Industry
Insight

2023 | Climate, environment, and circular economy

The future of plastics in the Norwegian aquaculture industry

NCE Seafood Innovation

The challenge

How can the life cycle of plastics used by the aquaculture industry become more circular?

***Photo** Anders Valseth*

Foreword

The Norwegian aquaculture industry is fully dependent on plastics, strong and light materials with qualities tailor-made for the harsh environment characterizing the Norwegian coastline. Therefore, there is a significant usage of plastic in sea farming operations.

While the pure volume in use is less problematic, it is a major challenge that the life cycle of plastics from the industry is mostly linear. Today, an alarming ⅔ of the plastic from the industry is sent to incineration or landfill. Also, much of the remaining '⅓ -recycling share' is not actually recycled within the industry but continues to be used in low-value products in other fields of application.

Plastic has in recent years received increasing attention from the industry. Projects to reuse and prolong the lifetime of equipment, flotation rings and other equipment made from recycled plastic, and endeavors to measuring the volumes in annual reports are among the initiatives the industry has taken.

At the same time, there is still a need to establish a common understanding of all the dimensions of the industry's use of plastic. The same applies to the definition of a common goal. With this work, we hope to contribute to unite the entire value chain around the status quo, and what we are working towards.

In this report, we illustrate the different equipment components and their contribution to the industry's plastic consumption based on established knowledge and research. Whilst acknowledging and raising awareness for the environmental challenges that come along with the use of plastics, we do not doom the material. We rather emphasize the importance of establishing more circular material flows to make its use more environmentally compatible.

With this ambition, this report aims to stir systemic changes in the entire value chain. We want to inspire for innovations in 1) core technology, 2) product design, and 3) revenue models by demonstrating both their necessity and their potential. In particular product innovation and new business models will be required to achieve a higher degree of circularity.

We have interviewed many key stakeholders across all segments of the industry, including fish farmers, suppliers of equipment, waste management companies, research institutions, plastic producers, and other players related to the value chain for plastic from aquaculture. Thus, this report is broadly based on 'industry insight'.

The report is meant as a contribution to strategy development in companies and industry stakeholders. Further, it is intended to provide foundation and direction for national incentives and political discussions around this topic.

We hope that this report will serve as a valuable contribution to fostering increased dialogue and enhancing the understanding for the plastic challenge and the industry's perspective.

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

Trude Jansen Hagland

Managing Director
NCE Seafood Innovation

"On our way to establish 'Circularity as a Service' and other new business models, AION believes in establishing closed-loop recycling for large industrial plastic volumes as one important solution.

Securing plastic from incineration and recycling large volumes of big bags into durable plastic pallets is a first important step, but progressing further, we need to ensure that products can retain their value indefinitely.

We need successful return schemes to ensure torn products are repurposed into new products – to really close the loop on the plastic material. For this, digital traceability is a key driver and more quantifiable data that can demonstrate results will help us to recruit more and more followers on our journey towards a fully circular plastics value chain."

Runa Haug Khoury
Founder & former CEO, AION

Photo *Anders Valseth*

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Summary

Executive summary

Due to its characteristics and price, plastic is the most important material in the sea farming operations of the aquaculture industry.
About 190 000 tonnes of plastic are in use at any time. Depending on products' lifetime, 8-15 % of this volume is replaced every year. The extensive plastic usage causes four major environmental concerns:

- Marine litter & environmental pollution through equipment leaked to nature
- CO_2 emissions related to production and incineration
- Chemical leakages, and
- Microplastic generation

The industry is taking steps to reduce environmental impacts, and recycling practices are getting smarter. This report paints a picture of a shift from a linear, partly recycling-based economy to a circular one.

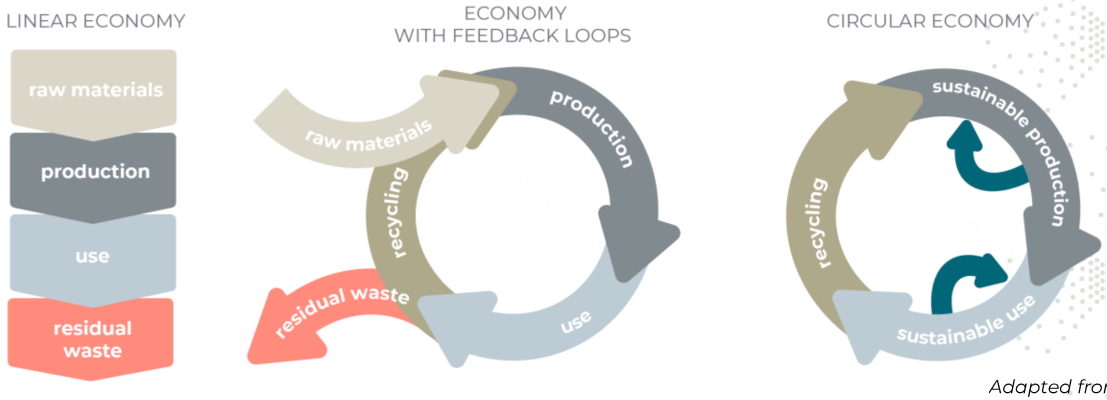
It acknowledges the positive developments around more recycling, but at the same time, it also emphasizes that recycling is just the initial phase of the transition process into a more circular economy.

It is important to clarify that circular economy is not a goal in itself. Instead, it is a versatile toolkit for environmental protection, reducing reliance on raw materials, and creating opportunities for innovative, new business models.

Transitioning to a circular economy, and especially circular utilization of plastic, gives a lot of benefits:

- Reduced energy and resource consumption
- Reduced greenhouse gas emissions
- Reduced amount of waste
- Reduced amount of marine litter, incl. macro- and microplastic
- Reduced loss of biodiversity through less landscape and habitat disruption
- Reduced supply risks (price volatility, availability and import dependency)
- Reduced costs (e.g., through extended lifetimes)
- New business model opportunities (e.g., leasing of equipment)

Differences between a linear, recycling, and circular economy



Adapted from Tweede Kamer (2014)

Barriers and steps towards a more circular system

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There are 6 main barriers to overcome to make the transition from a linear economy and recycling to a circular economy.
9 different actions and strategies have been identified to enable the transition

Barriers

- Large distances between facilities
- Limited knowledge sharing and data quality
- Profitability & alternative cost
- Variable quantity and quality
- Performance requirements
- Immature supply chains

Strategies

Taxes and regulations

1. Extended Producer Responsibility (EPR)
2. CO_2 tax
3. Fees or prohibitions on depositing plastic waste in landfills

Product design & material traceability

4. Product lifetime extension
5. Products containing recycled plastic
6. Material information & traceability

Plastic innovation

7. Public innovation and recycling funding
8. Alternative materials
9. New business models

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Who is responsible?

To realize the transition, everybody needs to do their bit. A clear task allocation and awareness for the distribution of roles will help to succeed

	Strategies	Mainly responsible	Comment
1	Extended Producer Responsibility (EPR)	Public authorities	Public authorities are to implement a thought-out and practically feasible EPR.
2	CO_2 tax	Public authorities	The CO_2 tax should be raised incrementally such that it gives enough time for adaption and incentive for change at the same time.
3	Fees or prohibitions on depositing plastic waste in landfills	Public authorities	Fees or prohibitions on depositing should be considered carefully. Disadvantages by incineration as a current alternative might outweigh the advantages of avoided tipping.
4	Product lifetime extension	Aquaculture companies, equipment suppliers	Employee training on maintenance practices can do a lot to extend the lifetime of equipment. Aquaculture companies need to facilitate good maintenance practices.
5	Products containing recycled plastic	Aquaculture companies, equipment suppliers, waste management companies	This is a 'three-person job'. While equipment needs to be designed for recycling, aquaculture and waste management companies need to take responsibility for separating equipment and materials.
6	Material information & traceability	Equipment suppliers, public authorities	Traceability needs to be realized technically in the design phase but could also be imposed. EPR will incentivize increased traceability.
7	Public innovation and recycling funding	Public authorities	Funding should be aimed at the development of alternative materials and new business models.
8	Alternative materials	Research institutions, start-ups, equipment suppliers	Pilot projects and collaboration between the three parts will ensure the development of industrially relevant material alternatives.
9	New business models	Start-ups, equipment suppliers, waste management companies, aquaculture companies	Innovation in core technology, product design and revenue models can disrupt and change current 'business as usual' for all parts of the value chain substantially.

"Plastic is an essential and valuable resource in salmon farming, and we depend on its unique material properties in many different types of equipment, especially in the sea phase. Therefore, we have to work towards continuously reducing the disadvantages that come with its use. At Grieg Seafood, we take concrete measures within our own organization (e.g. product lifetime extension through employee training), but we also collaborate on product development projects with other players."

Tor Eirik Homme
CSO, Grieg Seafood

"We have established models for return services, and this will provide wide-ranging opportunities. This is something we will continue to develop for increasing resource efficiency and establishing a circular economy."

