Industry Insight

2022 | Future Feed Ingredients

Future ingredients for Norwegian salmon feed

NCE Seafood Innovation

Foreword

NCE Seafood Innovation

Increasing the supply of sustainable raw materials for feed is the biggest single bottleneck to be solved, both if we want to achieve the ambitious goals set by the Norwegian government* and address the demand for sustainable feed ingredients from the industry. Indeed, it is recognized that the industry cannot achieve significant growth from the status quo without a breakthrough in this field.

There have been many initiatives in recent years and there are numerous early-phase projects addressing the possibilities of producing future feed ingredients ongoing as we speak. Despite numerous efforts, we are still left with a precarious need for sustainable novel feed ingredients. The truth is that today only 0.4% of the current feed mix comes from what is supposed to be sustainable novel ingredients. [15] The gap between ambition and practice is larger than most people imagine – and the demand from the industry remains unsatisfied.

Sustainable feed ingredients are often discussed, and we will argue that definitions are not used uniformly in the discussion. We believe that the need for sustainable feed ingredients cannot be met only by novel ingredients. If we are aiming to achieve results in this area in the near future, we need to explore all possibilities – also existing alternatives, like animal by-products.**

Addressing the topic of 'Future Sustainable Feed Ingredients', NCE Seafood Innovation gathered research institutions, industry pioneers and a panel of sector specialists to sum up the accumulated knowledge as well as to point out the major problem areas that need to be resolved going forward. The initiative was led by a steering group of leading experts and leaders from industry, and the report is broadly based and was elaborated with cluster partners and members.

Our ambition is that this report will give 'industry insight' in an effective format, and that it will contribute to the knowledge foundation in strategy processes at companies and industry stakeholders in the field. In addition to provide a foundation for political discussions around this topic.

On behalf of the steering group – we hope that this report will be a valuable contribution to more dialogue, and to an expanded understanding of a complex challenge and the industry's perspective.

And lastly, I would like to thank EY for your great contribution in putting this report together.

Nina Stangeland

Nina Stangeland, Managing Director
NCE Seafood Innovation

* In reference to the Norwegian government's Hurdal policy platform from 2021 [9] and the mission *Sustainable feed* from October 2022 [20] ** Due to scope limitations, this report does not discuss the use of by-products from salmonids directly, details around plant-based ingredients, nor feed derived from genetically modified organisms (GMOs) in this edition.

NCE Seafood Innovation

Costs are the largest barrier. Novel, sustainable feed ingredients are, and will be, more expensive in the commercialization period compared to traditional ingredients. Who should carry the cost of these novel feed ingredients in the salmon industry?

We believe this should be addressed by 'supply chain thinking'. In order to ensure scalability to the volumes that the industry need, we must be able to distribute the costs among all involved parties in the whole value chain. Our experience over the last few years at Cargill is that implementing and scaling novel and sustainable ingredients takes time. In a period of transition, national incentives will also be needed to secure the speed of this transition.

This report also identifies several other barriers to sustainable growth such as improving quality of novel feeds, scaling up production, overcoming regulatory obstacles, and getting funding and strategy in place. These are all important, however, the final chain must not be overlooked, the consumers. The transition towards more sustainable feed ingredients will require a higher focus on education of end consumers. Overcoming the obstacles and providing sustainable feed ingredients may force a higher price on the consumer product, and that willingness to share the cost need to be created.

Furthermore, increased circularity in food production, like inclusion of animal by-products may challenge the consumers mindset on what the recipe of future sustainable feed ingredients in a salmon consist of.

- Fredrik Witte, Managing Director, Cargill Aqua Nutrition North Sea

***Photo** NCE Seafood Innovation by Silje Katrine Robinson*

Background

Involvement across the value chain

NCE Seafood Innovation

The project has aimed to include all relevant actors in the value chain to ensure broad involvement, quality assurance and stakeholder commitment

Steering group

Einar Wathne
Chairman of the Board
NCE Seafood Innovation

Fredrik Witte
Managing Director
Cargill Aqua Nutrition North Sea

Håvard Walde
General Manager
Skretting

Maria Helsengreen
Partner/Principal, Consulting
EY

Nina Stangeland
Managing Director
NCE Seafood Innovation

Focus group

Industry partners

Lerøy Seafood Group	Harald Sveier, R&I Manager
Grieg Seafood	Tor Eirik Homme, Director Feed & Nutrition
Cargill	Ted Mollan, Supplier Development Manager
Benchmark Genetics	Kate Furhovden Stenerud, Regional Sales Manager South

R&D partners

NMBU	Margareth Øverland, Professor Aquaculture Feed
SINTEF Ocean	Ida Grong Aursand, Senior Business Developer
Nofima	Mari Moren, Research Director
NORCE	Renate Kvingedal, Research Director Industrial Biotech

Members

Lingalaks	Kristian Botnen, CEO
Bremnes Seashore	Geir Magne Knutsen, Director Strategy & Development
BioMar	Vegard Denstadli, Technical Director

Working group

Sturla Lie
Consultant – Technology Transformation, EY

Björgólfur Hávarðsson
Innovation Manager, NCE Seafood Innovation

Dominik Flatten
Project Manager – Sustainability, NCE Seafood Innovation

Elise Sæle Dahle
Project Developer, Land Meets Ocean

& other expert resources

The interviewees

Input from industry experts has been critical to ensuring updated metrics and identifying relevant opportunities and barriers for the scale-up of novel feed ingredients

Company	Category	Expert resource	
SINTEF	General introduction to novel feed ingredients	Ida Grong Aursand, Senior Business Developer	
	Mesopelagic fisheries	Eduardo Grimaldo, Senior Research Scientist	
	Photoautotrophic microalgae	Tom Ståle Nordtvedt, Senior Research Scientist	
Havforskningsinstituttet	Novel marine ingredients, insects and blue mussels	Erik-Jan Lock, Research Manager, Feed and Nutrition	
NORCE	General introduction to novel feed ingredients, photoautotrophic microalgae, and microbial organisms	Gro Elin Kjæreng Bjerga, Research Director, Marine Biotechnology	
Norges miljø- og biovitenskapelige universitet (NMBU)		Margareth Øverland, Professor Aquaculture Feed	

Company	Category	Expert resource	
LERØY	General introduction to novel feed ingredients and blue mussels	Harald Sveier, R&I Manager	
SKRETTING	General introduction to novel feed ingredients	Mads Martinsen, Director Marketing and Sustainability	
Cargill		Ted Mollan, Supplier Development Manager	
Nofima		Mari Moren, Research Director	
Grieg Seafood		Tor Eirik Homme, Director Feed & Nutrition	
Innovasjon Norge	Financial support systems	Ole Jørgen Marvik, Special Advisor, Life Sciences	

Strong scientific foundation

NCE Seafood Innovation

Existing scientific reports and research have been used as a starting point for mapping resource potentials

Utilization of feed resources in Norwegian farming of Atlantic salmon and rainbow trout in 2020 (Nofima, 2022)

Raw material efforts – feed for the future (Bellona, 2021)

Sustainable feed for Norwegian Salmon (SINTEF, 2020)

Received: 1 October 2021 | Revised: 26 January 2022 | Accepted: 20 February 2022

DOI: 10.1111/raq.12673

REVIEWS IN Aquaculture

REVIEW

Future feed resources in sustainable salmonid production: A review

Sissel Albrektsen[1] | Raine Kortet[2] | Peter Vilhelm Skov[3] | Elisabeth Ytteborg[1] | Susanne Gitlesen[4] | Dorinde Kleinegris[4] | Liv-Torunn Mydland[5] | Jon Øvrum Hansen[5] | Erik-Jan Lock[6] | Turid Mørkøre[1] | Philip James[1] | Xinxin Wang[1] | Ragnhild Dragøy Whitaker[1] | Birthe Vang[1] | Bjarne Hatlen[1] | Ehsan Daneshvar[7] | Amit Bhatnagar[7] | Linda B. Jensen[8] | Margareth Øverland[5]

[1]Nofima, Bergen, Norway
[2]Department of Environmental and Biological Sciences, University of Eastern Finland, Joensuu, Finland
[3]DTU Aqua, Section for Aquaculture, The North Sea Research Centre, Technical University of Denmark, Hirtshals, Denmark
[4]Norce, Bergen, Norway
[5]Department of Animal and Aquacultural Sciences, Faculty of Biosciences, Norwegian University of Life Sciences, Ås, Norway
[6]Institute of Marine Research, Bergen, Norway
[7]Department of Separation Science, LUT School of Engineering Science, LUT University, Mikkeli, Finland
[8]Skretting, Stavanger, Norway

Correspondence
Sissel Albrektsen, Nofima, P.O. Box 5844 Oasen, NO-5828 Bergen, Norway.
Email: sissel.albrektsen@nofima.no

Funding information
NordForsk, Grant/Award Number: 82342

Abstract

Aquaculture is one of the most resource-efficient and sustainable ways to produce animal protein. The Food and Agriculture Organization predicts that cultivated aquatic species will provide around 53% of the world's seafood supply by 2030. Further growth of intensive farmed aquatic species may be limited by a shortage of feed resources. The aquaculture sector therefore needs to intensify its search for alternative ingredients based on renewable natural resources. A significant increase in production will require an accelerated transition in technology and production systems, better use of natural available resources, development of high-quality alternative feed resources and exploitation of available space. The present review discusses the urgent need to identify appropriate alternative ingredients for a sustainable future salmonid production. We describe and evaluate the most promising marine ingredients, including low-trophic species (mesopelagic fish, zooplankton, polychaetes, macroalgae and crustaceans), novel microbial ingredients (bacteria, yeast and microalgae), insects (black soldier fly, yellow meal worm and crickets), animal by-products (poultry meal, meat and bone meal, blood meal and hydrolysed feather meal) and by-products from other commercial productions (trimmings and blood). Furthermore, we discuss the available volumes and need for new processing technologies and refining methods to ensure commercial production of nutritionally healthy ingredients. The essential production steps and considerations for future development of sustainable and safe seafood production are also discussed.

