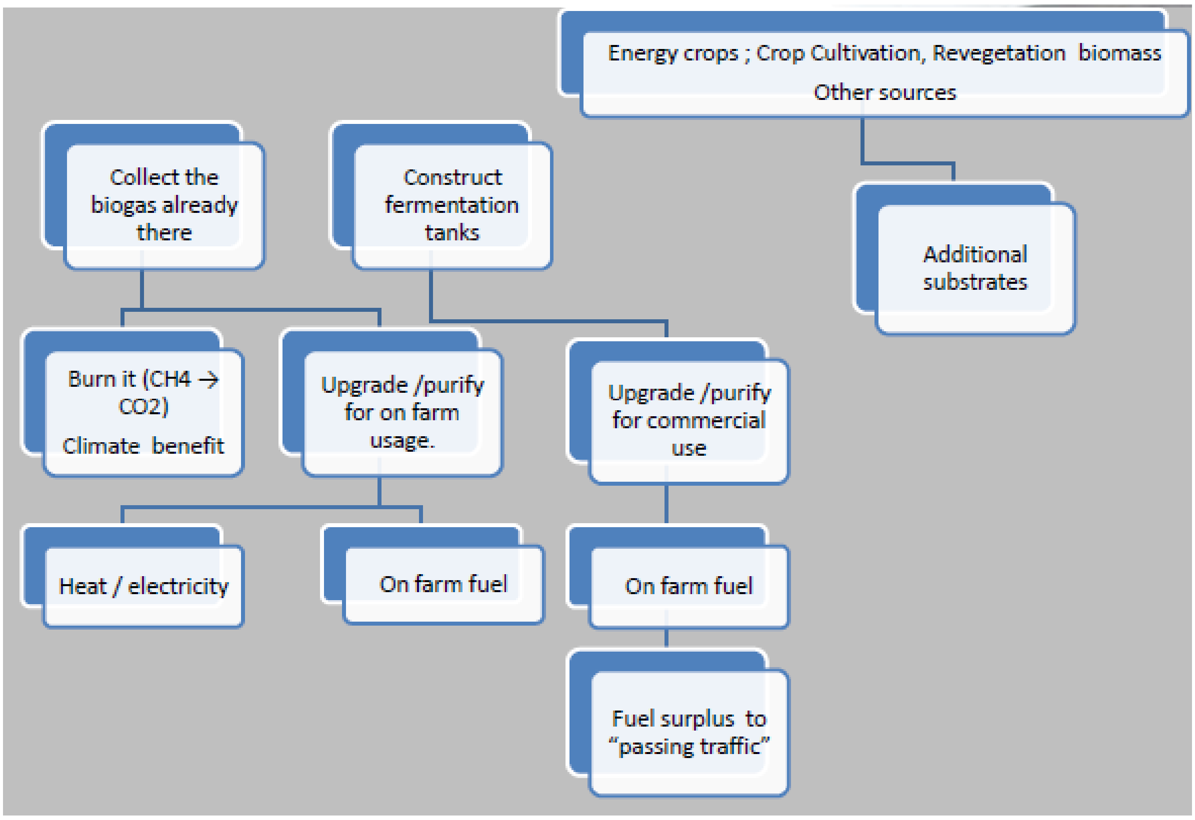

Figure 4. Possible stepwise implementation of utilisation of organic residues from agriculture in Iceland for biogas production. Figure from Gudmundsson (2010).

Enhancing "organic" agriculture would increase the utilisation of biodegradable sidestreams from Icelandic agriculture. Increased use of agricultural sidestreams in compost, later to be utilised as fertiliser on traditional hay- or cornfields and on eroded land for reclaim would be even more effective. It would also reduce the import of synthetic fertilisers. A third option is to increase the utilisation of barley and rape milling by-products into fish feed etc.

2.2.2 Dairy processing by-products

Mjólkursamsalan (MS) is the biggest processor of milk in Iceland. It has five dairies processing about 110 million tons of milk every year. Mjólkursamlag Kaupfélags Skagfirðinga is the second biggest processor of milk in Iceland and owns a small dairy; Mjólka. It processes about 20 million litres of milk each year. These dairies serve the main wholesale and retail market in Iceland. In 2015 they exported dairy products amounting to ca. 5 million litres of fresh milk, 994 tons of skyr were exported and about 500 tons of skim milk powder (Samband afurðastöðva í mjólkuriðnaði 2016; http://sam.is/Files/Skra_0074967.pdf).

There are smaller dairies serving niche markets like Arna with lactose free dairy products and Biobu processing organic milk. About 11 on-farm dairies produce fresh and fermented milk, cheeses, ice cream and confectionery. It is roughly estimated that they process 3 million litres of milk every year.

Mjólkavirkið is the only dairy processor in the Faroe Islands producing fresh milk, cream, fermented products and products with long shelf life from 7.5 million litres of milk.

Increased yield of raw milk into products, reduced energy use and less disposal of residues are the environmental goals of the dairy industry in Iceland. Improved use of by-products like cheese whey and acid whey from producing fermented product like yogurt, skyr and from cheese making is the most important challenge when it comes to improving yield and decreasing residues in the dairy industry.

Better utilisation of whey in the dairy industry abroad and in Iceland over the last 30-40 year is the best example how to turn by-products into valuable products. Sophisticated techniques like reverse osmosis and membrane filtration can first isolate and concentrate chemical components like whey proteins. Separation and treatment with enzymes can turn them into smaller fractions with properties that can tailor make them for certain food applications or for food supplements or functional foods.

Proteins in skyr whey are isolated and recirculated into the skyr resulting in improved yield and better texture of the product. Lean cream is concentrated proteins from cheese whey. It is the main ingredients in the sports drink Hleðsla.

Equipment for protein processing is expensive and needs to process large amounts of whey to be economically and technically viable. A new whey protein plant in Sauðárkrókur, processing 40 million litres of cheese whey is the key to new developments in this field in Iceland. A range of protein ingredients will be produced and utilised in various food and drink applications. They can also be hydrolysed under controlled conditions to produce food supplements or functional foods to different target groups. The research and development focus should be here, as well as on the remaining streams containing lactose, minerals and vitamins.

In an exploratory project on producing bioactive compounds, antioxidative and antihypertensive properties were found in peptide fractions from cheese whey (Hamaguchi et al. 2009).

Milk in many modes (MIMM) is an Iceland fund that supports and finances innovation projects utilising milk. The fund was initiated in 2017 and projects funded in the first year were on using proteins from milk in cosmetics, milk liqueur where alcohol is processed from whey and food supplement from colostrum.

2.2.3 Slaughterhouse outputs

There were 9 sheep slaughterhouses in Iceland slaughtering 545 thousand lambs in 2015 (KVH Hvammstangi; SAH Blönduós; KS Sauðárkrókur; Nordlenska Húsavík; Fjallalamb Kópasker; Sláturfélag Vopnfirðinga; Nordlenska Höfn; Seglbúdir and SS Selfoss). Six of them also slaughter cattle and horses together with Nordlenska, Akureyri and the slaughterhouse in Hella. About 16.000 cattle and 7.900 horses were slaughtered in 2015. Six houses: Stjörnugrís; Nordlenska Akureyri; Benní Jensen, Akureyri; Hella and SS Selfossi slaughtered 78 thousand pigs in 2015 (Matvælastofnun 2016). There are poultry slaughterhouses at Hella, two in Mosfellsbær and one in Höfn. Combined they slaughtered 4.9 million poultry in 2014 (Hagstofa Íslands 2017).

Carcass meat production in Iceland 2014 was 10.100 tons of sheep meat; 3.495 tons of beef; 6.472 tons of pork; 1.200 tons of horse meat and 8.046 tons of poultry (Hagstofa Íslands 2017). In the Faroe Islands in 2011, two authorised slaughterhouses, one on a central island and one on a small island only reachable by helicopter, slaughtered 3.000 of the 70.000 sheep slaughtered. The rest was home slaughtered. Sheep meat production amounts to about 1.100 tons of carcass meat. 193 cattle were slaughtered in 2015 yielding 57 tons of carcass meat. Neqi a/s in Narsaq, South Greenland slaughtered about 20 thousand sheep in 2015. Neqi also slaughters up to 1.000 moskus ox/year in Kangerlussuaq (Central Greenland). Caribou Green Aps slaughters about 800-1.000 reindeer at their slaughterhouse in Isortoq reindeer station in West Greenland.