Hanne Digre
Chief Sustainability Officer, ScaleAQ

Photo *Anders Valseth*

Contributions

Multistakeholder involvement

Steering group

Tor Eirik Homme

CSO
Grieg Seafood

Anne Hilde Midttveit

Head of ESG & Quality
Lerøy Seafood Group

Hans Kleivdal

Deputy EVP
NORCE

Cecilie Lind

CEO
Norwegian Retailers' Environment Fund

Solveig Holm

Senior Project Manager
NCE Seafood Innovation

Workshop group

CircMar	Espen Ramsbacher *Chief Executive Officer*
Land Meets Ocean	Elise Sæle Dahle *Project Developer*
Lerøy Seafood Group	Olaug Godøy *Chief advisor EU taxonomy/CSRD*
NORCE	Anna Kraaijeveld Enerstvedt *Researcher*
NORCE	Anne Ingeborg Myhr *SVP Biotechnology and Circular Economy*
ScaleAQ	Njål Tvedt *Regional Manager South*
The Norwegian Seafood Federation	Marit Bærøe *Director Aquaculture, Northern Region*

Working group

NCE Seafood Innovation	*Dominik Flatten* *Project Manager - Sustainability*
Norwegian Retailers' Environment Fund	Synnøve Fagerhaug Dalen Project Manager Circular Plastic Economy
EY	*Vegard Sjursen* *Director*
EY	*Alma Larsen* *Senior Consultant*
EY	*Sebastian Nyvoll* *Senior Consultant*
EY	*Jonas Englund* *Senior Consultant*

Industry insight from value chain stakeholders

The industry insights presented in this report stem from interviews with 16 key actors representing the aquaculture's plastic value chain. We would like to thank all interviewees for their valuable contributions

Manufacturing	Fish farming	Waste management	R&D	Technology & Advisory
AKVA Group, Arges, Isola, Scale AQ	Bremnes Seashore, Grieg Seafood, Lerøy	Nofir, Oceanize, Ragn-Sells	NORCE, NTNU, SALT, SINTEF	AION, empower.eco

The interviewees

Manufacturing

AKVA GROUP — Trude Olafsen, *Global Solutions Manager & Business Developer*


arges — Bjørnar Bull, *Managing Director*


isola — Trond Risberg, *Environmental and Documentation Manager*


SCALE AQ — Hanne Digre, *Chief Sustainability Officer*


Fish farming

BREMNES SEASHORE — Andreas Moe Larsen, *ESG Manager*


Grieg Seafood — Jostein Iversen, *Global Sustainability Advisor*


LERØY — Rudi Jakobsen, *Lead of ESG Industry & Market*


R&D

NORCE / North Atlantic Microplastic Centre — Gunhild Bødtker, *Senior Researcher Centre Leader*


NTNU — Paritosh Deshpande, *PhD, Associate Professor*


SALT — Marte Haave, *Senior Scientist*


SINTEF — Henrik Brynthe Lund, *Research Scientist (PhD)*


Waste management

RAGN SELLS — Trond Leganger, *Region Manager*


oceanize — Tom Richard Hamland, *Business Developer*


Nofir — Heidi Ruud, *Sustainability Manager*

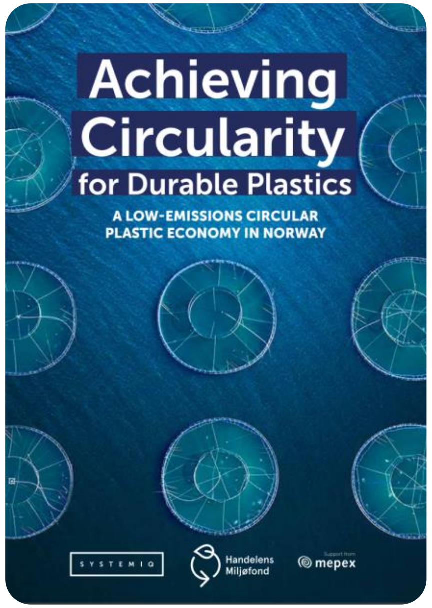

Technology & Advisory

AION — Runa Haug Khoury, *Founder & former CEO*

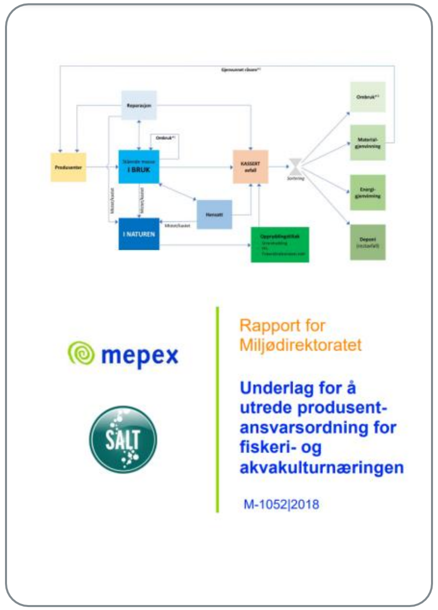

empower.eco — Wilhelm Myrer, *CEO & Founder*


Strong scientific foundation

Existing scientific reports and research have been used as a starting point and fact base



Achieving Circularity for Durable Plastics (SYSTEMIQ & Mepex, 2023)



Basis for investigating the producer responsibility scheme for the fisheries and aquaculture industry (Mepex/Miljødirektoratet, 2018)

Waste Management in Sea-Based Aquaculture (SINTEF Ocean, 2017)

From Aquaculture Plastics to Value (SINTEF Digital, 2022)

“At NORCE, we are working towards and supporting industry collaboration with regard to the utilization of what is mostly considered waste materials today.

In addition to the bioeconomy- and biotechnology-focused BIOSIRKEL-project, we would welcome a corresponding comprehensive 'PLASTSIRKEL'-project. If we are to develop more lasting or alternative materials and new business models, this system change needs to be supported by public funding schemes.”

Anne Ingeborg Myhr
SVP Biotechnology and Circular Economy, NORCE

“As a producer of seafood, we are directly dependent upon clean seas to produce safe and sustainable products. Every kilogram plastic saved means 5 kilograms less CO_2e, and in our commitment to a clean ocean, it is important that we work to reduce, recycle, and innovate to use less plastic.”

Anne Hilde Midttveit
Head of ESG & Quality, Lerøy Seafood Group

Photo *NOFI*

Part 1

Rationale & scope

‘Plastic Fantastic’ – a key material for the industry

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Plastic features many characteristics that make it an extremely competitive material. Therefore, the aquaculture industry is highly dependent on this resource and uses large volumes of it, with a quite long average lifetime of 10 years

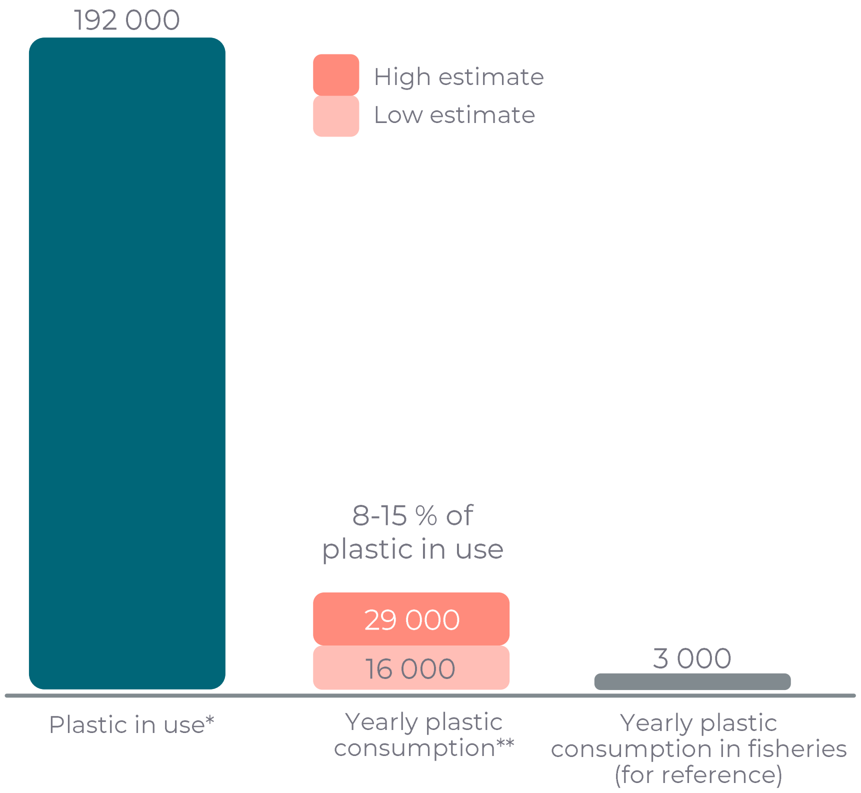
Why plastic?

★★★★★

- Versatile and malleable
- Cheap
- Strong, sturdy, and durable
- Light in weight
- Not affected by seawater corrosion

Plastic **combines many favorable material properties** like no other material. Especially, its weight combined with its resistance against seawater makes it **irreplaceable** for seawater farming operations.