KEYWORDS
aquaculture, circular economy, emerging feed resource, ingredient, salmonid, seafood production

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.
© 2022 The Authors. *Reviews in Aquaculture* published by John Wiley & Sons Australia, Ltd.

Rev Aquac. 2022;1–23. wileyonlinelibrary.com/journal/raq 1

Future feed resources in sustainable salmonid production: A review (Albrektsen et al, Animalia, 2021)

NCE Seafood Innovation

For salmon farmers in the Americas, ingredients from land animal by-products (poultry) are important components in the feed, representing 20-30% of the total mix.

- Tor Eirik Homme, Director Feed & Nutrition, Grieg Seafood

Blue mussels are both high in nutrition, have a high digestibility and can be produced along the Norwegian coastline. They can become a strong second leg to our aquaculture industry.

- Harald Sveier, R&I Manager, Lerøy Seafood Group

We have to develop more raw materials for salmon feed. Marine resources are important, but also alternative and novel feed ingredients. Waste products such as forest waste can have potential, as well.

- Geir Magne Knutsen, Director Strategy & Development, Bremnes Seashore

***Photo** NCE Seafood Innovation by Silje Katrine Robinson*

NCE Seafood Innovation

Future feed ingredients summed up

Executive summary

The global need for area-efficient, sustainable food is rapidly increasing, and utilizing more ocean-based resources is expected to be a crucial part of the solution.

Feed is by far the largest component with regards to both greenhouse gas emissions and costs in the salmon industry. The Norwegian governments' Hurdal policy platform has created national ambitions for salmon feed in Norway, stating that all feed should come from sustainable resources by 2030 and feature an increased share of Norwegian resources. This report aims to visualize the gap between these political ambitions, the current status and predictions towards 2030.

There is a crucial need to increase national industrial production of novel feed ingredients, while improving sustainability along existing value chains will be paramount.

In Norway, the novel feed ingredients that are closest to industrialized production are blue mussels and photoautotrophic microalgae. Both novel marine ingredients, insects, and microbial ingredients have potential in the long run.

Revisiting land animal by-products that were a major part of the available resources prior to bovine spongiform encephalopathy, and still are in the Americas, holds promise but requires increased customer acceptance and consumer education. Marine animal by-products is another underutilized source for highly nutritional feed ingredients.

To meet national ambitions for feed and salmon production towards 2030, the following critical success factors have been identified:

1) Meeting future demand through a portfolio of resources
2) Developing an overall strategy for bioresources
3) Developing a strategy for sustainable feed ingredients, and
4) Introducing incentives to scale-up production of Norwegian feed ingredients

***Photo:** Shutterstock*

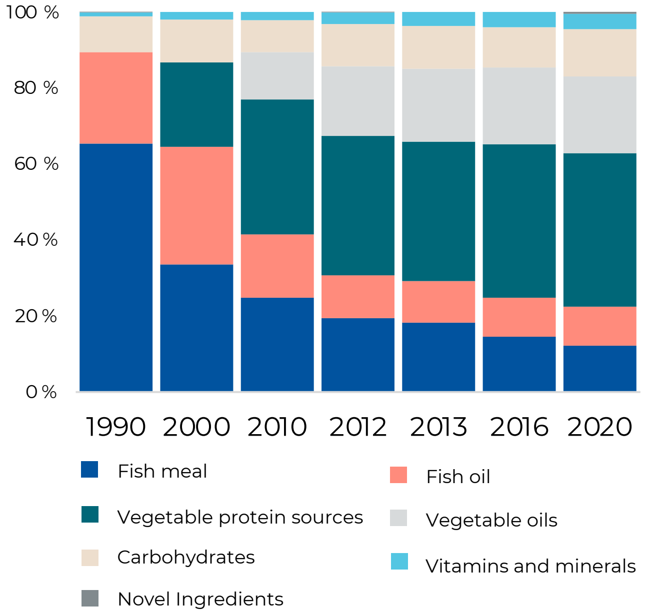
Feed gap requires solutions to critical bottlenecks

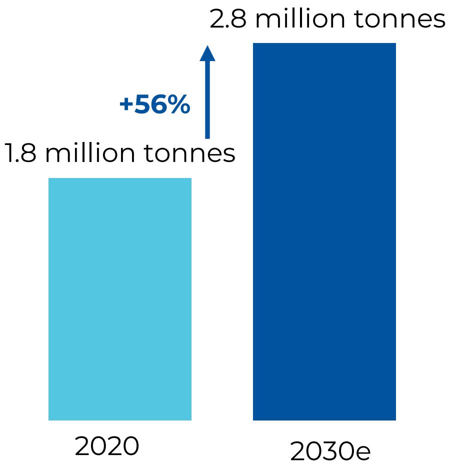
The situation is critical - to meet the increased demand for sustainable feed, production of novel feed ingredients must be industrialized

Only 0.4% of Norwegian salmon feed consists of novel ingredients, and none are produced in Norway [10]

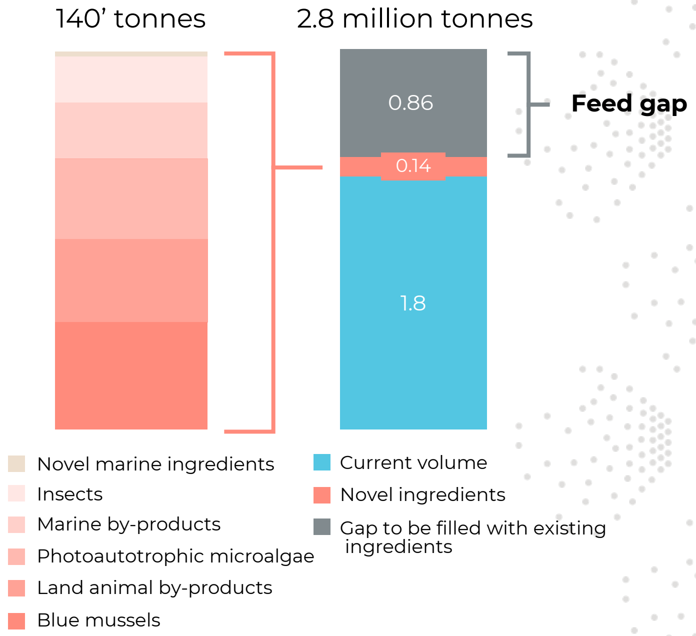
To meet the growth ambitions in national salmon production towards 2030, a feed volume growth of ~1 million tonnes is necessary* [10]

Our analysis indicates that only 140' of the 1 million tonnes necessary volume growth can be met by Norwegian-produced ingredients. [7] Improving sustainability along existing value chains will therefore be paramount.





* based on current feed conversion ratio (FCR) measured in dry weight



Political ambitions for sustainable feed

NCE Seafood Innovation

National ambitions state that all salmon feed should be sustainable by 2030, and more ingredients should come from Norway and CCU inputs

Hurdalsplattformen, the 2021 political platform of the Norwegian government, sets some ambitious goals for developing sustainable feed raw materials for Norwegian aquaculture.[9] In addition, the government has recently reinforced the emphasis on feed ingredients through including the mission *Sustainable feed* in 'Long-term plan for research and education'.[20]

While being ambitious, it remains unclear how this should be interpreted and realistically achieved. Hurdalsplattformen's ambitions on sustainable feed (ingredients) and for the aquaculture industry as such are threefold:

1) All feed in the Norwegian aquaculture industry should be from 'sustainable' resources by 2030
2) Stimulate increased sustainability through a production program of sustainable feed from Norwegian resources
3) Facilitate carbon as an input factor to feed production through carbon capture and utilization (CCU)

Undoubtedly, the industry shares the same ambition as the Hurdalsplattformen on point 1). But let's be clear – we cannot address and succeed with 100% sustainable feed ingredients by 2030 by focusing on local ingredients (2) and CCU inputs (3) only.

Hurdalsplattformen – National ambitions for sustainable feed

NCE Seafood Innovation

8% of today's feed ingredients are from Norwegian resources, about 35% are from European resources and at least 38% are from sources outside Europe. [15] To reach ambitions 2) and 3) in the Hurdalsplattformen by 2030 from the existing level of 0.4% novel feed ingredients [15] seems unrealistic.

More realistically and in a best-case scenario, Norwegian (local) feed ingredients (2) and the use of carbon/CCU (3) in feed production can contribute to scale up the production of novel sustainable feed ingredients from 0.4% to a significantly higher share in 2030.

The development of novel feed ingredients is undoubtedly of material importance and broadly addressed. However, substituting all existing ingredients by novel and local sustainable feed ingredients by 2030 will most likely not be possible, given the significant volume gap, the time constraint and lack of economic incentives.*

On the other hand, ambition 1) should and could be addressed more broadly and potentially give significant and faster results in relation to future sustainable feed in the Norwegian aquaculture industry by 2030.

This ambition should include a broader approach to:

- industrializing novel feed ingredients in a broader geographical context (Norwegian, Nordic, European) for national consumption
- improving sustainability along the value chain of existing feed ingredients
- closer interaction across different biosectors (agriculture, fishery, aquaculture, and others)
- revisiting animal by-products that have seen less use at a national level over the last twenty years

Further, sustainability aspects like the processing of animals close to their natural habitats, as well as social sustainability, should be taken into consideration. Leaving out these aspects would be a loss for all parties.

Stating ambition 1) in the Hurdalsplattformen as the overall target and addressing it more broadly than formulated in ambitions 2) and 3) will determine the path, speed, and success in regard to future sustainable feed ingredients by 2030.