Streams from slaughterhouses may be divided into edible parts (carcase, edible offal, viscera, blood); animal by-products not intended for human consumption and edible co-products. Edible co-products are parts of animals that are unsuitable for human consumption when they are produced at the slaughterhouse, but which can later be processed for use in human food, e.g. hides and skins processed into gelatine and collagen, sheep intestines processed into sausage casings, and stomach (omental) fat processed into lard/tallow (Food Standards Agency 2016; https://www.food.gov.uk/business-industry/guidancenotes/meatregsguid/coproductbyproductguide) .

Strict rules (EC regulation No 114/2002) on keeping certain animal by-products not intended for human consumption out of the food chain to ensure high levels of safety and health must be kept in mind and in particular prohibit intra-species recycling.

Animal by-products are separated into 3 categories.

- Category 1. Products of animals suspected of being infected by a transmissible spongiform encephalopathy (TSE) or in which the presence of a TSE has been confirmed. Specified risk materials, such as tissues likely to carry an infectious agent. Should be disposed of as waste by incineration in an approved incineration plant or processed by a specific method in an approved plant and buried in a landfill.

- Category 2. Includes manure and digestive tract content; all animal materials other than those belonging to category 1 collected when treating waste water from slaughterhouses; Products of animal origin containing residues of veterinary drugs and contaminants in concentrations exceeding the Community limits; products of animal origin, other than category 1 material, that are imported from third countries and fail to comply with the Community veterinary requirements; Animals other than category 1 that have not been slaughtered for human consumption. Should, except in the case of manure, be directly disposed of as waste by incineration in an approved incineration plant; processed in an approved plant by a specific method, in which case the resultant material shall be marked and finally disposed of as waste; in the case of manure, digestive tract content, milk and colostrum not presenting any risk of spreading a communicable disease, either a) used without processing as raw material in a biogas or composting plant or treated in a technical plant, or b) applied to land; used in a technical plant to produce game trophies.

Category 3. Includes parts fit for human consumption. Also hides and skins, hooves and horns, pig bristles and feathers originating from animals that are slaughtered in a slaughterhouse and were declared fit for human consumption; blood obtained from animals declared fit for human consumption after undergoing an ante mortem inspection, other than ruminants slaughtered in a slaughterhouse; animal by-products derived from the production of products intended for human consumption, including degreased bones and greaves; former foodstuffs of animal origin, other than catering waste, which are no longer intended for human consumption for commercial reasons or due to problems of manufacturing or packaging defects; raw milk originating from animals that do not show any signs of a communicable disease; shells of eggs originating from animals that do not show any signs of a communicable disease; blood, hides and skins, hooves, feathers, wool, horns, hair and fur originating from healthy animals; catering waste other than category 1.

Category 3 raw material can be: directly disposed of as waste by incineration in an approved incineration plant; used as raw material in a pet food plant; processed by a specific method in an approved processing, technical, biogas or composting plant; composted or processed in a biogas plant in the case of category 3 catering waste.

15.000 tons is an educated guess of the quantity of edible slaughterhouse products other than carcases and co-products produced in Iceland every year. Hides and skin are salted and sold to companies in Iceland or exported. The company Icelandic By-products ehf collects, processes and exports sheep intestines. Export of livers, hearts, kidneys and other organs is increasing. Better utilisation of rest raw materials from slaughterhouses in Iceland depends on improved separation of category 1, 2 and 3 by-products and company/municipal; regional; country level services/facilities for incineration and composting. Pilot and development projects have been carried out on biogas productions and composting. There are opportunities in increasing the volumes of valuable traditional products or biotechnology based products. Significant research and development efforts and patient investments are needed for success.

Some small projects on increased value and better use of slaughter products carried out in the last decade include:

Value from slaughter and meat processing by-products

The technical aim was to adapt and develop processes to convert by-products from being low value food, feed and sidestreams to high value products for export. The aim was also to train young scientists. The project included development of casing processes, better utilisation of organs and bloods, and freeze drying of products for biotechnological development (Þorkelsson et al. 2011).

Biomolecules from slaughter and meat processing by-products

Literature study concluding that there are opportunities in isolating and processing proteins and peptides from all sorts of by-products from beef, poultry and pork slaughter (Kristjánsdóttir et al. 2011).

Proteins from blood of slaughter animals

Blood has a protein content of up to 20%. Blood can be fractionated into plasma (55-65%) and erythrocytes (35-45%). The plasma is usable in food both fresh and as a protein powder. It is used in food products for example sausages, bread and as an egg replacer in baking. Blood plasma is also utilised in laboratories as a cell culture media and for antibody measurements. The utilisation of erythrocytes is limited because of bad flavour and strong colour. There are six steps in the production of protein powder from blood: collection, storage, centrifugation, condensation, filtration and drying (Guðjónsson 2012).

Bioactive substances from by-products of sheep slaughter

Hearts, liver and kidneys were hydrolysed with enzymes and peptide fractions tested for bioactivity. The smaller fractions showed some antioxidative and antihypertensive properties (Jónsdóttir 2012). In 2017, the Icelandic company, Pure Natura located in Sauðárkrókur North East Iceland launched four different products as encapsulated whole food supplements from desiccated lamb livers and hearts in combination with some Icelandic herbs.

2.2.4 Horticulture

Harvest and product losses in Icelandic horticulture are too high. The harvest season of outdoor grown vegetables is very short and postharvest storage and processing is limited. There is an oversupply of greenhouse vegetables in certain months of the year and processing to extend shelf life is limited. Furthermore, there are always harvests that do not meet market requirements in shape, size and appearance. Finally, the distribution/logistic chain for fresh vegetables can be improved.

In 2011 two students started a company, “Made in sveitin”, with the aim of producing and marketing salsa sauces from greenhouse vegetables not fit for direct marketing. The company received good attention, put products on the market but only lasted two years. The interest of using vegetables wasted during harvest in catering local schools, old people homes etc. was studied and a pilot study in IQF freezing of broccoli, cauliflower and carrots was made. There was interest and the production was successful (Þorkelsson et al. 2012). However, lack of long term funding and strategy ended the activities in Matís innovation centre at Flúðir.

2.2.5 Household and municipal residues

Municipal residues in Iceland have decreased from 2004 to 2012 from about 500 kg to about 340 kg/inhabitant. This is in line with the policy of prioritising waste prevention, followed by reuse, recycling, other recovery, and finally disposal or landfilling. Treating waste as a resource has social and economic benefits. Better waste management can secure resources, create jobs and improve the economy. Waste prevention and management have a central role in enhancing resource efficiency and creating a circular economy that enables society to maximise the economic returns on scarce resources (http://www.eea.europa.eu/soer-2015/europe/waste).

The Environment Agency of Iceland estimates that about half of the waste generated in the country is biodegradable of which roughly 40% are put towards a landfill or incinerated thus not utilised and 60% are actively reused or recycled. In the Faroe Islands 2/3 of organic residues in the capital region are diverted towards power generation. In Torshavn 18% of the waste is recycled, however, 14% could have potential for increased utilisation whereas garden residues account to 5% of the waste generated. By-products from slaughtering of 50 to 60 thousand sheep is included in the estimated 3.000 tons of biodegradable residues generated from fish processing plants, slaughterhouses, restaurants and hotels. The situation in Greenland is in many ways similar to the Faroe Islands, with limited arable land for cultivation. Total utilisation is rich in the tradition in Greenland where resources were scarce.

A significant portion of household waste is biodegradable, around 23% in Icelandic households. This amounts to over 100 kg of biodegradable residues per Icelander annually.

Biodegradable household and municipal residues include:

- Organic residues in landfills
- Food residues
- Organic residues for composting

Generally, mixed household residues are put into a landfill. Biodegradable residues in landfills produce gas through anaerobic digestion by microbes. Some of these gases are harmful greenhouse gases, such as methane. Limiting the volume of biodegradable residues from households will both reduce area required for landfills and greenhouse gases emitted at those sites.

The utilisation of bioresources can be increased by raising awareness of these harmful consequences and putting a monetary value on what is being wasted. Making it easier for the public to separate bioresource sidestreams from mixed household waste, such as having separate compost bins and household collection, is important. Thereby making the resource accessible for increased utilisation.

