

BlueGreen Mission

Feed ingredients of the future: bioprocessing and the need for process infrastructure.

Norwegian Centres of Expertise
NCE Aquaculture

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BlueGreen Mission

Feed ingredients of the future: bioprocessing and the need for process infrastructure.

A knowledge base on the opportunities for production of new ingredients for green and blue feed, plus clarification of future processing infrastructure needs in the pilot and commercial phases.

About the BlueGreen Mission report

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Contents

Sample of respondents 5
Purpose 6
Summary 7
- Norwegian ambition for 2040 7
- Knowledge base 7
- National governmental focus on production of ingredients 8
- Industry-focused measures 9

Background 10
Status of ingredients in current feed 13
- Aquaculture 13
- Agriculture 15

Opportunity for ingredients produced in norway 17
- Aquaculture 18
- Agriculture 20

Carbon footprint in the production of feed 21
Potential substrates for low-trophic feed ingredients 22
- Sludge 22
- Timber 23
- Barriers to the scaling up of raw materials 24

Processing 26
- Opportunities for cooperation 26
- Bioprocessing 27

Raw materials as input in future feed 30
- Blue mussels 32
- Grass 36
- Microalgae 37
- Fungi 38
- Bacteria 40
- Krill 41

Secondary fishing and aquaculture 46
Secondary agriculture 47
Polychaetes 48
Gammarider 50
Market 51
Products 52
Validation and commercialisation 53
Instruments for testing, documentation, validation and commercialisation 56
Need for pilot facility with testing prior to scaling and full-scale production 57
Infrastructure available today 58
Pilot facilities: test infrastructure for raw materials 58
Framework conditions 60
Reflections on further work on establishment of new infrastructure 62
Conclusions and implications 64
Norwegian ambition for 2040 64
Knowledge base 64
National governmental focus on production of ingredients 65
Industry-focused measures 65

Sample of respondents

Initially, we contacted existing business networks, organisations and institutes when compiling the data for this report. Our aim was to obtain information from a nationally representative sample accounting for and contributing significant findings on the status of the bioprocessing industry, plus a need to meet societal challenges and deal with necessary restructuring for success in a competitive industry development. Of this sample, about 80% is based on interviews and 20% is based on information submitted or information obtained from websites.

ACD Pharmaceuticals AS
MOWI Feed AS
Lofoten Biomarine AS
Nutrimar AS
Vesteraalens AS
Ecoprot / Pronofa ASA
Zooca Calanus AS
Ocean Tunifeed AS
Greentech Innovators AS
Finnfjord AS
Biomega Norway AS
Aker Biomarine ASA
Fiskå Mølle AS
Bio Tech Ocean AS
Folla Alger AS
Invertapro AS
Norgesfôr AS
Nutrishell AS
Felleskjøpet Fôrutvikling AS
Vesterålen Marine Olje AS
Ocean Forest AS
Seaweed Solutions AS
Lofoten Blue Harvest AS
Tango Seaweed AS
Arctic Seaweed AS
Norgeskjell AS
NMBU Foods of Norway
NIBIO
Nofima AS avd ATC
Nofima AS, avd. Biotep
Greenspot Mongstad
Cimbio AS
Gas 2 Feed AS
FjordAlg AS
Spirehagen AS
Bioco AS
NoMy AS
Greenitives AS
Orkla ASA
Norwegian Seaweed association AS
SINTEF SeaLab
SINTEF Ocean
SINTEF Senter for bioprosessering og ingrediensforskning (BIOPRO)
SINTEF Planktonsenteret
Norilia AS
Thalasso Biotech AS
Borregaard
Cargill AS (Ewos)
Cargill Innovation Center
Pelagia AS, avd. Bergen og Bodø
Aquarius AS
Hordafôr AS
Skretting AS
Skretting ARC AS
BioMar AS
Polarfeed AS
AMOF-FJELL Process Technology AS
Optimar AS
Elea Technology
NUAS Technology AS
Eagle Enviro AS
Marel Norge AS
Baader Norge AS
Skala AS
Arcticflow AS
Entec AS

Purpose

This report describes various bioresources that can be included in feed, how these potential ingredients are intended to be processed, and how they may candidates for piloting through the catapult scheme managed by the Industrial Development Corporation of Norway (Siva) on behalf of the Ministry of Trade, Industry and Fisheries.

Good availability of pilot facilities for testing is required in order to make the transition from lab trials to industrial scaling. The purpose of these pilot facilities is to allow different processes to be tested on a limited volume of raw materials, but using the same technology that will be included in a full-scale factory.

The report examines the need for technology and access to the same through a sample of respondents in Norway. The aim of the report is to gain an insight into the industry's needs for mobile and stationary facilities, along with who wishes to offer access to existing facilities. Willingness to invest and plans to set up new infrastructure have also been examined.

Various types of bioresources that are expected to be included in the value chain for feed production are examined in order to gain an insight into future needs for technology.

Norwegian catapults, funded by Siva, can help to identify, establish and invest in infrastructure for testing prior to scaling.

A project funded by Siva provides a basis for the report. The Ocean Innovation catapult and the consortium responsible for the Catapult Future Foods initiative, comprising NCE Aquaculture, Nord University, Nord Innovasjon and LetSea, have worked in partnership to complete this project.

The outcome will provide guidance for further discussion and cooperation with stakeholders developing and operating such infrastructure for testing. The report's ambition is to help strengthen the competitiveness of Norwegian industry and its ability to succeed in the low-emission society by reducing the carbon footprint of Norwegian protein production.

Glossary:

In this report, biomass before it is processed is referred to as "raw material". Moreover, raw material is termed "ingredient" when processing is complete.

Summary

The ambition is to promote sustainable production of feed ingredients for agriculture and aquaculture.

NORWEGIAN AMBITION FOR 2040

Since the Norwegian aquaculture industry began more than five decades ago, Norway has built an entire value chain in the production of Atlantic salmon, from broodstock to market. This has created one of Norway's most important industries, which represents important global food production and has helped to develop strong business environments all along our coast, which is hugely important for employment and the development of sustainable local communities. That said, Norway has a strong history as an agricultural nation, producing animal and vegetable products.

The Government has used a number of strategic documents to focus on reducing the carbon footprint and encourage production of raw materials based on Norwegian commodities for use in feed. Ambitious goals have been set for 2040, and also form the basis of the Hurdal Platform and the Long-term plan for research and higher education. The ambition is to promote sustainable production of feed ingredients for agriculture and aquaculture.

KNOWLEDGE BASE

The information that emerges in this report largely corresponds to the existing knowledge base and supports previous recommendations from the reports entitled *Råvareløftet* [The Raw Material Promise] and *Bærekraftig fôr til norsk laks* [Sustainable feed for Norwegian salmon].

If it is assumed that new feed production inputs have to be competitive in terms of price, a significant national effort will be required at present if new value chains are to be established that provide ingredients for feed with a lower carbon footprint than is the case for current raw materials.

As things stand at present, a number of ingredients have been identified that have the potential to assist with the development of new feed production inputs. Although a number of the ingredients have come a long way when it comes to documenting and verifying certain species that can be used, the potential of many species has not been revealed as yet. There is a need for significant investment in documentation of the raw materials and the development and verification of production technology in order to determine whether it would be possible to use these in commercial production.

One of the bottlenecks that has to be resolved to ensure further sustainable growth in Norway's protein production involves creating access to larger volumes of feed ingredients which have lower greenhouse

gas emissions than the raw materials of today. This will help to ensure greater stability in the market for ingredients. Given the need for new ingredients, one ambition is to create a new value chain based on circular principles by harvesting and cultivating low in the food chain. A targeted initiative to develop such value chains will require major national efforts and strategic investment through the policy framework, research communities and relevant industrial partners being key.

A large selection of stakeholders involved in production of new commodities were interviewed when working on this report. Access to the feed market is of secondary priority for a number of the raw materials that are currently approaching commercialisation. Markets such as pet food and human consumption, which pay more for smaller volumes, are primary and where the ambition to supply feed will come about when the effect of the primary product has been maximised and a volume is achieved that will be competitive on price with other feed raw materials that are imported at present. However, this requires time and a lot of capital.

NATIONAL GOVERNMENTAL FOCUS ON PRODUCTION OF INGREDIENTS

A number of programmes are currently partially addressing the need for targeted efforts. Bionova, for instance, is a recently established programme that is aiming to help operationalise what was indicated as a "mission" for sustainable feed in the Long-term plan for research and higher education. The grant budget for Bionova for bioeconomy projects currently stands at between NOK 100,000 and NOK 3,000,000. There is a need to significantly reinforce such initiatives if Norway is to achieve the ambitions defined up to 2040. There is a need for such programmes to define objectives for development of individual raw materials/ingredients into sustainable commercial products. Priority should be given to funds that can assist with:

- Identification, documentation and development of new ingredients for food, feed, health food, etc.
- Extended research efforts on various substrates in the production of single and multicellular organisms, including sludge and by-products from agriculture/aquaculture and using household waste as a substrate, with the aim of providing decision data for regulatory authorities.
- Extended focus on developing technical and chemical processing of new raw materials. Hydrolysis is one example of this.
- Extended production expertise involving interaction of technology and biology. Cultivation of single-cell fractions and fermentation is one example of this.
- Life cycle assessments (LCAs) of raw materials/ingredients in parallel with verification.

- Development of testing of technologies that help to reduce energy and greenhouse gases.

INDUSTRY-FOCUSED MEASURES

The path to piloting and commercial scale presents a challenge on account of the need for investment capital and risk mitigation for verification, production and processing facilities. Besides identifying potential and commercialising these new raw materials, there is a major need for research and development in order to determine which processing is optimal for the development of each individual ingredient.

Every one of the raw materials described in this report requires significant investment in order to enter a commercialisation race.

There is a need for a national strategy that includes a risk mitigation plan, and hence funds for the following should be given priority:

- Co-investment race for establishment of full-scale production facilities.
- Facilitation of synergies with industrial hubs in areas with available inputs which can be used in the production of new ingredients for feed. One example of this could be the process industry and other central industrial points.

The catapult system is dedicated to mitigating risks in the innovation system by offering test infrastructure for production piloting. When piloting new raw materials as ingredients in food, feed, health food, etc., the catapult initiative can help to ensure that resources are prioritised for:

- Validation and documentation of the impact of the raw material as an ingredient in food, feed and health food (small-scale and full-scale).
- Concessions with time restrictions for testing different recipes with the inclusion of new feed ingredients.
- Verification and establishment of infrastructure for piloting new production systems for harvested and cultivated raw materials.

An initiative of this kind can also apply and make use of infrastructure in the university and college sector and at research institutes, research organisations, Centres for Research-based Innovation (SFI centres) and private research stations such as LetSea and GIFAS that are capable of documenting the effect of feed raw materials on fish in full-scale offshore production.

- Infrastructure for processing new raw materials.
  - ~ Estimating the level of investment required in order to meet current and upcoming processing needs presents a challenge as many of the raw materials are in the early stages. That is why establishing a national resource group is recommended where owners of public and private test infrastructure are represented. The aim of this will

be to evaluate investment needs to ensure full utilisation of current infrastructure, as well as meeting the need for new infrastructure.

~ It will be important to ensure that raw material production and processing are in close proximity so as to ensure the quality and durability of the raw materials.

Close proximity to the resource is of major importance: Respondents have communicated a need to be able to test the processing of raw materials with a view to optimising the properties of the ingredients. One specific challenge involves the stability of the raw material in terms of shelf life, which means that any processing capacity must be available locally. Some raw materials can be stabilised, but this may result in loss of nutrients for some ingredients, or impact on the quality of the product. Norwegian catapults can make processing of raw materials available together with the industry, and establishing a national resource group is recommended where owners of public and private test infrastructure are represented. The objective must be to evaluate investment needs to ensure full utilisation of current infrastructure, as well as meeting the need for new infrastructure.

Background

The world is changing. Climate, trade, political unrest, war, access to raw materials, inflation and a growing world population are all factors that require new approaches and innovation. As a nation, Norway needs to examine the opportunities for self-sufficiency in feed commodities for both land animals and aquaculture going forward. Over the last few years, a number of reports have shone a spotlight on new raw materials that have potential as ingredients in the feeds of tomorrow, for both agriculture and aquaculture. A number of these are commodities where there is a need to develop new technologies and new methods for scaling up and piloting. Reports published by Bellona[1], SINTEF[2] and NCE Seafood Innovation[3] provide estimated potential production figures for new feed commodities. These reports indicate that scaling up to significant production volumes presents the biggest challenge to achieving feed self-sufficiency targets. A number of raw materials are currently at the lab scale and small pilot scale phases, and there is reliance on testing the production of the raw materials on an industrial pilot scale in order to obtain “proof of concept”.

Almost 2 million tonnes of feed concentrates[4] were used in Norwegian agriculture in 2022, with around 46% of the ingredients being imported.

1 Bellona, *Råvareløftet* (2022).
2 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).
3 NCE Seafood Innovation, Future ingredients for Norwegian salmon feed (2022).
4 Norwegian Agriculture Agency, Kraftfôrstatistikk (2022).

Just over 2 million tonnes of feed[5] were used for aquaculture as well, with about 95% of the ingredients being imported. The value of imports for the latter is estimated at NOK 26–30 billion.

Importing ingredients for feed helps to increase the carbon footprint of the finished product purchased by consumers. There is a significant difference in the carbon footprint of cattle and farmed salmon. Farmed salmon currently have a production and pre-transport footprint of 3.8 CO2e/kg[6], while the footprint for cattle is 17–22 CO2e/kg[7]. For salmon, most of the carbon footprint is accounted for by the import of feed raw materials. There is significant potential to reduce the carbon footprint of feed for salmon by altering the composition of ingredients.

Soya currently has a carbon footprint of 4–7 CO2e/kg, while, for example, antarctic krill has a footprint of 2.5 CO2e/kg. The carbon footprint can be lowered by altering the composition of ingredients in the feed. This could also potentially increase the utilisation and effect of the feed itself in that the raw material will have other qualities that will also have a positive effect. National raw material production can help to reduce the carbon footprint associated with importing ingredients, as well as reducing the risk associated with predictable availability. One challenge in this regard will be to achieve a raw material produced in Norway that is competitive in terms of price.

Importing raw materials will not constitute most of the carbon footprint for agriculture; but given the current political climate, the industry will still be vulnerable if the supply of raw materials is cut. In other words, raw material production in closer geographical proximity to where new recipes for new raw materials are developed can reduce the carbon footprint associated with importing ingredients, as well as reducing the risk associated with predictable availability.

The import of feed raw materials in agriculture is largely linked to the protein element, which mainly comprises corn, rapeseed and soya. At present, 93% of the protein in Norwegian feed concentrates comes from imported raw materials[8]. As things stand at resent, agriculture consumes some 30% of the total amount of soya imported, while the rest is used for to fish feed.

The price of feed is the most important cost factor for both aquaculture and agriculture at present, where feed costs make up about 60% of the first-hand value of chicken and about 60–70% of salmon. Innovation in raw materials and raw material production also has to aim to develop production methods that are economically sustainable and competitive.

A major green transition in which Norway produces its own feed raw materials more extensively could have major positive ripple effects in the

5 Norwegian Seafood Federation, Akvafakta.no, Akvafakta årsstatistikk (2022).
6 Johansen, U. Klimafotavtrykk av norsk laks, Faktaark.
7 Animalia.no, Kjøttproduksjon og klima (25.10.21).
8 Magnus Petersen et al., Debattinnlegg Nationen, Framtidas matproduksjon: Regjeringen spenner bein på egne mål (02.03.23).

form of value creation and jobs. Besides the fact that this may help to increase seafood exports (both raw materials and processed products), it may also result in the export of knowledge and technology in respect of the cultivation, harvesting and processing of new raw materials to create sustainable feed.

The government has launched two new "moon landings" in its Long-term plan for research and higher education[9]. These are national social "missions" where one of the aims is to ensure that all feed for farmed fish and livestock should come from sustainable sources[10].

The Hurdal Platform of 2021[11] indicates that the government must *"Stimulere til økt bærekraft gjennom et eget program for produksjon av bærekraftig fôr basert på norske ressurser"* [Encourage increased sustainability through a separate programme for the production of sustainable feed based on Norwegian resources] and *"Sette mål om at alt fôr til havbruksnæringen skal være fra bærekraftige kilder innen 2030"* [Define a target indicating that all feed for the aquaculture industry should be from sustainable sources by 2030]. Thus the Hurdal Platform defines ambitious targets for the development of sustainable raw materials so as to ensure access to raw materials for agriculture and meet the ambitions of the Norwegian aquaculture industry for growth.

Besides the targets for feed, the Hurdal Platform proposed the creation of the Bionova tool. Bionova was initiated in 2023 and aims to help bring about innovation and value creation in the bioeconomy associated with agriculture, forestry and aquaculture. Bjørnar Skjæran, Minister of Fisheries and Ocean Policy, stated on 6 October 2022 that *"Gjennom opprettingen av Bionova legger vi også mer til rette for en mer kraftfull oppfølging av bioøkonomien, og bærekraftig fôr vil være en del av dette"* [The creation of Bionova will also allow us to facilitate more powerful follow-up of the bioeconomy, and sustainable feed will form part of this]. A national social mission relating to sustainable feed was launched at the time of the national budget in 2022.

Given the current distribution between marine and onshore commodities and political ambitions, it is possible to ask the question:

Where can new, sustainable commodities for feed be grown/harvested/caught, and how can new value chains be verified and established that are capable of producing sufficient volumes through all stages to meet the anticipated demand, as well as being competitive on price?

The food sector in Europe is a major energy consumer: the amount of energy that is needed to grow, process and pack food and transport it to the tables of European citizens represents 17% of the EU's gross energy

9 Larsen, H., Khrono, To nye «månelandinger» og mindre søknadsbyråkrati (04.10.22).
10 Ministry of Education and Research, Langtidsplanen for forskning og høyere utdanning 2023–2032 (2022).
11 Government, Hurdalsplattformen 2021–2025.

consumption in 2013, which is equivalent to about 26% of the EU's total energy consumption in the same year[12].

Agriculture, including crop cultivation and animal husbandry, is the most energy-intensive phase of the food system, representing almost 33% of the total energy consumed in the food production chain.

Industrial processing is the second most important phase of the food life cycle and accounts for 28% of total energy consumption. Together with logistics and packaging, these three phases of the food life cycle "beyond the farm gate" are responsible for almost 70% of total energy consumption in the food system.

Food waste actually occurs at every stage of the food chain, the end-of-life phase – including final disposal of food waste – merely accounting for just over 5% of total energy consumption in the EU food system. The EU generated 100 million tonnes of food waste in 2014, primarily at household level and in production. Different food products need very different amounts of energy per unit mass, depending on the type of product, its origin and the type of processing to which it has been subjected. Refined products and products of animal origin generally need several times more energy than vegetables, fruit and cereals.

Hence lower energy consumption is an important prerequisite for the industrial growth of Norway going forward, as well as for innovation initiatives and development of more energy-efficient raw material production. This has been used as a basis for the further recommendations.