Volumes of plastic* (in tonnes)



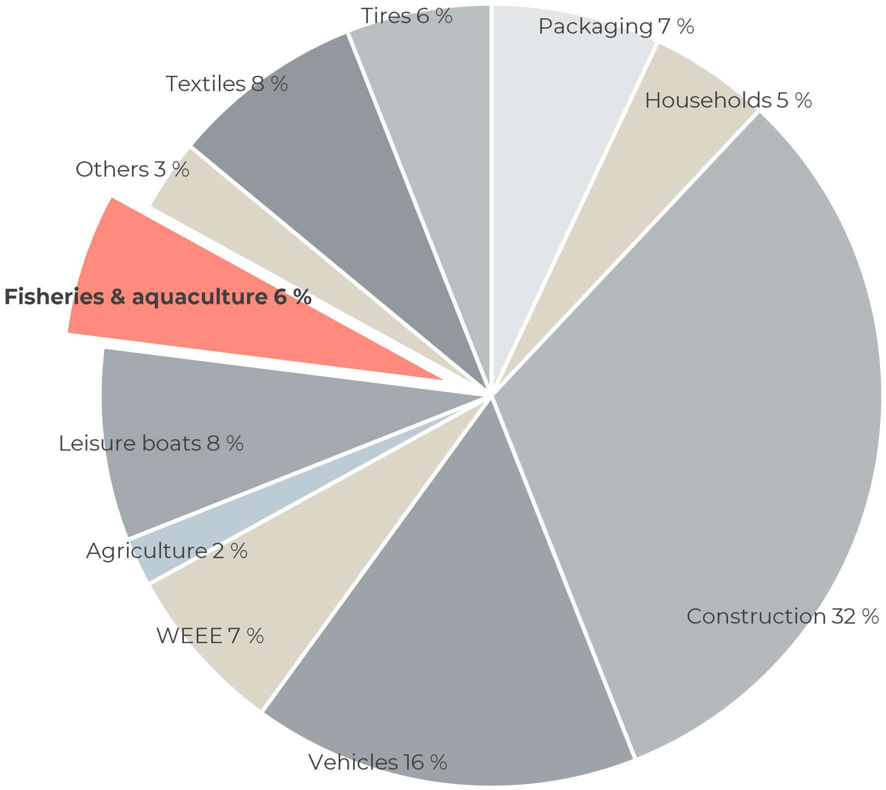
Plastic in use / Yearly plastic consumption

≈ **10 years average lifetime**

** The volumes stem from SINTEF which estimated the volumes in 2017.[30] Newer estimates of volumes are not currently available.*
*** Volume replaced yearly, mostly by virgin plastic (i.e., new, unused plastic)[5]*

Plastic volumes in a national context

Both in terms of plastic in use and yearly plastic consumption, aquaculture has a good share (6%) of the total national plastic volumes in Norway[12]



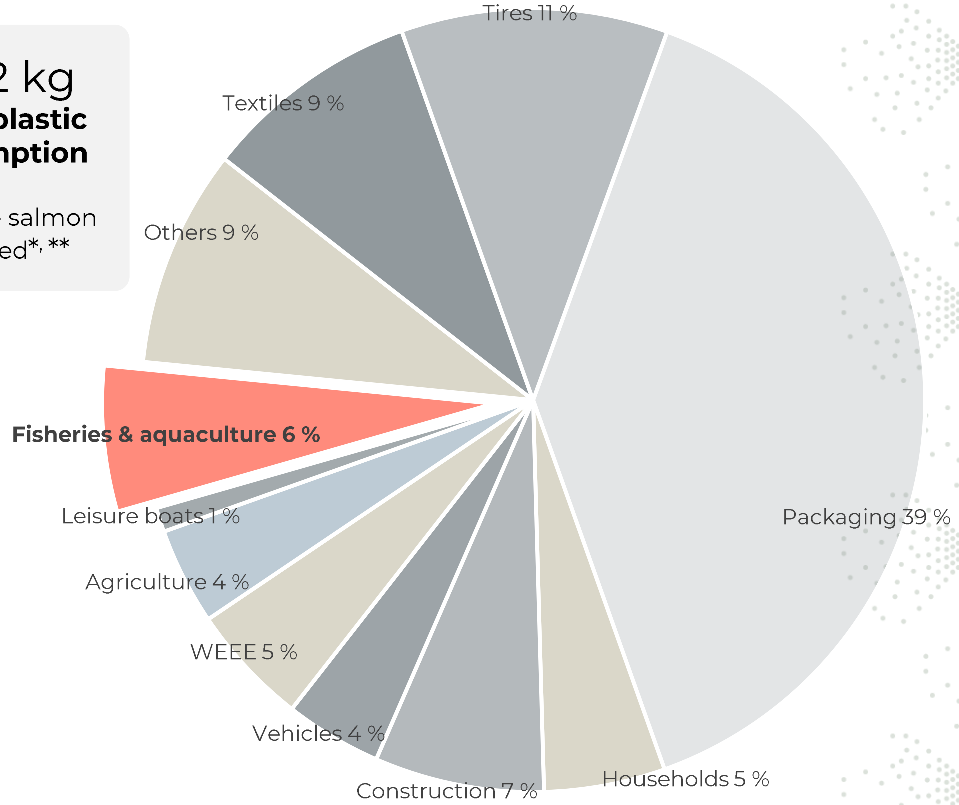
Estimated volumes of **plastic in use** by product category*

147 kg
plastic in use

per tonne salmon produced*, **

12-22 kg
yearly plastic consumption

per tonne salmon produced*, **



Estimated **yearly plastic consumption** by product category*

** Based on estimated plastic volumes from 2017[30] and 2018[12] ** and actual grow out production (in WFE) in 2017[21]. Newer estimates of plastic volumes are not currently available.*

Environmental challenges & dilemmas

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Plastic use involves four main environmental challenges that also involve different dilemmas. Being aware of them holistically is a prerequisite for being able to tackle them without causing more damage than good

1. Marine litter & environmental pollution
2. CO_2 emissions
3. Chemical leakages
4. Microplastic generation

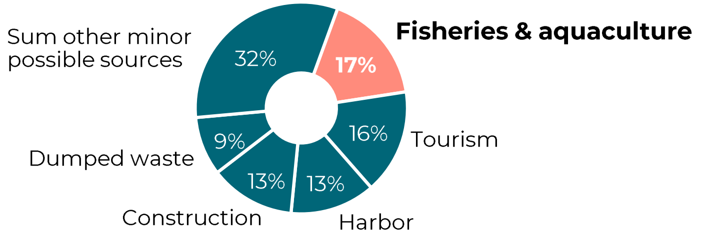
1. Marine litter & environmental pollution

Marine litter causes several problems; it negatively impacts nature, and marine life can be trapped, strangled and killed by plastic debris from aquaculture.[33]

Estimates suggest that as much as **2,0 %** or roughly **560 tonnes** of the yearly plastic consumption is leaked into nature.[*, 34]

Further, macroplastics lost, and even the clean-up of macroplastics that have been exposed to the environment for some time, can also generate microplastic over time.

Fishery & aquaculture is the #1 source of (identifiable) marine litter in Norway[**, 13]



2. CO_2 emissions

Plastics are responsible for **4,5 % of all global CO_2 emissions**.

CO_2 emissions associated with plastics are twofold: both their **production** and **burning** after use cause CO_2 emissions.[17]

Producing 1 kg of plastic requires about 2 liters of oil.[14]

The exact amount of emissions per kilogram is dependent on the circumstances of production and waste treatment.

Closing and narrowing product loops by repairing, reusing and recycling is key to reducing aquaculture's carbon footprint.

* Plastic leakage is difficult to measure and there are only rough and debatable estimates. There is, however, no doubt about the fact that the industry is leaking plastic (see figure).

** N.B.: This is the national average and there are significant regional differences. In Northern Norway, Fisheries & aquaculture's share is largest, making up even 35 %.

Environmental challenges & dilemmas

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Plastic use involves four main environmental challenges that also involve different dilemmas. Being aware of them holistically is a prerequisite for being able to tackle them without causing more damage than good

3. Chemical leakages[37]

Plastic products contain a mixture of potentially toxic chemicals, such as Bisphenol A (BPA).

If the chemicals are contained within the plastic, they pose no risk.

However, new studies find that ocean plastic decomposes when exposed to the ocean, sun, and other environmental conditions.

Also, chemicals have been proven to leak into the ocean. Several adverse health impacts are associated with too high chemical exposure, and adverse impacts on marine life have also been seen.

4. Microplastic generation[10, 33]

Microplastic is small plastic pieces < 5 mm. Microplastic has already been found in many organisms, soils and waters and even in human blood. The hazards posed by microplastic are not fully understood yet, but it is reasonable to assume that the effects are not positive. We know that the plastic used in aquaculture leaves microplastic in the ocean and therefore, the industry needs to address this issue.

Known causes

- Wear and tear on feed pipes (pneumatic transport of pellets) and nets
- Grinding of feed pipes
- Cutting rope
- High-pressure rinsing of the nets
- Marine litter

A trade-off dilemma?

Some scientific studies indicate that recycled plastic may leach more toxic chemicals than virgin plastic or lose more microplastic particles.[9]

This indicates a trade-off dilemma in recycling between reducing CO_2-emissions and reducing the pollution caused by chemicals or microplastic.

More fish, more plastic! Or maybe less?