Sparsely populated areas and long distances make it difficult to adapt solutions for bigger and more densely populated regions to solve problems with organic residues in Iceland, Greenland and the Faroe Islands. Here we need solutions adapted, suitable and practical for sparsely populated remote areas.

2.2.6 Food waste

Food waste is a global environmental, social, and economic problem. Food loss at the consumption level in developed countries has been reported to be about 30% of the total calories purchased (Lipinski et al. 2013). A study on European food waste levels showed that approximately 88 million tonnes of food are wasted yearly within the continent (Stenmarck et al. 2016). In 2016, the Environment Agency of Iceland (EAI) conducted a study on food waste levels in Iceland (Kristinsdottir and Gunnarsdottir 2016). The study was twofold, quantifying food waste both from households and industries. The results indicated that food waste in Iceland is similar to that of other countries in Europe. A substantial amount of food is wasted in Icelandic households with each individual wasting on average 23 kg of edible food and 199 kg of liquids annually. The largest sources of food residues from Icelandic companies were found within the restaurant and food production industries. Reducing household, catering and restaurant food residues should be a priority. Public and private actions are already in place aiming at changing the way people look at buying and throwing away good food and food that has exceeded its declared shelf life (http://www.matarsoun.is). The EAI, along with several other governmental agencies and NGOs, has run a public awareness campaign against food waste in Iceland. This campaign has consisted of numerous different projects, including the abovementioned food waste study, an information website on food waste and how to reduce it, collaboration with food industries, and educational material on food waste for elementary schools. Frequent media coverage on the campaign and its projects has indicated their success which hopefully results in increased awareness and less food waste.

An even further incentive to reduce food waste in the West Nordic countries is the fact that most agricultural products consumed are imported with the associated carbon footprint. Arctic climate and poor soil conditions limit agricultural production in the countries. Grazing and production of hay for feeding livestock during the winter months is the main utilisation of wild and cultivated vegetation in Iceland. It is the basis for sheep, dairy and horse farming. Barley and rape are also produced in small amounts. Most of the crop goes into feed for pigs, poultry and cattle. Outdoor horticulture exists but is quite limited and vegetables like tomatoes, cucumbers and paprika are produced in Iceland for local consumption using geothermal energy for heating and hydroelectric power for light in greenhouses.

Products and biodegradable residues in meat processing, baking, fast food outlets, canteens, restaurants etc. have the potential to be utilised more efficiently. An encouraging case worth mentioning is the company Orkey in Akureyri that was founded in 2007 around the idea of converting used frying oil and left-over animal fat to biodiesel for ships.

3 Underutilised biomass

Several biological resources within the West Nordic region, in addition to the rest raw materials discussed above, can and should be increasingly utilised in a sustainable manner for value creation. These include primarily algae, wood and plants (lignocellulosic biomass), and marine invertebrates. Of these, algae have the greatest current potential.

3.1 Algal biomass

3.1.1 Macroalgae

Macroalgae, or seaweeds, are abundant within the West Nordic region and are a major underutilised biomass (Jörundsdottir et al. 2015). Macroalgae are of great interest for their availability, fast growth, high levels of carbohydrates and valuable bioactive compounds. Furthermore, they do not require land or fresh water for growth, and therefore do not compete with agriculture or food production (Jung et al. 2013). Macroalgae are a significant global commodity, valued at about $15 billion annually as a raw material. Research has clearly demonstrated that marine seaweeds contain highly active ingredients which can find many different applications within the food, pharmaceutical and cosmetic industries.

Wild growing macroalgae, found in rocky shallow intertidal zones may be sustainably harvested in high quantities in coastal areas and shallow fjords, as done in Iceland (http://www.thorverk.is), or cultivated in bulk off shore, as currently done in the Faroe Islands (http://oceanrainforest.com). The West Nordic countries have vast resources of macroalgae which are currently hardly being utilised despite significant opportunities to do so.

For harvesting wild macroalgae, an assessment of biomass volume, growth and utilisation methods needs to be performed to ensure a sustainable industry. An estimate of the macroalgal biomass has only been done in some areas along the coast of Iceland. For example, it has been roughly estimated that about 2.000.000 tons of two common kelps occur in Breiðafjörður bay (Iceland), a region of great potential for large scale macroalgal utilisation. A more detailed estimation of the available algal biomass in the bay is currently being performed, led by the Icelandic Marine Research Institute. Similar assessment studies need to be performed in other key areas within the West Nordic region. Development of commercial production of algal biomass has huge future potential. For cultivation of macroalgae, various technological, environmental and spatial assessments need to be performed, but techniques involving large-scale cultivation, harvesting and processing of macroalgae are currently being developed in various research projects with the participation of the West Nordic region. Furthermore, regulations and laws regarding offshore cultivation of macroalgae need to be further developed.

In Iceland, only one processor, Thorungaverksmidjan in Reykhólar (Thorverk), utilises seaweed extensively, harvesting about 22 thousand tons a year, thereof about 18 thousand tons of *Ascophyllum nodosum*. This is considerably less than what has been estimated as the total harvesting capacity for the region. Thorverk´s production is a simple primary processing of drying and grinding of seaweed that goes into further processing abroad where the greatest value creation and knowledge is obtained. There are significant opportunities associated with the use of unutilised macroalgal biomass in Iceland. Companies within Iceland; Marinox, UNA skincare and Taramar, extract bioactive ingredients from naturally harvested macroalgae for use in their products, currently only for skincare. Conditions for economical pre-processing and biorefining of algal biomass are particularly favourable in Iceland, due to low energy costs and availability of geothermal heat and there is commercial interest in macroalgal biorefinery investment in Iceland. In the Faroe Islands, the company Ocean Rainforest cultivates macroalgae in open ocean cultivation systems and aims at becoming a leading supplier of cultivated macroalgae for food, feed, cosmetic, pharmaceutical, nutraceutical and energy products. They sell their products frozen or dried and are currently working towards further developing their cultivation methods, as well as looking into developing biorefining techniques. Tari, also located in the Faroe Islands, is another company currently developing macroalgal cultivation. Within Greenland, some efforts have been put towards the potential cultivation of macroalgae and private companies have applied for permission to collect macroalgae for commercial production (Lange et al. 2016). The company Maki Seaweed Greenland sells locally collected dried macroalgae and the company Ulu Care utilises local macroalgae in soaps produced in South Greenland, which are also sold locally in Greenland.

The extensive seaweed resources available in the West Nordic region are among the most pristine in the world and in addition to only a fraction of it being harvested and used, extensive efforts are not being made to create value added products from the high value ingredients produced by macroalgae.

Macroalgae are a rich source of proteins, minerals, iodine, vitamins and non-digestible polysaccharides in addition to bioactive compounds with potential health benefits. In recent years, macroalgae have gained popularity as a source of compounds with highly interesting biological activities as they have developed a unique metabolic system enabling them to survive under extreme conditions. Macroalgae are utilised as food, although in low quantities in the Nordic region, and their polysaccharides, mainly agar and alginate, are used for various industrial applications as relatively low value compounds. For novel value streams and added value compounds from macroalgae, cascading biorefinery applications need to be developed (van Hal et al. 2014) where multiple value streams are created, and focus is set on high-value products. A cascading biorefinery aims at fractionating the different components of the biomass to sell or to convert them into higher-value components using organisms and/or enzymes. Macroalgae are of particular interest in this context as they contain both valuable components such as the bioactive molecules and colorants, as well as being a raw material of value for bioconversion for production of platform chemicals, energy and feed.