Status of ingredients in current feed

AQUACULTURE

Current feed for salmon is made up of different recipes and varies in terms of the amount of marine commodities, depending on the nutritional needs of the salmon at different stages of their lives. Table 1 is taken from the report entitled Utnyttelse av fôrressurser i norsk oppdrett av laks og regnbueørret i 2020 [Utilisation of feed resources in Norwegian salmon and rainbow trout farming in 2020][13], which shows the amount of feed ingredients used in feed for aquaculture in 2020.

12 The conscious club, Food & Energy (22.05.19).
13 Aas, T. et al., Utnyttelse av fôrressurser i norsk oppdrett av laks og regnbueørret i 2020. Faglig sluttrapport (2022).

Type of ingredient	Tonnes	Percentage
Vegetable protein	800 266	40,5
Vegetable oils	397 793	20,1
Carbohydrate sources	247 039	12,5
Marine protein	239 710	12,1
Marine oils	203 598	10,3
Other	8 126	0,4
Micro ingredients	80 177	4,1
TOTAL	**1 976 709**	**100**

Table 1 / Ingredients used in salmon feed in 2020, expressed in tonnes and as a percentage[14]. Figures taken directly from the report by Aas, T. et al., Utnyttelse av fôrressurser i norsk oppdrett av laks og regnbueørret i 2020. Faglig sluttrapport (2022)

	Ingredient	Tonnes	Percentage
Vegetable	Soya protein concentrate	413 611	20,9
Protein sources	Wheat gluten	193 904	9,8
	Guar protein	84 677	4,3
	Sunflower	67 798	3,4
	Pea protein	27 306	1,4
	Corn gluten	12 971	0,7
Vegetable oils	Rapeseed oil	356 499	18
	Linseed oil	25 874	1,3
	Soya oil	7 392	0,4
	Camelina oil	7 022	0,4
	Coconut oil	1 006	0,1
Carbohydrate sources	Wheat	127 878	6,5
	Faba beans	70 568	3,6
	Pea meal	48 592	2,5
Marine protein sources	Fishmeal from reduction fisheries*	174 172	8,8
	Fishmeal from trimmings	65 539	3,3
Marine oils	Fish oil from reduction fisheries*	164 611	8,3
	Fish oil from trimmings	38 986	2
Other	Insect meal, single-cell protein, fermented product, microalgae	8 126	0,4
Microingredients	Vitamins, minerals, amino acids, astaxanthin, etc.	80 177	4,1
Sum		**1 976 709**	**100**

Table 2 / Vegetable ingredients used in Norwegian salmon feed in 2020, expressed in tonnes and as a percentage. Figures taken from the report Aas, T. et al., Utnyttelse av fôrressurser i norsk oppdrett av laks og regnbueør- ret i 2020. Faglig sluttrapport (2022).

14 Aas, T. et al., Utnyttelse av fôrressurser i norsk oppdrett av laks og regnbueørret i 2020. Faglig sluttrapport (2022).

Moreover, table 2 indicates the content of ingredients (quantities and percentages) in feed for salmon and trout.

At present, soya protein concentrate constitutes the biggest single element in the feed of today; and if we consider the evolution between 1990 and 2020, there has been a significant change in the composition of salmon feed: The composition of the feed has changed from 89.4% fishmeal and fish oil and 0% vegetable oils in 1990 to 22.4% fish meal and fish oil and 60.5% vegetable oils and protein sources in 2020. Nowadays, the feed also contains about 0.4% new ingredients, such as insect meal, single-cell protein, fermented products and microalgae. Replacing the percentage of soya protein in Norwegian salmon feed with new resources requires an industrial boost on a national level.

AGRICULTURE

Farm animals, with the exception of poultry, primarily eat a combination of grass and feed concentrate. Poultry only eat feed concentrate.

About half of the feed concentrate used in agriculture at present is made up of Norwegian ingredients, but it also contains a significant percentage of imported ingredients. Figure 2 below shows that, as in aquaculture, the percentage of imported ingredients in the form of food and feed grain has increased steadily in recent years. According to the feed concentrate statistics issued by the Norwegian Agriculture Agency, the percentage of



Figure 1 / Food and feed grain of Norwegian or foreign origin used in feed concentrate shows what Norwegian livestock eat

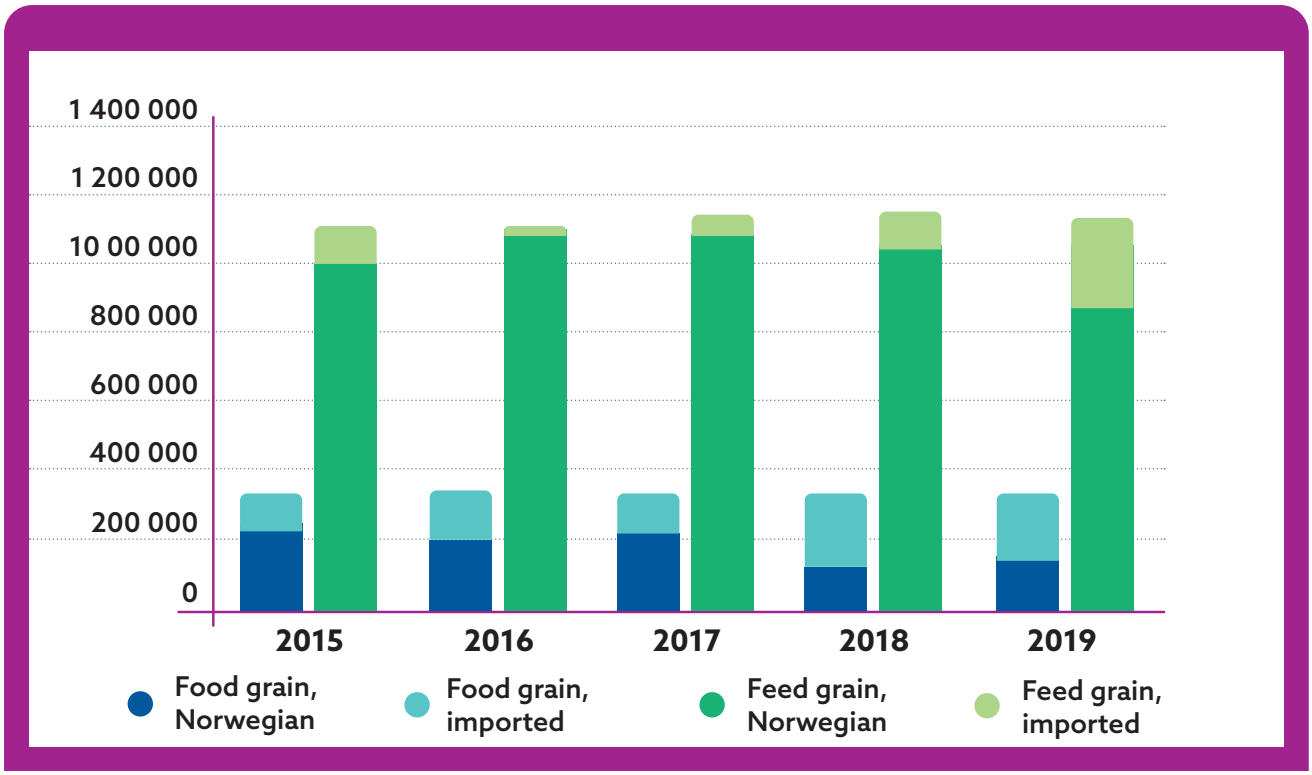


Figure 2 / Where do the raw materials in feed concentrate come from?[16]

Norwegian ingredients in feed concentrate has fallen from 76.3% in 2000 to 54.2% in 2022[15]. Variation can also be seen in the recipes for the feed concentrate between the various animals farmed nowadays. Feed concentrate for monogastric animals contains more imported raw materials because the animals need a correct combination of nutrients in their feed, such as amino acids[17]. That said, feed producers are constantly adjusting their feed mixes depending on the availability and price of raw materials. All corn gluten and rapeseed pellets were imported in 2022.

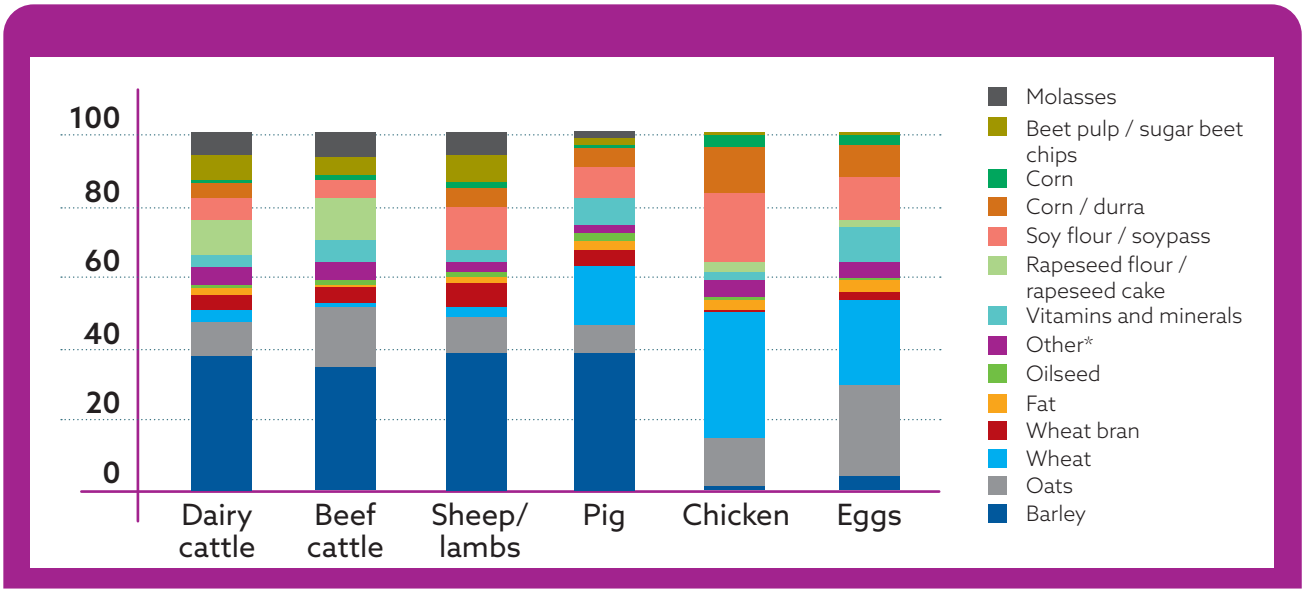


Figure 3 / Recipes for the various species[18]

15 Matprat.no, Hva er kraftfôr? (24.10.2019).
16 Kjos, A. et al., Kjøttets tilstand 2020, Status i norsk kjøtt- og eggproduksjon (2020).
17 Personal communication with Steffen Adler, NIBIO.
18 Kjos, A. et al., Kjøttets tilstand 2020, Status i norsk kjøtt- og eggproduksjon (2020).

Holistically producing some of the raw materials included in feed concentrates today on Norwegian soil will present a challenge due to climate and availability of land. Moreover, any cultivation of commodities as ingredients for feed must be sustainable on an economical level so as to prevent production having to be subsidised over time.

Opportunity for ingredients produced in Norway

A total of around 4 million tonnes of feed concentrates and fish feed were used in 2022. According to the report entitled *Råvareløftet* [The Raw Material Promise] [19], implementing a comprehensive package of measures for the development of new feed ingredients in Norway will make it possible to achieve annual production of 672,000 tonnes of new dry raw materials by 2030 and 1,106,000 tonnes of new feed raw materials by 2040. This means potentially increasing Norwegian raw materials in fish feed from about 8% in 2022 to 42% in 2030 and 64% in 2040.

The *Råvareløftet* report highlights by-products from fisheries, salmon fishing, agriculture, insects, microalgae and tunicates as the raw materials with the greatest potential to become the ingredients with the highest volume by 2030.

In its insight report[20], NCE Seafood Innovation writes that feed production must increase from 1.8 million tonnes in 2020 to 2.8 million tonnes if we are to meet national salmon production ambitions by 2030.

Their analysis indicates that by 2030, it will be possible to produce 141,000 tonnes of the required amount of dry ingredients in Norway.

The insight report highlights low-trophic species, photoautotrophic microalgae, agricultural by-products and fisheries/farming as having the greatest potential to become the ingredients with the highest volume by 2030.

SINTEF Ocean has assessed 23 sources of feed in its report entitled Bærekraftig fôr til norsk laks [Sustainable feed for Norwegian salmon][21]. SINTEF Ocean has designated insects, phototrophic macroalgae, wood as a substrate for microorganisms, grasses, small zooplankton and mesopelagic fish as the raw materials with the greatest potential and volume up to 2050.

The figures presented in these three reports indicate that variations are present in terms of both volumes and raw material types. This report does not verify the analyses, but the results are used as a basis to ensure that there is actually a quantifiable foundation for estimating volume for the production of Norwegian feed ingredients.

These findings form part of the decision data relating to factors such as how the catapult can make a difference. This can be done by contributing

19 Bellona, Råvareløftet (2022).
20 NCE Seafood innovation, Future ingredients for Norwegian salmon feed (2022).
21 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).

funding and provision of appropriate infrastructure for testing and piloting before full-scale industrial processing is possible.

No major effort has gone into investigating potential ambition for growth in agriculture, and agriculture largely looks at which potential ingredients are being explored by marine experts in terms of feed concentrate. However, replacing a significant percentage of imported feed ingredients with raw materials produced in Norway by 2030 and 2040 will present a challenge.

Given the above-mentioned reports, the ambitions for sustainable new Norwegian feed ingredients to meet such a large percentage of needs by 2030 do appear to be unrealistic. One fundamental prerequisite for further growth in ingredient production in Norway involves access to sufficiently large volumes of raw materials with the desired nutritional content, functional properties and competitive pricing, alongside significant capital resources for investment. Realistic options may include:

- Development of sustainable offshore cultivation systems.
- Catching new resources such as zooplankton and mesopelagic species.
- Cultivation of microalgae with the correct fatty acids.
- Conversion of natural gas, wood or grass to form bioprotein/biolipid.
- Production of insects.
- Conversion of biocommodities such as wood, straw and grass into protein and fatty components using marine organisms, for example.

AQUACULTURE

Given the fact that 95% of feed ingredients for marine species are imported at present, significant resources will be required in order to replace these with sustainable self-produced ingredients, while also increasing seafood production at the same time.

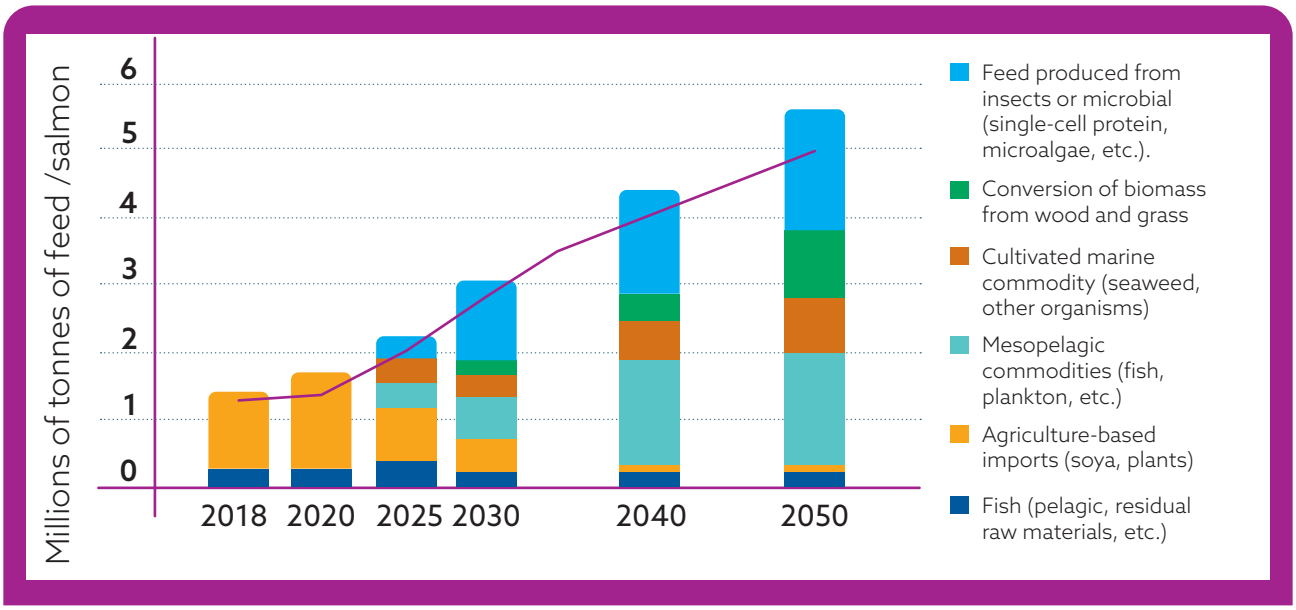


Figure 4 / Composition of feed for future scaling[22]

22 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).

The graph below from the report entitled Bærekraftig fôr til norsk laks shows just how much new ingredients will be needed if we are to achieve the ambition of bringing about a fivefold growth in production by 2050.

The question is, which ingredients will be available and commercially attractive for inclusion in feed production in such a timeframe?

A summary of previous works indicates the following points as measures for scaling up new production of commodities for feed[23 24 25]:

- Develop a strategy for more sustainable production methods for marine commodities, such as imposing strict limits on catches and stricter rules on the handling of residual raw material trimmings.
- Increase the percentage of renewable energy and energy-efficient production methods in the production process for feed ingredients in order to reduce the carbon footprint and minimise the environmental impact of production.
- Develop and adopt new technologies that can help to improve efficiency and reduce waste in the production of ingredients for feed.
- Develop and adopt alternative protein sources in feed, ideally ones that are low in the food chain, in order to reduce the carbon footprint of the feed.
- Advance and improve the technologies that are used to produce feed, with a view to increasing efficiency and reducing environmental impact.
- Introduce incentives for scaling up the production of Norwegian feed ingredients.
- Increase research into and development of sustainable production methods and technologies in order to reinforce the knowledge base for sustainable feed production.