Without a system change, the much-cited production ambitions will lead to a significant increase in the industry's plastic consumption

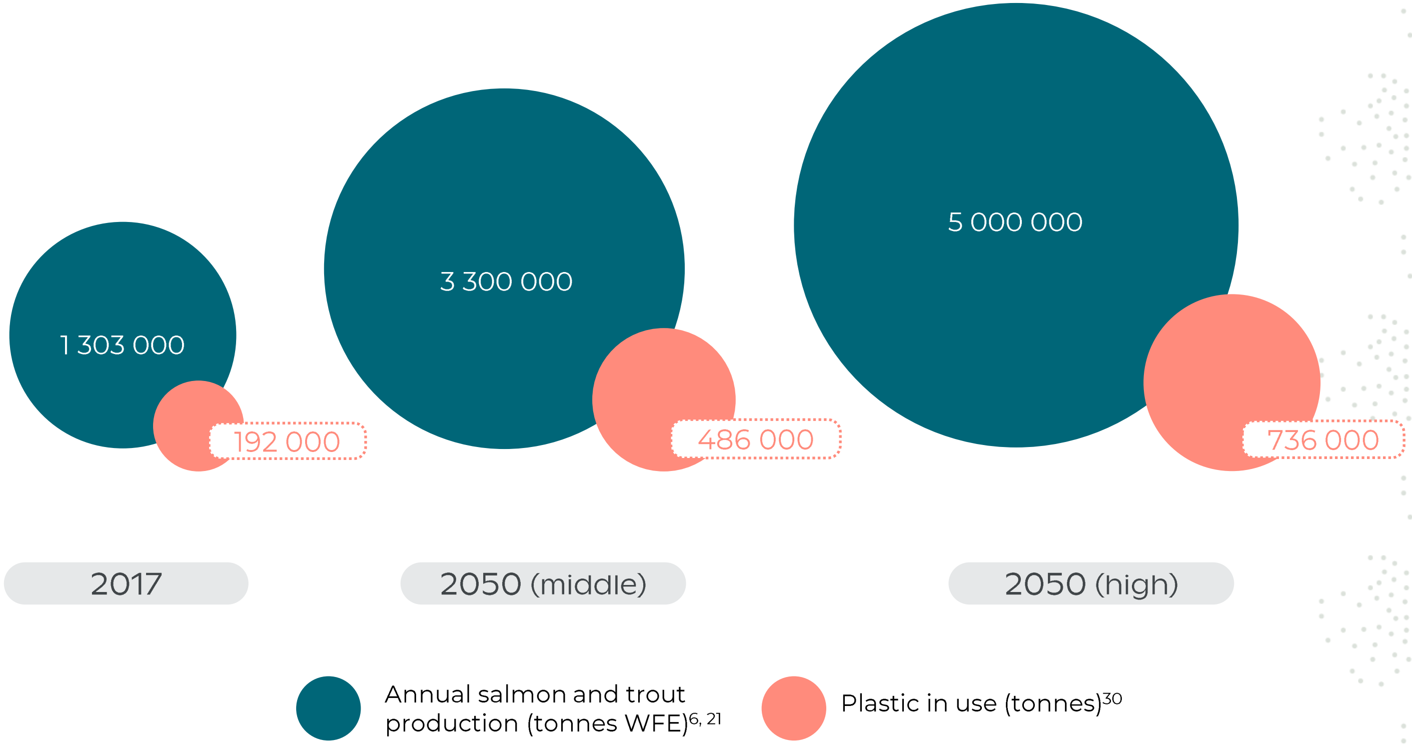
Scaling production = scaling plastic consumption?

The Norwegian government has stated ambitions to increase salmon production from today's level of 1.3 million tonnes[21] to 5 million tonnes in 2050.[6]

The increasing share of production at larger offshore farms and less plastic intensive land-based production facilities will probably contribute to a slight decrease of plastic/tonne of fish by 2030.[34]

However, without other systemic changes and plastic-reducing and -preserving measures, the plastic volumes will still multiply more or less corresponding to production increases.

To mitigate the environmental impacts related to plastic consumption, the industry needs to change current 'business as usual'.



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3 good reasons to focus on sea farming

Plastic waste from sea farming operations is set to be the main focus of this report, as it can be considered most material both in terms of volume, potential and need for circularity, and environmental risk

1 Volume

Plastic is by far the largest waste category for the aquaculture industry. Further, no other part of the value chain involves as much plastic as sea farming operations.

This is because of its **dependence on a light and corrosion-resistant material** and the **massive biomass volumes** in the grow-out stage compared to land-based production.

2 Potential & need for circularity

Compared to other materials, plastics have little established procedures for disposal and recycling. Most importantly, most plastics have a **low residual value** and thus a lower financial incentive for proper waste management.

In addition, sea farming operations feature **less straightforward logistics** than land-based facilities which often have **limited possibilities in terms of space for equipment and waste sorting**. Also waste collection is more challenging due to remote geographical locations.

3 Environmental risk

Both the production and current ways of disposal (burning) of plastic waste involve **CO_2 emissions**.

Equipment lost, chemicals leached, or microplastic generated at sea-based locations end up in the environment right away and are **difficult to recover**.

Therefore, sea farming operations have a particularly high environmental risk.

Out of scope

In general, the report's main focus is increased circularity, and therefore, it emphasizes systemic changes rather than symptomatic treatments.

The three aspects to the left could suggest to also include **product packaging**. However, packaging has been scoped out due to its comprehensive implications on food safety.

Another aspect not covered by this report is **alternative materials**, as this is a quite immature field of research.

"More knowledge is necessary to make sure that recycled plastics do not lead to more leakage of toxic chemicals or microplastics in the ocean. Solving one problem by opening two new ones would be detrimental in every respect and our ambition is to contribute to avoiding such developments and guide the industry towards the most environmentally friendly solutions by solid research."

Hans Kleivdal
Deputy EVP, NORCE

***Photo** Anders Valseth*

Part 2

About the use of plastics in aquaculture

Dimensions of plastics

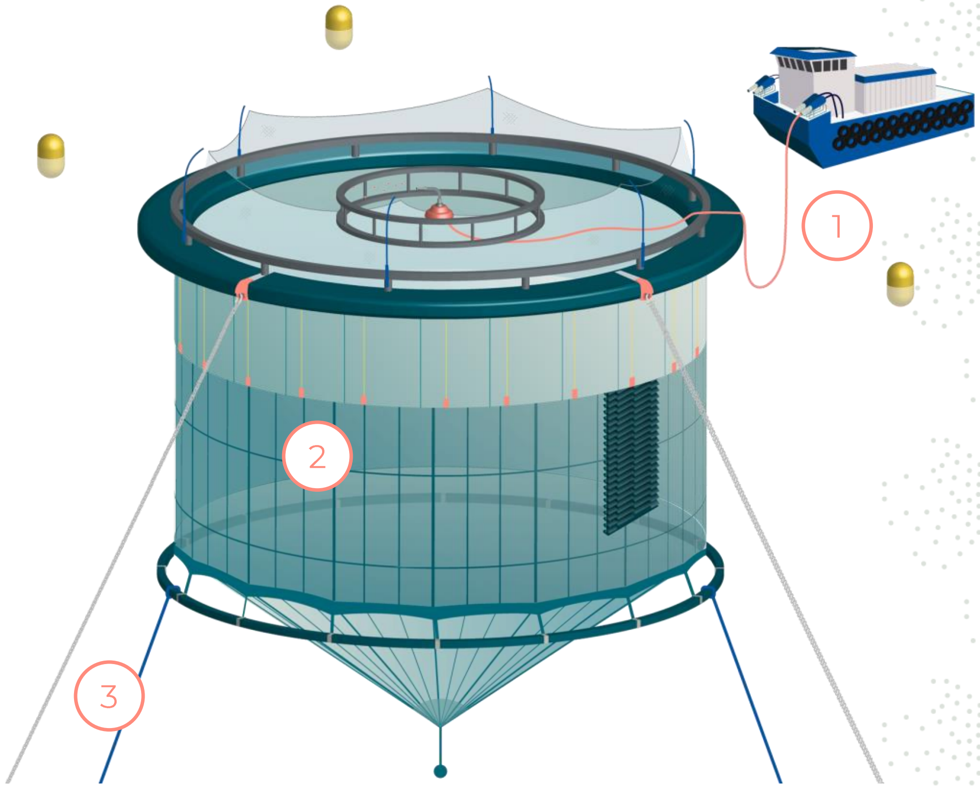
Understanding the components of a net-pen is essential for being able to reduce and avoid the use of plastic

A salmon farming location usually consists of:

1. Feeding barge and feed tubes
2. Several net-pens (typically 6 – 8)
3. Anchoring to secure the net pens

Most equipment in all these three main categories consists purely of, or contains considerable proportions of, plastics.

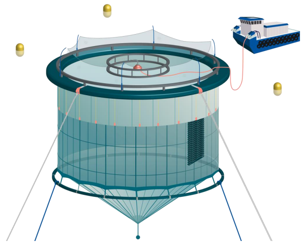
For a detailed fact pack including plastic volumes and descriptions of each equipment component, see appendix.



Plastic volumes & distribution

The floating ring, walkway and railing make up more than half of the plastic in use

Plastic in use (in tonnes*)[30]



The **total volume** of plastic in use in Norwegian salmonids sea farming exceeds **190 000 tonnes** and floating rings with walkways make up the largest proportion[1]

Lumpfish shelter	1 000
Lice skirt	1 000
Rope, 'consumption', not for anchoring. Rope 10-30mm.	2 000
Feed tubes	4 000
'Hamster wheel'	7 000
Bottom ring	16 000
Mooring rings and feed fleet, rope/nylon	17 000
Nets	36 000
Flotation ring, walkway and railing	108 000
Total plastic	192 000

** rounded to nearest 1000*

"We must stop just bragging about collecting plastic on seashores. We must prevent the plastic from getting there."

Tom Richard Hamland
Business Developer, Oceanize

"Comparing the price for virgin plastic with recycled plastic is similar to comparing a clementine to a fruit basket."

Paritosh Deshpande
Associate Professor, NTNU

Photo *Anders Valseth*

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Plastics! Same same but different

The aquaculture industry uses a variety of plastic types (polymers) featuring different degrees of recyclability and degradation

Polymer	1 PET	2 HDPE	6 PS	3 PVC	5 PP
Recyclability[25]	Commonly recycled	Commonly recycled	Commonly recycled	Rarely recycled	Rarely recycled
Estimated marine degradation rate[5]	No degradation	4,3 µm year	No degradation	No degradation	7,5 µm year
Areas of use in aquaculture	• Rope 10-30 mm	• Flotation ring, walking and railing • Nets • Mooring ring and feed barge • Bottom ring • 'Hamster wheel' • Feed tubes • Lumpfish shelter	• Flotation ring, walking and railing • Mooring ring and feed barge	• Flotation ring, walking and railing • Mooring ring and feed barge • Lice skirt	• Mooring ring and feed barge • Rope 10-30 mm

This page contains the most important types of plastic to demonstrate the variety of materials used but is not an exhaustive overview of all types of plastic used in aquaculture. Other types of plastic used include e.g., PA-Nylon or UHMwPE (nets).