* The barriers in Part 3 of this report will highlight this in more detail.

Barriers and critical success factors

NCE Seafood Innovation

Overcoming the following barriers has been identified as especially critical to solve for substantial growth of future feed ingredients [10]

- Lack of regulatory framework for efficient use of bioresources
- Lack of national strategy and funding for bioresources and feed ingredients
- Lack of customer acceptance and consumer education
- Lack of scale increases cost curves
- Quality of novel ingredients not meeting necessary standards

Critical success factors to meet national needs for feed and salmon production towards 2030 [10]

- Future demand must be met by a portfolio of resources
- Develop an overall strategy for bioresources
- Develop a strategy for sustainable feed ingredients
- Incentives to scale-up production of Norwegian feed ingredients

NCE Seafood Innovation

The most important thing the Norwegian aquaculture industry can do to reduce the carbon footprint of the feed is to make sure that current macro ingredients are improved by setting industry standards for its raw material suppliers – like we did for suppliers of soy protein concentrate (SPC) from Brazil, who are now completely deforestation free in their whole value chain. These are the kinds of efforts where the industry needs to align and work in concert.

The key potential for fish farmers and feed suppliers to produce a more sustainable fish or feed than their peers is to enter long-term collaborations and commitments with partners and suppliers of novel sustainable ingredients to help them reach scale and to get a future competitive advantage by reducing the footprint compared to industry average.

Increasing Norwegian production of raw materials may be government policy, but we believe significant financial incentives will be needed to drive such a development forward. The industry will always prefer the ingredients with the lowest cost and lowest footprint, irrespective of where they are produced, and the emissions related to transport make up a negligible proportion of the total emissions of any raw material.

- Håvard Walde, General Manager, Skretting

Photo: *NCE Seafood Innovation*

NCE Seafood Innovation

Table of contents

NCE Seafood Innovation

A novel Norwegian source of protein should be at least 100 000 tonnes to contribute substantially as a novel feed ingredient in fish feed.

- Mari Moren, Research Director, Nofima

We have a unique opportunity to address the global challenge on how to produce sustainable food, by focusing on 100% utilization of all raw material. We need to upcycle all fractions that humans do not eat. Sustainable utilization of by-products from all food production both in blue and green sectors, as a premium feed ingredient in animal feed, makes sense both in terms of environmental footprint and increased circularity. It is better for the planet by using less, it is better for the animals due to better animal health and lower mortality rate, and reduced carbon footprint for the food production. A win-win that is possible to act on now.

- Edgar Skjervold, Chief Executive Officer, NUTRIMAR

***Photo:** Getty Images*

NCE Seafood Innovation

01

Status of salmon and feed ingredient production

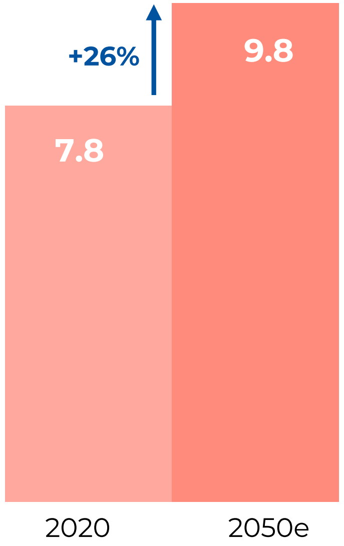
Population growth demands swift action

NCE Seafood Innovation

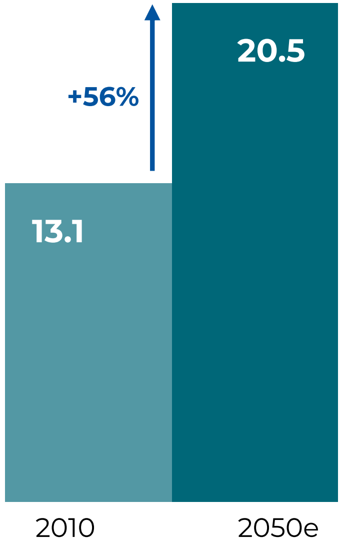
To meet the demand of a growing population, developing area efficient resources will be critical

A global population of 10 billion in 2050 is expected to cause a 56% food gap compared to calories produced in 2010 [25, 27]

Population growth
(billion)



Food production
(trillion calories per year)



The need for sustainable ecosystems, climate change, and water scarcity are key challenges for future food production [4, 27]

Land-use and biodiversity

50% of vegetated land is currently used for global agriculture, and with ‘business as usual’ towards 2050, an area twice the size of India is needed for agricultural expansion. Agriculture has also been the greatest source of biodiversity loss, and without changes, will continue to be so.

Climate change and decarbonization

There is a 11 gigatonne GHG gap between expected emissions from agricultural production and land-use change in 2050, and the target necessary to keep the rise in global temperature below 2 °C.

Water scarcity

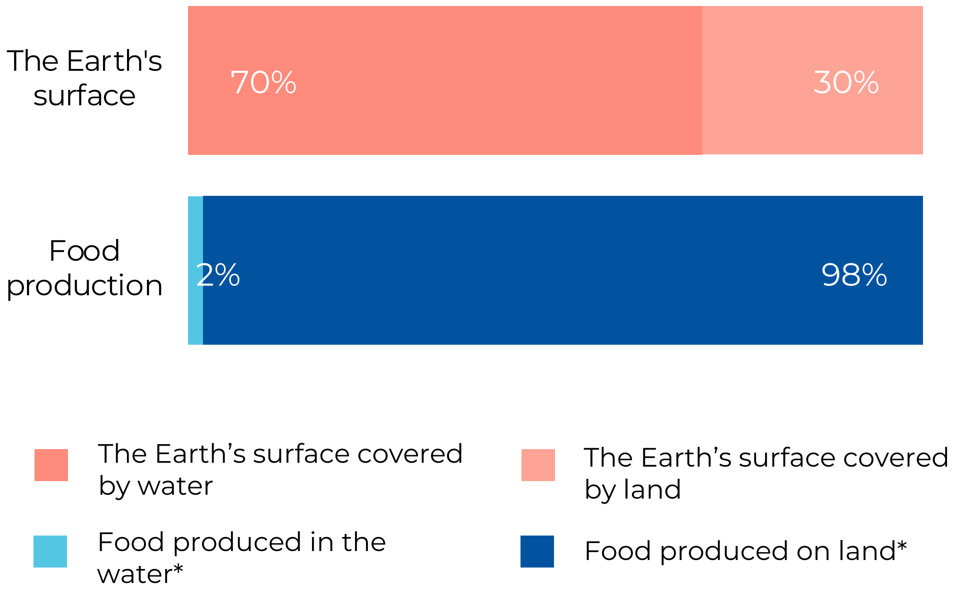
Agriculture is the main reason for freshwater depletion, accounting for 70% of all freshwater withdrawals, and more than 90% of all consumed water.

Oceans to become key to resolving global protein needs

NCE Seafood Innovation

Resources from the oceans are underutilized compared to land-based resources, and can greatly contribute to meet future demand sustainably

70% of the Earth is covered by oceans, but only 2% of our food is obtained from the sea*. Aquaculture will be key in future food supply [6]



* measured in calorie intake

Salmon has low emissions and water consumption, and high protein retention compared to similar protein sources [14, 15, 24]

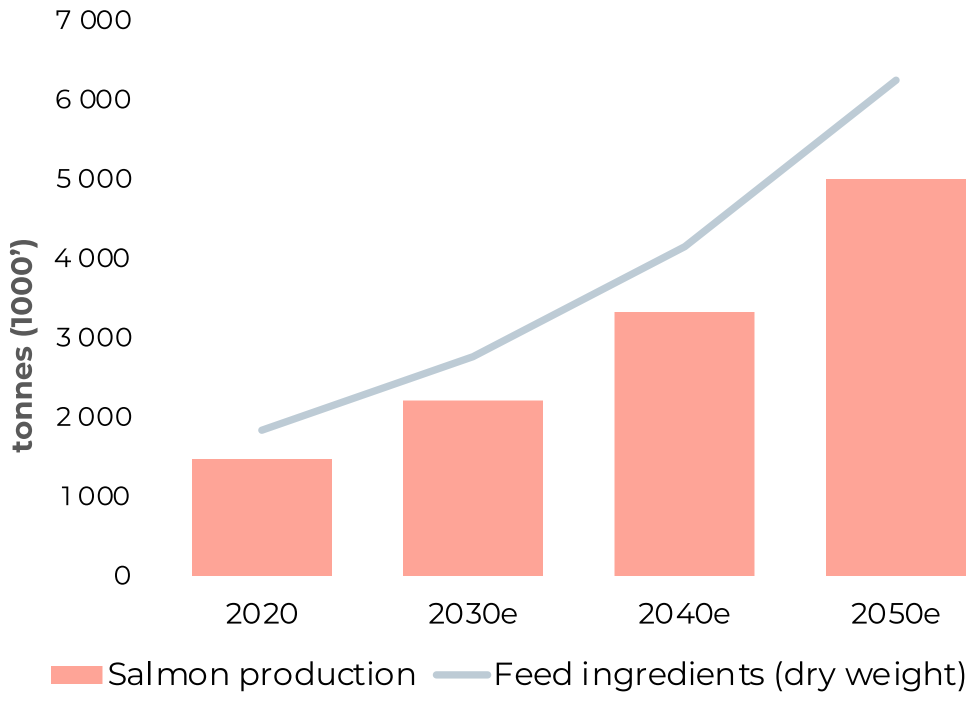
kg CO_2 per kg edible meat

Resource efficiency	Poultry	Salmon	Pork	Beef
Protein retention	37%	28%	21%	13%
FCR	1.9	1.3	3.9	8.0
Edible meat per 100 kg feed	39 kg	56 kg	19 kg	7 kg
Water consumption (liter per kg edible meat)	4 300 l	2 000 l	6 000 l	15 400 l

Sustainable feed key to future growth

One of the major challenges for salmon aquaculture growth will be to produce enough feed, while ensuring sustainability and coverage of nutritional needs

National ambitions of 5 million tonnes of salmon in 2050 will require 6.2 million tonnes of feed ingredients* [15, 16, 17]



* with current conversion ratio measured in dry weight

Sustainable and affordable feed are vital components for future salmon production growth [24, 26]

Without air transport included, feed production accounts for 75-83% of greenhouse gas emissions per unit of salmon delivered to the market. To further grow and reduce emissions:

- New technologies and improvements throughout the value chain for existing ingredients are necessary
- Novel, sustainable ingredients must be developed

Feed is the largest cost component in salmon production, accounting for 41% of total costs in 2020, and 46% of production costs. Since then, costs for imported feed have increased considerably. The war in Ukraine has caused a rapid shift in feed prices, as the country is the world's third largest exporter of wheat, second largest producer of sunflower seeds (after Russia), and a major producer of fertilizers.