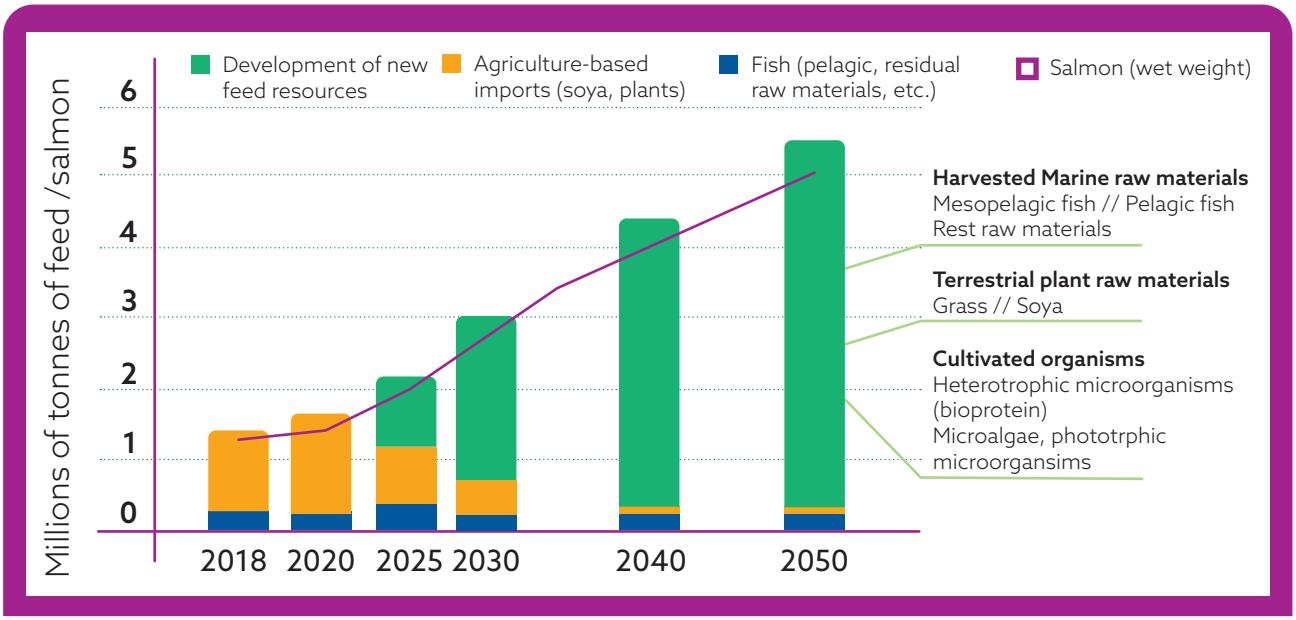


Figure 5 / A possible view of the future for salmon feed production in Norway for production of 5 million tonnes of salmon in 2050 [26].

23 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).
24 Bellona, Råvareløftet (2022).
25 NCE Seafood Innovation, Future ingredients for Norwegian salmon feed (2022).
26 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).

- Devise a separate strategy / programme for new feed resources and incentives for scaling up.

A holistic strategy that takes these measures into account could help increase the percentage of Norwegian ingredients in the feed while also maintaining sustainable production practices, thereby helping to bring about healthier, more sustainable production of protein on a national level. That said, it is important to evaluate which potential new ingredients to focus on in terms of chemical composition, production and processing. A number of projects are currently in progress, testing how fish are managing to utilise new feed ingredients. The results of this will have an impact on which raw materials to focus on. The figure below paints a potential picture of the future, estimating where efforts should be made in order to achieve the growth ambition by 2050.

That said, it is important to mention that these collective points will be unable to meet needs overall, given a fivefold increase in production in 2050. Hence the report places significant emphasis not on the ambition for growth, but on the possibility of producing sustainable new raw materials on a national basis.

AGRICULTURE

Going forward, there will be a major need to replace larger volumes of ingredients in current feed concentrates with more sustainable ingredients. However, there is also a potential to streamline production at present by using less feed concentrate in the diets of animals[27].

Research is currently ongoing which involves testing potential new raw materials for feed concentrates. Raw materials such as yeast, seaweed, insects and bacteria have been tested on a number of species such as pigs, chickens, sheep and cows. A number of these raw materials have been found to improve the quality of meat and milk, shelf life and flavour[28].

The challenge faced by agriculture is that there is less private investment capital available to boost the production of new raw materials. Given this fact, the developments taking place in the blue sector are of particular interest for agriculture, knowing that the same raw materials may also be of relevance for land animals[29].

Nevertheless, it is necessary to mention the fact that multiple forces are at work to deal with the challenges on the agricultural side of things. Initiatives such as Foods of Norway and the NIBIO pilot facility in combination with the "ONETWO" project funded by the Agriculture and Food Industry Research Funds are vital initiatives for the development of future feed concentrates.

27 Personal communication with Steffen Adler, NIBIO.
28 Personal communication with Margareth Øverland, Foods of Norway
29 Personal communication with Margareth Øverland, Foods of Norway

Carbon footprint in the production of feed

A feed made up of new ingredients requires the carbon footprint of the feed to be reduced, while also meeting animals' nutritional needs and safeguarding their health. New ingredients cannot have a major impact on the environment, nor disrupt the natural ecosystem. Taking air freight out of the equation, feed for salmon accounts for 75–83% of the carbon footprint of salmon to market[30].

The Circular Bioeconomy Framework (CBF) could provide an important tool with the objective of producing food without depleting resources that are already under major pressure[31].

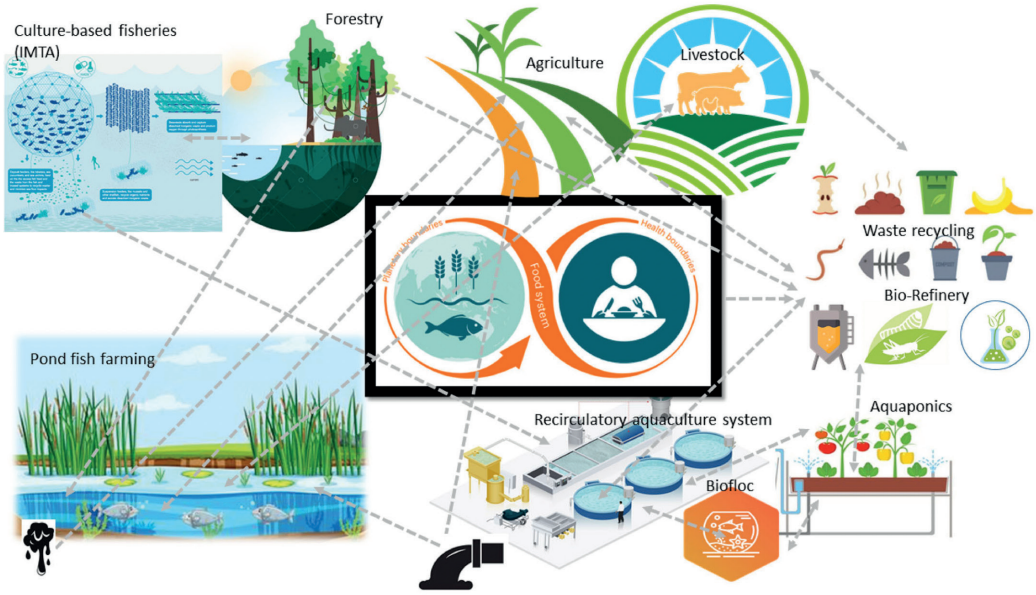


Figure 6 / Circular Bioeconomy Framework between agriculture and aquaculture [32]

Intelligence on the utilisation of feed resources is important if we are to assess and enhance the sustainability of Norwegian ingredient production for both the aquaculture industry and livestock production[33].

Imports of feed raw materials currently have an obvious impact on the carbon footprint of the finished product intended for consumption. There are currently two different ways of quantifying this:

- Life Cycle Assessment (LCA) involves systematic mapping and assessment of impact on the environment and resources throughout the life cycle of a product[34].
- Land Use Changes is a term describing the release of carbon into the atmosphere as a result of deforestation and converting the land into cultivated land or pastureland. This is of particular relevance for raw materials such as soya that originate from the rainforest areas, but also for corn, rapeseed and other plant-based raw materials.

Overall, these two methods quantify the CO2 volumes included in our production of protein.

30 Bellona, Råvareløftet (2022).
31 Colombo et al., Towards achieving circularity and sustainability in feeds for farmed blue foods (2022)
32 Colombo et al., Towards achieving circularity and sustainability in feeds for farmed blue foods (2022)
33 Bellona, Råvareløftet (2022).
34 LCA.no, Hva er LCA? (2022).

Importers of feed raw materials issued a statement in January 2021, following pressure from the aquaculture industry, indicating that they will not import raw materials grown on land deforested after August 2020 from this point onwards. This was an important step towards reducing the carbon footprint of imported raw materials[35]; although that said, it is necessary to consider the big picture and look at several options.

The government is aiming to ensure that all raw materials to be included in feed are sustainable as far as possible. Manufacturers have recently spent a long time working out which calculation method and factors quantify the sustainability footprint of manufactured goods most accurately. Moreover, it will be important to establish standards so that the data can be compared.

Potential substrates for low-trophic feed ingredients

SLUDGE

It is mandatory nowadays to collect sludge from onshore aquaculture. Sludge is made up of around 50% uneaten feed and fish faeces. Sludge contains fat, protein, carbohydrate and minerals[36], including phosphorus and nitrogen. These minerals are essential for all life. Research groups such as NIBIO and SINTEF Ocean have discovered that a number of new feed ingredients can be produced using sludge as a substrate. Polychaetes[37], gammaridae[38] and insects, for instance, can feed on sludge and help to bring about a more circular economy. Trials show that a number of multicellular organisms that are fed on sludge from fish farms become rich in marine fatty acids and minerals.

Sludge from fish farms cannot be used as a feed ingredient for multicellular organisms at present. To utilise the nutrients, it is necessary to work with primary production of bacteria and algae – for example – before this sludge can be used again as a feed ingredient. This is comparable to agricultural production, where it is used for primary production of plants which go on to be used as feed for animals.

This challenge is due to regulations that do not approve sludge as a substrate for multicellular organisms[39]. To bring about a change in the regulations in these areas, it is necessary to increase the knowledge base regarding infectious agents and undesirable substances; how these are affected by the treatment method, effects on use and importance for food safety[40].

35 Saue, O.A., Aftenposten article, Nå nekter norske oppdrettere å kjøpe soya fra selskaper som hugger regnskog (15.01.21).
36 Kraugerud, R., Verdt å vite om slam fra fiskeoppdrett (17.02.23).
37 Egge, H., Dette nyttige krypet lever av slam fra fiskeoppdrett, SINTEF.no (13.09.19).
38 Prosjektet Biocycles, SINTEF Ocean
39 Muri, C., Hva skal framtidens oppdrettsfisk spise? (09.05.22).
40 Government, Havbruksstrategien.

Utilisation rate	Sludge / organic materials	Dissolved nutrient salts
Biogas	Permitted	Not applicable
Pyrolysis	Permitted	Not applicable
Fertiliser	Permitted	Permitted
Animal feed ingredient	Not applicable	Not applicable
Substrate for single-cell protein production	Permitted	Permitted
Algae	Permitted	Permitted
Aquaponics, incl. mushroom production	Permitted	Permitted

Table 3 / Summary of potential uses of sludge [41]

TIMBER

Timber is mainly made up of 40% cellulose, 25% hemicellulose and 20–30% lignin, but the proportions may vary. Lignocellulose hydrolysates are regarded as providing a good substrate for cultivation of fungi and microalgae. It provides good biomass and lipid production[42]. Some 11 million solid cubic metres (sm3) of spruce and pine are currently being harvested as lumber and pulpwood in Norway.

Råvareløftet refers to wood as an important substrate for cultivation of large volumes of proteins[43]. Foods of Norway is constantly researching the extent to which various yeasts can be cultivated on wood and seaweed.

According to the report entitled Prosess21[44], access to wood and residual raw materials is referred to as being in short supply, while forecasts from Veikart for prosessindustrien [Roadmap for the process industry][45] show that an estimated 14–20 million sm3 of forest commodities are needed by 2050. It may also be mentioned that Prosess21 contains no references to or discussions of marine raw materials as a bioresource for the Norwegian process industry.

41 Hilmarsen, Ø. et al., Kunnskaps- og erfaringskartlegging om effekter av og muligheter for utnyttelse av næringsstoffer fra oppdrett, Delrapport 3: Utnyttelse av organisk materiale og næringssalter (2020).
42 Oil from oleaginous microbial biomass derived from Norwegian resources as a sustainable alternative to replace Fish/Plant oils in fish feed, Research Council of Norway Project Databank.
43 Bellona, Råvareløftet (2022).
44 Prosess21, Hovedrapport.
45 Federation of Norwegian Industries, Veikart for prosessindustrien (2016).

BARRIERS TO THE SCALING UP OF RAW MATERIALS

Surveying potential new feed raw materials involves a few common challenges that it will be important to address with future growth in mind[46 47 48]:

- Lack of regulations for efficient use of bioresources, such as sludge as a substrate for production of multicellular organisms.
- Lack of governmental strategy in respect of bioresources, funding and new feed ingredients.
- Lack of scale-up plans and pilot factories.
- There is a major need for technological development in order to automate processes, which in turn may result in more cost-effective production.
- Reduction of greenhouse gas emissions in connection with the use of climate-intensive ingredients such as soybeans and fish oil, plus the transportation of feed and fish to and from facilities.
- Access to land.
- Many different commodities must be utilised, and we should:
  - ~ Harvest and cultivate organisms that are low in the food chain.
  - ~ Develop technology for the value chain as a whole, from sustainable harvesting / cultivation to processing and product.
  - ~ Devise a separate strategy / programme for new feed resources.
- Availability of renewable energy at a competitive price

While the need for new raw materials is increasing, there are a number of challenges hindering the development of new raw materials industry. Working on the basis of a large number of interviews with researchers, industry stakeholders and public authorities in connection with the roadmap and barrier studies in *Råvareløftet*, a clear picture has emerged to indicate that there are general structural challenges that have to be resolved in order to implement the new feed resources. There are specific examples of factors such as:

1. Raw materials that are close to implementation, but that are hindered by regulations that are not adapted to a circular bioeconomy.
2. Raw materials that are available but not used at present on account of market considerations and consumer preferences.
3. Raw materials requiring larger initial investments in order to be produced, and that lack capital to be able to scale up to an industrial level.
4. Incorrect prioritisation of bioresources, whereby resources that could be included in feed production are used for lower-value purposes that take priority over food production.

46 Bellona, Råvareløftet (2022).
47 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).
48 NCE Seafood Innovation, Future ingredients for Norwegian salmon feed (2022).

RAW MATERIAL	TECHNO-LOGICAL MATURITY	BARRIERS	Sludge as an input
Blue mussels	Demon-stration	Low degree of automation in production and access to cultivated land	
Tunicates	Pilot	Automation of processes for cultivation, harvesting and processing.	
Macroalgae	Small-scale	A lack of volume constitutes the primary barrier to allowing macroalgae to contribute (indirectly) to more sustainable salmon feed.	
Insects	Small-scale	Regulatory barriers preventing use of various types of organic waste as a substrate.	X
Grass	Concept validation	Technological maturity	
Phototrophic mi-croalgae	Pilot	Technological maturity and biological challenges in making the transition to large-scale production	X
Heterotrophic microalgae	Small-scale	Access to appropriate commodity sources for efficient large-scale production in Norway.	X
Fungi	Pilot	Identifying sufficient substrate for large-scale production, as well as R&D work in order to increase production efficiency and profitability.	X
Bacteria	Demon-stration	Need for technological development and regulatory amendments	X
Gammaridae	Demon-stration	Regulatory barriers preventing use of various types of organic waste as a substrate, plus a need for development.	X
Polychaetes	Demon-stration	Regulatory barriers preventing use of various types of organic waste as a substrate	X
Krill	Large-scale	Opportunity to increase catch volume, more documentation needed.	
Mesopelagic raw material	Concept validation	Lack of intelligence on ecosystem effects, efficient fishing technology and a lack of green energy carriers for fishing vessels. Processing.	
Calanus finmarchicus	Pilot	Regulatory restrictions in the form of quota permits make efficient catches difficult.	
Secondary fishing/ aquaculture	Large-scale	Volume of residual raw material landed, customs taxation on processed goods sends more residual raw material out of the country	
Secondary agriculture	Large-scale	Regulatory restrictions	

Table 4 / Technological maturity and barriers to growth.

If we consider the most relevant raw materials with emphasis on obstacles and barriers to achieving industrial volume, working on the basis of the summaries in *Råvareløftet*, Future ingredients for Norwegian salmon feed[49] and other reports, considerable work will be required for each of the raw materials before industrial production can be achieved.

Besides the specific barriers referred to above, there are more general barriers that are not directly linked with the raw material, but that will affect opportunities to industrialise the species in question.

49 NCE Seafood Innovation, Future ingredients for Norwegian salmon feed (2022).

Processing

Given the availability of raw materials, the challenge at present is in achieving technological maturity so as to switch from piloting to full-scale production. To use a raw material as an input for feed, it is necessary to be able to produce significant quantities over time, and the product has to be stable in storage and of robust quality.

The data for this report has been obtained mainly by means of interviews, correspondence and accessible websites. The findings are based on contact with 67 respondents made up of industrial companies, equipment suppliers and pilot facilities. The sample was selected on account of the fact that we began by contacting a few selected individuals, who in turn told us about other stakeholders that we ought to interview.

There was a great deal of variation in technological and organisational maturity, and a number of the stakeholders processing new feed commodities were at the lab scale phase (typically up to 20 kg of raw materials per batch), but with a desire to switch to pilot production (0.1–3 tonnes of raw materials per batch). A number of the more mature respondents in possession of full-scale processing facilities stated that they have available capacity in their production areas for leasing processing capacity. The challenge lies in obtaining access to a sufficient volume of commodity for large-scale production (more than 3 tonnes of commodity in per hour).

Processing equipment is divided into the following three main categories in this report: 1) Lab that typically handles up to 20 kg per batch, 2) Pilot 100–3000 kg per batch, and 3) Factory in full-scale operation. There is a need in the market to trial infrastructure that can be scaled to fit a factory site. This means that lab infrastructure cannot be used, and that there is a need for pilot facilities for the testing of processes before building a factory.

Three pilot facilities are available through equipment suppliers, and nine respondents who are showing an interest in or planning to build pilot facilities (100–3000 kg of raw materials in per hour).

OPPORTUNITIES FOR COOPERATION

- Almost all our respondents expressed a desire to work together on pilot facilities or to share / access unused capacity at their own processing plants.
- A number of them wanted to join forces to implement pilot facilities for bioprocessing.
- It would have been beneficial to have a mobile plant (such as two 20-foot containers) configured for the desired commodity, possibly with their own power supply, along with people with expertise on how to run it.

- Use the Lego principle to assemble the right technology at a mobile facility prior to dispatch.

BIOPROCESSING

Bioprocessing covers all the processing that a raw material has to undergo from the time it leaves the place where it grows, or possibly the factory (residual raw material),

until it is turned into a finished product that is ready to be supplied to manufacturers producing feed for aquaculture or land animals. A raw material may need to be processed due to a number of considerations, such as:

1. Making the nutrients more accessible (eliminating physical barriers).
2. Concentrating and extracting the essential commodities that are needed.
3. Providing stability in storage for a commodity with a short shelf life.

All commodities used as inputs in feed require mechanical and/or chemical processing before they can be supplied to feed producers. This report has surveyed processing for all raw materials currently identified as potential ingredients for the feeds of tomorrow. A number of these raw materials have to be developed in order to achieve optimal processing, but manufacturers often have opinions on how this could potentially be done.

We have divided processing into six different operations so that we can visualise the operations involved in ingredient processing.