Lifetime – a leverage for reduced consumption?

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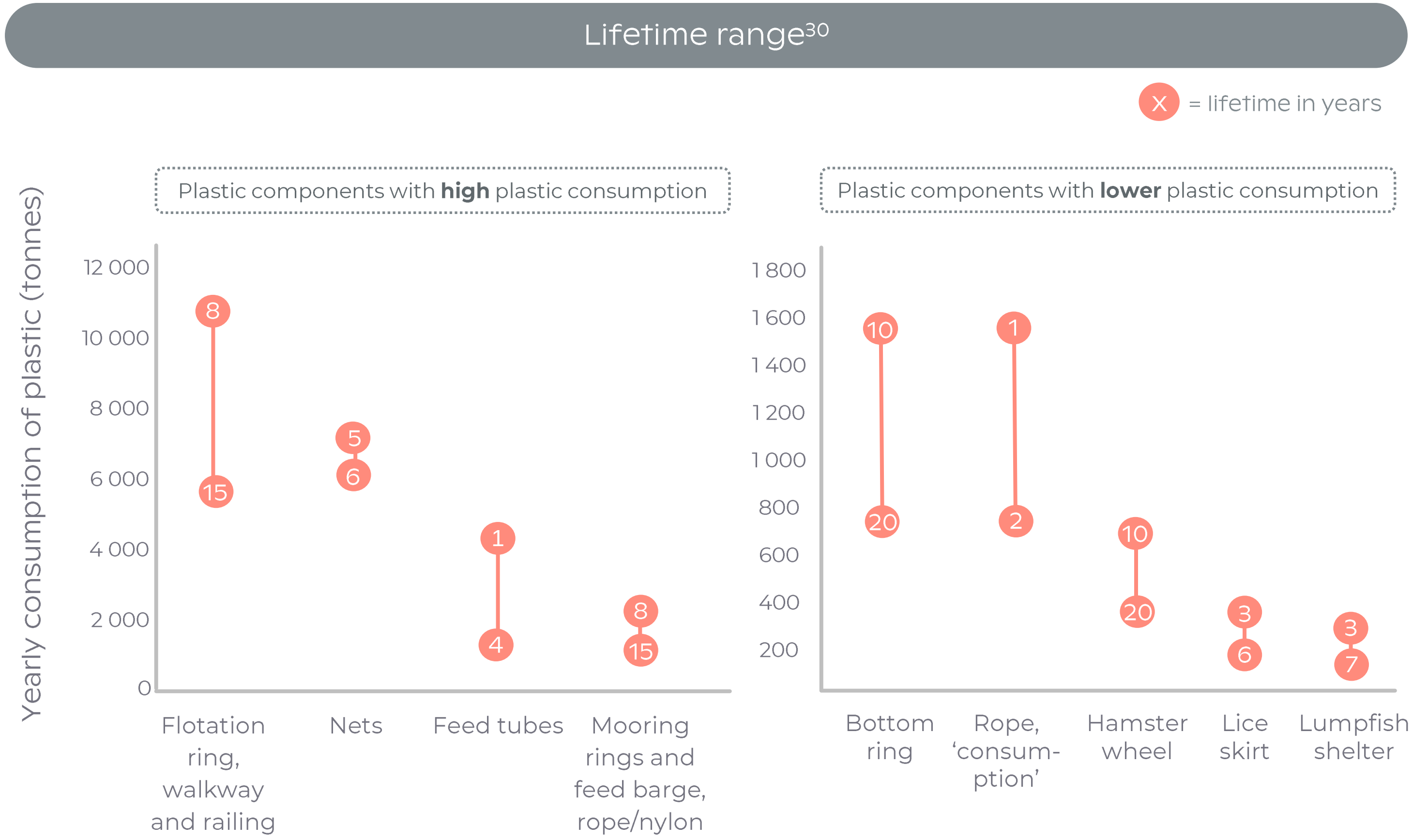
The large volume in use is not an issue in itself. However, regarding the consumption of plastic, working to prolong the lifetime of the equipment components has significant potential



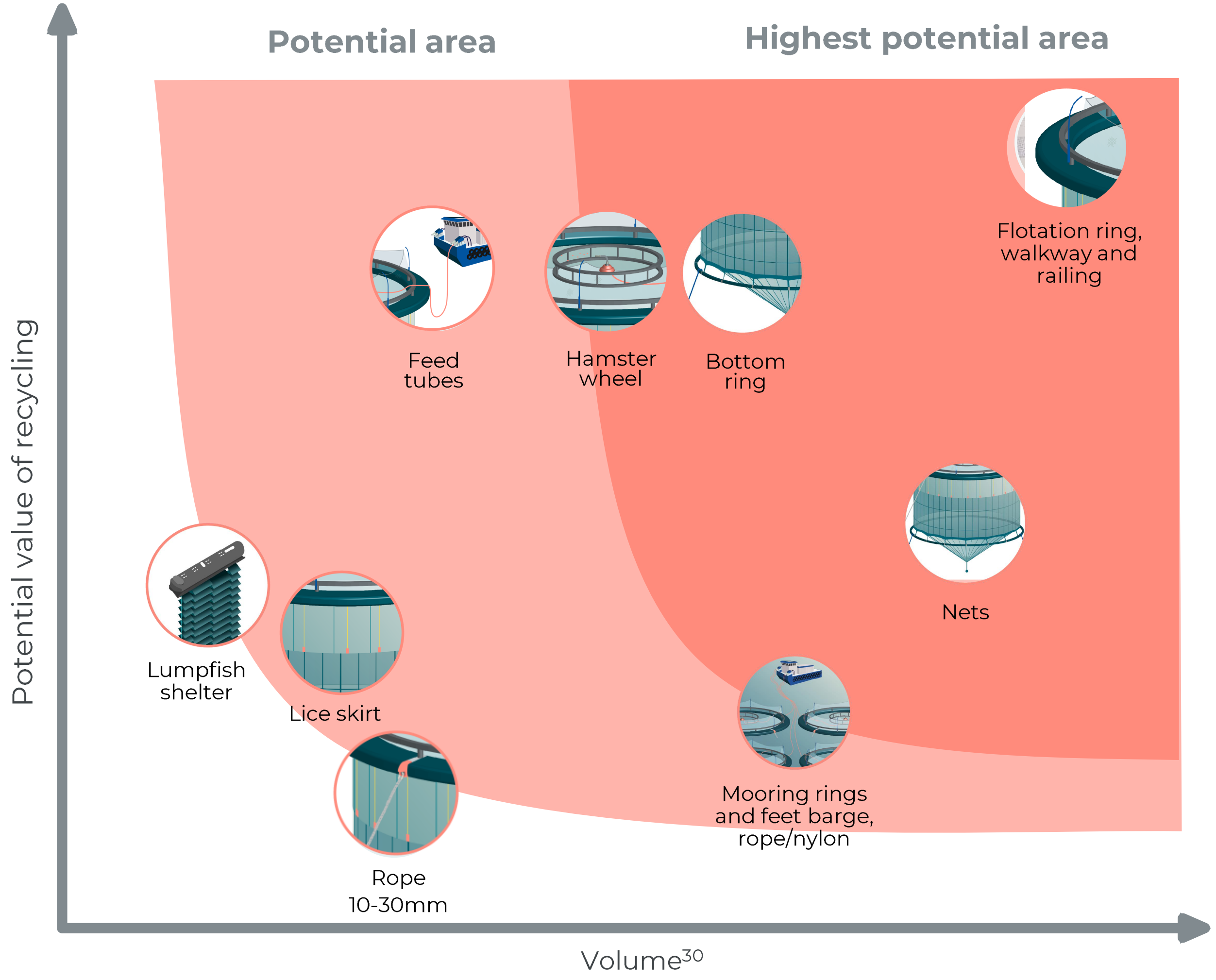
Depending on the achieved lifetime of the plastic components, the salmon farming industry has a **yearly consumption** between **15 816 and 29 005 tonnes.**

Put simply:
Lifetime measures can (almost) halve the industry's plastic consumption.

The lifetime of plastics in the industry is relatively high compared to other industries.[32] Plastic consumption depends largely on the lifetime of products. The lifetime depends on several factors such as weather conditions and the quality of maintenance. If the lifetime is to be maximized for all components, the effect on plastic consumption will be massive.

Varying potential for change

The overall potential for change for a certain equipment component can be described as a dependency between the potential value of recycling and the share of plastic volume for that component



Some products, like floating rings and walkways, are easier to recycle than others. The plastic volume rankings in the chart are data-based, while the potential value of recycling is more subjective, and based on input from the industry.