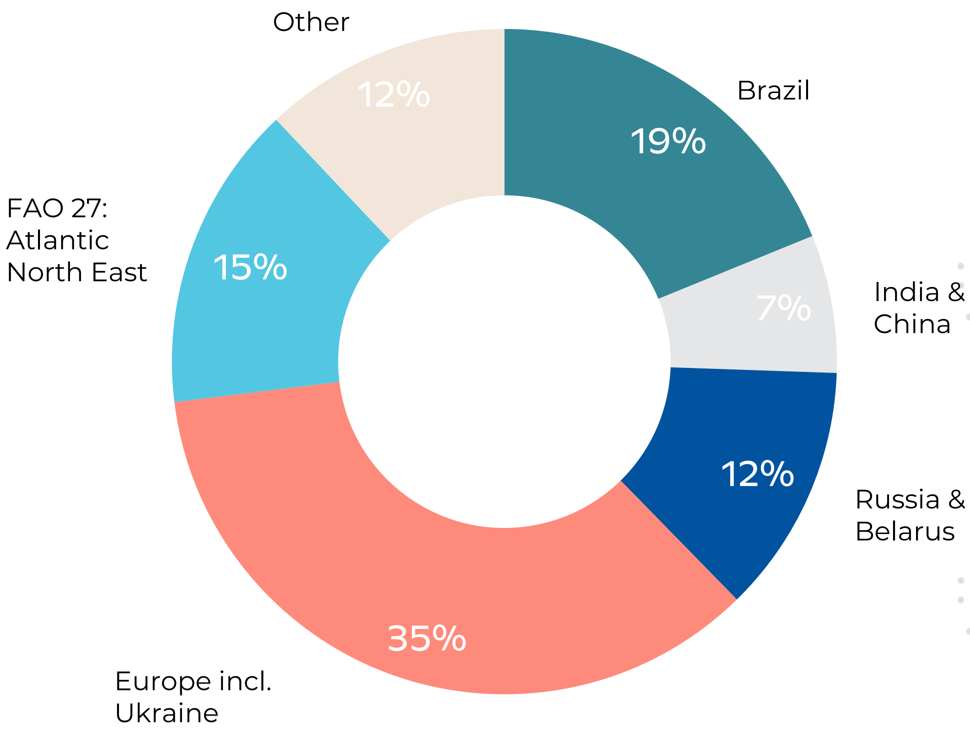
Imports dominate Norwegian salmon feed production

Almost 2 million tonnes of ingredients were used in Norwegian salmon feed in 2020, with 92% imported ingredients

Norway accounted for only 8% of total feed ingredients in 2020 [15]

- 1.98 million tonnes of feed ingredients were used in salmon feed in 2020, with 8% coming from Norway (fish meal and oils).
- 92% of all ingredients were imported, mainly plant-based ingredients from Europe (~700' tonnes), Brazil (~370' tonnes) and Russia/ Belarus (240' tonnes).
- The largest amount of marine ingredients came from the Atlantic North East fishing area (FAO 27), with a total of about 295' tonnes. Of this share, 96' tonnes came from offcuts.

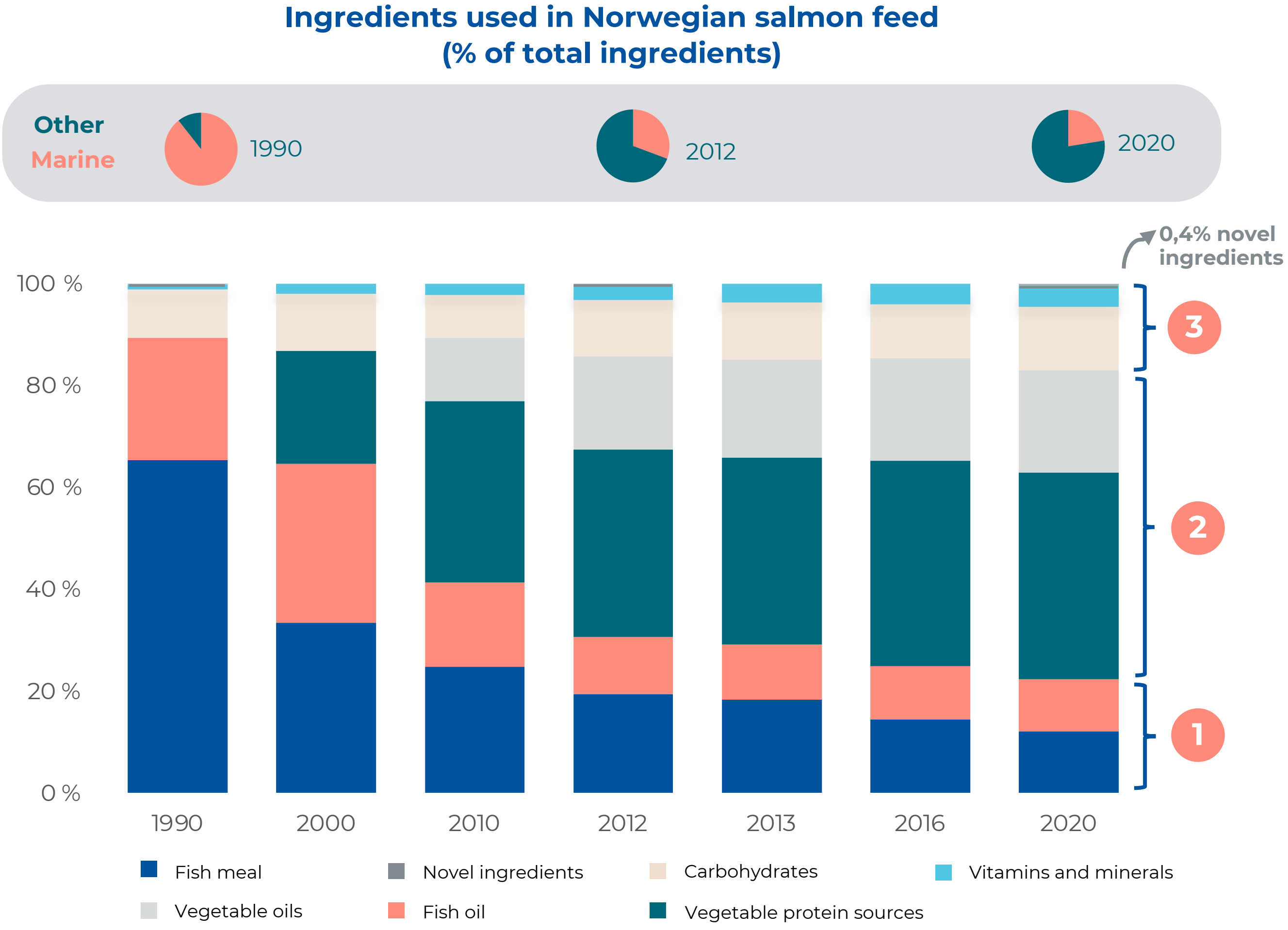
Origin of ingredients used in Norwegian salmon feed in 2020 (Norwegian feed ingredients included in FAO 27) [15]



Increase in novel feed raw materials necessary for growth

NCE Seafood Innovation

Today's feed mainly consists of land-based sources, with soy being the dominant ingredient source. Only 0.4% are novel ingredients. [15]



1 Marine ingredients at record low levels in 2020

- The dominant protein and oil source for fish feed in 1990 (~90%)
- Reached a record low share in 2020, with approximately 22% of total feed ingredients

2 Plant-based ingredients the dominant source in fish feed

- Plant-based protein and oil accounted for more than 60% of total feed ingredients in 2020
- Soy the dominant protein source with nearly 21% of ingredients share total
- Canola oil the dominant oil source with 18% of ingredients share total

3 Novel ingredients a small fraction of total feed volumes

- Novel ingredients (insect meal, single cell proteins, microalgae, etc.) accounted for 0.4% (8 130 tonnes) of total ingredients in 2020
- Carbohydrates stable in recent years, 12.5% in 2020
- Micro ingredients (vitamins, minerals, amino acids, etc.) stable around 4%

NCE Seafood Innovation

The future sustainable salmon feed will consist of a diverse portfolio of raw materials. To speed up the commercialization of novel, sustainable raw materials, we need the players to join forces and distribute the cost along the value chain. This will necessitate that the actors invest in flexible solutions enabling them to handle a differentiated product range from raw material to final product.

- Ida Grong Aursand, Senior Business Developer, SINTEF Ocean

Scalability and sustainability depend on geographical variations. Several feed ingredients require a focus that is wider than only national. Sustainable scaling might be better outside of Norway.