Macroalgae are divided into three classes based on the photosynthetic pigments; brown (*Phaeophyta*), green (*Chlorophyta*) and red (*Rhodophyta*). Brown seaweeds (including kelps) are the most relevant and abundant type of seaweeds available for wild harvesting within the West Nordic region for biorefining and biotechnological applications. The brown seaweeds, such as *A. nodosum*, *Saccharina latissima* and *Fucus vesiculosus*, are rich in bioactive compounds including polyphenols, carotenoids (e.g. fucoxanthin) and sulphated polysaccharides (fucoidans) that could potentially be exploited as functional ingredients for human health applications. Research has shown that brown algae generally have better antioxidant properties than other algae (Nagai et al. 2006; Wang et al. 2009) and that macroalgal extracts from brown algae species have superior antioxidant activities in food model systems (Wang et al. 2009; Wang et al. 2010). It is believed that this is partly due to very specific polyphenols found in brown seaweed called phlorotannins. Phlorotannins (polyphloroglucinol phenolics), the dominant polyphenolic secondary metabolite in brown algae, have during the last decade developed great research interests due to multiple biological activities such as antioxidant, antibacterial, anticancer, anti-inflammatory and antidiabetic properties. Phlorotannins are very active antioxidants and the unique skeleton of phlorotannins may be one of the reasons for their great antioxidant activity (Wang et al. 2009). Phlorotannins have much higher activity than polyphenols from land plants such as rosemary (Shin et al. 2006; Shibata et al. 2008). Currently, only a few natural food antioxidants are commercially available on the market but consumer demand for the replacement of synthetic antioxidants with natural alternatives is growing. The concentrations of polyphenols within brown seaweed have been found to vary according to season, habitat, and local environmental factors such as salinity, UV irradiation, light and nutrient availability.

Extracts produced from brown seaweed have shown other unique properties such as anti-inflammatory and strong anti-diabetic characteristics *in vitro* by the inhibition of carbohydrate hydrolysing enzymes. Effects of increasing collagen production in skin cells (*in vitro* studies) and preventing extracellular matrix breakdown by inhibition of metalloproteases (MMPs) have also been observed (Matís, unpublished results). Fucoidans and laminarin are two of the standard polysaccharides that are abundant in brown algae. They are known to possess numerous health benefits, especially fucoidans, which have been reported to have antitumor activity (Synytsya et al. 2010), immune modulation activity (Kim and Joo 2008) and anticoagulant activity (De Zoysa et al. 2008). Extraction of natural biomolecules from brown seaweed species for added-value for cosmetics, pharmaceuticals and hydrocolloids for food applications, chemicals, textiles and proteins for food and feed ingredients is therefore of huge interest. However, extraction and bulk processing methods for bioactive compounds from macroalgae need to be further developed and optimised. Figure 5 schematically shows different categories of products, both primary from processing and extraction, as well as secondary, from bioconversion of the biomass using organisms and/or enzymes.

After harvesting, macroalgae are generally pre-treated by washing to remove salt residues, impurities or epiphytes. Prior to extraction the macroalgae are stored in freezer or dried (freeze dried or at lower temperature) followed by milling such as wet milling. In order to increase yield a pre-treatment of cell disruption can be performed using e.g. enzymes or acids. The extraction of bioactive compounds includes different types of solvents (water, alcohol, etc.) and conditions (temperature, pH, pressure, etc.). The yield of bioactive compounds is highly dependent on the extraction method. Novel extraction methods include enzyme assisted extraction, ultrasound, microwave and pressurized extraction.

Figure 5. Schematic presentation of major product categories from biorefining of brown macroalgal biomass.

In addition to the mentioned processing and extraction of macroalgal components, biorefinery applications for biological conversions and/or enzymatic modifications of macroalgal carbohydrates into platform and specialty chemicals and energy carriers, as well as for food and feed, are also of upmost interest (Wei et al. 2013). Such products may also be referred to as secondary products and are presented in the green segment in Figure 5.

Marine algae contain large amounts of polysaccharides, both cell wall structural and storage polysaccharides. The polysaccharides are species-specific and in brown algae they consist of about 30-50% of the biomass wet weight. They are alginic acid, fucoidan (sulphated fucose), laminarin (β-1, 3 glucan), mannitol and cellulose. Alginate is a major component of algal biomass and composed of the uronic acids guluronate and mannuronate (Wei et al. 2013).

These structurally complex, heterogeneous and sulphated carbohydrates make macroalgae a challenging feedstock for bioconversion. Furthermore, there is considerable seasonal variation in the amount of carbohydrates in macroalgae. Selected organisms, mainly bacteria, fungi/yeast and insects have the ability to use these unique carbohydrates for growth yielding a range of novel products such as platform chemicals and chemical building blocks (including succinic acid, furans and glucaric acid), textiles and bioplastics, energy (liquid fuels and biogas) and protein rich feed. However, cost effective, large scale utilisation of macroalgal biomass is currently limited by the lack of efficient processing technologies, including biorefinery conversion organisms and processing enzymes. Steps towards the identification and development of such organisms are underway and important to further utilise the biomass in an economic way, including metabolic engineering of strains for increased carbohydrate utilisation (Wargacki et al. 2012; Wei et al. 2013). Matís in Iceland has been working on the engineering of thermophilic bacterial strains, both aerobic and anaerobic, for production of bioactive compounds, chemicals and biofuels for several years. Thermophilic strains and their enzymes are robust and versatile with properties which may be hugely beneficial to industrial applications in biomass conversions, particularly for macroalgae which benefit from elevated temperature processing due to high viscosity. The processing of macroalgae for bioconversion, following harvesting and pre-treatment (drying, milling, chemical, biological and/or enzymatic hydrolysis) takes place in a fermentation, anaerobic or aerobic digestion. The end-products are subsequently collected, often isolated using a range of techniques. An example of a cascading macroalgal biorefinery concept is shown in Fig. 6, showing the different processing steps and products. This concept, published by van Hal et al. (2014), is based on the Dutch Seaweed Biorefinery Program (http://seaweed.biorefinery.nl), where an approach to maximise value from brown seaweeds was taken.

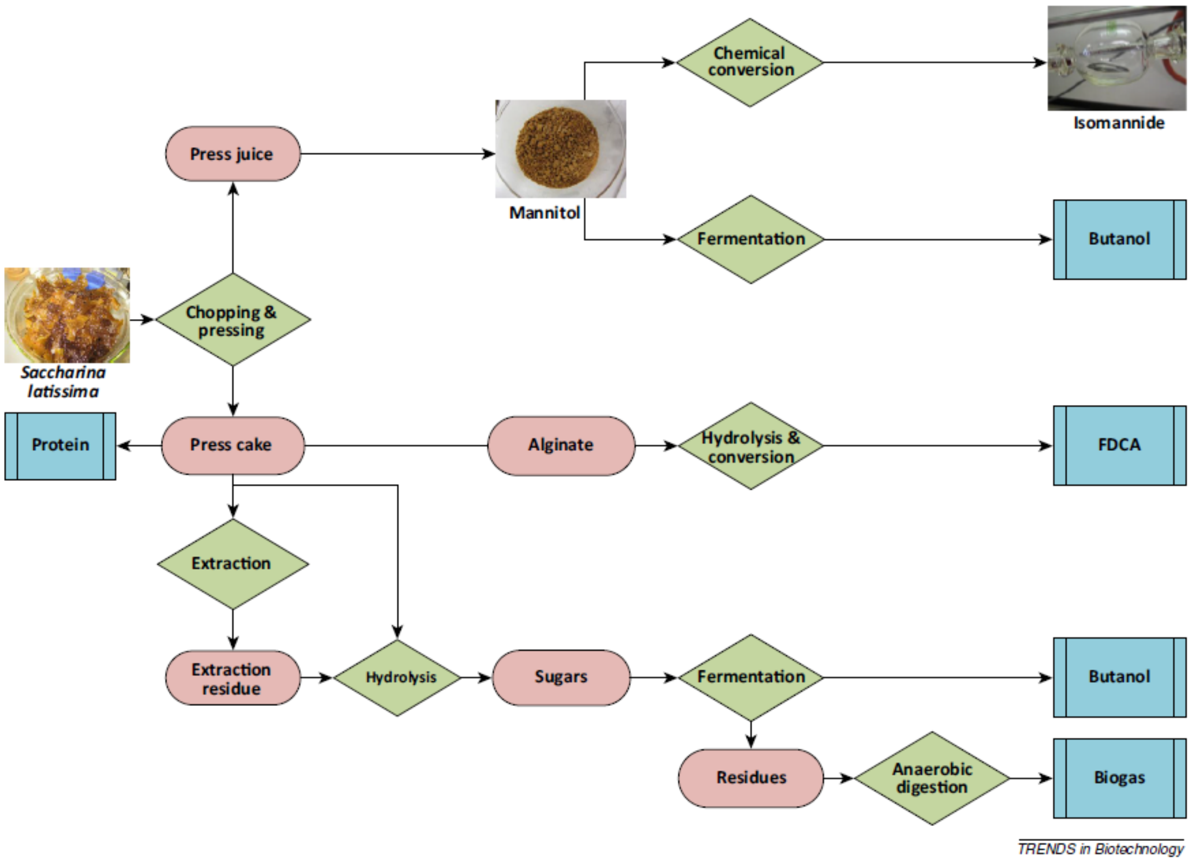

Figure 6. A schematic representation of a cascading macroalgal biorefinery from the brown macroalgae Saccharina latissima showing intermediate products (pink ovals), the conversion steps (green diamonds), and final products (blue rectangles). The pictures depict the fresh seaweed, the intermediate mannitol, and the end-product. FDCA: furan dicarboxylic acid. Figure from van Hal et al. (2014).