Evaluating the potential value of recycling, two main criteria have been applied:

1. Some plastic types, like HDPE or PET, are easier to recycle than others
2. Plastic equipment that consists of several plastic types is often more difficult to recycle. These mixed plastics can be difficult to separate into their individual components, which is essential for proper recovery of the raw materials

Laws & regulations addressing the use of plastic

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	Aquaculture Act § 10[19]	NS 9415:2009[27]	EU Directive[8]	ISO 17273	Extended producer responsibility[8]
	2005	2009	2019	2024	2024
Laws and regulations	"Aquaculture facilities shall be established, operated, and abandoned in an environmentally responsible manner."	Introduction of the Norwegian standard for floating aquaculture farms (NS 9415:2009), which was later revised in 2021.	The EU's Directive on the reduction of the impact of certain plastic products on the environment (2019/904/EU). Reporting from the year 2022.	'Waste management and reduction from aquaculture in natural water bodies – Principles and guidelines' is expected to be in place by June 2024.	Extended Producer Responsibility (EPR) for aquaculture gear containing plastic needs to be in place by 31.12.2024.
Impact	The Aquaculture Act regulates aquaculture activities in Norway. The act imposes environmental responsibilities on the fish farmers, including collection of used equipment and waste. Suppliers are responsible for providing properly designed products.	The standard imposes regulations on the quality of the plastic that is used in aquaculture activities to avoid fish from escaping. Recycled plastic can be used, if the quality is sufficiently high. Circular economy aspects are not accounted for.	All producers of aquaculture gear containing plastic in the EU and EEA are subject to extended producer responsibility. The regulation becomes effective on the 31st of December 2024.	The goal of this international standard is to reduce pollution from aquaculture globally, which includes, among other things, reducing macro and microplastics in water and minimizing pollution of beaches and other coastal areas.	The industry expects the Extended Producer Responsibility (EPR) to further drive the circular economy and create incentives to recycle and use recycled materials.

Industry actions mitigating environmental impacts

The aquaculture industry is already taking different measures to reduce its environmental impact. In addition to measures on current equipment, it also contributes to the development of more equipment from recycled materials

Operational routines & policies

Farmers are teaching their employees about the importance of waste sorting and are establishing operational routines that also limit the loss of equipment. These are overarched by corporate policies.[17]

As an example, projects on the reuse of rope by untying knots instead of cutting them have been enforced by several industry players. Recently, an open online course on good plastic waste management has also been released.

Development of recycled material quality and equipment

Together with manufacturing and waste management companies, farmers are running a range of promising pilot projects. Amongst others, the projects feature

- The world's first recycled plastic pen[3]
- Sustainable utilization of hard plastics from aquaculture (POCOplast)[31]
- Walkways from recycled plastics from discarded cages[2]
- Lifetime extension of pens[29]

Tracking of equipment

The industry and the suppliers are increasing the marking and tracking of equipment, e.g., with traceable rope. A first step in plastic management is to measure the waste by category and understand the full lifecycle.

Recollecting waste and cleaning beaches

The industry contributes significantly with cleaning beaches and the coastline, cleaning up after themselves but also collecting substantial amounts of other types of waste from other sources.[11]

"The project group of the collaborative and knowledge-building project 'POCOplast' strongly supports this report as it is highly complementary and in line with our main objective to provide new knowledge on how the concept of circular economy may be applied and to enable sustainable value chain development around post-consumer plastics from the Norwegian aquaculture industry.

We hope that our 25 concept cards for making plastics from aquaculture more circular can provide a step-by-step cookbook to many of the aspects this report presents and illustrates educationally on a strategic industry level."

Henrik Brynthe Lund
Research Scientist (PhD), SINTEF Digital

Photo *NOFI*

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Part 3

About the life cycle of plastics

Today, the life cycle of plastic is highly linear

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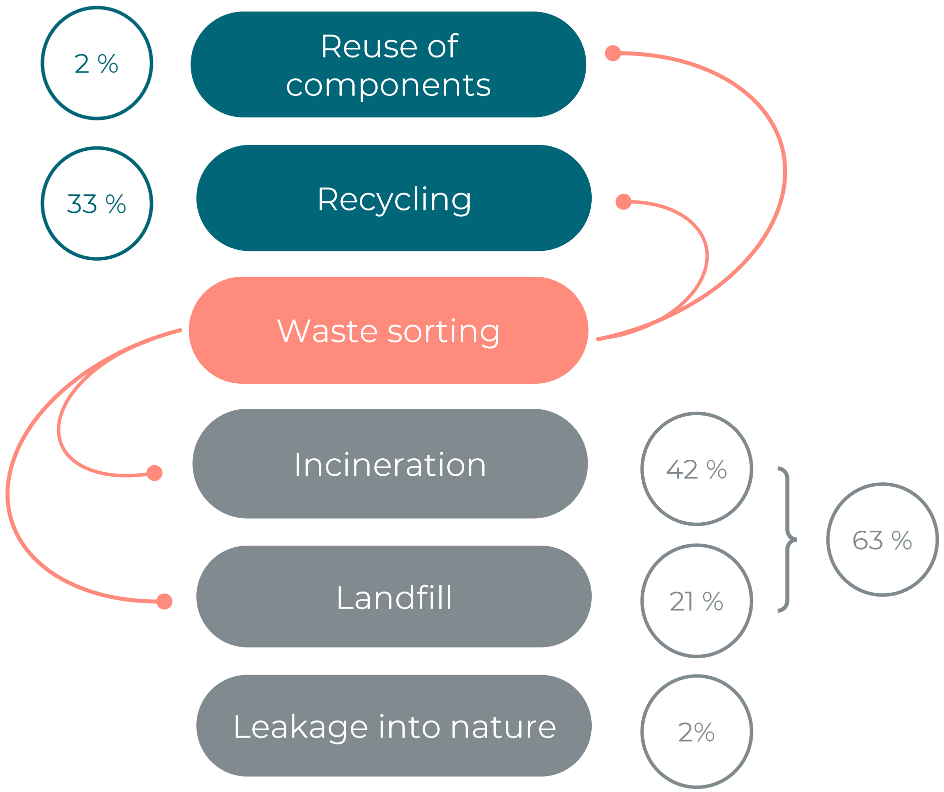
Currently, mechanical and chemical recycling (material recovery) makes up about ⅓ of the industry's waste, while almost ⅔ are going to either incineration (energy recovery) or landfill[34]

Distribution of plastic disposal*



It is important to note that also much of the **'⅓ -recycling share' is <u>not</u> recycled within the industry** but continues to be used in low-value products in other fields of application. Even though this results in a **slowdown** of plastic material consumption, it **does not close the material loops** in the long term.

Availability of data on repair and reuse of equipment is weak, but there is evidence for a **strong culture of repair**, especially for the nets.

Still, plastic from most aquaculture gear has a linear life cycle and changing this requires a change of perspective.

** Norwegian aquaculture, 2020, corrected for net addition to stock*

'Circularity' today means mostly recycling

Even though little of today's waste volumes stays within the industry and only 2 % of equipment components are reused, the network of recycling actors* has become increasingly sophisticated

Recycling/ reuse of components	Mechanical recycling	Production of recycled plastic granules	Production of components	Assemble components into products	On-site installation	Use & waste sorting
Nofir – Collects and transports aquaculture waste	Oceanize – Mechanical recycling	Arges – Produces plastic granules from used feed pipes	AKVA Group – Produces aquaculture equipment		Scale AQ – Produces aquaculture equipment	Aquaculture companies
Ragn-Sells – Collects and transports aquaculture waste	Replast – Mechanical recycling	Oceanize, Noprec (Norwegian Plastic Recycling) – Produces plastic granules	Aquafil – Produces nylon from recycled nets			
Retura – Collects and transports aquaculture waste			Plasto – Automated production			

** The companies shown in the illustration are not an exhaustive list of actors, but shall only exemplify the steps of the recycling process shown*

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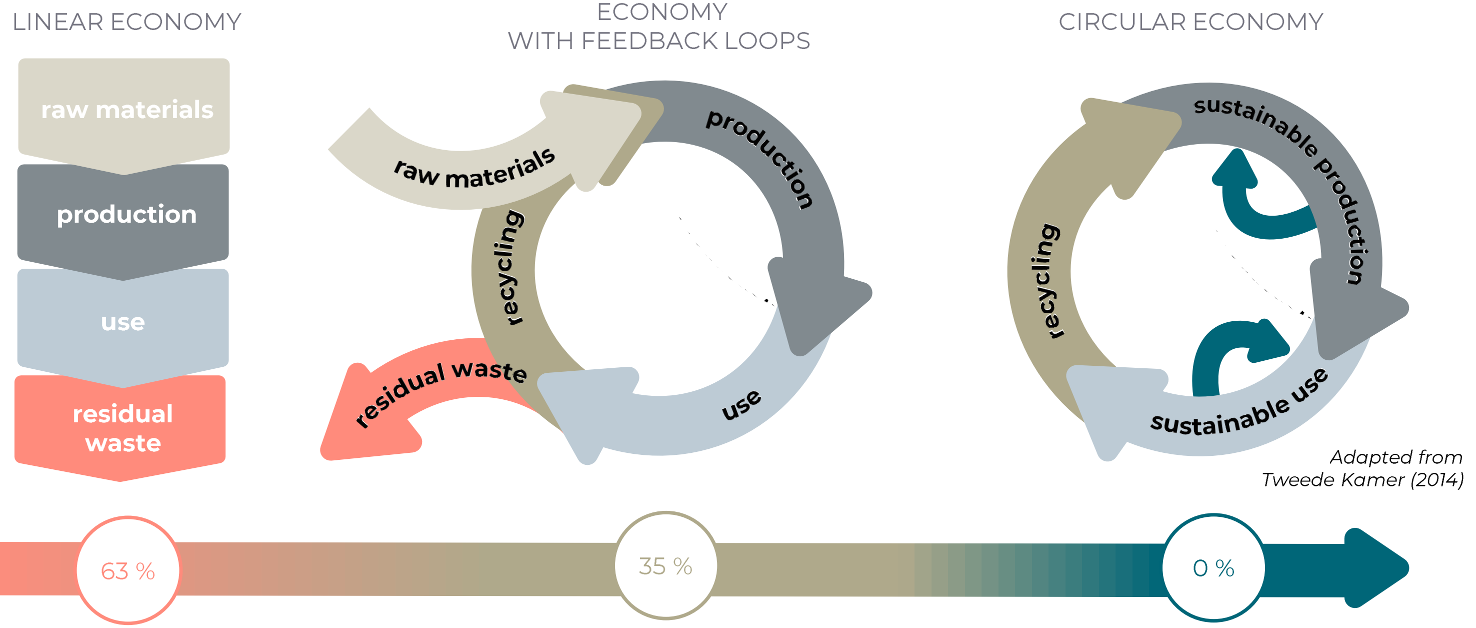
Transitioning to a fully circular economy

Plastics' life cycle today is mostly linear with some feedback loops (recycling). Targeting all benefits of a circular economy, the resource loops must be fully closed

Differences between a linear, recycling, and circular economy[36]



Status of circular transition in Norwegian aquaculture*

The recycling economy and a fully circular economy differ from each other in that the recycling economy does still involve the input of raw materials and the generation of waste, while the **loops are closed** in a circular economy.