- Renate Kvingedal, Research Director Industrial Biotech, NORCE

We must develop more local feed ingredients from our natural resources. Foods of Norway at NMBU is working on developing microbial ingredients from these resources using biotechnology.

To realize the commercial potential, we need to – in cooperation with industry and the authorities – continue to document the benefits of these ingredients and address bottlenecks for upscaling.
This collaboration will be critical, because only by working together can we succeed.

- Margareth Øverland, Professor Aquaculture feed, NMBU

Photo *NCE Seafood Innovation by Silje Katrine Robinson*

NCE Seafood Innovation

02

Status of novel feed ingredients

Future ingredients facing demands

NCE Seafood Innovation

For novel ingredients to become relevant, they must be sustainable, meet well-established nutritional needs, and have high technical qualities [10]

Sustainability should be measured along the entire value chain and include measures for both resource use, emissions and economical viability

Minimize use of natural resources

- Energy
- Area (incl. competition for food crops and land from bioenergy)
- Freshwater
- Fully utilize all bioresources (incl. animal by-products)

Minimize emissions and toxic materials

- GHG and local emissions
- Biodiversity and environmental ecosystem degradation
- Waste

Maximize sustainable economic growth

- Competitive prices in a global market
- National, sustainable value creation
- New value chains and circular business models

A common denominator for success with sustainability will be to establish production in circular hubs with shared resources.

Several promising sources of future feed raw material

NCE Seafood Innovation

Future ingredients can be categorized into harvested novel marine and plant-based ingredients, farmed organisms and underutilized resources

Harvested resources [10, 23]

Novel marine ingredients

- Mesopelagic fish
- *Calanus finmarchius*
- Krill

Plant-based ingredients**

- Grass
- Tree biomass

Farmed organisms [10, 23]

Insects

- Black soldier fly
- Mealworms

Marine low-trophic species

- Blue mussels***
- Polychaeta
- Gammaridae
- Tunicate
- Seaweed

Microbial ingredients

- Bacteria
- Yeast
- Fungus
- Heterotrophic microalgae

Photoautotrophic microalgae****

Underutilized resources [10]

Land animal by-products*****

- Poultry
- Pork

Marine by-products

- Whitefish
- Pelagic fish
- Aquaculture*

* Due to scope limitations, this report does not discuss the use of by-products from salmonids directly, nor feed derived from genetically modified organisms (GMOs) in this edition. ** Plant-based ingredients are not evaluated in depth due to lack of potential by 2030. *** This report focuses mainly on blue mussels due to their production potential by 2030 **** Photoautotrophic microalgae are also microbes but analyzed separately due to their production potential by 2030. ***** Only from poultry and pork production according to current EU legislation.

Novel marine resources
– Promising but much R&D remains

NCE Seafood Innovation

Novel national, marine ingredients have potential in the long run, but not likely to be a large part of feed ingredients by 2030 [5, 10, 11, 19, 23]

Overview

- Novel marine ingredients includes mesopelagic fish, *Calanus finmarchicus* (Calanus), and krill, where Calanus is the only regulated species for commercial harvesting in Norway
- Commercial regulations for Calanus were implemented in 2019, with allowable harvesting of 254 000 tonnes. Of this volume, only 8 000 tonnes are within the 1 000 meters depth quota, where one player has existing catch technology to harvest the resource.
- Several ongoing research projects about mesopelagic fish, e.g., the EU Horizon-projects (SUMMER and MEESO) or SFI Harvest. So far, the results for identification and sustainable catching methods have not been very promising.
- Krill is currently not allowed to be harvested in Norwegian waters. Promising results from harvesting in Antarctica can pave the way for regulation and industrialization in Norway.

Key numbers

Estimated 8 000 tonnes harvested Calanus, or ~752/ 564 tonnes protein/ oil in 2030

- Potential for larger growth of Calanus, but requires that technologies also work outside the 1 000 meters depth quota
- Krill with considerable potential but depends on regulations. Aker Biomarine plans to harvest 55-60 000 tonnes of krill in Antarctica in 2020
- No commercial licenses likely to be in place for mesopelagic fish before 2030

High quality ingredients for marine protein and oils

- Estimated ~40% protein of dry weight krill and Calanus

High costs for both mesopelagic and Calanus

- Mesopelagic must have minimum avg. harvest rate of 40 tonnes/ hour to be profitable – far from the current average of 3.5
- Highly varying cost for Calanus (estimates of NOK 10-100 per kg wet weight)

Novel marine resources
– Promising but much R&D remains

Novel national, marine ingredients have potential in the long run, but not likely to be a large part of feed ingredients by 2030 [5, 10, 11, 19, 23]

Strengths

- ✓ Excellent protein and marine oil resource that can be harvested from the oceans
- ✓ Strong fishery experience and competence in Norway a competitive advantage with regards to efficient harvesting and processing technologies
- ✓ Significant volumes for all species likely in the Norwegian exclusive economic zone in the North Atlantic sea
- ✓ Necessary research, mapping and regulations in place for commercial harvesting of Calanus within the 1 000 meters depth quota
- ✓ Established technology for krill processing
- ✓ Regulations established for initial trial fishing of mesopelagic fish

Barriers

- ✗ Limited knowledge of where and how to locate novel marine ingredients (except for Calanus within the 1 000 meters depth quota)
- ✗ Biomass from krill and Calanus also attractive as high-grade products
- ✗ By-catch a major challenge for all species due to inefficient detection technologies
- ✗ Processing of mesopelagic fish should be done immediately after harvesting
- ✗ Lack of biological and ecological ecosystems knowledge and standards for unregulated species and some regulated (e.g., krill)
- ✗ Lack of incentives for resource mapping/trial fishing

High level evaluation of barriers to industrialized production by 2030

Volume potential by 2030	Development level	Cost efficiency	Norwegian competitive advantages	Positive impact on sustainability	Customer acceptance	Scaling potential Beyond 2030
Low	Medium	Low	High	Medium	Medium	?

Low · Medium · High · ? Uncertain · * High ≥ 30 000 tonnes

Insects
– Regulations hamper insect-based options

NCE Seafood Innovation

Insects can become a valuable future ingredient if regulations allow for organic waste to be used as feedstock [5, 7, 10, 23]

Overview

- Insects are a natural part of the diet for wild salmon, and some insect species have been allowed for fish feed in EU and Norway since 2017
- Future growth highly dependent on regulations for organic waste to be used as feed for insects
- Large potential as feed ingredient if food waste can be used as feed stock (global demand of 500 000 tonnes protein in 2030) [4]
- Important to understand supply chains for relevant feedstocks for upscaled production
- Pronofa and Invertapro with ambitious goals and partnerships with relevant industry partners
- Foreign companies are presently the major driving force in the development of insects as feed ingredients and have located themselves close to approved large-scale feedstocks

Key numbers

Estimated 17 000 tonnes insect meal in 2030/ 6 500 tonnes protein (assuming organic waste can be used in production)

High protein levels

- Very similar to soy with ~60% protein

High production costs

- More than double the price of fish meal

Insects
– Regulations hamper insect-based options

Insects can become a valuable future ingredient if regulations allow for organic waste to be used as feedstock [5, 7, 10, 23]

Strengths

- ✓ High protein and lipid composition
- ✓ Potential to contribute to circular food system, where insects upcycle waste
- ✓ Low area and freshwater use
- ✓ High feed utilization and low GHG emissions per kg product
- ✓ Positive effects for fish welfare and health
- ✓ Regulations in place for resource and product
- ✓ Established technology for processing insects
- ✓ Little waste, insect waste (frass) can be used as fertilizer

Barriers

- ✕ European and Norwegian legislation requires larvae to be grown with plant-based products, with a few exceptions for animal ingredients (e.g., fish meal). Sludge and waste could be valuable feedstocks but are currently not allowed
- ✕ Low digestibility
- ✕ Problematic fatty acid profile
- ✕ Energy-demanding processing
- ✕ Insects not likely to be able to compete with soy on price, and only with fish meal in circular systems including waste as feedstock
- ✕ Traceability and quality of feedstock from food waste

High level evaluation of barriers to industrialized production by 2030

Volume potential by 2030	Development level	Cost efficiency	Norwegian competitive advantages	Positive impact on sustainability	Customer acceptance	Scaling potential Beyond 2030
Medium	Medium	Low	Medium	Medium	Medium	Medium

Low · Medium · High · ? Uncertain · * High ≥ 30 000 tonnes

Blue mussel farming
– A renaissance

NCE Seafood Innovation

Blue mussels with potential to become an important protein source for Norwegian salmon feed by 2030 [5, 10, 23]

Overview marine low-trophic species*

- Blue mussels, polychaeta, Gammaridae, tunicates, and seaweed are low trophic resources that can be a part of circular value chains, recycling and upcycling nutrients. Further, blue mussels and seaweed absorb and store CO_2.
- Due to relatively low protein and fat levels, seaweed is not likely to become relevant as a resource in salmon feed
- Tunicate meal with relatively high protein levels, but hard to produce high quality products
- Both Gammaridae and polychaeta can upcycle the bioresidue from biogas production to high value protein and omega-3 but available volumes are still too low for commercial feed production
- Blue mussels an excellent protein and industrialized fatty acid resource with good technical qualities. Closest to production and with very positive CO_2-footprint.