Suggested actions

An important initial step that needs to be taken to prepare for large scale utilisation of wild macroalgal biomass is that an assessment of sustainable utilisation of areas of interest needs to be performed, regarding annual harvesting possibilities for the species of interest.

There is considerable worldwide interest in the large-scale cultivation of macroalgae, also within the West Nordic region. However, bulk cultivation, harvesting, processing and storage technologies need to be further developed and established.

Furthermore, operating regulations and permit procedures need to be supporting and clear and stakeholder views, including those of coastal communities and tourism, need to be included in the development process.

There is a pressing need for researchers, developers and SMEs, to have access to biorefinery facilities for product development.

Bioprocessing organisms and enzymes for processing of macroalgae need to be further developed.

3.1.2 Microalgae

Microalgae are a group of aquatic organisms, consisting of photosynthetic eukaryotes and Cyanobacteria (blue-green algae). Microalgae have been used for human food for centuries and have in recent years come into focus for their potential utilisation in production of health food, feed, pharmaceuticals and nutraceuticals (Garcia et al. 2017; Matos et al. 2017), with particularly certain microalgal taxa, e.g. *Spirulina* and *Chlorella*, used as a protein source or health supplements in food and feed (Enzing et al. 2014). Microalgae have also shown to be a valuable natural source of a variety of highly valuable bioactive compounds such as proteins, colourants and antioxidants (e.g. astaxanthin, carotenoids), beta-glucan, organic acids and lipids, including omega-3 fatty acids (Yaakob et al. 2014; Garcia et al. 2017; Matos et al. 2017) which opens the possibility of further use in food, feed and health products. The bioactive compounds produced vary between strains and although they have been partially screened, novel compounds may still be found (Serive et al. 2017). Furthermore, microalgal components such as lipids and carbohydrates are also gaining interest for their potential utilisation in production of bioenergy, primarily biodiesel (Tan et al. 2015).

Marine microalgae are the primary producers of omega-3 fatty acids, including EPA and DHA, which are currently sourced mainly from fatty fish. Omega-3 fatty acids are essential in aquaculture and have become a widely used food supplement as their benefits on human health become more and more evident, including prevention of cardiovascular and inflammatory conditions, beneficial effects on the nervous system and in skin care products. The demand for omega-3 fatty acids is increasing and microalgae present a sustainable source of these highly valuable natural products. Microalgae have a great potential for omega-3 fatty acid production since they are their natural primary producers, they can grow under various growth conditions both autotrophic and heterotrophic and they do not need arable land for growth. Lipid production is closely linked with growth phases with an increase in lipid production as a stockpiling response to stress and different lipid accumulation mechanisms are found in phototrophic and heterotrophic cultures, which opens the possibility of directing cultures towards lipid production through growth conditions (Adarme-Vega et al. 2012; Chang et al. 2017).

Microalgae produce a range of carotenoids, including astaxanthin and lutein. Carotenoids are shown to have anti-inflammatory and anti-oxidative activity in humans and epidemiology suggest that carotenoids can play a role in prevention against cardiovascular conditions, diabetes and cancer (Raposo et al. 2015). Astaxanthin, the most well studied, it is a very potent antioxidant and is widely used in food supplements, nutraceuticals and cosmetics. It is also an essential nutrient in aquaculture, particularly to give cultured salmon and trout their red colour. The majority of the astaxanthin currently on the market is synthetically produced and along with a growing market, the consumer demand for naturally produced products is increasing (Lorenz and Cysewski 2000; Garcia et al. 2017). Naturally produced astaxanthin and other carotenoids are therefore a very high-value product of microalgae cultures.

Autotrophic microorganisms, including microalgae and cyanobacteria, also produce other photosynthetic pigments including chlorophyll a, b and c and phycobilins. Most strains produce more than one type of pigment and the types produced vary between groups of organisms and the wavelengths of light they are adapted to utilise. Some of these pigments are already used industrially as dyes in the food and cosmetic industries and in the pharmaceutical industry, particularly as antioxidants (Yaakob et al. 2014). Consumer demand for organic pigments is constantly increasing and with it the potential value of products made by microalgae or other phototrophic microorganisms.

A recent study has shown that while strains can vary greatly in their production capabilities, individual isolates may have a potential in production of more than one biomolecule in the same growth cycle (Minhas et al. 2016). In addition, after extraction of the high-value biomolecules such as omega-3 fatty acids and carotenoids, other products produced by microalgae can also be utilised, including lipids other than omega-3 fatty acids in production of biodiesel and the remaining protein rich biomass as feed in aquaculture or agriculture (Adarme-Vega et al. 2012) although such multi component production has not yet been commercialised (Enzing et al. 2014). Cultivation of microalgae therefore has a potential as a sustainable source of high-value products with little rest raw material.

Microalgae and other phototrophic microorganisms live in abundance in Iceland and its surrounding marine waters and Matís has researched these areas and their microbial life for several years. Among the output of this work are approximately 50 strains of microalgae that have been isolated from hot spring effluents in geothermal areas in several locations in

Iceland. The majority of strains were isolated at temperatures ranging from 20-40°C where most strains isolated at the lower end of that range are eukaryotic microalgae, but strains isolated at the higher end of the range are mostly cyanobacteria. Various strains of autotrophic and heterotrophic bacteria have also been isolated and cultured in the laboratory, including strains of Heliobacterium that contain bacteriochlorophyll g and green non-sulphur bacteria. Many of these strains are available in the Icelandic Strain Collection and Records (ISCaR) at Matís (http://iscar.matis.is/), and have been isolated and maintained as a pure culture and subjected to preliminary screening of pigment production. Each strain has been assigned a taxonomical classification based on 16S and 18S rRNA gene sequencing and environmental conditions such as temperature and pH recorded, along with additional information such as salinity and dissolved oxygen for some sampling sites. The University of Copenhagen hosts a large collection of mostly heterotrophic bacteria from Greenland, of which many are pigmented.

Studies of the Greenland ice sheet have shown that heavily pigmented and actively photosynthesising microalgae and cyanobacteria are present on the ice surface (Yallop et al. 2012). This ecosystem can affect adjacent aquatic and terrestrial ecosystems and with the rapid environmental changes in the Arctic due to global warming it may undergo significant changes in the near future, providing a unique opportunity for research and a potential source of novel strains (Anderson et al. 2017). Research into how microorganisms contribute to Arctic melting is currently ongoing (Witze 2016). Other studies have found a diverse collection of cyanobacteria in microbial mat communities harvested in coastal hot springs on Greenland´s east coast (Roeselers et al. 2007). Microbial samples from such extreme environments are likely to contain previously unknown strains with a potentially valuable pigment production.

To date, published data on species of microalgae or other phototrophic microorganisms in the Faroe Islands has been extremely sparse (Djurhuus et al. 2015).

Traditionally, microalgal cultivation has been done in open ponds, but mass cultivation in enclosed photobioreactors for increased efficiency and reliability has gained much interest. Within the West Nordic region, Iceland has good potential for microalgal cultivation because of relatively low energy prices, availability of sustainable green energy, abundant geothermal hot water and CO_2. In addition, the application of LED lighting technology has in recent years reduced the energy requirement for microalgal cultivation and utilisation of this technology also allows for directed production of specific bioactive compounds by microalgae, opening opportunities to maximise product value. Recent reports show that growth of microalga and production of lipids, pigments and antioxidants can be stimulated further by application of magnetic fields to cultures (Bauer et al. 2017; Ferreira and Sant'Anna 2017; Santos et al. 2017), adding to the potential of microalgae culture in biotechnology and production of high-value compounds. Furthermore, microalgal cultivation can be applied to lower CO_2 greenhouse gas emissions through utilisation of industrial exhaust gasses.