1	**Mechanical:**	• cutting • mixing	• crushing • pressing
2	**Preservation –** treatment needed to stabilise the product, and addition during processing of:	• acids • alkalis	• enzymes • fermentation
3	**Heating** – heating in the 40–90 ^{0}C range:	• boiling	• blanching
4	**Separation** – includes three levels:	• decanter centrifuges (liquids containing 15% or more solids + particle size greater than 10 microns) in combination with filters (liquids with solids content of 5% or less + particle size less than 1 micron)	• disc stack centrifuges (liquids with solids of less than 25% + particle size between 0.1 micron and 150 microns) • membrane filters (liquids with solids content of 5% or less + particle size less than 1 micron)

5	**Hydrolysis**	• In enzymatic hydrolysis, the raw material is ground with water before the mixture is homogenised and enzyme is added[50]. The time required for hydrolysis varies depending on the raw material and the temperature used (often between 35 and 65 degrees Celsius). The enzymes used in the hydrolysis process are important for the reaction conditions and the desired final product. Enzymes from animal, plant-based and microbial sources have been used for the production of protein hydrolysate. The enzyme is inactivated at the desired degree of hydrolysis by heating the solution to temperatures of 85 to 95 degrees for between 5 and 20 minutes[51]. As a process, hydrolysis requires a great deal of customisation based on the properties of each individual ingredient, and it will require a degree of development of the new feed ingredients.	• In particular, acid hydrolysis is used where it is necessary to pre-preserve a raw material over time before it can be processed further. This is applicable when using silage, for example. Acid ensiling is mainly used to preserve residual commodities that are to be used for feed and are not for human consumption. A number of types of acid can be used in acid ensiling, but formic acid is the most commonly used at present. The fish pulp decomposes when conditions are optimal, i.e. at a pH of 3.5–4.5 and a temperature between 5 and 40 degrees Celsius (the higher the temperature, the faster the decomposition)[52]. The silage is then transported to factories that process it further to make hydrolysates, for example, which can go directly to feed producers[53].
6	**Drying**:	• evaporation • heat pumps	• dryer

The processing is divided roughly into the operations presented in Table 5. The table shows which operations are performed most frequently, in no particular order, and irrespective of the handling of side streams (substances and water fractions) throughout processing. Wet raw materials will normally be split into different streams, where there are different processing cycles for substances and water fractions. Side streams and processing of this nature are not taken into consideration here. The purpose of the table was to gain an insight into the primary operations to be applied for the various raw materials. The most frequent operation for all raw materials is mechanical. This is then followed by the operations for separation and drying (see Figure 7).

A number of by-product commodities will be supplied for further processing as silage. This is a tried and tested and established technology, and so it will not be the first choice for the catapult as an investable technology. However, pilot infrastructure for processing may be of relevance for enhanced operations linked with the processing of finished silage.

The necessary processing operations for each individual raw material can be seen in Table 5. The aim of this is to highlight which operations

50 Guerard, F., 2007. Enzymatic methods for marine by-products recovery. In: Maximising the Value of Marine By-Products.
51 Zamora-Sillero, J. et al., 2018. Peptides from Fish By-product Protein Hydrolysates and Its Functional Properties: an Overview.
52 RUBIN Foundation, Håndbok i ensilering (1993).
53 Personal communication with Ola Flesland, Pelagia.

are needed for the various raw materials. A number of the raw materials require a great deal of dewatering (both separation and drying), and energy will be an important element for the future if we are to be able to preserve these raw materials. The last column shows energy consumption estimates in kilowatt-hours (kW) per tonne of dry raw material output. A number of manufacturers indicate that getting the raw materials for processing quickly is crucial, and that alternatively, poor storage stability

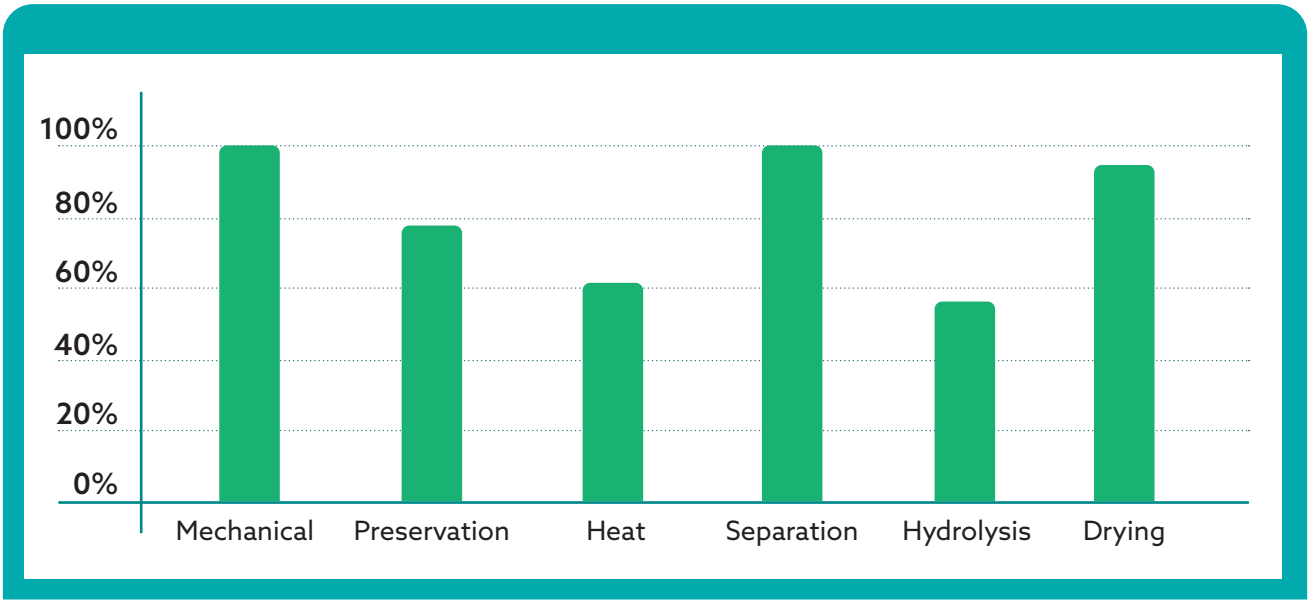


Figure 7 / Operations

Raw	Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	kWh/tonne Energy
Blue mussels	x	x	x	x	x	x	1800
Tunicates	x	x		x		x	1500
Insects	x		x	x		x	1500
Grass	x		x	x	x	x	1500
Microalgae	x			x		x	1800
Fungi	x	x	x	x		x	1800
Bacteria	x			x		x	1800
Krill	x		x	x		x	1800
Mesopelagic	x	x	x	x	x	x	1800
Macroalgae	x	x		x		x	8000
Calanus finmarchicus	x	x		x	x	x	1800
Secondary fishing and aquaculture	x	x	x	x	x	x	1800
Secondary agriculture	x	x	x	x	x	x	1800
Polychaetes	x		x	x		x	1800
Gammaridae	x		x	x		x	1800

Table 5 / Distribution of operations involving raw materials

and degradation of quality will require stabilising measures. Given this fact, the location of processing plants and energy efficiency are of major significance.

The table assumes that most raw materials will be dried, because our respondents indicated that they have to deliver dry raw materials to the next link in the value chain. However, some stabilised raw materials, including seaweed and insects, are also delivered wet. Energy consumption will be lower in such cases.

We have included gammaridae and polychaetes in addition to the raw materials referred to in the *Råvareløftet* report.



Various raw materials included in feed. Photo: unknown

RAW MATERIALS AS INPUT IN FUTURE FEED

An attempt has been made, on the basis of previous works examining potential raw materials as input in feed, to compile the raw materials and look more closely at how these are processed at present; or, in instances where the raw material is in an early phase, at how they are intended to be processed.

It is also important to indicate that the report does not decide which raw materials are solely estimated to offer the greatest potential to achieve

the greatest inclusion in feed over time, but, rather, what infrastructure is needed for pilot processing of more raw materials. Many of the raw materials described bear similarities with established processing capacity in a number of ways, and so there is an offering available at pilot facilities such as Biotep (Nofima) and Mobile Sealab (SINTEF Ocean). Furthermore, and as stated, there are a number of established manufacturers of feed raw materials with capacity available at their facilities.

A red ellipse can be seen in Figure 8. This indicates the link in the value chain to which our respondents' interviews relate. The foundation for estimating energy consumption for the various raw materials has been assessed in the light of findings from the Marine innovation arena project[54]. The emphasis in the value chain is on wet raw materials processing.

Energy-mass balance in value chains

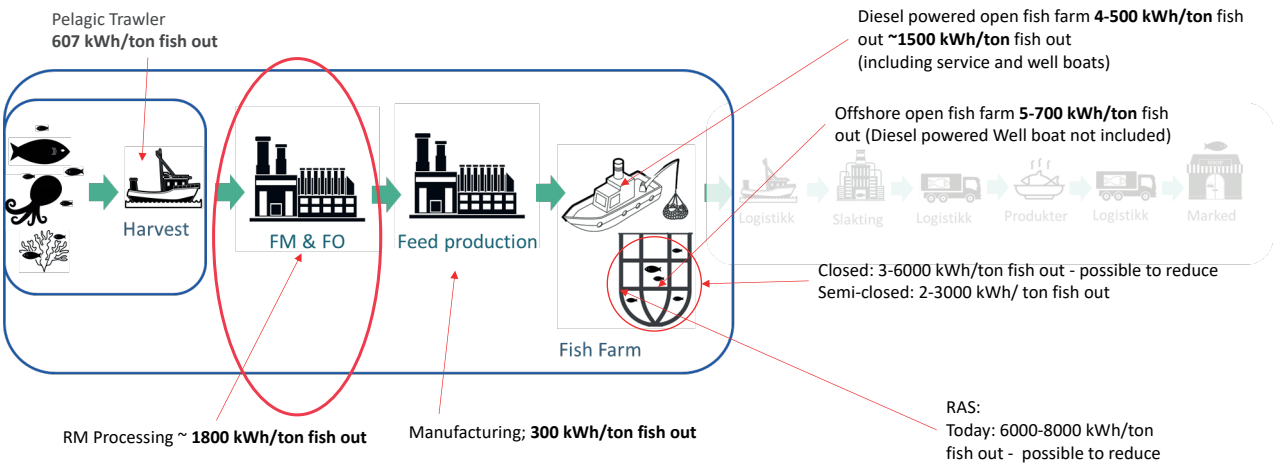


Figure 8 / Energy-mass balance in value chains.

The reports entitled Life Cycle Assessment of Recirculating Aquaculture Systems[55], Analyse av lukka oppdrett av laks – landbasert og i sjø: Produksjon, økonomi og risiko [Analysis of closed onshore and offshore salmon aquaculture: Production, economy and risk][56],The Global Feed LCA Institute and Greenhouse gas emissions of Norwegian seafood products in 2017[57] form the background to the calculations.

Figures for fish waste processing are calculated at 1800 kilowatt-hours per tonne of dry raw material. One of our respondents indicated consumption of 6000–10000 kilowatt-hours per tonne of dry raw material from seaweed using current technology. Moreover, one objective in connection with technology development and piloting is to achieve 1500–2500 kWh per tonne of dry raw material at the pilot stage and reduce this towards 750–1250 kWh

54 Marin innovasjonsarena – et nasjonalt løft for marine råvarer | VIS (visinnovasjon.no).
55 Xingqiang Song et al., Life Cycle Assessment of Recirculating Aquaculture Systems: A case of Atlantic salmon farming in China.
56 Analyse av lukka oppdrett av laks – landbasert og i sjø: produksjon, økonomi og risiko, FHF-prosjekt 901441.
57 Winther, Ulf et al., Greenhouse gas emissions of Norwegian seafood products in 2017 (2020).

in full-scale production. Combined with waste heat, this may help to bring about a more sustainable industry and reduce energy costs. Estimates are used as a basis for all other raw materials, given an assumed water content percentage and the operations expected to be included.

The tables beneath each raw material indicate which of the six operations are needed to process the raw material. Furthermore, Energy provides a rough estimate, in terms of consumption in kilowatt-hours, for processing a wet raw material to produce one tonne of dry raw material. Our respondents have indicated that energy consumption is vital and that they would prefer to use renewable energy as far as possible.

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x	x	x	x	x	x	1800

BLUE MUSSELS

Blue mussels are an interesting raw material offering major potential for inclusion as an ingredient in feed. Blue mussels can help to lower the carbon footprint for feed, and it is also possible to produce such feed in conjunction with other industries. Furthermore, cultivating blue mussels could help to establish a Circular Bioeconomy Framework (CBF) by binding offshore nitrogen and phosphorus.

Cultivation of blue mussels has historically been trialled in the past, where challenges such as technology and earnings potential meant that the venture was not viable. Many offshore facilities were abandoned, which is why the Directorate of Fisheries has spent many years investing considerable effort in clearing up abandoned facilities[58]. Technology development and earnings potential will be important elements in future growth[59].

Recent research from the Institute of Marine Research indicates that the Hardangerfjord alone may offer potential of up to 200,000 tonnes. However, such a significant volume will impact the volume of zooplankton, but the results may provide scope for consideration of just how much potential there is on a nationwide level.[60]

In a Norwegian context, blue mussels are a new potential feed input product. One stakeholder in particular, Ocean Forest, is currently working actively on the planned production of meal from blue mussels. Full production is not in progress as yet, but *Råvareløftet* and their own website indicate that they have invested heavily in developing processing technology, particularly mechanical technology to remove shells and byssal threads. Significant volumes of blue mussels are produced for human consumption worldwide at present. 2.1 million tonnes of blue

58 Directorate of Fisheries, Annual Report 2021.
59 Bellona, Råvareløftet (2022).
60 Gatti, Paul et al., "Mussel farming production capacity and food web interactions in a mesotrophic environment". Aquaculture Environment Interactions 15 (2023).

mussels were produced in 2018, China, Chile and Spain being the biggest producers[61].

It is also estimated that around 27% of what is taken up by the sea is downgraded and could potentially be used as input in future feed [62].

Blue mussels contain high EPA and DHA levels and may contain up to 68% protein at certain times of the year.

Processing involves mechanical removal of shells and byssal threads before moving the meat into enzymatic hydrolysis, where oil, stickwater and insoluble protein and fat are separated. The oil is then separated and cleaned. Stickwater and insoluble protein and fat then go on to be dried for the production of meal.



Picture of blue mussels. Photo: Stein Mortensen, HI.

61 Seafish.org, Aquaculture profiles, Mussels (2023).
62 Naik, Azza et al., Characterisation of Seasonal Mytilus edulis By-Products and Generation of Bioactive Hydrolysates (2020).

TUNICATES

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x	x		x		x	1500

Ciona intestinalis (often referred to as tunicates) is a new, low-trophic farmed species with good nutritional composition of marine proteins and fatty acids[63]. Tunicates and blue mussels are both species of interest for production as they both bind nitrogen and phosphorus from the surrounding environment. Pronofa estimates in an article in Teknisk Ukeblad[64] that using an area of 5 km2will allow 50,000 tonnes of protein meal to be extracted. Almås, K.A et al.[65] state in their report that assuming that an area of 33–50 km2 will be needed to produce 100,000 tonnes of protein meal is more realistic. Moreover, the report indicates that producing 100,000 tonnes of tunicate protein will meet around 5% of the protein requirement by 2050 (given the ambition for a fivefold increase), along with 2 to 6% of the fat requirement.

Tunicates contain about 95% seawater, and removal of water and salt accounts for much of the processing. This is an energy-intensive operation. Moreover Almås, K.A et al. indicate that significant amounts of protein and lipid can be lost: this presents a challenge when processing tunicates. The processing of tunicates is currently undergoing some development, and up to now the water has been removed mechanically using screws and a



Picture of Tunicates. Photo: Pronofa ASA

63 Bellona, Råvareløftet (2022).
64 Valmont, Odd Richard, Teknisk Ukeblad article, Insektbasert protein kan bli vekstbransje verden over norske Pronofa slåss om posisjon (28.11.21).
65 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020)

hydraulic press. It is also necessary to separate the grease and oil, possibly by means of hydrolysis, before drying the product. Using tunicates as a raw material presents two challenges. Firstly, they contain large amounts of salt, and whether a good removal method has been developed is not known. Also, the raw material is not stable in storage (about 1 day) before being processed, so stabilising the product using chemicals (e.g. acid) is necessary to ensure continuous operation at a processing plant. The distance between the site where the tunicates are harvested and the processing facility will also have an impact on the need for raw material stabilisation.

INSECTS

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x		x	x		x	1800

Seven insect types are currently approved for production in Norway: housefly, black soldier fly larvae, 2 types of flour beetle larvae and 3 types of crickets. One of the flour beetle larvae types and black soldier fly larvae are in commercial production at present[66].

The insects are able to eat most organic waste, and giving black soldier fly larvae marine feed means that the larvae oil will demonstrably contain more omega-3[67].

Production of insects as feed raw materials has been established commercially, but the volumes available present a challenge. Low raw material availability drives up the price of the feed, making it unattractive to customers. It is also important to mention regulatory challenges, as restrictions on which substrate to feed the larvae are currently applicable. This is making it difficult to scale up production, particularly in rural areas. That said, it is important to indicate that inclusion of insects in feed for



Black soldier fly larvae. Photo: Skretting

66 Bellona, Råvareløftet (2022).
67 Valmont, Odd Richard, Teknisk Ukeblad article, Insektbasert protein kan bli vekstbransje verden over – norske Pronofa slåss om posisjon (28.11.21).

both fish and land animals has been tried and tested with good results, some trials indicating that inclusion of up to 15% demonstrated good results for both the growth and intestinal health of salmon[68]. Black soldier fly larvae and mealworms have been tested for the most part. The larval yield comprises about 40% protein and 30–35% oil.

Insect processing to produce feed varies, but as with heat processing for the traditional meal/oil industry, the larvae are boiled in a pulp at up to 90 degrees before being transferred to a separator, where stickwater, dewatered pulp and grease are separated.

The grease will also be recleaned via a separator and transferred to a storage tank. The stickwater is evaporated still further before the concentrated stickwater and pulp are dried in a dryer. Finally, the meal is ground and packed into large bags.

GRASS

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x		x	x	x	x	1800

Extraction of grass protein is a familiar technology in countries such as Ireland, but little is known about how applicable the raw material is as a fish feed ingredient[69].

Grass is an available resource in Norway, where technology for cultivation and harvesting is well developed. NIBIO is currently running an active project by the name of ONETWO. The aim of this project is to biorefine meadow plants into protein concentrates that can be included as a protein source for chicken, and eventually other species as well[70].

Processing grass to extract the protein is a known technology nowadays, but there is still room for improvement. At present, the grass is processed by finely cutting it mechanically before pressing it in order to extract the juice, which contains most of the soluble protein in the pulp. The juice is then heated to a temperature of 80–85 degrees Celsius in order to precipitate the protein.

Production results in two residual fractions: press cake and brown juice. The press cake can be used as a feed ingredient for ruminants. Research has shown that feeding ruminants press cake made by means of protein extraction makes for better utilisation of the phosphorus and nitrogen in the grass, reducing the amount of minerals released into cow dung by 25%[71].