* This report focuses mainly on blue mussels due to their production potential by 2030

Key numbers blue mussels

Estimated 40 000 tonnes blue mussel meal 6/ 26 000 tonnes protein in 2030

- If ensilage technology is improved, volumes can further be increased (e.g., the Hardangerfjord alone could easily produce 200 000 tonnes of blue mussels)

High quality ingredient with ~65% protein and comparable FCR to fish meal in traditional processing

- Currently a bit lower digestibility/ higher FCR using ensilage

Cost-effective compared to fish meal when utilizing excess (subsidized) European blue mussels

- Still a way to go to become cost-efficient with farming in Norway

Blue mussel farming
– A renaissance

Blue mussels with potential to become an important protein source for Norwegian salmon feed by 2030 [5, 10, 23]

Strengths blue mussels

- ✓ Excellent protein and fat resource that can be produced or harvested from the oceans
- ✓ Considerable volume potential
- ✓ Can contribute to circular systems with e.g., seaweed and salmon by upcycling nutrients and reducing carbon footprint
- ✓ Low footprint also when processing and in conservation
- ✓ Denmark utilizes blue mussels especially in the Baltic sea to absorb nitrate and phosphor fertilizer spills from agriculture. The availability of large Danish volumes improves short-term scaling possibilities.
- ✓ Producing protein mass through effective ensilage technology reduces costs to competitive levels

Barriers blue mussels

- ✕ Challenging to process/ separate the different parts of the blue mussels
- ✕ Energy-intensive drying process to produce blue mussel meal
- ✕ Ensilage technology currently results in lower salmon weight gain, and higher FCR
- ✕ Without similar incentives as in Denmark, cost-effective blue mussels farming is likely to be dependent on successful ensilage processing
- ✕ Licenses and zoning not adjusted to blue mussel farming in Norway
- ✕ Requires quite a lot of space
- ✕ Potential conflict with producing blue mussels for human consumption

High level evaluation of barriers to industrialized production by 2030

Volume potential by 2030	Development level	Cost efficiency	Norwegian competitive advantages	Positive impact on sustainability	Customer acceptance	Scaling potential Beyond 2030
● High	● Medium	● Medium	● High	● High	● High	● High

● Low ● Medium ● High ? Uncertain * High ≥ 30 000 tonnes

Microbes
– Hold great promise

NCE Seafood Innovation

Microbial ingredients with large potential if alternative fermentation substrates can be utilized [5, 10, 23]

Overview

- Microbial ingredients include bacteria, yeast, fungus, and microalgae (photoautotrophic microalgae are dealt with separately, see next section). All ingredients to produce microbes, as well as feed ingredients from microbial production, are available on the global market.
- Several initiatives from Foods of Norway and Nordic Feed. Biorefinery and enzyme technology utilizing tree biomass and food waste to produce microbial ingredients
- Gas fermentation from Gas2Feed aims to utilize CO_2 to produce feed ingredients
- National infrastructure for fermentation and biomass production in Stavanger to develop new fermentation processes and facilitate piloting/scaling

Key numbers

Highly uncertain national potential towards 2030 [7]

- Several ingredients with large potential, but fermented ingredients depend on sugar price development, while gas fermentation is still in development stage

High quality ingredients with protein levels ranging from 50-80% and up to 90% digestibility

- Heterotrophic microalgae with high amounts of fat (> 50% oil and 30% DHA)

Currently not cost-competitive vs. protein from fish meal or fish oil due to high sugar prices.

Microbes
– Hold great promise

NCE Seafood Innovation

Microbial ingredients with large potential if alternative fermentation substrates can be utilized [5, 10, 23]

Strengths

- ✓ Ingredients can be produced all-year and transform side-stream feedstocks into high-grade ingredients
- ✓ Established technology for fermentation with sugar as substrate
- ✓ Minimal area and freshwater use
- ✓ Potential to utilize a broad range of feedstocks, such as residual waste, biomass from trees (second generation sugars), CO, CO_2, CH_4, and H_2

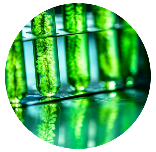
Barriers

- ✗ Profitability hard due to the competition with food and fuel, where sugar is required as feedstock for all processes. Use of sugars can be challenging in terms of sustainability.
- ✗ National infrastructure not ready for industrialized production of single cell proteins
- ✗ Gas fermentation is a complicated process with uncertainty around scale-up and investments
- ✗ Large product quality variations
- ✗ High energy costs, especially for gas fermentation

High level evaluation of barriers to industrialized production by 2030

Volume potential by 2030	Development level	Cost efficiency	Norwegian competitive advantages	Positive impact on sustainability	Customer acceptance	Scaling potential Beyond 2030

Low Medium High ? Uncertain * High ≥ 30 000 tonnes



Microalgae
– Already scaling

NCE Seafood Innovation

Photoautotrophic microalgae with potential to become an important protein and oil source for Norwegian salmon feed by 2030 [5, 10, 23]

Overview

- Large initiative under development in Finnfjord, which received NOK 93.3 million from the Green Platform scheme. Utilizes CO_2, seawater, light, and excess heat to produce microalgae.
- Two parts; the AlgOpti (industry) led by Finnfjord, Cargill, Br. Karlsen and Nofima, and AlgScaleUp (knowledge-building with SINTEF, UiT, Cargill and Finnfjord
- National pilot for photoautotrophic microalgae at Mongstad, to optimize technology and demonstrate in pilot scale
- Mixotrophic growth of microalgae is an alternative production method where inorganic carbon (CO_2) using photosynthesis as well as organic carbon sources are used simultaneously

Key numbers

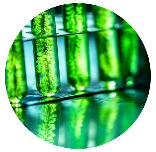
Finnfjord releases 300 000 tonnes CO_2 yearly, which can lead to 30 000 tonnes of microalgae dry weight. This equals 10 500 tonnes of protein and 9 000 tonnes of oil.

- Global production per 2022 ca. 25 000 tonnes dry weight

A good mixture of proteins and oils, with ~35% and ~30% of dry weight respectively in the algae utilized in Finnfjord

- Average in microalgae is about 50% protein

High uncertainty, but if production can be scaled and is done in circular hubs, costs are estimated to reach levels of fish meal (protein) and oils (EPA/DHA)



Microalgae
– Already scaling

NCE Seafood Innovation

Photoautotrophic microalgae with potential to become an important protein and oil source for Norwegian salmon feed by 2030 [5, 10, 23]

Strengths

- ✓ Potential as a resource for both protein, oils, and pigments (such as astaxanthin)
- ✓ Can utilize emissions and waste (e.g., CO_2 and wastewater from aquaculture and biogas production) to stimulate industrial symbiosis in circular hubs
- ✓ Utilizing larger algae reduces the need for light and water and increases the likelihood of scalable production

Barriers

- ✕ Dewatering very energy intensive
- ✕ Uncertain and untested biology, both in terms of nutrient content and whether the algae actually upcycle CO_2
- ✕ Currently small-scale production
- ✕ Needs to develop energy-efficient lighting concept
- ✕ Photoautotrophic microalgae have a low productivity, low protein conversion rate

High level evaluation of barriers to industrialized production by 2030

Volume potential by 2030	Development level	Cost efficiency	Norwegian competitive advantages	Positive impact on sustainability	Customer acceptance	Scaling potential Beyond 2030
High	Medium	Medium	Low	Medium	High	?

Low | Medium | High | ? Uncertain | * High ≥ 30 000 tonnes

Land animal by-products
– Time to reassess

NCE Seafood Innovation

Revisiting underutilized available resources [1, 2, 10, 12, 13, 18, 22, 27]

Overview

- By-products from poultry and pork legally approved for fish feed since 2013 in EU (by-products from ruminant origin are legally banned)
- Products available: carcass, feather meal, protein concentrates, blood meal, fat, bone meal
- Established feed ingredients in Chile and Canada (20-30% inclusion)
- In Europe, soy protein concentrate substitutes animal by-products
- Relevant technology available off-the-shelf
- Commercially available in large quantities, predictable supply

Key numbers

Large numbers available: Global terrestrial production of poultry and pork: 250 million tonnes (50-70% by-product)

In Norway: 86 000 tonnes of by-products from poultry (ca. 20% dry weight) and a potential of ~40 000 tonnes of by-product from pigs (ca. 35% dry weight)

Today's utilization: pet food, meat and bone meal, other feed ingredients, human consumption and bioenergy

In Scandinavia: A potential for ~330 000 tonnes of by-products from poultry and ~700 000 tonnes of by-products from pork

EU-28: A potential for ~9.6 million tonnes of by-products from poultry and ~7.2 million tonnes of by-products from pork

Verified high nutritional content. High digestibility

Cost-effective production. Established commercial market

Land animal by-products
– Time to reassess

NCE Seafood Innovation

Revisiting underutilized available resources [1, 2, 10, 12, 13, 18, 22, 27]

Strengths

- ✓ High nutritional content and high digestibility for some by-products
- ✓ High familiarity within the salmon industry
- ✓ Large quantities commercially available, both locally and globally
- ✓ No technological barriers
- ✓ Low carbon footprint

Barriers

- ✕ Market acceptance is limited for emotional and ideological reasons, and a lack of faith in food safety regulations. This influences market adoption in Norway and Europe.
- ✕ Legal demands for minimum heat treatment reduces nutritional quality
- ✕ Strong competition from pet-food sector, at a high commercial value
- ✕ Establishing separate production line to handle processed animal proteins (PAPs) from pork

High level evaluation of barriers to industrialized production by 2030

Volume potential by 2030	Development level	Cost efficiency	Norwegian competitive advantages	Positive impact on sustainability	Customer acceptance	Scaling potential Beyond 2030
High	High	High	Medium	High	Low	?

Low · Medium · High · ? Uncertain · * High ≥ 30 000 tonnes

Marine by-products
– too good to waste

Whitefish holds the largest volumes of underutilized available resources [10, 21]

Overview

- Both by-products for whitefish and pelagic fish are utilized for feed production today. However, there is a substantial potential for better utilization from whitefish. Only 56% of the by-products from whitefish are being used today.
- The biggest available fraction from whitefish is codheads, which contains high value protein
- Pelagic and farmed fish are mainly processed abroad. By-products are therefore hardly available for the Norwegian feed industry.
- Norwegian marine by-products are being used for human consumption (food and food ingredients), feed (fish, land animals and pet food) and biogas production (fuel)

Key numbers

Whitefish: 140 000 tonnes of by-products are not utilized today, mostly from the ocean-going fleet

Pelagic fish: 100% utilization today

Aquaculture: 94% of by-products are utilized today. Only the blood is left unutilized. However, the volume available will increase as the industry is growing.