Extensive experience in research and application of microalgae has already been established in Iceland with several industrial initiatives on microalgal cultivation in bioreactors currently ongoing. Microalgae culture for research of metabolic pathways is established at the Centre for Systems Biology at the University of Iceland and for production of astaxanthin at Algalíf and KeyNatura. At the Blue Lagoon, cyanobacteria are utilised as a key ingredient in a full range of skin treatment products and in a psoriasis treatment clinic. The company Algaennovation is working towards opening a large-scale microalgae production in Iceland, focusing on the production of starter feed for the aquaculture sector. Matís has comprehensive experience in strain isolations, culture of photosynthetic microorganisms and biotechnological applications of microorganisms, particularly of geothermal and marine origin, and has recently implemented a lab-scale photobioreactor culture system to strengthen its capabilities in research of microalgae and other phototrophic microorganisms. The system includes a photobioreactor with adjustable LED lighting and options for automated control/monitoring of culture conditions such as temperature, pH and density. With automation of these factors, manual intervention during culture times is minimised to maintain ideal culture conditions and reduce risk of contamination. A simpler multi-cultivator with LED lighting is also included in the system and is ideal for preliminary testing of culture conditions, for example for comparison of strains or media, with up to eight cultures at a time. Both culture vessels can be used either anaerobically or aerobically with specific control of gas compositions, for example CO2 percentage. LED based culture vessels enable a far more specific control of light conditions compared with conventional culture under fluorescence/white light and therefore greatly increases the potential of research into growth and production of phototrophic microorganisms.

The first steps towards biotechnological applications of locally sourced microalgae within the West Nordic region are to compare strains and identify those that have a potential in biotechnology and industry, based on growth rate, production potential, etc. Strains already isolated need to be investigated further in this respect and more species/strains can also be isolated from a number of extreme habitats in the West Nordic Region. Molecular taxonomic analyses can also help to find suitable species/strains by identifying closely related taxa that share phylogenetically conserved desired traits but might be more suitable for industrial scale cultivation. Furthermore, bioreactor culture conditions need to be developed further and optimising culture conditions for individual species/strains with the aim to maximise efficiency as production systems is a key point in an economical utilisation of microalgae. This will involve adjustment of media and light conditions on laboratory scale, comprehensive screening for high-value metabolites produced and characterisation of genomes and metabolomes. Scale-up to industrial size cultivation systems will follow, as well as reduction in cultivation costs to make microalgae production economically competitive. Extraction methods for primary products such as lipids and pigments will need to be optimised and component separation technologies to allow for multiple component production will need to be developed (Enzing et al. 2014).

In 2011, the global marine biotechnology market with microalgae as a main component, was estimated at €2,4bn, with an expected yearly growth of 10%. Over the past decade, 75% of the production volume of microalgae were used as dietary supplements with a growing market for high-value ingredients such as omega-3 fatty acids. As this market increases, the primary source is diminishing as fish stocks are declining, while at the same time there is a clear consumer trend in the demand for natural products. Omega-3 fatty acids such as EPA and DHA have a very high value per ton of dry weight microalgae and relatively few major producers have brought fatty acids of a microalgal source to market (table 2) (Enzing et al. 2014). It is documented that lipid production in microalgae can be induced by changes in culture conditions and that omega-3 fatty acids can be separated from other microalgal lipids (Adarme-Vega et al. 2012) which together could provide a good test case for multiple product microalgal production in a biorefinery concept. It is therefore recommended here for biotechnological use of microalgae in the West Nordic Countries, a priority should be placed on defining photobioreactor culture methods and induction of lipid production in selected species/strains.

Table 2. Microalgae components as food and feed products.

	Production volume (tons/year dry weight)	**Number of producers** (key players)	**Value of production volume** (yearly turnover)	**Potential market** (synthetic / traditional forms)
EPA/DHA	240	>4	>300m USD	14m USD
Astaxanthin	300	>8	10m USD	200m USD
β-Carotene	1200	>10	n/a	285m USD
Phycobilins	n/a	>2	n/a	>50m USD

Table adapted from Enzing et al. (2014).

3.2 Lignocellulosic biomass

Woods are scarce in the West Nordic region but in Iceland forestry is a growing business. Plans suggest that forests will fourfold in the area in the next 40 years but will then only cover 40.000 hectares. Furthermore, substantial land is available for fast growing special feedstock plants and prospects may lie in cultivation of oilaceous crop plants and for the cultivation of fast growing plants (e.g. salix species) for biomass feedstock production. Land is abundant but large areas are not suitable for traditional agriculture.

The main interest in the use of wood into valuable feed or food products in Iceland have focused on producing Single Cell Protein (SCP) from forest industry sidestreams (Alriksson et al. 2014). The aim is to develop a product with the same nutritional standards as fish meal, and focus on which microorganisms are best suited and which sidestreams in cellulose and paper industry would be best suited for the production of SCP. The Nordic pulp and paper industry has traditionally been very strong but today it suffers from decreasing demand of their products and tough competition from Asia and South America. Development of new innovative products from wood, such as feed, is essential for the competitiveness and survival of the Nordic forest industry. Spent sulphite liquor is produced in large amounts and a single mill can generate about 250 m^3 per hour. Commercial attempts to produce SCP from spent sulphite liquor has also previously been carried out but there are no plants in operation today (Ugalde and Vastrillo 2002).

There is no ground for cellulose and paper industry in the West Nordic region. However, residual material from the wood industry could be treated with similar methods as the sulphite process and produce wood pulp in digesters with high ratio of spent cooking liquor (brown or red liquor) which can be further enzymatically treated or directly fermented with microorganisms to produce valuable proteins and/or other valuable products.

In Iceland about 1.220 km^2 are cultured grass fields, i.e. 1.2% of the land. Grass can be a valuable source of proteins and valuable lipophilic chemicals. Leaves, weeds and grass can be processed in a Green Biorefinery producing proteins in the form of green proteins, white proteins and single cell proteins, silage fodder and lactic acid or lysine (Kamm et al. 2009). Existing agricultural structures of the green crop processing industry offer good opportunities for the implementation of biorefinery technologies that will help increasing value of agricultural crops. As an alternative to the current drying process, this Green Biorefinery fractionates the raw material (alfalfa, clover, grass) mechanically into a liquid (press juice) and a solid fraction (press cake). The press cake mainly consists of fibrous materials whereas the press juice contains water soluble resources (e.g. amino acids, proteins). The press juice can be separated by a secondary fractionation into proteins and fermentation medium.

Suggested actions

Perform a validation of resources from wood and other agricultural biomass such as alfalfa, clover, grass.

Perform pre-evaluation of a sulphite process-like method and other methods for the breakdown of wood material from West Nordic wood industry.

Perform a pre-feasibility study of the use of Green Biorefinery methods to produce valuable product fractions in collaboration with European scientist and demonstration plants.

3.3 Marine invertebrates

Marine invertebrates are a highly diverse group of animals and are regarded as a major source of novel natural products with biotechnological potential. The marine environments in the West Nordic region harbour many invertebrates such as molluscs, gastropods and crustaceans which have a long history as fishery resources. Some species, such as the green sea urchin (*Strongylocentrotus droebachiensis*) and Iceland scallop (*Chlamys islandica*) are high-value export products and are considered delicacy food items. Other, especially benthic, marine invertebrates such as sponges, hydrozoa, tunicates, cold-water corals and sea anemones have so far found little to no biotechnological utilisation in the West Nordic region although they are generally considered a major source for novel natural product discovery. The diversity and distribution of benthic marine invertebrates in the West Nordic region has previously gained attention through projects such as BIOFAR (Bruntse and Tendal 2000) (Marine Benthic Fauna of the Faroe Islands, 1988-1990 and 1993-1995) and BIOICE (Benthic Invertebrates of Icelandic waters, 1991-2004) with the latter alone identifying almost 2,000 different species in Icelandic waters (Omarsdottir et al. 2013).