Press cake can also be dried and used for completely different purposes such as insulation in buildings, paper, etc. The brown juice contains various sugars and minerals that may potentially be used as additives[72].

68 Pabodha Weththasinghe, Nutritional, health, and technical properties of black soldier fly (Hermetia illucens) in Atlantic salmon (Salmo salar) feeds (2021).
69 Biorefinery Glas, H2020 EIP project, 2020.
70 Personal communication with Steffen Adler, project manager ONETWO, NIBIO.
71 Serra, E., Report on potential of press cake as a fodder source for dairy cows, 2020.
72 Personal communication with Gjermund Bahr, NIBIO.



Pressed grass juice and press cake. Photo: Biorefinery GLAS

MICROALGAE

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x			x		x	1800

Phototrophic algae

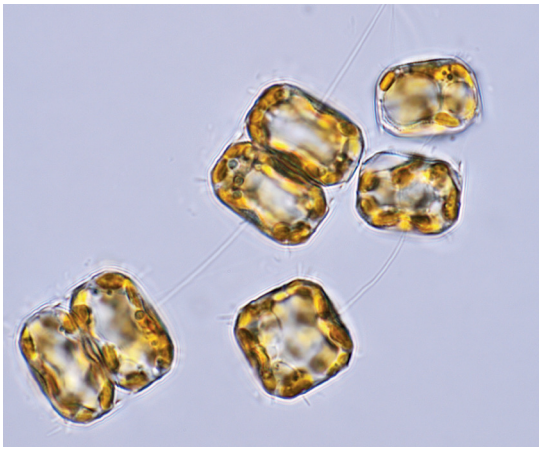


Photo of phototrophic microalgae. Photo: Nord University

Phototrophic algae are a new and interesting source of important raw materials for sustainable new feed that can provide both marine fatty acids and proteins. A number of stakeholders have already established trial facilities for phototrophic algae production. Algeparken på Mongstad and Finnfjord Smelteverk are two of the stakeholders currently planning to scale up from pilot production. Algae production uses CO2 as a carbon source, with light as an energy source and silos or photobioreactors as production equipment. Current barriers in respect of technology and biology have to be overcome in order to produce large volumes at competitive prices.

Heterotrophic algae

Smaller volumes of heterotrophic algae have already been used in commercial fish feed. The algae are imported from the US and Brazil, where it is grown using sugar as a commodity. The algae is rich in omega-3 fatty acids and may become an important commodity if the price can be reduced. One of the challenges will involve replacing sugar and using waste or side streams as a commodity in order to reduce the price of the feed and improve its carbon footprint[73]. Heterotrophic algae are not produced commercially in Norway at present, although a number of research projects have been initiated. The microalgae Schizochytrium has proven to offer good values of the omega-3 fatty acid DHA in this regard.

Algae processing starts with harvesting of the algae from photobio-reactors. The algae contain a great deal of water. The first step in algal biomass concentration is centrifugation. Microalgae contain rigid cell walls. Crushing these cell walls facilitates nutrient extraction and increases bioavailability when the algae is used as a feed ingredient. The cell walls can be crushed mechanically in a ball mill, for example. Research has shown that different microalgae require different mill conditions, as the ball material, the feed rate and the humidity affect the crushing of the cells[74]. The biomass can also be used directly as a feed ingredient. Alternatively, it may be passed on to a process in which various nutrients are extracted and separated.

FUNGI

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x	x	x	x		x	1500

Yeast and mycelium can be grown on the basis of residual raw materials/ side streams from wood and agriculture with a view to converting this into single-cell protein. Single-cell protein can also be included in feed for livestock, and the results from research projects to date have been promising.

Products made from yeast are often divided into two groups:

1. Derivatives such as glucans, etc., which are added to feed as a microingredient.
2. Yeast protein, which up to now has been a new potential raw material as a feed input.

Feed concentrates are commercially available at present which include yeast products as an ingredient, and these have proven to be an important component promoting intestinal health in both land animals and fish. Studies have also shown that yeast has a positive effect on the health of the intestines of pigs, chickens and cows[75].

73 Bellona, Råvareløftet (2022).
74 Personal communication with Mette Sørensen, Nord University.
75 Håkenåsen, Ingjerd, Novel protein sources in diets for weaned piglets – effect on growth performance, gut function, and health (2022).

Yeast included in feed concentrates has also been proven to enhance the cheesemaking properties of cow's milk[76].

That said, Finnish company eniferBio has manufactured its fungus product Pekilo, which is made up mycoprotein. This can grow on cheaper raw materials than yeast. Trials using Pekilo and yeast as an included feed ingredient have demonstrated that feed utilisation and growth were enhanced in salmon[77] [78]. Pekilo is low in fat and contains no trans-fat, and it has been used in food since 1985[79]. It is produced by means of a specific biorefining process with fermentation of carbohydrates derived from food industry waste[80].

The industry is showing a great deal of interest in alternative sources of protein for feed for salmon farming, with the proviso that the price and sustainability is as competitive as for soya. Studies show that the cost of production for the single-cell protein mycoprotein Quorn – where the microfungus Fusarium venenatum plays a key role – and soya are almost on a par, Quorn costing USD 460–550 per tonne and soya meal costing USD 425 per tonne[81].

The same article highlights a research gap in modelling the bioprocessing of lignocellulose-derived single-cell protein before it can be used in food.

The barriers to using fungi as a raw material for feed lie in developing a more efficient process for producing fungal protein from cellulose, as well as gaining access to enough sustainable and affordable biomass for use as a substrate. Trials are currently in progress with a view to testing various other substrate types, including agricultural by-products, seaweed and other organic waste.

The processing of yeast protein varies based on which fungus is intended to be used, but breaking down the cell walls of the yeast will be an important element in this regard. Research from Foods of Norway has demonstrated that this can be achieved by means of autolysis, where the pulp is heated to 50 degrees for 16 hours[82]. The pulp can also be centrifuged before being dried to make meal.

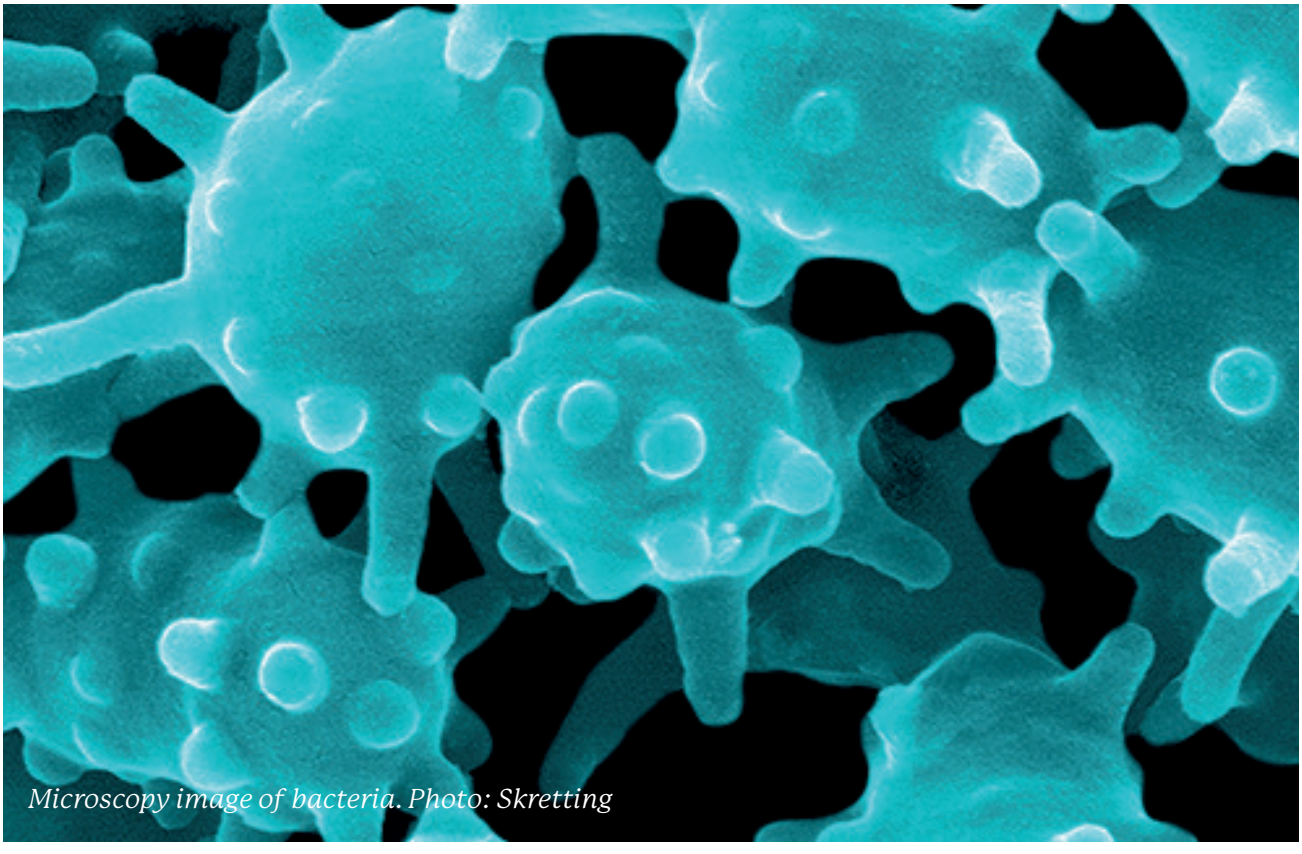
76 Personal communication with Margareth Øverland, Foods of Norway.
77 Dønnem, Ingjerd, article in Foods of Norway (18.01.23).
78 Farmed salmon can grow on Norwegian spruce trees instead of Brazilian soybeans | NMBU (foodsofnorway.net).
79 Gilani, G.S. et al., Protein; Sources of Food-grade Protein, 2003.
80 T. Aggelopoulos et al., Solid state fermentation of food waste mixtures for single cell protein, aroma volatiles and fat production (2013).
81 Upcraft, T. et al., Protein from renewable resources: mycoprotein production from agricultural residues (2021).
82 Lagos, Leidy, NMBU article, Gjær som fôringrediens: Hvordan prosessering av gjær påvirker fordøyelighet og immunrespons i Atlantis laks (29.08.19).

BACTERIA

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x			x		x	1800

At present, several bacterial species could potentially be included as ingredients in feed. To date, four species have been identified that would be suitable for commercial production. All four species contain high protein levels of 70–80%[83], and moreover bacteria production is making effective use of space. Bacteria can grow on various media, including methane, ethanol or hydrogen in combination with CO2. Bacterial meal has been trialled as an ingredient in pig feed, with good results in terms of better animal health and better meat quality[84]. Consideration of bacteria as a feed input is in the early stages, but according to Tlusty et al.[85], the bacterium M. extorquens has presented promising results in fishmeal, replacing up to 55% of the meal with bacterial flour.

The processing of bacterial meal varies depending on which bacteria are to be used, but one method involves centrifuging the pulp from the reactor, mechanically removing the water using filters and presses and finishing off with thermal drying. R&D at the "joints" of the process is needed in order to ensure that the properties for the commodities are safeguarded as effectively as possible[86].



Microscopy image of bacteria. Photo: Skretting

83 Bellona, Råvareløftet (2022).
84 Personal communication with Margareth Øverland, Foods of Norway.
85 Tlusty M et al., A transdisciplinary approach to the initial validation of a single cell protein as an alternative protein source for use in aquafeeds. (2017).
86 Personal communication with Margareth Øverland, Foods of Norway.

KRILL

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x		x	x		x	1800

Antarctic krill (euphausia superba) is currently caught in the Southern Ocean, near Antarctica. Some 4% of the total biomass available (estimated at 500 million tonnes) is taxed at present, and commercial fishing has received the highest sustainability scores, according to the annual report published by the Sustainable Fisheries Partnership[87]. Aker Biomarine is one of the leading stakeholders in respect of this fishing, currently reporting catches of about 65% of their total quota, which gives them scope for growth[88]. Discussions are also in progress on whether to open up new catch areas in the Southern Ocean. The potential volume of krill in feed for both fish and land animals has not been established on account of the attractiveness of krill for biopharmaceuticals and human nutritional supplements. However, krill is currently a commercially available supplement for pet food and fish feed. Studies on salmon have indicated that krill has a number of positive effects on the health of salmon, including improvement of intestinal, heart and liver health, fillet quality and feed intake, in addition to increasing growth[89] [90] [91].

There is potential for valuable transfer of technology and knowledge from commercial krill fishing to Calanus finmarchicus and mesopelagic fish catches[92]. Aker Biomarine currently has its own fishing trawlers which process their catches on board. The krill is caught using trawl technology and pumped directly onto the boat, where the krill is boiled before passing into a separator where the oil is separated out. The pulp then goes on to dry for the processing of flour.



Picture of Antarctic krill. Photo: Cecilie Thorsen Broms, HI

87 Veiga, P., Reduction Fisheries, SFP Fisheries Sustainability Overview (2021).
88 Personal communication with Maja Bævre-Jensen, Aker Biomarine.
89 Olsen, R.E. et al., The replacement of fish meal with Antarctic krill, Euphausia superba in diets for Atlantic salmon, Salmo salar (2006).
90 Hatlen, B. et al., The effect of low inclusion levels of Antarctic krill (Euphausia superba) meal on growth performance, apparent digestibility, and slaughter quality of Atlantic salmon (Salmo salar) (2016).
91 Presentation by Maja Bævre-Jensen, Aker Biomarine (14.03.23).
92 Bellona, Råvareløftet (2022).

MESOPELAGIC FISH

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x	x	x	x	x	x	1800

Mesopelagic fish is a hitherto untapped resource offering major potential as a feed ingredient. A number of communities have attempted to establish the extent of the mesopelagic fish biomass, with figures ranging from 2 to 19.5 gigatonnes worldwide[93]. The fact that both locating and catching the fish effectively is demanding at the moment presents a challenge.

Mesopelagic fish are found all over the world and play an important part in transporting CO2 from the surface to the depths, as it migrates 200–1000 m and swims to the surface to eat[94]. In Norwegian waters, Mueller's pearlsides, glacier lantern fish and krill are the most interesting species for commercial fisheries.

Mesopelagic fish contain good amounts of both protein and oil and are comparable with common pelagic species in terms of content. Mesopelagic fish have a very short shelf life, however, and maintaining their nutritional status presents a challenge as the raw material oxidises rapidly. This causes the fish to turn rancid and lose palatability and nutrients. Moreover, glacier lantern fish contain high levels of wax esters and cadmium, which may impact on use of the fish as a feed ingredient[95].

Other challenges as regards the use of mesopelagic fish include the fact that there is currently no commercial fishing of this species, and incentives have to be put in place to make this type of fishing attractive to commercial industry. Moreover, green technology will have a major impact on the carbon footprint of the raw material, as will the development of efficient technology for both locating and catching the fish.

The processing of mesopelagic fish will vary depending on which species is caught. Glacier lantern fish will probably require separate processing in order to remove wax esters and cadmium if large volumes of this species are caught.

With active fishing, all catches will probably have to be ensiled on site and transported for processing. Moreover, the silage will be heated before being separated into the oil, stickwater and insoluble protein and fat fractions. Stickwater and insoluble protein and fat may continue to meal production, which involves evaporation and drying.

93 Hidalgo, M. & Browman, H., Developing the knowledge base needed to sustainably manage mesopelagic (2019)
94 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).
95 Bellona, Råvareløftet (2022).



Picture of mesopelagic fish. Photo: Maria Madina, SINTEF Ocean

MACROALGAE

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x	x		x		x	8000

Macroalgae has historically been used as a feed supplement in agriculture in times when little access to other feed sources was available. Nowadays, macroalgae is widely harvested commercially for extraction of ingredients for products in a number of markets. Alginate, laminarin and fucoidan are all examples of ingredients[96].

The two latter ingredients are of relevance as inputs in feed. Fucoidan has been demonstrated to offer lots of health benefits as a supplement in feed for salmon and animals and food for humans[97].

96 Personal communication with Heidi Meland, Norwegian Seaweed Association.
97 Hany, A. et al., Health benefits and potential applications of fucoidan (FCD) extracted from brown seaweeds in aquaculture: An updated review

Fermented seaweed has been demonstrated to have a positive on intestine health and increase growth in land animals when used as a supplement to regular feed[98 99]. Moreover, macroalgae have been demonstrated to reduce the amount of methane gas emitted by cows, offering potential for them to improve their carbon footprint to a significant degree[100].

Macroalgae contains little protein and fat, and hence is not particularly appropriate as a significant ingredient in feeds for salmon and livestock. The amount of iodine in some macroalgae species may result in poisoning in land animals, but blanching has demonstrated to be an effective way of reducing the concentration.

Although macroalgae is not attractive as a major feed input, it is important to include this industry in our survey on account of the significant ongoing efforts to build up this new industry. It may also be possible to include macroalgae in the same processing infrastructure as several of the other feed ingredients referred to in the report. Furthermore, macroalgae could potentially be used as a substrate for low-trophic organisms such as bacteria, fungi and insects[101].

Macroalgae processing varies depending on the species to be produced and the end-product envisaged. Macroalgae is not stable in storage, and there has been a great deal of research into what kind of stabilisation



Photo of sugar kelp. Photo Henning Steen, HI.

98 Choi, Y.J. et al., Effects of Dietary Fermented Seaweed and Seaweed Fusiforme on Growth Performance, Carcass Parameters, and Immunoglobulin Concentration in Broiler Chicks (2014).
99 Mahrose, K. et al., Seaweeds for Animal Feed, Current Status, Challenges, and Opportunities (2022).
100 Battaglia, M. Article; The conversation, Seaweed could hold the key to cutting methane emissions from cow burps (2016).
101 Bellona, Råvareløftet (2022).

gives the best yield[102] [103]. Blanching and removing water in multiple processes is highly energy-intensive, and so some manufacturers would like to try and deliver wet material to customers, but in turn this may cost more on account of shipping.

CALANUS FINMARCHICUS

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x	x		x	x	x	1800

Calanus finmarchicus is a copepod found in abundant numbers in the Norwegian Sea. This is a zooplankton and has a very important part to play as food for fish fry[104] and adult fish, such as mackerel, herring and blue whiting. The biomass is estimated at around 30 million tonnes of standing biomass, with annual new production of around 300 million tonnes. This species has been a scarce marine resource up to now. There is currently one commercial operator working with Calanus finmarchicus in Norway (Calanus AS – Zooca), and they have recently constructed a separate processing facility designed especially for the processing of this particular species. The products are made up of protein hydrolysate, which is mainly used as an ingredient in marine aquaculture feed, and oil, which is used for health foods in capsule form.

Calanus finmarchicus is a promising species as a potential raw material ingredient in marine feed thanks to its high levels of both protein and omega-3. Calanus finmarchicus is also rich in astaxanthin and, like krill, has been demonstrated to increase the palatability of feed for salmon. At present, all the oil produced by Zooca is used for human consumption, while the feed industry has access to this oil on account of the insoluble protein and fat emerging from the process, which contains a little oil and astaxanthin as well as protein. In Norway, Skretting AS, working in partnership with Andfjord Salmon and Zooca, has devised a separate feed containing Calanus finmarchicus. This is known as Calanus® Plus[105].