13% of all Norwegian marine by-products are utilized for human consumption, **67%** in feed production, both to fish, land animals and pet food, and approximately **20%** for biogas production

Verified high nutritional content. High digestibility

Cost-effective production of the feed ingredient, but cost intensive investments early in the value chain (fleet procurement)

Marine by-products
– too good to waste

NCE Seafood Innovation

Whitefish holds the largest volumes of underutilized available resources [10, 21]

Strengths

- ✓ High nutritional content. High digestibility
- ✓ Source for valuable protein and marine oils
- ✓ Both by-products for whitefish and pelagic fish are utilized for feed
- ✓ Relevant technology available off-the-shelf
- ✓ Better utilization can improve the environmental footprint and increase circularity. Aligned with the UN's Sustainable Development Goals (SDGs) and food first principles.

Barriers

Whitefish

- ✕ Seasonal volume variation
- ✕ Demand for new technology in ocean-going fleet, lack of incentives for the fleet to bring the by-products to land
- ✕ High investments and low price in feed ingredients market
- ✕ Set volume, no predicted growth

Better utilization (pelagic/ aquaculture)

- ✕ Established value chain for biogas production. Higher investments for establishing other processing.
- ✕ A substantial part of exports is whole fish, including the by-products

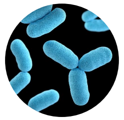
High level evaluation of barriers to industrialized production by 2030

Volume potential by 2030	Development level	Cost efficiency	Norwegian competitive advantages	Positive impact on sustainability	Customer acceptance	Scaling potential Beyond 2030
Medium	Medium	Medium	Medium	High	High	?

Low · Medium · High · ? Uncertain · * High ≥ 30 000 tonnes

Production potential summarized

Our evaluation of major barriers to industrialized production of future ingredients in Norway by 2030 [10]

	Novel marine ingredients	Insects	Marine low-trophic species	Microbial ingredients	Photoautotrophic microalgae	Land animal by-products	Marine by-products
Volume potential by 2030*	Low	Medium	High	Medium	High	High	Medium
Development level	Medium	Medium	Medium	Medium	Medium	High	Medium
Cost efficiency	Low	Low	Medium	Low	Medium	High	Medium
Norwegian competitive advantages	High	Medium	High	Medium	Low	Medium	Medium
Positive impact on sustainability	Medium	Medium	High	Medium	Medium	High	High
Customer acceptance	Medium	Medium	High	Medium	High	Low	High
Scaling potential beyond 2030	?	Medium	High	High	?	?	?

Plant-based ingredients are not evaluated in depth due to lack of potential by 2030.

Low | Medium | High | ? Uncertain

* High ≥ 30 000 tonnes

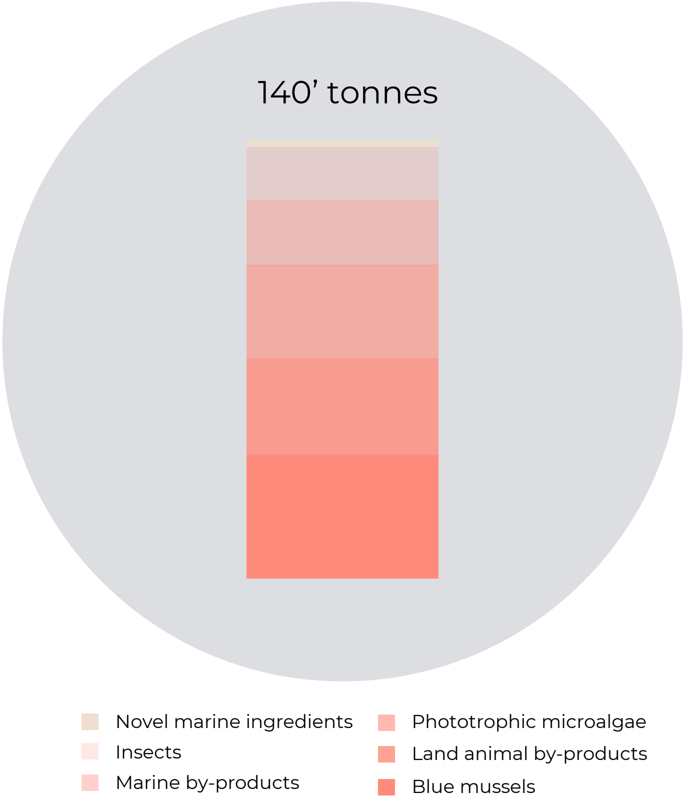
The highest volume potentials by 2030

Blue mussels, land animal by-products, and photoautotrophic microalgae have the largest volume potential by 2030 [10]

Blue mussels, land animal by-products and photoautotrophic microalgae are likely to contribute to the largest volumes of future feed ingredients by 2030.

The ingredients are evaluated as having the largest short-term potential due to concrete investment plans and/or access to raw materials. Whether the ingredients can meet projected targets comes down to two main factors:

1. Will the industry accept higher feed costs from introducing the novel ingredients?
2. Will consumers accept the use of novel feed ingredients and/or increased prices?



In order to meet national ambitions from the Norwegian government's Hurdal policy platform, a portfolio of ingredients must be developed

One type of ingredient cannot meet the future feed demand alone, it will be critical to research, develop, scale and industrialize less mature ingredients as well.

Among the less mature ingredients, several have significant potential looking beyond 2030. If, for example, the technology for identification and harvesting of novel, marine ingredients is improved to a cost-efficient level, this ingredient type has significant scaling potential looking beyond 2030.

Land animal by-products are good protein sources of high nutritional value. Using by-products is at the heart of circular food production and is central to ensuring a sustainable production of seafood. Hence, it will be worth addressing current challenges linked to variability in quality, risk of contamination and market acceptance to leverage land animal by-products as an important tool for realizing sustainable growth and achieving the major climate goals the industry has set.

- Marianne Koch, Sustainability Manager, Cargill Aqua Nutrition

We anticipate an increased competition, where players in the market for biofuel will have a higher ability to pay for raw materials compared to the feed industry.

- Ted Molland, Supplier Development Manager, Cargill Aqua Nutrition North Sea

Important with a broad approach in general, and short term, to look into utilizing by-products we are currently not using due to market restrictions. In addition to the circularity and sustainability potential, it is vital to keep focus on core nutritional value in the development of novel ingredient alternatives.

- Vegard Denstadli, Technical Director, BioMar

***Photo**: Cargill*

NCE Seafood Innovation

03

Barriers and critical success factors towards 2030

Barriers to growth

Overcoming the following barriers has been identified as especially critical for substantial growth of future feed ingredients [10]

Lack of regulatory framework for efficient use of bioresources

Lack of scale increases cost curves

Lack of national strategy and funding for bioresources and feed ingredients

Quality of novel ingredients not meeting necessary standards

Lack of customer acceptance and consumer education

Photo: *Lerøy Ocean Forest*

NCE Seafood Innovation

Barriers to growth continued

NCE Seafood Innovation

Lack of regulatory framework for efficient use of bioresources [10]

Regulations for Norwegian aquaculture and fisheries are centered around existing species and are not properly adjusted for novel marine species. There is also a lack of strategy in place for how national resources should be prioritized in terms of feed, food, and fuel.

- Novel farmed species such as seaweed and blue mussels currently apply for licenses under the same criteria and processes as salmon farming, even though the species are different in terms of necessary area and environmental impact. The species can, for example, contribute to circular systems by upcycling nutrients and reducing carbon footprint. **Specific zoning/license regulations for different species is therefore essential.**
- **Regulations related to the use of sludge and waste as feedstocks (e.g., to produce insects and microbial organisms) heavily impact the potential of novel ingredients**. Both sludge and waste could be crucial in solving sustainability issues and as valuable novel ingredients in circular models.
- Subsidization of certain products cause a skew towards specific resource use, ref. feed-food-fuel issues. **Determining how national resources should be regulated/subsidized will heavily impact the future of novel ingredients.**
- With increasing use of genetically modified organisms (GMOs) in global plant-based production, future growth through unmodified soy can become problematic both in terms of availability and price. Loosening up on regulations might become necessary, not only improving access to soy, but also to resources with better nutrient compositions and lower emissions than existing ingredients (e.g., genetically modified canola).

Lack of scale increases cost curves [10]

Lack of scale and resource scarcity are the most important barrier for the national growth of novel feed ingredients, as current prices are not competitive with existing alternatives.

- **Natural stocks of pelagic fish are insufficient to cover the future demand of fish feed, and 'new' marine species are hard to find and harvest.** Volumes are currently far from the requirements for industrialized feed production.
- **With regards to land-based resources, there is an ongoing battle about whether available biomass should be used for feed, food or fuel**. Several of the farmed resources (e.g., microbial organisms) are dependent on sugars in the fermentation process, a currently expensive resource as it is also in high demand for bioethanol. In contrast to the feed industry, national biogas projects are heavily subsidized, leading to reduced competitiveness of perhaps more circular initiatives.
- **Most of the novel feed ingredients require considerable energy for processing, resulting in less cost-competitive and sustainable ingredients for low-scale volumes**.
- To realize the potential of novel, national feed ingredients, cooperation between companies, R&D and political actors is crucial to develop scalable projects in circular hubs. **Individual actors will not be able to realize the possibilities alone, especially in full-scale, complete concepts.**

Barriers to growth continued

NCE Seafood Innovation

Lack of national strategy and funding for bioresources and feed ingredients [10]

Despite many R&D initiatives, few national ingredients are close to industrialized production in a short-term perspective. To scale up production, the industry needs to work closely together in circular hubs with shared resources and competence, supported by national incentive programs.