Circular economy should not be seen as a goal in itself, but as a toolkit for protecting the environment and reducing raw material dependence, and as a possibility space for new business models.

Benefits of circular economy

- Reduced energy and resource consumption
- Reduced greenhouse gas emissions
- Reduced amount of waste
- Reduced amount of marine litter, incl. macro- and microplastic
- Reduced loss of biodiversity through less landscape and habitat disruption
- Reduced supply risks (price volatility, availability and import dependency)
- Reduced costs (e.g., through extended lifetimes)
- New business model opportunities (e.g., leasing of equipment)

** 2% are estimated to be leaked into nature, see also slide 36*

Beyond recycling: circular strategies

'Recover' and 'Recycle' only constitute the two lowest levels of circularity. The plastic life cycle must be fully circularized by increasingly applying the full repertory of circular strategies (10 'R's)[26]

	R9	R8	R7	R6	R5	R4	R3	R2	R1	R0
Group	**Useful application of materials**		**Extend lifespan of product and its parts**					**Smarter product use and manufacture**		
Strategy	RECOVER	RECYCLE	REPURPOSE	REMANU-FACTURE	REFURBISH	REPAIR	RE-USE	REDUCE	RETHINK	REFUSE
Description	Incineration of materials with energy recovery	Process materials to obtain the same (high grade) or lower (low grade) quality	Use discarded product or its parts in a new product with a different function	Use parts of discarded product in a new product with the same function	Restore an old product and bring it up to date	Repair and maintenance of defective product so it can be used with its original function	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials	Make product use more intensive (e.g., through sharing products, or by putting multi-functional products on the market	Make product redundant by abandoning its function or by offering the same function with a radically different product
Practical examples: Nets from the aquaculture industry	Burn nets and use the energy	Process the plastics from the nets and make something new	Use parts of old nets in new nets with a different function	Use parts of old nets in new nets with the same function	Refurbish old types of nets and use them longer	Repair nets and use them longer	Re-use of nets as they are	Produce less nets or use less resources to produce them	Produce nets with reduced climate and environmental footprint	Stop to produce nets containing plastics

Linear economy → **Increasing level of circularity** → **Circular economy**

Rule of thumb:
Higher level of circularity = fewer natural resources and less environmental pressure

Adapted from Potting et al. (2017)

Achieving circularity through innovation

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According to the report 'Achieving Circularity for Durable Plastics' by Systemiq, the aquaculture industry has the potential to reach 83 % circularity by 2040.[34] Making the plastic life cycle more circular demands innovation

3 areas for innovation[26]

1 Core technology

Innovation in core technology, i.e., the specific technology around which a product is centered, is mainly of interest for recycling. Therefore, technology innovation does not tend to go beyond low-level circularity strategies.

2 Product design

Innovation in product design is often required for high-level circularity strategies. It is about pushing the boundaries of what plastics can do and how they can meet evolving consumer and environmental demands.

3 Revenue models

Innovation in revenue models is often required for high-level circularity strategies, as well. This can include subscriptions, usage-based fees, data monetization, and more.

Socio-institutional change

This involves **reviewing written and unwritten rules, customs and beliefs**. Socio-institutional change is often needed to give new technology a place in society. The higher the level of circularity, the more radical socio-institutional change is usually needed. Socio-institutional change can be central in circular economy transitions itself (and facilitated by enabling technology), but most often it is needed (indirectly) to facilitate innovation.

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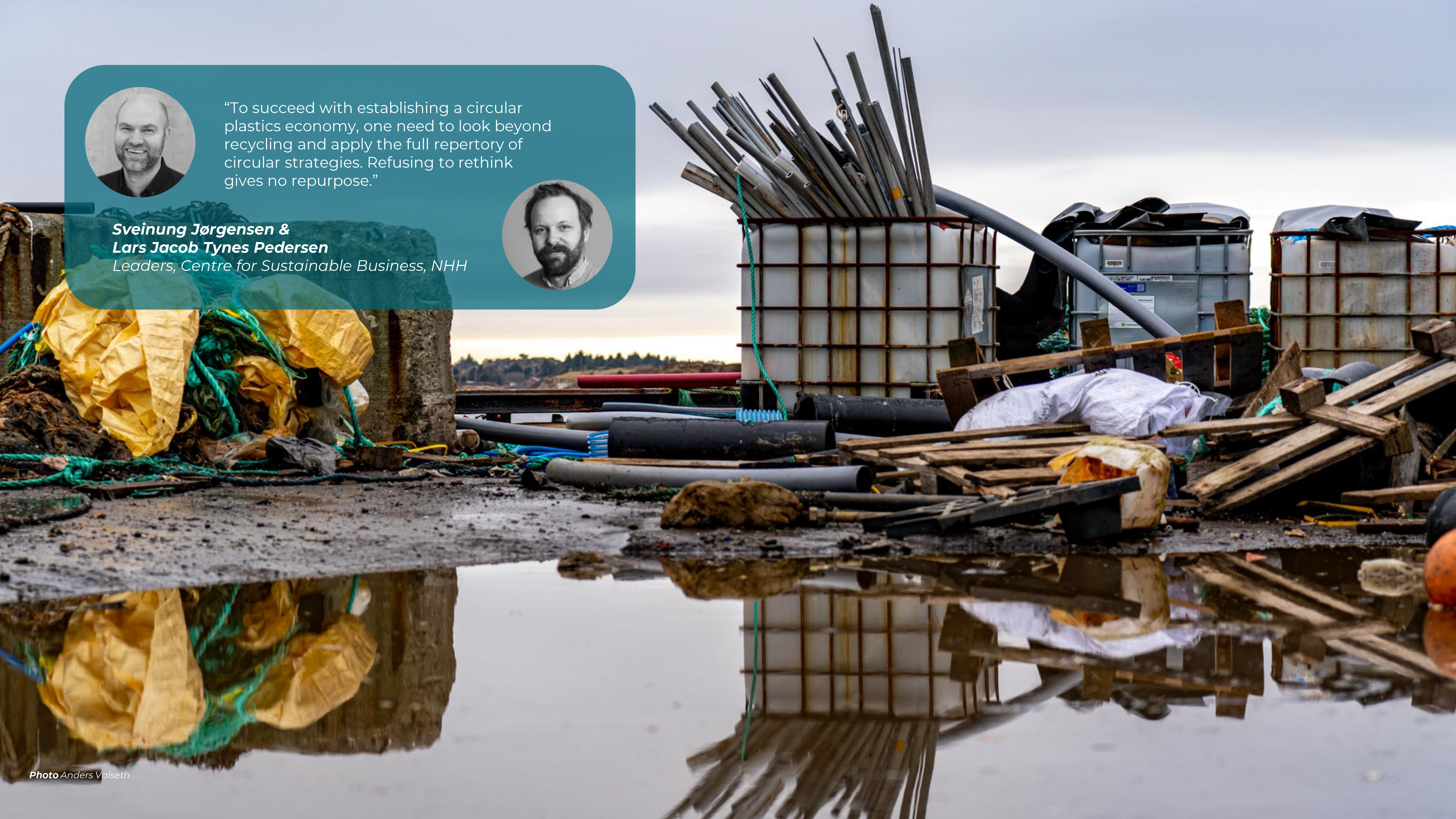
Part 4

How to establish a more circular system



“To succeed with establishing a circular plastics economy, one need to look beyond recycling and apply the full repertory of circular strategies. Refusing to rethink gives no repurpose.”

Sveinung Jørgensen &
Lars Jacob Tynes Pedersen
Leaders, Centre for Sustainable Business, NHH

Photo *Anders Valseth*

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Barriers to a more circular system

To establish a more circular value chain for plastics, six main barriers must be overcome or solved

Large distances between facilities

- Expensive waste collection due to the long Norwegian coastline
- Large distances from aquaculture sites to waste management facilities

Limited knowledge sharing and data quality[32]

- Limited knowledge about reused and recycled plastic. Recycled is often considered to be of lesser quality
- What happens with the waste after collection is a 'black box' for players in the industry. Poor tracking is a barrier

Profitability & alternative cost

- The circular value chain must be profitable in all steps
- Virgin plastic is cheap
- Today, it is often cheaper to incinerate or deposit plastic waste in landfills, than to recycle. Recycling companies compete against traders' and landfills' low tipping fees

Variable quantity and quality

- Equipment has varying material composition
- Blended plastic waste. To minimize costs, producers mix different plastic types, which makes recycling challenging
- Bad sorting makes high-quality recycling challenging

Performance requirements

- The producers of aquaculture gear deliver on quality and performance requirements
- NS 9415 sets strict requirements on the quality of the plastic

Immature supply chains[7]

- The lack of reliable supply networks hinders the establishment of circular business models
- Eco-industrial partnerships* are not yet established
- Net-pens are larger today than before, making the parting and collection of the plastic technologically challenging

** Collaborations between businesses to improve environmental and economic performance through the exchange of resources such as materials, energy, waste and by-products.*

"There is a significant untapped potential for lifetime extension through conscious plastic handling and maintenance practices. We hope that that the open online course, 'Praktisk talt plast', that we at Bellona helped to develop can be an important contribution and practical tool to exploit the reduction potential inherent to product lifetime."