A joint quota for Calanus finmarchicus (254,000 tonnes per year) has been distributed now.

Furthermore, a number of permits have been issued to ships (limited trawl permit for Calanus finmarchicus and trawl permit for Calanus finmarchicus). Exploiting the permits to the fullest has presented a challenge, for various reasons. Some of the permits issued define restrictions insofar as it is not possible to conduct several different types of fishing from the same boat. This means that fishing boats that normally have their low season in the summer cannot use this time to catch Calanus finmarchicus. That said, it will cost a lot more for Zooca to have to

102 Personal communication with Nikolai Buer, Lofoten Blue Harvest.
103 Personal communication with Tarald Sivertsen and Torben Marstrander, Folla Alger.
104 Røttingen, I., Tilstanden i økosystem Norskehavet – Institute of Marine Research (2011).
105 Andfjord Salmon website, Andfjord.no (13.07.22).


Calanus Finnmarchicus, Photo Institute of Marine Research

invest in a completely separate fishing fleet so that they can gain access to the raw material. That is why more work has to be done on interesting the fleet in catching Calanus finmarchicus during the season. Furthermore, work has to be done on making this type of fishing available to appropriate vessels that show an interest but do not have permits at present.

Moreover, Zooca[106] and *Råvareløftet* indicate that there is a need for investment in more efficient fishing technology and development in this field[107]. Calanus finmarchicus is present in large volumes in the Norwegian Sea, and it takes quite a long time to sail out to the catch area. Furthermore, Calanus finmarchicus is more scattered in the sea, which means that new fishing technology will need to be developed.

The Zooca factory will be able to handle both fresh and frozen material when processing Calanus finmarchicus. The raw material enters an enzymatic hydrolysis step after thawing and then goes on into a three-phase decanter, separating Calanus finmarchicus into oil, stickwater and insoluble protein and fat. Stickwater and insoluble protein and fat are then evaporated to form a hydrolysate and a protein meal that feed producers can use.

SECONDARY FISHING AND AQUACULTURE

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x	x	x	x	x	x	1800

By-products from the seafood industry have been emphasised by both SINTEF and Bellona et al.[108 109] as a vital aspect in finding sufficient commodities that will allow Norway to be self-sufficient and provide its

106 Personal communication with Ole Petter Pedersen, Zooca
107 Bellona, Råvareløftet (2022).
108 Bellona, Råvareløftet (2022).
109 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).

own ingredients for feed. Significant amounts of commodity are lost to the sea at present on account of a lack of fishing fleet capacity and a lack of earnings potential when it comes to landing the residual raw material.

Moreover, most farmed fish produced are currently sent to the EU gutted with heads for further processing. The *Råvareløftet* report highlights the fact that an estimated 176,000 tonnes of residual raw materials that were left unused in 2018[110]. This estimate includes residual raw materials that are left in the sea at present, residual raw materials from shellfish, blood and heads, which go to the EU at present, and dead fish, which are currently categorised as Category II material and are not permitted for use as feed inputs.

Residual raw materials from aquaculture cannot be used as new salmon feed input as things stand at present, but they can be included in feed concentrates for agriculture and pet food, and for human consumption.

Hydrolysis as a way of utilising meal and oil fractions is widespread in the processing of fishing by-products. The bone fraction is also utilised and can be used as a feed input for land animals[111]. The oil fraction stands at around 7–19% EPA + DHA, depending on the residual raw material in question. The protein fraction stands at 13–19%[112].

SECONDARY AGRICULTURE

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x	x	x	x	x	x	1500

Agricultural residual raw materials can be divided into two fractions at present:

1. Residual raw materials of vegetable origin (cereals, fruits and vegetables).
2. Animal by-products (from all farm animals).

The vegetable fraction has no potential as a fish feed ingredient at present, but parts of it could be used as an animal feed input. The challenge presented by the residual fraction of vegetable origin from agriculture is that much of it is distributed all over Norway and is not necessarily intercepted by centralised facilities, as with animal slaughter[113].

The animal commodity varies depending on the animal used to produce the commodity. Animals with a large saturated fat fraction, such as cattle and sheep, will not be as useful as ingredients in feed for fish such as chicken[114].

The regulations for preventing the spread of transmissible spongiform encephalopathies (TSEs) prevent the use of residual fraction of cattle

110 Bellona, Råvareløftet (2022).
111 Rubin, report 308/65, Anvendelse av fiskebeinmel. Bein separert ved ensilasjeproduksjon.
112 Tangen, Irene, Karakterisering av avfallsstrømmer i matindustri (2016).
113 Lindberg, D. et al., Kartlegging av restråstoff fra jordbruket (2016).
114 Animalia, Kjøttets tilstand (2021).

origin for producing new food[115]. The pet food market takes a significant percentage of secondary commodities of animal origin from agriculture at present. The commodity could potentially also be used as a substrate for production of low-trophic organisms such as insects or microorganisms, but this will require amendment of the legislation[116] [117].

Bioco is using enzymatic hydrolysis to further refine a residual raw material of chicken and turkey origin. The residual raw material is milled as soon as it is received, and enzymes are added. Moreover, the pulp undergoes hydrolysis in tubes before the enzymes are rendered inactivate and the pulp is separated into three fractions: grease, stickwater and insoluble protein and fat (sediment)[118]. Stickwater and insoluble protein and fat are evaporated to form flour.

POLYCHAETES

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x		x	x		x	1800

Polychaetes is a collective term for annelid worms, of which there are more than 15,000 marine species worldwide. 750 of these have been registered in Norway to date[119]. These worms have been popularly used by anglers as bait for a long time, and 121,000 tonnes are harvested worldwide each year.

Polychaetes clean the seabed and also contain good levels of protein, omega-3 and astaxanthin. Furthermore, polychaetes are very attractive

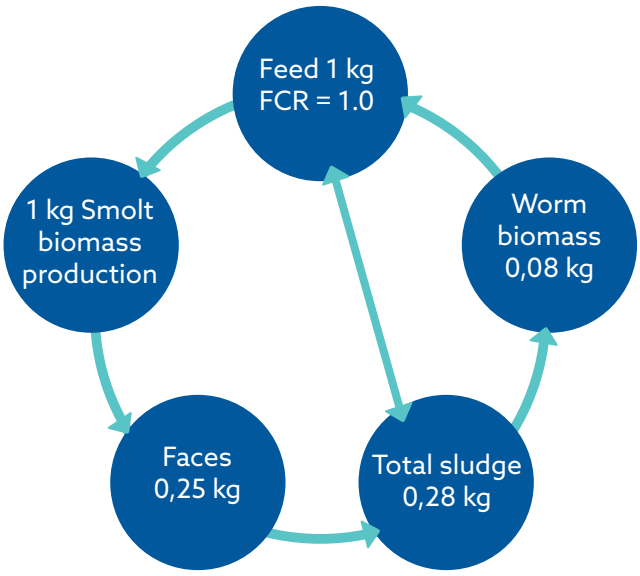


Figure 9 / Potential in polychaetes production, based on residual raw materials from salmon production.

115 Lovdata, Forskrift om forebygging av, kontroll med og utryddelse av overførbare spongiforme encefalopatier (TSE) (2004).
116 Bellona, Råvareløftet (2022).
117 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).
118 Personal communication with Heidi Alvestrand, Bioco.
119 Sømme, Lauritz S.; Bakken, Torkild: flerbørstemark in Store norske leksikon at snl.no (16.12.21).

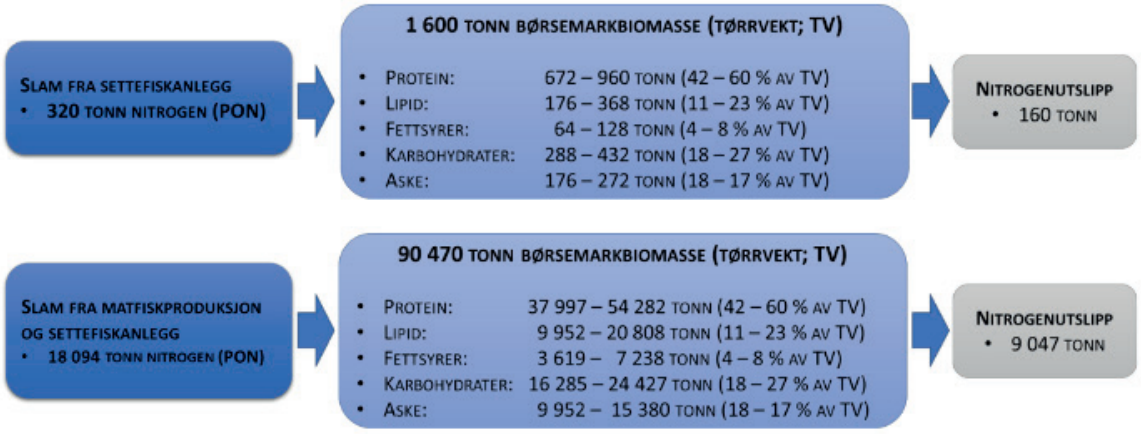


Figure 10 / Theoretical production yield of polychaetes produced on sludge from production of hatcheries (top) and all emissions from the aquaculture industry in 2019 (bottom), calculated on the basis of annual emissions of particulate organic nitrogen (PON).

as feed for shrimps, as they contain hormone-active substances that help promote shrimp viability and sexual maturation. Over time, polychaetes have become more interesting for research communities to explore as a potential source of feed for salmon[120]. The background to this is provided by the ability of the soil to use waste streams such as sludge from farming as a substrate for growth and the nutrient values, particularly in the form of unsaturated fatty acids. There is potential to produce polychaetes using sludge as a substrate, where it is estimated that it will be possible to produce 8% biomass from polychaetes per kg of salmon produced at smolt facilities using the waste[121] [122].



Polychaetes. Photo: Bjarne Kvæstad, SINTEF Ocean

120 Brown, Nicholas et al., Utilization of waste from a marine recirculating fish culture system as a feed source for the polychaete worm, Nereis virens (2011).
121 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).
122 Haiqing Wang, et al., Growth and nutritional composition of the polychaeta Hediste diversicolor (OF Müller, 1776) cultivated on waste from land-based salmon smolt aquaculture (2018).

The figures in the illustration on the next page have been taken from SINTEF and show the potential for production of polychaetes based on sludge volume in 2019[123].

Polychaetes have not been established as an ingredient in commercial feed production as yet. Of Polychaetes volumes harvested at present, much of the biomass will be sold as entire polychaetes[124]. A meal/oil fraction will be most expedient as a feed ingredient, and it is assumed that the same type of processing as for insects may be appropriate.

GAMMARIDS

Mechanical	Preservation	Heat	Separation	Hydrolysis	Drying	Energy
x		x	x		x	1800

Gammaridae are low-trophic crustaceans that can be cultivated at high densities and fed on dead organic matter. There are almost 400 marine species in Norway, and SINTEF has been researching two of these species for over a decade.

Their results have indicated that these organisms can be cultivated on different side streams from bio-based industries, such as waste products from agriculture and the seaweed industry[125]. The biomass from gammaridae is made up of two main fractions: fat (7–14% of dry weight), including HUFA-rich phospholipids and astaxanthin, and a fraction primarily made up of proteins (43–52% of dry weight). It also contains a number of other valuable components such as chitin, vitamins and minerals.

The protein fraction contains all the amino acids deemed essential for marine fish. As stated, the fat fraction contains omega-3 HUFA and includes both DHA and EPA[126]. A number of studies have shown that gammaridae may be able to produce omega-3 despite being fed a diet that does not include omega-3. This makes gammaridae a very exciting raw material for the feed of the future, where the challenge largely involves finding new supplies of omega-3. SINTEF has also trialled the use of sludge from aquaculture as a substrate for gammaridae, with inspiring results.

Gammaridae processing has not been established commercially as yet and development will be needed, but it has been estimated – through personal communication with SINTEF Ocean – that gammaridae can be processed as dry and wet commodities and there is no need for hydrolysis. However, dewatering, separation and drying will be needed[127].

123 Hilmarsen, Ø. et al., Kunnskaps- og erfaringskartlegging om effekter av og muligheter for utnyttelse av næringsstoffer fra oppdrett (2020).
124 Personal communication with Ida Grong, SINTEF Ocean.
125 Prosjektet BIOCYCLES, SINTEF Ocean.
126 Personal communication with Gunvor Øie, SINTEF Ocean.
127 Personal communication with Ida Grong, SINTEF Ocean.

Market

The report shows that many potential raw materials have been identified as feed ingredients to date. However, some of these raw materials will probably never leave the lab stage on account of cost vs. yield and a lack of a large enough market willing to pay for them. As part of the survey, therefore, respondents who are planning production on a commercial scale were asked to identify the markets in which they are active or to which they would like to acquire access.

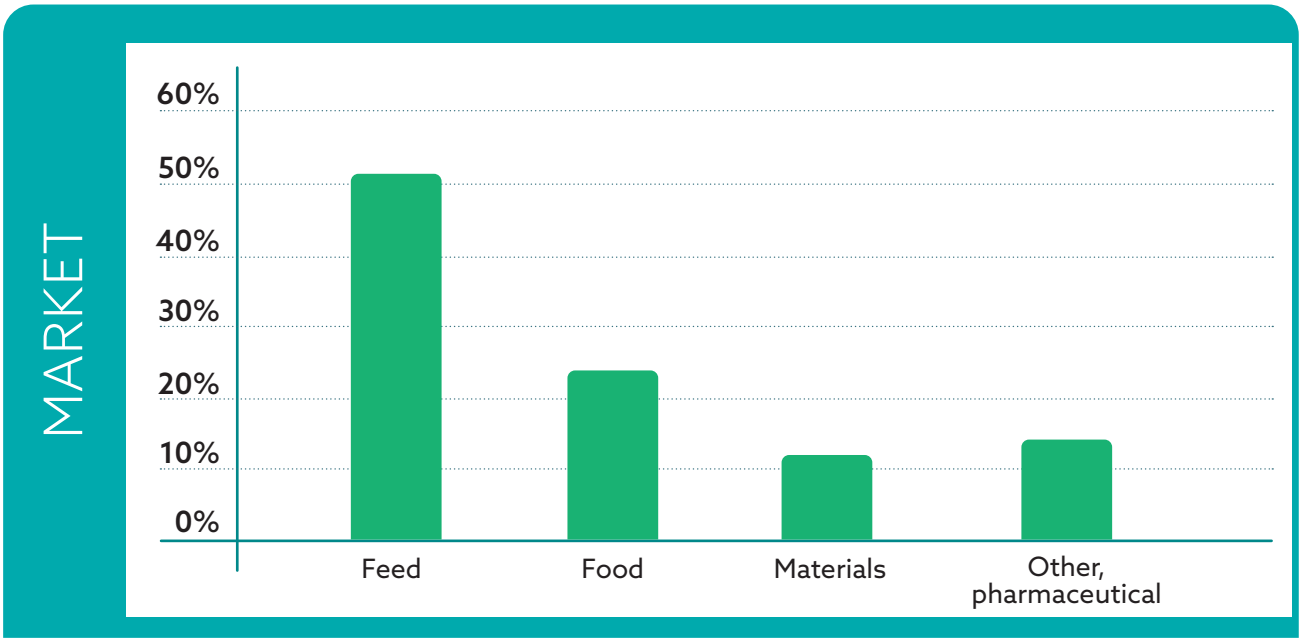


Figure 11 / Market distribution

It is apparent from Figure 11 that feed accounts for over 50% of the sample, and food accounts for almost 25%. The rest is divided between materials, pharmaceuticals and other, with over 10% for each. Many stakeholders who responded that the feed market is of interest want to gain access to other markets primarily because there is more willingness to pay. The feed market will then be desired as a secondary market over time, in that:

1. Stable and sufficient production volume is established and the preferred primary market is saturated.
2. There is a side stream in primary production that is of relevance as an input in the secondary market.

The competitive situation in the primary market could present a challenge with such a strategy. This primary market would determine earnings, as well as achieving a sufficiently large volume and sufficiently stable production for a side stream that a feed producer would regard the ingredient as being attractive to their market.

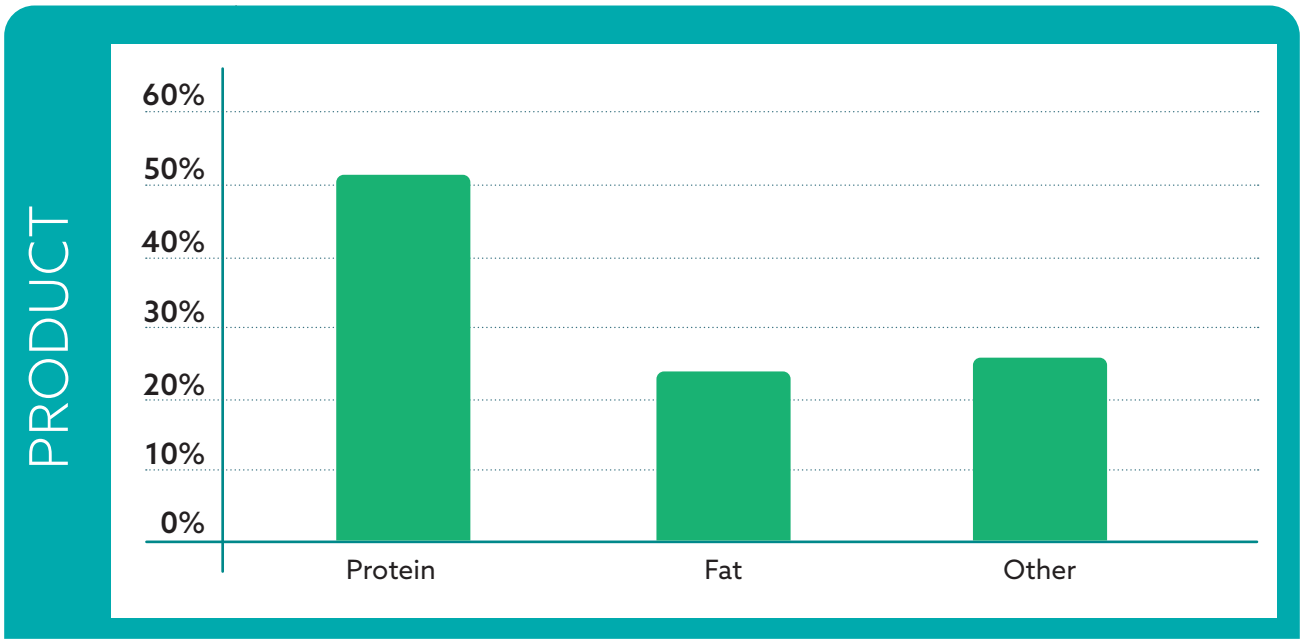


Figure 12 / Content distribution

Products

One of the primary elements when deciding which raw materials to invest in going forward will be based on the contents of the raw material and its potential as an ingredient for feed or as a benefit to other markets.[128 129 130 131]

The products manufactured – or intended to be manufactured – are divided into the main categories of protein, fat (including omega-3 oils) and other (fertilisers, calcium carbonate, cellulose, energy and materials).