- Most of the current incentive schemes for feed ingredients target small-scale R&D development. This is obviously important to map the potential of novel ingredients in terms of nutritional qualities, etc., but has not been enough to stimulate industrial production. Innovation funding and/or risk capital for actors contributing to the realization of cost-effective, sustainable feed ingredients is in demand from the entire industry.
- Current incentives schemes mostly target technology development, and only to a very small extent resource mapping/trial fishing of new species. To realize the potential of novel marine ingredients (e.g., mesopelagic fish), supported trial fishing is likely to stimulate increased market access for more actors.
- A national strategy encompassing entire value chains and an industrial symbiosis that takes account of the expected aquaculture taxonomy standards will be crucial to realize sustainable use of bioresources. Norway is heavily dependent on EU policies, and national strategies should be formulated to meet increased standards of sustainability (e.g., CO_2 fees and other emissions such as sludge/nutrients, etc.)

Quality of novel ingredients not meeting necessary standards [10]

Existing feed ingredients, and especially marine resources, perform well when considering price, performance and fish health, and few new resources are competitive on all dimensions.

- Fish meal and oils are both high in relevant nutrients, perform well on sustainability, contribute to low FCR from high digestibility, and are cost-effective compared to plant-based resources. Increased use of marine ingredients such as mesopelagic fish would therefore be ideal, had it not been for the resource availability issues. It is therefore important to also prioritize efforts towards farmed organisms with similar characteristics to fish meal and oils, e.g., blue mussels.
- **Switching to alternative ingredients is hard without compromising either quality or cost.** On average, soy has less protein and is less digestible than fish meal but is very cost-competitive and ideal for bulk production of protein. Protein alternatives such as insect, photoautotrophic microalgae, and tunicate meal have both lower protein levels and digestibility as well as currently being more expensive than fish meal.
- Due to the lower digestibility of several novel ingredients, utilizing these ingredients will cause more sludge to be produced, causing both cost and environmental issues. **When evaluating novel ingredients, both production costs and quality are paramount. Resources leading to more sludge are not an alternative, as sludge regulations are likely to increase costs for salmon farmers.**

Barriers to growth continued

NCE Seafood Innovation

Lack of customer acceptance and consumer education [3, 10]

Customer acceptability remains an important issue with some raw materials. PAPs and insect-based meals are both feed ingredients where customers' acceptance comes into play. While the use of PAPs has been limited in Europe two decades after the outbreak of bovine spongiform encephalopathy (BSE) in cattle, the perceptions about insects are more subjective and context based.

- The reason for reduced customer acceptance of PAPs is the outbreak of BSE and consequent ban on use of PAPs in animal feed in 2001. While allowed in fish feeds for salmon farmed for EU markets since as far back as in 2013, use has been low since.
- A 2017 [5] study, funded by the Scottish Aquaculture Innovation Center (SAIC), showed that customer acceptance for, in that case, avian PAPs was high, while retailers were more cautious, fearing food scares. Incidentally, use of PAPs in salmonid feed in the Americas is common and can exceed 20%.
- The uptake of pork and poultry PAPs in European livestock feed may be slow, due to the above causes, as well as constraints on only single species feed mills being used. It is probable that acceptance of those raw materials in salmonid feeds will develop along similar lines – with prices and availability of other important raw materials being an important driver.
- Based on the 2017 study [5], the need for education in the customer segment may not be of major importance for the reintroduction of avian PAPs into salmon feed. The resistance being in the retailer segment.

Ambitions to be supported by cooperative multinational efforts

NCE Seafood Innovation

Critical success factors to meet national needs for feed and salmon production towards 2030 [10]

Future demand must be met through a portfolio of resources

- Salmon feed demand cannot be met by a single ingredient and improving value chains for existing ingredients must have top priority
- Blue mussels, microalgae, and animal by-products have potential to contribute to overall feed growth but are expected to have limited influence on overall share of feed ingredients in 2030. Towards 2050, future ingredients can grow to become a key contributor to Norwegian resources

Develop an overall strategy for bioresources

- Norway needs to develop an overall 'feed-food-fuel' strategy and to map available biomass and prioritize resources that maximize circular ripple effects. This should also include a mapping of available sludge and waste as resources
- Clearly define the need for national ingredients (e.g., degree of self-sufficiency, local industry, etc.) in relation to Nordic/ European ingredients
- Develop a learning platform to ensure cross-boarder collaboration at a wider geographical level, i.e Nordic/ European
- Look across sectors (agriculture, fishery, aquaculture) to ensure a most efficient use of by-products and increased sustainability in feed production

Develop a strategy for sustainable feed ingredients

- Develop science-based targets and taxonomy standards for aquaculture and fisheries in relation to future feed ingredients
- Evaluate an extended sustainability concept along the entire value chain and prioritize ingredients with highest sustainability
- Develop specific zoning and licenses for marine species such as seaweed and blue mussels to accelerate the production of oceanic ingredients
- Interact with potential 'feed ingredients countries' for improvement of sustainability from existing raw materials
- Include the agricultural sector to increase scale and circularity

Incentives to scale-up production of Norwegian feed ingredients

- Sustainable feed ingredients are expected to naturally become more cost-competitive following CO_2 fees and taxonomy incentives
- Support for resource mapping and trial fishing
- Industry targeted incentives to realize circular models for feed ingredients, such as large-scale Green Platform-schemes
- Resource waste restrictions for aquaculture, providing incentives for the most sustainable ingredients
- Consider 'differential contracts' to reduce risk
- Develop farming licenses for testing novel feed ingredients
- Support schemes for upcycling nutrients and CO_2
- Reactivate PAPs as ingredients in salmonid feed

References

#	Contributor	Reference
1	AgriAnalyse	Jordbruket i Sverige I Unionen (2021)
2	Albrektsen et al	Future feed resources in sustainable salmonid production: A Review (2022)
3	All about feed	Animal by-products in feed: A global update (2021)
4	Bellona	Bærekraftig havbruk 2030 (2020)
5	Bellona	Råvareløftet – Fôr for framtida – en ny næring tar form (2021)
6	European Commission	Food from the Oceans (2017)
7	Feed Navigator	Demand for insect protein could hit 500 000 tons by 2030 (2021)
8	Feed Navigator	'Little Consumer Resistance To The Idea Of Using Avian Protein In Salmon Feed' (2017)
9	Hurdalsplattformen	Hurdalsplattformen – For en regjering utgått fra Arbeiderpartiet og Senterpartiet 2021-2025 (2021)
10	Industry Experts	Interviews and meetings
11	Intrafish	Aker Biomarine forventer produksjon av 55.000-60.000 tonn krillmel årlig - og en dobling av omsetningen innen 2025 (2021)
12	Landbrug & Fødevarer	Fjerkræbranchens Årsstatistik 2020 (2021)
13	Landbrug & Fødevarer	Statistik 2020 Grisekød (2021)

References

#	Contributor	Reference
14	Mowi	Salmon Farming - Industry handbook (2021)
15	Nofima	Utnyttelse av fôrressurser i norsk oppdrett av laks og regnbueørret i 2020 (2022)
16	Nofima	Resource utilization of Norwegian salmon farming in 2016 (2019)
17	Nofima	Resource utilisation and eco-efficiency of Norwegian salmon farming in 2010 (2011)
18	Our World in Data	Our World in Data
19	Paoletti, Nielsen, Sparrevohn, Bastardie, Vastenhound	Potential for Mesopelagic Fishery Compared to Economy and Fisheries Dynamics in Current Large Scale Danish Pelagic Fishery (2021)
20	Regjeringen	Langtidsplanen for forskning og høyere utdanning 2023 – 2032
21	SINTEF Ocean	Analyse marint restråstoff 2021 (2022)
22	SINTEF Ocean	BioDigSirk-rapporten (2022)
23	SINTEF Ocean	Bærekraftig fôr til norsk laks (2020)
24	SINTEF Ocean	Greenhouse gas emissions of Norwegian seafood products in 2017 (2019)
25	Statista	Development of the world population from 1950 to 2050 (2021)
26	The Norwegian Fisheries	Lønnsomhetsundersøkelse for matfiskproduksjon - Gjennomsnittsresultater for hele landet (2021)
27	WRI	Creating a sustainable food future - A menu of solutions to feed nearly 10 billion people by 2050 (2019)

NCE Seafood Innovation

There is an enormous potential in improving the footprint of feed and thus of farmed salmon. It will require to challenge the present, make some bold decisions, changes, and upfront investments, collaborate in the value chain and communicate the message to the consumer.

- Einar Wathne, Chairman of the Board, NCE Seafood Innovation

Disclaimer

The information presented in this report has been compiled mainly from scientific reports and interviews conducted with the industry experts – both to be found in the 'Background' part of this report. Further references are indicated where necessary, even though this report is not expected to fulfill the criteria of a scientific paper.

Production potential numbers are deduced from scientific research, the interviews conducted and the industry players' production plans and forecasts. Given that this report encompasses input from a wide range of different research institutions and industry players, conclusions drawn, and calculations made by NCE Seafood Innovation based on this research do not necessarily represent each contributor's individual opinion.

Each quote in this report is published with the written consent of its author.

***Photo** NCE Seafood Innovation, Johan Wildhagen, Norwegian Seafood Council*

Industry Insight

2022 | Future Feed Ingredients

The Seafood Innovation Cluster AS

Thormøhlens gate 51
N-5006 Bergen
Norway

post@seafoodinnovation.no

EY
Building a better working world

Thank you for your contribution to the production of this report

NCE Seafood Innovation