Sessile marine invertebrates that lack a hard, protective layer or other means of defence are known to produce a multitude of bioactive compounds to deter potential predators. These compounds have been found to include, amongst other properties, anti-microbial, anti-cancer and anti-inflammatory activities and are thus highly interesting for the pharmaceutical and cosmetic industries. Sponges, for instance, are thought to be one of the largest producers of bioactive natural compounds, contributing almost half of all novel marine natural product discoveries since 1990 (Leal et al. 2012). Cnidarians are another group of marine invertebrates that produce a multitude of bioactive compounds, some of which are already on the market and many others are in clinical development (Rocha et al. 2011).

Apart from bioactive compounds with relevance for the pharmaceutical and cosmetic industries, some active compounds pose interesting features for industrial applications such as natural anti-fouling compounds for coatings on ship hulls and aquaculture netting, potentially replacing traditional chemicals with harmful effects on the aquatic environment (Sjogren et al. 2004). Enzymes with different biotechnological applications are another target for bioprospecting, especially from extreme habitats such as the deep sea, cold habitats and geothermal hot vents (Debashish et al. 2005).

Although marine invertebrates are considered a promising source for natural product discovery, little is known about the potential of species found in the waters of the West Nordic region. A targeted approach towards bioprospecting novel natural products from invertebrates is necessary to shed light on the so far untapped potential of this marine resource. In this context, attention should not only be payed to the invertebrate species itself, but also its associated microbiota (bacteria and fungi) which is in many cases the producer of the compound or enzyme of interest.

In order to assess the biotechnological potential of this resource it is firstly necessary to identify specific areas with a large diversity of biotechnologically interesting invertebrate phyla, including an extensive exploration of invertebrate populations in extreme marine sites. Following sample collection, high-throughput techniques for screening the bioactivity of invertebrate extracts, as well as their isolated microbes would be applied. Extracts with positive activity are further evaluated by fractionation and elucidation of pure compounds for further bioactivity testing. In addition to this approach, the genetic information of the invertebrates and their associated microbes would be mined for enzymatic pathways producing bioactive secondary metabolites of interest.

Interest in marine natural product discovery is increasing worldwide, fuelled by a need for new pharmaceuticals and industrially relevant bioactive compounds. Marine invertebrates are currently an underutilised resource in the West Nordic region, but pose a highly relevant resource for bioprospecting of novel natural compounds.

3.4 Novel species in a changing environment

In the last few decades, global warming has become evident in the West Nordic region and significant effects are already seen in flora and fauna. In Iceland, height limits of birch have moved upwards, forestry and soil conservation work has become easier and growing of cereals has formed a new branch of agriculture. Frequency of new bird species settling increased towards the end of the 20th century and an increasing number of insect species winters in Iceland. These changes are believed to result both directly from rising summer temperatures, milder winters and the formation of new habitats through increased vegetation (Björnsson et al. 2008).

Sea temperatures have also been rising and are expected to continue to do so, particularly in the arctic region. Glaciers, permafrost and sea ice are all predicted to retreat and sea ice will possibly disappear completely from the North-Greenland Ocean in late summers. These changes are a major concern for the West Nordic countries where marine products are an important source of food and a major source of national income. In Iceland, the main fish stocks are closely monitored and changes in stock size and distribution of several main exploitable stocks have already been observed and linked with rising sea temperatures.

Distribution of groundfish has increased in the northern regions and their total stock sizes have increased. 26 previously unknown species of fish have been caught within Iceland's 200-mile exclusive fishery zone in recent years, most of which have their habitat further south in the Atlantic Ocean while several examples of under-utilised species that were mainly found to the south of Iceland are now found further north. A new species of flatfish, flounder, has settled in Icelandic transitional waters and has most likely migrated there from the Faroe Islands, while distribution of other marine organisms such as the common shrimp and soft clam has increased along Iceland´s coastline. Rare newcomers from further south are also found around Iceland in more abundance than before (Björnsson et al. 2008), the most prominent example being mackerel which has become an exploitable stock with landings in Iceland at 169 thousand tons in 2015, increasing from 30 thousand tons in 2007 (Marine Research Institute 2015). Some of the same developments are observed in Greenland, which shares parts of the fish stocks with Iceland. In the 1960s Greenland experienced a large increase in cod stocks migrating further north coinciding with warmer waters. Cod fishing has gone from a peak at almost 500.000 tons/year in the 1960s to none around the change of the century. Since the 1970s, cod fishing has largely been replaced by shrimp (42% of export in 2016) and halibut (29% of export in 2016). A number of novel species have been observed in recent years in Greenland. Some of these observations may however be due to increased monitoring and better methodology implemented in recent years rather than changes in climate.

The main increase in available biomass from novel species due to climate change are under-utilised fish stocks, both as sidestreams from processing of newly exploited fish species and as the entire biomass of species that have become abundant but are not yet exploited by the fishing industry. Development of novel products and technologies using sidestreams from newly exploitable fish stocks such as mackerel should have been and are a priority. These resources are likely to contain various potentially valuable biomolecules such as enzymes, lipids, proteins and other nutrients and the experience in utilising such resources by biotechnology has already been gained by extensive research in cod over the last years and decades (see section 2.1.1). Similar approaches could be used for biomass of other novel species, including fish stocks and other marine resources. As a preliminary to investment in biotechnology infrastructure and technology development, novel species that are relatively abundant in the region and are likely to contain biomolecules of high-value need to be listed and their availability estimated. Other sources of available biomass from novel species are side-products from forestry and cereal growing, opportunities for utilisation of those by biotechnology are covered in section 2.2.

4 High-north specific opportunities

Unique flora and fauna are found in the Arctic's natural environment with more than 21 thousand species of mammals, birds, fish, invertebrates, plants and fungi found that have adapted to the cold and harsh environment and have the ability to survive in extreme conditions (CAFF 2013). Extreme environments are characterised by geochemical and physical extremes, defining the edges of the compatibility with life. Diverse extreme environments have been described and they are colonised by highly adapted organisms called extremophiles (Rothschild and Mancinelli 2001).

Various types of extremophiles are found in the West Nordic countries, particularly in Iceland and Greenland, including terrestrial thermophilic bacteria, psychrophilic and alkaliphilic marine microbes and microbes from the cryosphere, submarine thermophiles, invertebrates, slow growing plants and lichens. These extremophiles are highly unique and have been shown to be an abundant source of enzymes, proteins, lipids and polysaccharides suitable for application for example in the food industry, chemical and pharmaceutical synthesis or in molecular biology. These organisms are also a potentially rich source of small bioactive molecules and polysaccharide derivatives with health promoting activities which can be used as dietary supplements or in cosmetics (Jörundsdottir et al. 2015).

Extreme geothermal areas are a source of robust and versatile organisms and their enzymes, which act under harsh conditions such as found in biorefinery and biotechnology processes. Because of their unique metabolic adaptations to their harsh environments, extremophiles are considered to have an enormous potential for biotechnological applications. Many industrially used organisms and enzymes are derived from mesophilic species, making them suboptimal for application in several industrial processes. Iceland is one of the most important and diverse geothermal areas in the world, varying highly in physiochemical properties. A polyextreme and unique environment, the ikaite columns of Southwest Greenland, harbours microbes adapted to both cold and extremely alkaline conditions. These sources of extreme organisms and their enzymes is of great biotechnological potential, which is not surpassed anywhere in the world. Thermophilic biospheres harbour a great diversity of organisms, many of which are versatile producers of polysaccharide degrading and modifying enzymes. Extrermophilic microorganisms are particularly difficult to cultivate and isolate in pure cultures and geothermal habitats harbour an enormous undiscovered diversity of novel organisms. Therefore, metagenomic approaches are useful to access these underexplored parts of the biosphere.

Studies of microorganisms adapted to Polar regions have shown that they adopt a variety of adaptive strategies, both at the molecular and cellular levels, that allows them to survive and grow in their extreme environment. A variety of phenotypic traits are involved, including changes in small molecules and lipid composition. To date, most screening projects of Polar microorganisms have focused on cold-adapted enzymes, of particular interest due to their potential value in the food industry and other processing industries where heating can be detrimental to the product or the cost of heating is restrictive (Pascale et al. 2012). With only a fraction of environmental prokaryotes receptive to laboratory cultivation and the advances in molecular biology that have come with the revolution of next generation sequencing and more recently, single-cell sequencing, the amount of genomic information available for bioprospecting has increased greatly.