Essentially, the ingredients indicated by our respondents are intended to be used as inputs for food and feed. Our respondents indicate that a pilot facility should be constructed that is capable of processing various raw materials. This can be achieved, for example, using facilities that can be configured with a preferred setup in order to trial a specific raw material and the need for different operations. One important element that emerged during the interviews was that many raw materials are unstable on account of short shelf life, and that having process capacity available locally will be important and save money.

A number of our respondents established in their primary market express a desire for test infrastructure to be available so that they can trial the development of other products as part of a potential growth strategy.

128 Lindberg, D. et al., Kartlegging av restråstoff fra jordbruket (2016).
129 Tangen, Irene, Karakterisering av avfallsstrømmer i matindustri (2016).
130 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).
131 Bellona, Råvareløftet (2022).

RAW MATERIAL	PROTEIN	FAT
Blue mussels	65%	8%
Tunicates	50–61%*	6–23%
Macroalgae	8%	–
Insects	35–69%*	23–47%
Grass	10–20%	–
Phototrophic microalgae	60–70%	10–20%
Heterotrophic microalgae	60–70%	55–75%
Fungi	30–50%	–
Bacteria	50–80%	–
Gammaridae	43–52%	7–14%
Polychaetes	54–58%	10–15%
Krill	62% +/– 8%	26% +/–6%
Mesopelagic raw material	12–15%*	5.5–8%*
Calanus finmarchicus	37–44%	16–34%
Secondary fishing / aquaculture	55-60%	10–35%
Secondary agriculture	55-60%	10–35%

Figur 13 / Fordeling av protein og fett (EPA/DHA)

This type of infrastructure for hire of facilities is vital for the development of products where there is insufficient knowledge of the impact in a new market. Some infrastructure is available to hire for test production at present, but limitations are defined depending on which raw material is to be tested, and for which market.

Validation and commercialisation

Validation and commercialisation are two crucial steps in making new feed ingredients available to the industry.

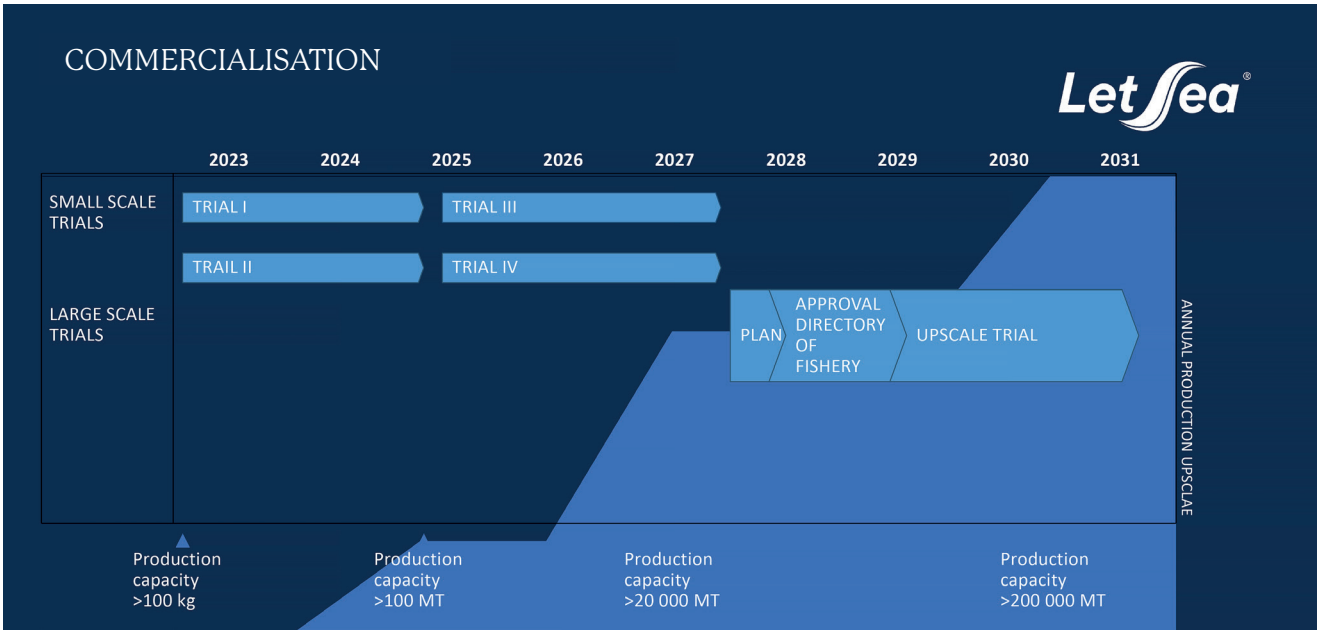
The figure below illustrates the path any new feed ingredient must take, from lab scale production to piloting and commercialisation, in combination with verification of the effectiveness of the raw material and its effect as an ingredient included in fish feed.

Whether the path to a commercial product as an ingredient included in feed for land animals would have been very different from the path for marine species is not known. The ingredient in lab scale production will answer the following questions during the validation step:

1. Can the raw material be produced, and if so, how?
2. How can the raw material be extracted and processed to form an ingredient?
3. Can the ingredient be included in feed, and if so, to what extent?

A great deal of research activity at present is surrounding new potential raw materials that may be included as feed ingredients. The university and college sector, research institutes and research organisations are able to conduct trials at their facilities. This usually requires the trial to form part of an ongoing project or programme in the research environment in question. Furthermore, there is an opportunity to test the production of a test feed and feeding at a number of feed producers' own research facilities. The fact that the results of the trials are not disclosed to the general public and are regarded as trade secrets could present a challenge in this regard.

The challenge on the path to commercialisation is to go from a volume designed for small-scale test production to production of a volume intended for a full-scale trial. Small-scale testing typically takes eighteen months, and the decision to scale up the volume further should be made not long afterwards. New elements may be discovered along the way that should also be tested, resulting in a need for another small-scale round and hence another eighteen months. This means that significant capital is required in the form of production and processing infrastructure; which is also a time-consuming factor. There are currently two private full-scale facilities in Norway where feeds can be trialled and stakeholders can ensure ownership of their own results: LetSea and Gildeskål Research Station.



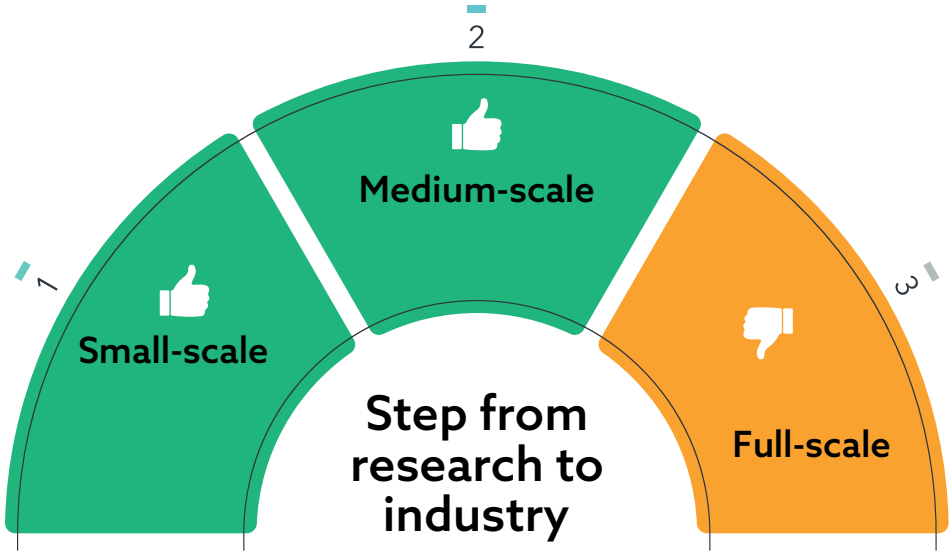
Feed producers are constantly working on testing. Feed producers are in possession of significant intelligence regarding the effects of the ingredients on animal growth and health. A number of raw material producers work in partnership with feed companies at present and gain access to their ingredients for inclusion in feed. Open access to the results of trials presents a raw material producer with challenges when trialling new raw materials with a feed company, as these results can be regarded as competitive intelligence. That said, feed producers say that including

new raw materials in feeds that are not fully commercialised presents a challenge, as these materials will have a significant impact on the price of the feed[132] [133].

The LetSea and Gildeskål Research Station (GIFAS) trial stations work with small-scale and full-scale trials for testing and validation of feed materials up to slaughter-ready size for verification of biological production and performance such as growth, feed utilisation, fish health, etc. The LetSea and GIFAS infrastructure allows full-scale offshore testing to be carried out up to the final slaughter weight.

Both stations are good examples of companies with in-depth expertise on what is needed to commercialise feed and how demanding it is to meet these needs.

The figure below illustrates the fact that the need for capital often presents what goes on to become the "valley of death" when heading towards commercialisation of new feed raw materials, despite market demand and political will being present. Investors in private and public contexts are more likely to contribute to a growth phase in which "proof of concept" is verified. Moreover, there are few public instruments available during this critical phase, which means that the full commercial production stage will not be reached.



132 Personal communication with Pål Arve Dypaune, Skretting. Personal communication with Thomas Johansen, BioMar
133 Personal communication with Henriette Hansen, LetSea AS.

INSTRUMENTS FOR TESTING, DOCUMENTATION, VALIDATION AND COMMERCIALISATION

The policy framework operates in the various R&D stages, from basic research to industrial research and experimental development. Maturity of technology is frequently measured on what is known as a TRL scale. This scale provides an indication of how much progress has been made in the development process and of what documentation is available for the performance of the technology, as well as the scale.

Industrial research (TRL levels 2–4) involves planned research or critical investigation with a view to acquiring new expertise and skills needed for the development of new products, processes or services, or to bring about considerable improvement in existing products, processes and services (i.e. experimental development). This includes the production of components for complex systems and may include the design of prototypes in a laboratory environment, or in an environment with simulated interfaces to existing systems as well as pilot lines where such are necessary for industrial research and, in particular, for validation of generic technology. Normally covered by programmes from the Research Council of Norway, etc.

Experimental development (TRL levels 5–7) may, for example, include activities that aim to conceptualise, plan and document new products, processes, or services. Normally covered by Innovation Norway, which covers levels 4 and 8 in exceptional cases, Enova, etc.

Experimental development may include production of prototypes, demonstrations, production of pilots and testing and validation of new or improved products, processes or services in contexts that are representative of the genuine operating conditions, with the primary purpose of further developing – in technical terms – products, processes or services which have not yet acquired their final form. This may include developing a commercially viable prototype or pilot where this must necessarily be the end-product, and insofar as it is too costly to manufacture solely for use for demonstration and validation purposes[134].

The foundation for taking research outcomes from the university and college sector, research organisations and research institutes on to commercialisation is provided via Technology Transfer Offices (TTO) and others.

Many of the raw materials to which reference is made in the report are at the basic research and industrial research stages. These have to be validated so that business foundations and business models can be devised that private and public investors can assess for the commercialisation phase.

134 Innovation Norway, Definisjon av teknologimodenhetsnivå (2023).

NEED FOR PILOT FACILITY WITH TESTING PRIOR TO SCALING AND FULL-SCALE PRODUCTION

The needs set out by our respondents can be summarised as follows:

Mobile and modular
Mobility for a pilot facility is desirable, allowing it to be transported by truck/boat to an appropriate location in order to ensure close proximity to other infrastructure and ensure good logistics for the biomass. The pilot facility should be able to fit into two 20-foot containers, for instance, with an alternative container with a generator to provide the energy necessary for bioprocessing.

Pilot facility – contents/equipment
A pilot facility with a modularity that allows different setups to be implemented is desired in order to attend to several processing variants based on the various bioresources and products downstream. This will enhance the value in use, and it will be necessary to examine the extent to which it will affect the cost of investment and operation.

Configuration and preparation prior to dispatch
Irrespective of modularity, it is desirable for configuration of the pilot facility to take place before it is dispatched. Our respondents wanted the pilot facility to be operational as soon as possible and at the lowest possible cost after having arrived at the site. This will allow the user to mainly spend time on testing, with adjustment of the various steps in the process.

Services/setup
A pilot facility for bioprocessing will require specialist expertise for setup, installation and operation/testing. Most respondents express a desire for such expertise to be included as services for the pilot facility. Other respondents – who offer pilot facilities at present – require expertise to be included so as to prevent damage and the risk of greater wear and tear due to improper use of such expensive equipment.

Supplementary work
A number of respondents regard it as natural to obtain clear instructions on first-line maintenance and cleaning of pilot facilities, which the tenant can follow at the location. That said, it is desirable for subsequent supplementary work with maintenance, returning to the basic setup and further cleaning of the pilot facility to be included in the package price for its hire.

Energy
Sites for pilot facilities may not have access to energy. If the demand for energy cannot be met at the site, it may be appropriate to hire a container with a suitable generator/battery instead of connecting to the mains or another available energy supply. One example of the power requirement for a respondent's pilot facility is up to 115 kW (500 amps in the 230-volt grid).

Price
Respondents estimate that investing in a mobile pilot facility may cost somewhere in the range of NOK 5–10 million with used components (with an evaporator, but without a dryer). Costs will amount to NOK 30–80 million for a pilot facility which includes new parts from different suppliers. That said, the price demanded for use of the facility must be at a level that raw material producers are capable of meeting. Expenses in the form of hire and staff to operate the equipment may incur a cost that would present a challenge to businesses in the start-up phase. That is why an investigation should be performed to find out whether there is scope to reduce costs in the catapult so that more parties are able to take advantage of the offering.

Infrastructure available today

Respondents wishing to offer capacity at their facilities are listed below. This presents a view of the situation in respect of available capacity and a desire for potential hiring at six pilot facilities and seven factories. It is important to note that the overall picture at a national level may be larger, as there has been no contact with all commercial facilities on a national basis.

PILOT FACILITIES: TEST INFRASTRUCTURE FOR RAW MATERIALS

This report assumes that a pilot facility has a receiving capacity of 0.1–3 tonnes of wet raw material per hour. A brief description of the equipment available at the facilities is also provided.

Mobile facilities

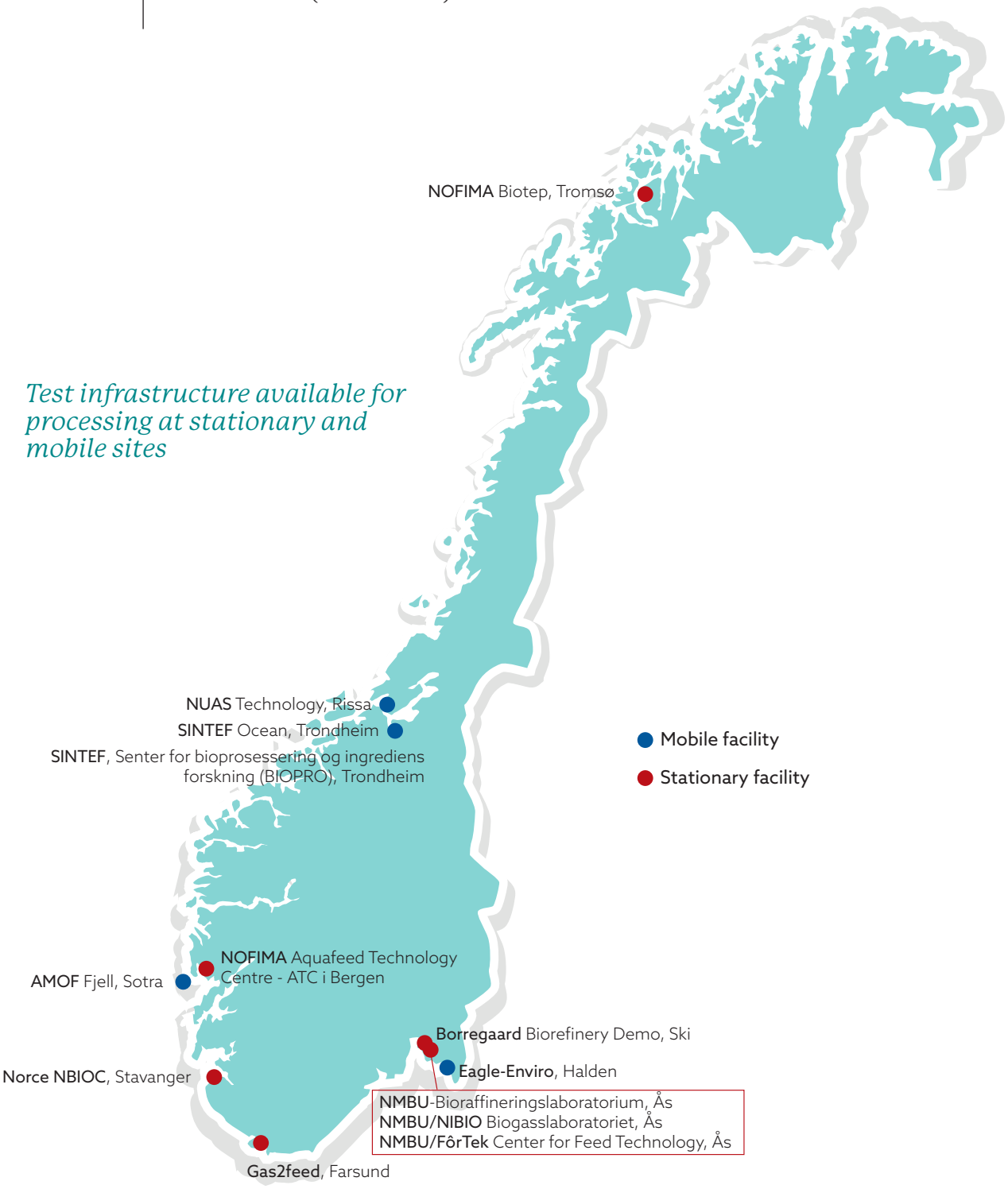
- SINTEF Ocean, Trondheim, Mobile Sealab: thermal separation 500–1000 kg of commodity per hour, 400–800 litres of hydrolysis.
- AMOF-Mjell, Sotra: test drying at a rate of 100 kg per hour (11 sqm, large 650 sqm drying area), 4.5 tonnes of commodity per hour, 40% dry matter.
- Eagle Enviro, Halden: membrane filtration, separation, enzyme processing, automatic remote control, 100–125 kg residual raw material, 2 batches per day.
- NUAS Technology, Rissa: hydrolysis, 1 mm mill, N2 additive in mammoth pump, stirring, oxidation, 2 tonnes per hour, 10 tonnes per day.

Stationary facilities

- Nofima Aquafeed Technology Centre – ATC in Bergen, partnership with NORCE and UiB: Pilot Plant, 200–500 kg of commodity in bioreactor and 50–1000 kg in mixer, extruder 200 kg per hour.
- Nofima Biotep in Tromsø: two 2000-litre hydrolysis tanks, capacity 500 litres per hour on the basis of hydrolysis tanks, 20–30 tonnes of commodity per week.