These unique genetic resources found in the West Nordic countries therefore present plentiful opportunities for bioprospecting and since most of these resources are currently underutilised, utilisation can in fact provide an important economic opportunity. In addition to the unique genetic resources resulting from adaptation to extreme environments, global warming is expected to cause the most dramatic environmental changes and faster warming in the Arctic than any other region due to polar amplification, putting pressure on organisms to further adapt to new or altered habitats, as is already documented for various Arctic wildlife populations (Jörundsdottir et al. 2015).

Arctic seaweed production is a unique opportunity that can be developed within the region as a supplement for commercial fisheries and with a potential for full utilisation in a biorefinery concept (section 3.1.1). The Arctic Technology Centre (ARTEK) in Greenland carries out research and innovation projects in Arctic technology, including constructions and transportation infrastructure in the cryosphere (snow, ice, permafrost) and the arctic marine environment, which is expected to contribute to increased innovation capacity when furthering the economy through the use of bioresources (Lange et al. 2016).

Fisheries and aquaculture account for over 91% of the Faroe Islands' total exports (in 2012) and marine bioresources are the most important biological resources. The Faroe Islands lead the Blue Bioeconomy program of the Nordic Council of Ministers (2015-2017) which aimed for collaboration within the West Nordic region where similar interests and bioresources are available. The program focused particularly on blue biotechnology, bioprospecting of marine organisms, microbes, algae and invertebrates, seaweed utilisation and complete fish harvests (Lange et al. 2016).

Similarly to biotech products from fisheries and aquaculture, high-north specific biotech products have been successfully developed through research collaborations between the Greenlandic biotech company Coldzymes (www.coldzymes.dk) and the University of Copenhagen, including two patented starch-modifying enzymes active at 0°C. Additionally, in 2017 the University of Greenland, Ilisimatusarfik, initiated the assessment of creating a research-based innovation house in Greenland partly inspired by Icelandic Matís (InnoLab Projektbeskrivelse, Hauptmann 2017). The municipality Sermersooq is currently implementing the innovation house, which will be focused on local food resources.

While there has been increased focus on biotechnological potential in Greenland there are no current products on the market and only one Greenlandic biotech company, which is also the only holder of a commercial license for biotechnological products from Greenland. In 2016 the Self Rule Government of Greenland updated their law on genetic and biological resources (law number 3 of the 3rd of June 2016), which ensures equitable sharing of profit from Greenlandic genetic resources with the Government of Greenland. The law is an implementation of the Convention of Biological Diversity and has set the framework conditions for biotech companies and research institutions working with genetic resources from Greenland, an important step towards further developments in biotechnology in the area.

The application of biotechnology for production of high-value products from biomass is a part of the bioeconomy development that is particularly suitable in the West Nordic countries due to their unique genetic resources, vast underutilised biomass and plentiful available space for dedicated cultivation of biomass as ingredient for biorefineries. Research into the biotechnological potential of extremophilic organisms in Iceland goes back to the 1980s but the main emphasis has been on thermophilic bacteria and enzyme bioprospecting. Increasingly, research now focuses on bioprospecting from cold adapted biotopes, metabolic engineering of bacteria for production of biofuel or platform chemicals and developing enzymatic activities for utilising marine polysaccharides as novel substrates in industry. Iceland can be considered an important high diversity region in terms of the Convention of Biological Diversity and many extreme but different biotopes remain that have not been researched, both terrestrial, coastal and marine (Jörundsdottir et al. 2015).

With the dominance of marine resources in the West Nordic countries and limited access to lignocellulosic biomass, a focus should be placed on utilising biomass of marine and microbial origin in a biorefinery concept, for full utilisation of the biomass for maximum value (Jörundsdottir et al. 2015). As outlined in this report, the West Nordic countries offer vast amounts of biomass suitable for development of high-value products through biotechnology and biorefinery processes. Food production by both agriculture and the fishing industry in the West Nordic countries uses clean air and water and the products from these industries are known for their freshness and good quality. This extends to the biodegradable residues from these industries, and this freshness creates a marketing opportunity for new products derived from these sources through biotechnology or biorefinery. The same applies to the underutilised biomass of natural sources, algae and marine invertebrates, sustainable harvesting of natural resources from pristine environments combined with production using clean water and green energy, should be emphasised when marketing these products towards the modern consumer that is concerned about environmental protection and sustainability. The local communities in the West Nordic countries should be the primary markets and they will therefore benefit from the availability of fully developed products, such as healthy food, high quality feed, health products and cosmetics that are produced in a sustainable way and has required a minimum of transportation. Production exceeding the domestic demand can be exported and marketed based on the same principles of freshness and sustainability (Jörundsdottir et al. 2015).

5 Conclusions

This report describes the major bioresources available for biorefining and biotechnological applications within the West Nordic region, for improved utilisation, sustainability and value creation. Furthermore, it identifies the major bioresource ingredients, processing technologies which are or may be applied, and possible end products obtained from processing of the different biomasses. Ongoing operations, processes and products, which are made through biorefining and biotechnological applications are covered.

The region's most important bioresources come from the marine environment, primarily as rest raw materials from fish and seafood processing, but also as underutilised algal biomass of huge potential. In addition, significant value lies within product development and value creation from agricultural side-streams.

The major conclusions of the report are the following:

- The region's most important bioresources for biorefining and biotechnology applications are of marine origin in the form of seafood rest raw materials and underutilised algal biomass.
- Major hindrances to increased utilisation and value creation through biorefining and biotechnology include the regions isolation and dispersed locations, lack of transport infrastructures and lack of public and private support through funding and investments, regulatory constraints and need for marketing support.
- Insufficient access to scale-up production facilities in the form of open-access biorefineries is another major hindrance to further processing and product development within the region.
- Improved information on feedstock supply, quantity, quality and seasonal availability is in many cases needed, as well as evaluation of how wild macroalgal biomass can be sustainably harvested.
- Transport of raw materials over vast areas is a challenge and marine raw materials are especially vulnerable and require thorough cooling.

- The seafood industry has been under critical attention regarding a more sustainable use of the oceans resources, including bringing increased proportions of catch to land, and the marine industry is under pressure to develop added value products.
- Iceland has valuable knowledge in biorefinery and biotechnological applications for value creation from fish rest raw materials and the Icelandic fishing industry is currently at the forefront in near full utilisation of cod. This knowledge and advantage should be transferred throughout the West Nordic region and applied to improve utilisation and increase value of other species of fish, as well as for different biomass types, such as those from agriculture.
- Considerable potential lies within the development of novel and value-added products from extraction of natural components from the available biomass, as well as from biological conversion of the biomass. Major products are proteins and bioactive compounds for use in pharmaceuticals, nutraceuticals, cosmetics, food and feed, as well as other food and feed components. Various chemicals and platform chemicals for industrial applications, energy carriers and fertilisers are also of importance.
- The region requires specially adapted solutions for utilisation of organic household residues that are suitable and practical for sparsely populated remote areas.
- Access to fresh water, geothermal heat and low prized green energy give Iceland a good advantage for biorefinery applications and further processing of biomass, as well as for cultivation of microalgae for production of specific bioactive compounds.
- Unique genetic resources are found within the West Nordic region in the form of extremophiles in cold and hot environments. These organisms are a source of compounds, such as secondary metabolites and industrially relevant enzymes, which should be further explored and utilised.

This report is intended to provide input into the ongoing strategy program of the West Nordic Bioeconomy panel, regarding biorefining and biotechnology opportunities and potential product developments for Iceland, Faroe Islands and Greenland.

To promote sustainable growth within the region, one of the strategies recommended by the West Nordic Bioeconomy panel is to stimulate the biorefinery and biotech industries. The findings of this report fully support that recommendation and demonstrate both the potential, as well as the obstacles faced. The recommended action is to increase access to affordable biomass, which in the West Nordic region primarily has its origin in the maritime industries. Another action recommended by the panel is to increase access to investment capital, both in the primary and secondary industries, and to increase research grants to establish proof of concept for novel applications of biotechnology or novel underutilised resources. These actions, in accordance with the scope of the report, are important and necessary to further developments based on biorefining and biotechnology within the region.

The West Nordic region possesses considerable opportunities and possibilities to improve its sustainable utilisation of bioresources, as well as generate added value from the available biomass. These opportunities should be utilised to the fullest and attempts in that direction need to be pushed, encouraged and supported in the coming years.

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