- Borregaard, Biorefinery Demo in Ski, 1800-litre digester, screw 9500 litres per hour, three 4500-litre hydrolysis reactors, decanter 150–1500 litres per hour, centrifuge 250 litres per hour,
- 150,000 litres of storage, evaporator takes in up to 620 kg per hour, fermentation of 30, 300 and 3000 litres.
- NMBU biorefinery laboratory at Ås: hydrolysis tanks (2 x 30 L+ 200 L), SIP bioreactors (30 L + 100 L), 3-phase separator, ultrafiltration and nanofiltration facilities, microfluidiser and spray dryer.
- NMBU/NIBIO biogas laboratory at Ås: steam explosion plant (temperature up to 230 °C, 20 and 100 L reactors) and 25 CSTR biogas reactors (10 and 20 L).

Test infrastructure available for processing at stationary and mobile sites



- NMBU/FôrTek, Center for Feed Technology at ÅsL Twin-screw Extruder 35–800 kg/h, pelletising 250–800 kg/h, grinding with hammer mill and roller mill, IsDeCa mixing with the option of adding 55% liquid-based hydrolysate and batch size from 30 kg to 1500 kg.
- NORCE NBioC, Stavanger, in partnership with NIBIO, Nofima, SINTEF, University of Bergen, University of Stavanger and UiT The Arctic University of Norway; sugar and gas-based fermentation.
- SINTEF Ocean, Senter for bioprosessering og ingrediensforskning (BIOPRO), Trondheim; 3 reaktorer: Two 150-litre reactors and one 200-litre reactor, with 3 vacuum systems, minimum pressure 0.01 mBar, evaporates 3.2 litres per hour.
- Gas2feed in Farsund: bacteria, to be transferred to pilot facility in mid-2023.

Factory plants
Test infrastructure available via commercial stakeholders

It is assumed that a commercial factory plant has a receiving capacity of more than 3 tonnes of input raw material per hour.

- Vesterålen Marine Oljer, Myre; capacity of 30 tonnes per hour, 7500 tonnes per year, capacity for hire in May to December approx. 2000 tonnes. Other fractions vary, manual labour.
- Zooca Calanus AS, Sortland; capacity of 10,000 tonnes per year, 100 tonnes per week, 2 tonnes per hour, capacity of around 2,500 tonnes for hire. Capable of receiving liquid and frozen pulp, can grind and pump in – hydrolysis plant – inactivation – 3-phase decanter (coarse phase).
- Aker Biomarine, Ski: the factory will be commissioned in mid-2023, 200 tonnes of dried meal per year, 12–24 kg of dried meal per hour, food-approved, free capacity, but unclear at what point in the year it will be available.
- Norilia, Bioco: raw materials from meat and poultry, up to 20,000 tonnes per year.
- Pelagia, Egersund and Måløy produces food, Karmøy, Bodø et al. produce feed: pelagic fish, Bodø has the freest capacity, 1200–1800 tonnes per day, most free capacity is available in summer and autumn, processing 100,000 tonnes per year.
- Aquarius, Lovund (Pelagia): silage, annual capacity 150,000 tonnes, capacity for hire 60,000 tonnes per year.

FRAMEWORK CONDITIONS

Taxonomy and funding
aunched by the European Commission in 2020, the EU taxonomy is a cornerstone of the EU Sustainable Finance Action Plan, where the EU's Green Growth Strategy (European Green Deal) defines the direction and framework for green transition.

The objective is to move capital and turn investments into more sustainable companies and forms of production, and to help the EU to transition into a competitive, sustainable economy.

New legislation was developed in Norway in 2021 on the basis of EU regulations. This means that Norwegian companies undertake to report on sustainability in accordance with EU regulations as well as the EEA Agreement through the EU Taxonomy Regulation and the new Act on Disclosure of Sustainability Information in the Financial Sector and a Framework for Sustainable Investments[135].

This defines how to sustainable activities are to be reported.

Financing institutions are becoming gatekeepers for the taxonomy. Consumers and businesses in need of funding may be measured in view of the extent to which their activities are defined as sustainable or unsustainable[136].

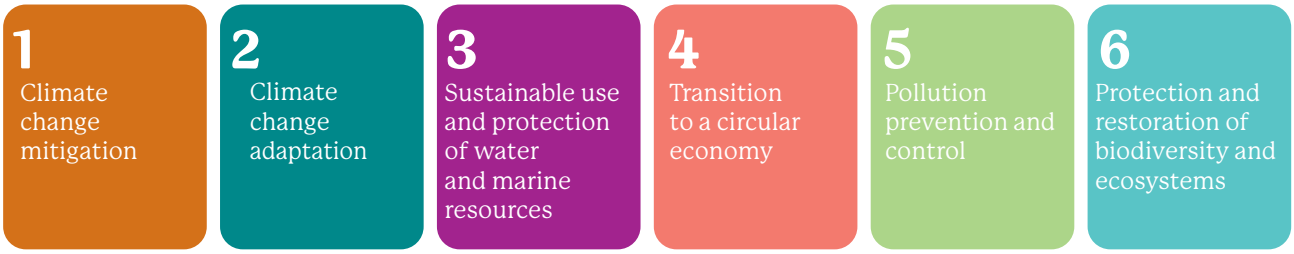
The EU is fronting international initiatives to promote economically, environmentally and socially sustainable development in order to address the climate crisis. One third of the investment of EUR 1.8 billion from the NextGenerationEU Recovery Plan and the EU's seven-year budget will fund the European Green Deal[137].

Portfolio management results in a shift in allowances announced under Pillar Two towards a triple helix cooperation (academia, industry, government). Major societal challenges require interdisciplinarity and a composite innovation environment. This is a initiative effort to facilitate green transition[138].

The government is following up a similar approach to the EU in its focus on interdisciplinary cooperation.

> *"Cooperation between stakeholders helping to bring about a crossover in order to utilise solutions and expertise from other industries will be important. Technology that has been deployed in the petroleum and maritime industries is now being developed for use in aquaculture"*[139].

The six environmental objectives of the EU taxonomy:



135 Law on Disclosure of Sustainability Information in the Financial Sector and a Framework for Sustainable Investments; LOV-1998-07-17-56
136 Nilsen, H. EUs taksonomi for bærekraftig aktivitet, Store norske leksikon (15.02.2022).
137 European commission, Climate, environment, and energy (europa.eu).
138 Rowan, N. et al., Empower Eco multiactor HUB: A triple helix 'academia-industry-authority' approach to creating and sharing potentially disruptive tools for addressing novel and emerging new Green Deal opportunities under a United Nations Sustainable Development Goals framework (2021).
139 Federation of Norwegian Industries, veikart for havbruksnæringen (2017).

Requirements for sustainability reporting
The European Commission implemented the Corporate Sustainability Reporting Directive (CSRD) on 5 January 2023. When the proposed directive could enter into force in Norway is unclear. All major corporations and all parent companies in large groups are obliged to report on sustainability. It is proposed that the obligation to report should also be extended to all listed small and medium-sized enterprises in the EEA, with the exception of very small companies (microenterprises)[140].

Regulatory barriers
Laws and regulations for the collection, transportation, storage, handling, processing, use and disposal of residual raw materials for various applications are evaluated in a number of projects. Existing regulatory frameworks determine what use of the material is possible. In particular, rules and regulations governing the use of residual raw materials from fisheries and aquaculture may have unintended effects. The category regarding residual raw material toxicology and quality has a significant impact on whether it can be used as an ingredient in food or feed. The feed market is made up of a number of submarkets with varying product requirements. Proteins in residual raw material from salmon can be used in feed for marine species other than salmon, while meal and silage from residual raw material from pelagic species and cod are included in salmon feed[141].

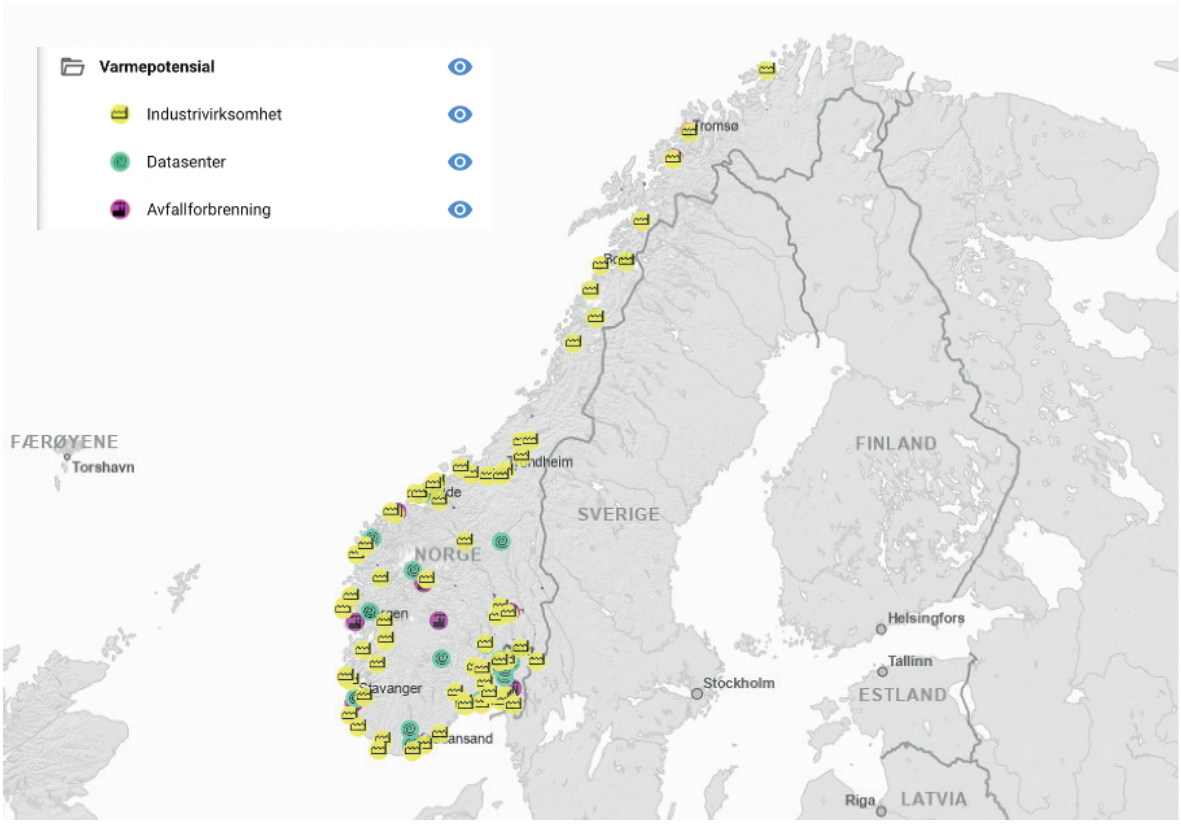
Reflections on further work on establishment of new infrastructure

According to the industry, it is important to have access to renewable energy for full-scale industrial facilities for bioprocessing, as well as predictability in respect of competitive pricing and the necessary power. Access to renewable energy is not crucial for pilot facilities. Mobile pilot facilities generally have a separate container with a generator providing energy for a limited test period. That said, considering co-location of pilot facilities where there is access to renewable energy, or where surplus energy and waste heat can be exploited, may be a strategic move. The Norwegian Water Resources and Energy Directorate (NVE) has an accessible overview of waste heat from industrial operations, data centres and waste incineration[142].

The map on the next page shows NVE's overview of waste heat. This overview indicates locations and the type of industry, but does not include details on output, volume, temperature, seasonal variation and stability.

Waste heat can be used for processing biological resources at various temperatures, e.g., drying sludge from farming and drying seaweed, while

140 European Commission, Corporate sustainability reporting (europa.eu).
141 Almås, K.A. et al., Bærekraftig fôr til norsk laks (2020).
142 NVE's theme map at temakart.nve.no.



residual heat can be used to farm tropical species such as shrimp and lobster. This allows utilisation of different temperatures to form part of a circular economy for different users sited in industrial areas of this kind.

Two examples are included in order to highlight the potential of such energy.

Example 1: Greenspot Mongstad

There are two waste heat streams at Mongstad. The 85 MW total energy is distributed with 70% of the water at 25°C and 30% of the water flow at 92°C. The Equinor cracker is the primary source of waste heat. This converts high-boiling oil fractions into lower-boiling hydrocarbons (petrol), thereby achieving better utilisation of the oil raw material. Some 20% of the waste heat should be used to heat the buildings at the Greenspot Mongstad industrial park.

Example 2: Elkem Salten Verk

Elkem Salten Verk has 45 MW of waste heat coming from the cooling circuits of the three furnaces at the ferrosilicon plant. Every furnace has its own circuit, but they are all connected together. Smolt producer Sisomar receives the furnace cooling water in a separate energy station, where they exchange cold raw water (temperature 1.5–8 °C) for the furnace cooling water at a temperature of 35°C. Sisomar receives 30 cubic of energy water per minute through the system, which is used to heat the production water during the production of 9.5 million smolts per year. Energy water is added after Sisomar has performed internal heat exchange of waste water with raw water into each department. Here, some 80%

of the energy is extracted from the discharge and transferred to the raw water. The estimated 45 MW of energy output is used solely for smolt production at present.

Conclusions and implications

NORWEGIAN AMBITION FOR 2040

Norway has built an entire value chain for the production of Atlantic salmon, from broodstock to market, since the Norwegian aquaculture industry was established around 50 years ago. This has created one of Norway's most important industries, representing vital global food production, and development of strong business corporate environments along our entire coastline, a factor of major importance for employment and development of sustainable local communities. That said, Norway has a strong history as an agricultural nation, producing animal and vegetable products.

The Government has used a number of strategic documents to focus on reducing the carbon footprint and encourage production of raw materials based on Norwegian commodities for use in feed. Ambitious goals have been set for 2040, and also form the basis of the Hurdal Platform and the Long-term plan for research and higher education. The ambition is to promote sustainable production of feed ingredients for agriculture and aquaculture.

KNOWLEDGE BASE

The information that emerges in this report largely corresponds to the existing knowledge base and supports previous recommendations from *Råvareløftet* [The Raw Material Promise] and *Bærekraftig fôr til norsk laks* [Sustainable feed for Norwegian salmon]. If it is assumed that new feed production inputs have to be competitive in terms of price, a significant national effort will be required at present if new value chains are to be established that provide ingredients for feed with a lower carbon footprint than for current raw materials.

A number of ingredients have now been identified that have the potential to assist with the development of new feed inputs. Although a number of the ingredients have come a long way when it comes to documenting and verifying certain species that can be used, the potential of many species has not been revealed as yet.

There is a need for significant investment in documentation of the raw materials, and in development and verification of energy-efficient and automated production technology, to make it possible to use these in commercial production.

One of the bottlenecks that has to be resolved to ensure further sustainable growth in Norway's protein production involves creating access to larger volumes of feed ingredients which have lower greenhouse gas emissions than the raw materials of today. This will help to ensure greater stability in the market for ingredients. Given the need for new ingredients, one ambition is to create a new value chain based on circular principles by harvesting and cultivating low in the food chain. A targeted initiative to develop such value chains will require major national efforts and strategic investment through the policy framework, our research communities and relevant industrial partners being key

NATIONAL GOVERNMENTAL FOCUS ON PRODUCTION OF INGREDIENTS

Programmes are currently partially addressing the need for targeted efforts. For instance, Bionova is a programme established recently that aims to help to operationalise what was defined as a "mission" for sustainable feed in the long-term plan for research and higher education. The grant budget for Bionova for bioeconomy projects currently stands at between NOK 100,000 and NOK 3,000,000. There is a need to strengthen such initiatives significantly if Norway is to achieve the ambitions defined by 2040. There is a need for such programmes to define objectives for development of individual raw materials/ingredients into sustainable commercial products. Priority should be given to funds that can assist with:

- Identification, documentation and development of new ingredients for food, feed, health food, etc.
- Extended research efforts on various substrates in the production of single and multicellular organisms, including sludge and by-products from agriculture/aquaculture and using household waste as a substrate, with the aim of providing decision data for regulatory authorities.
- Extended focus on developing technical and chemical processing of new raw materials. Hydrolysis is one example of this.
- Extended production expertise involving interaction of technology and biology. Cultivation of single-cell fractions and fermentation is one example of this.
- Life cycle assessments (LCAs) of raw materials/ingredients in parallel with verification.
- Quantification of sustainability in energy efficiency for different operations

INDUSTRY-FOCUSED MEASURES

There is a major need for research and development in order to determine which processing would be optimal for each of the different ingredients.

The path to piloting and commercial scale presents a challenge on account of the need for investment capital and risk mitigation for verification, production and processing facilities. Every one of the raw materials described in this report requires significant investment in order to enter a commercialisation race. There is a need for a national strategy that includes a risk mitigation plan, and hence funds for the following should be given priority:

- Co-investment race for establishment of full-scale production facilities.
- Facilitation of synergies with industrial hubs in areas with available inputs which can be used in the production of new ingredients for feed. One example of this could be the process industry and other central industrial points.

The catapult system is dedicated to mitigating risks in the innovation system by offering test infrastructure for production piloting. When piloting new raw materials as ingredients in food, feed, health food, etc., the catapult initiative can help to ensure that resources are prioritised for:

- Validation and documentation of the impact of the raw material as an ingredient in food, feed and health food (small-scale and full-scale).
- Concessions with time restrictions for testing different recipes with the inclusion of new feed ingredients.
- Verification and establishment of infrastructure for piloting new production systems for harvested and cultivated raw materials.

An initiative of this kind can also apply and make use of infrastructure in the university and college sector and at research institutes, research organisations, Centres for Research-based Innovation (SFI centres) and private research stations. In northern Norway, communities such as LetSea and GIFAS could be important contributors when it comes to documenting feed raw materials for full-scale offshore aquaculture.

- Infrastructure for processing new raw materials.
- Estimating the level of investment required in order to meet current and upcoming processing needs presents a challenge as many of the raw materials are in the early stages. Establishment of a national resource group is therefore recommended, were owners of public and private test infrastructure are represented, with the aim of evaluating investment needs in order to ensure full utilisation of current infrastructure, while also meeting the need for new infrastructure.
- It will be important to ensure that raw material production and processing are in close proximity so as to ensure the quality and durability of the raw materials.

Close proximity to the resource is of major importance: Respondents have communicated a need to be able to test the processing of raw materials with a view to optimising the properties of the ingredients. One specific challenge involves the stability of the raw material in terms of shelf life, which means that any processing capacity must be available locally. Some raw materials can be stabilised, but it is not known whether this will result in loss of nutrients or impact on the quality of the product. Norwegian catapults can make processing of raw materials available together with the industry, and establishing a national resource group is recommended where owners of public and private test infrastructure are represented alongside stakeholders working with waste heat and renewable energy. The objective must be to evaluate investment needs to ensure full utilisation of current infrastructure, as well as meeting the need for new infrastructure.