Silje Båtsvik Risholm
Senior Advisor, Aquaculture, Bellona Foundation

***Photo** Anders Valseth*

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Steps towards a more circular system

To develop a (more) circular plastic economy, 9 different strategies and actions must be employed. The transition demands change on all levels; systemic, institutional, industry and on the individual company level

Taxes and regulations

1. **Extended Producer Responsibility (EPR)** will make producers of equipment containing plastic responsible throughout the products' life cycle
2. Increased **taxes and fees on virgin plastic or related factors** can be anticipated to make the use of recycled plastic more competitive
3. Prohibit or impose a fee on **disposing of plastic waste in landfills**

Product design & material traceability

4. Increase **product lifetime** through product design and good maintenance and repair
5. Introduce requirements in the product regulation or eco-design regulation* on a **minimum amount of recycled plastic** in aquaculture gear
6. Digitalization of product information through **digital passports** to make the value chain more transparent

Plastic innovation

7. **National and EU innovation funding programs** to promote innovation on plastic circularity
8. Introduction of **alternative materials** where applicable
9. Development of **new business models**, e.g., leasing of equipment components

* Eco-design considers environmental aspects at all stages of the product development process, striving for products which make the lowest possible environmental impact throughout the product life cycle.

EPR, taxes, and fees as pushing measures

A circular system requires clearer allocations of responsibility and profitability throughout all steps in the value chain. EPR will place responsibility for waste on the producer. Taxes and fees will change current financial conditions

1 Extended Producer Responsibility (EPR)

What is EPR?
EPR makes the producer of aquaculture equipment containing plastic responsible for the post-consumer stage of a product's life cycle. The **producers will be responsible for covering the cost of separate collection of the plastic waste and awareness raising work**. In addition, they shall report on the quantity of plastic that is introduced to and collected from the market.[22]

How does EPR affect plastic use and consumption?
EPR promotes environmentally friendly product designs and value chains by shifting the responsibility for the waste of the aquaculture gear containing plastic upstream to the producer. This incentivizes the producers to take environmental factors related to plastic pollution into consideration when designing their products.[22]

What is the current status?
To comply with EU directive 2019/904, Norway must have an EPR for aquaculture equipment containing plastic by December 31st, 2024.[8]

2 CO_2 tax

Increasing prices on virgin and incinerated plastic will make recirculated plastic more competitive. Those prices are affected by CO_2 taxation. Norway's CO_2 tax is set to significantly increase towards 2 000 NOK per tonne of CO_2 towards 2030.

CO_2 tax 2023[25]		**CO_2 tax 2030**[35]
952 NOK per tonne CO_2	→	2 000 NOK per tonne CO_2

3 Fees or prohibitions on depositing plastic waste in landfills

In many cases, depositing recyclable plastic waste in landfills is cheaper than recycling. Prohibiting or imposing a fee on disposing of plastic waste in landfills, would incentivize waste management companies to recycle plastic waste and more actively develop a market for recycled plastic waste.

Focus on existing products and materials

Product focus can extend product lifetime and increase the share of recycled plastics. Insight into material compositions and improved traceability are key for better recycling as well as generating new business models

4 Product lifetime extension[34]

Lifetime extension through better gear design, and repair and reusage practices is the measure with the largest potential impact on yearly plastic consumption and has the potential to reduce plastic demand by 36 % in 2040.

Considering today's standing mass of 190 000 tonnes of plastic, a scenario with a short lifetime leads to a yearly consumption of 29 000 tonnes, while a scenario with a long lifetime reduces the consumption to 15 800 tonnes!

5 Products containing recycled plastic

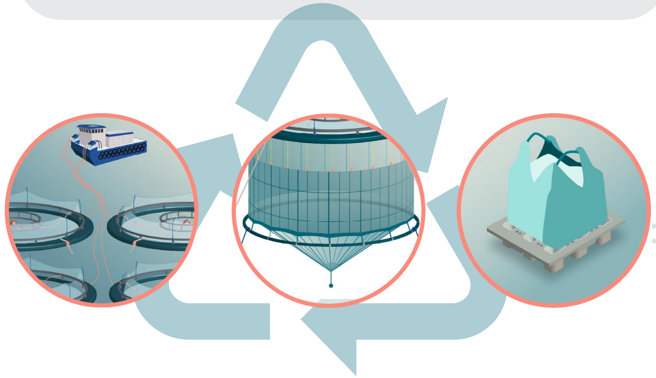
Demanding that recycled plastic is mixed into aquaculture equipment, secures industry demand.
This has **three major prerequisites**:

1) Product design needs to ensure that the materials from products made from different materials are **easily separable** to enable proper waste management.
2) Recycling needs to ensure that materials end up in the original type of product, aka **closed-loop recycling** (e.g., walkway-to-walkway or feed tube-to-feed tube). All other types of recycling will make materials end up as residual waste in the long run.
3) Material **standards** (like NS 9415) **need to account for circular economy** aspects and should possibly be revised.

6 Material information & traceability

To improve transparency, plastic products should come along with information describing the content of different plastic types, comparable to the display of the nutritional content indicated on food packaging.

Digital passports can make the value chain more traceable and promote new solutions related to cooperation, logistics, and product development.



Innovation in materials & business models

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Alternative materials, including biodegradable plastics, can potentially replace plastics in some applications, whereas new business models have substantial system changing potential for high-level circularity

7 Public innovation and recycling funding

Today, recycling is not a core focus of public funding programs, and there should be more funding available to promote the circular economy.

There is a need to develop public funding schemes in Norway and the EU to support circular economy projects relevant to plastic waste from aquaculture. It is key to support the entire value chain to stir both the development of

- 8 alternative materials and
- 9 new business models

8 Alternative materials

Alternative materials have not been a focus of this report, as this is a quite immature field of research, especially in industrial terms. However, in the long run, their importance is expected to increase, even though we do not know today, what role they can play in aquaculture equipment.

Biodegradable plastics can be suitable substitutes where it is difficult or expensive to remove plastics completely. However, for most applications, it is still better to reduce the plastic usage instead.[35]

9 New business models

New business models have the potential to disrupt the sector for industrial equipment, just as AirBnB disrupted the hospitality industry.

Even though this type of innovation requires most socio-institutional change, it has also the biggest potential for high-level circularity (see also slide 39).

Especially **leasing models**, i.e., product-as-a-service, but also product sharing and general innovations and **changes in product ownership** have been emphasized during our research to be expected to be established anytime soon.

What now?

Let's go for systemic changes in the entire value chain and inspire each other to innovation in technology, product design, and new business models!

Photo *Anders Valseth*

"We must actively work towards reducing the presence of plastics in society and shift our focus from treating the symptoms to addressing the root causes."

Gunhild Bødtker
Senior Researcher, NORCE
Centre Leader, North Atlantic Microplastic Centre

"Our cost increase on plastic bags in Norwegian retail shows that habits can be changed if we push the right buttons. Making circular systems more financially competitive is important to drive change, this can be achieved both through R&D to lower costs and a fiscal system that stimulates circularity."

Cecilie Lind
CEO, Norwegian Retailers' Environment Fund

Photo *Anders Valseth*

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References

References

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#	Source	Reference	Year
1	AION	AION	2023
2	AKVA group	Lower CO_2 footprint with sustainable materials	2022
3	AKVA group	AKVA group utvikler verdens første merd av resirkulert materiale	2023
4	Avfall Norge	Om bransjen	2023
5	Chamas, Moon, Zheng, Qiu, Tabassum, Jang, Omar, Scott, Suh	Degradation Rates of Plastics in the Environment	2020
6	Dagens Næringsliv	Regjeringen vil ha kraftig vekst i lakseproduksjonen – på visse betingelser	2021
7	Deshpande, Skaar, Brattebø, Fet	Multi-criteria decision analysis (MCDA) method for assessing the sustainability of end-of-life alternatives for waste plastics: A case study of Norway	2020
8	European Union	DIRECTIVE (EU) 2019/904 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL	2019
9	Geueke, Phelps, Parkinson, Muncke	Hazardous chemicals in recycled and reusable plastic food packaging	2023
10	Gomiero, Have, Kögel, Bjorøy, Gjessing, Lea, Horve, Martins, Olafsen	TRACKing of PLASTtic emissions from aquaculture industry (TrackPlast)	2020
11	Grieg Seafood	Annual Report 2021	2021
12	Handelens Miljøfond	Materialstrømmen til plast I Norge – hva vet vi?	2020
13	Hold Norge Rent	Rydderapporten 2022	2022
14	Jortveit	Fullt mulig å kutte klimagassutslippene fra plast	2018
15	Kapital	Vil revolusjonere fisketransporten	2022
16	Kasper Jakobsen	Sirkulær plast I oppdrettsnæringen	2020
17	Lerøy Seafood	Water and waste management	2022
18	Mepex / Norwegian Environment Agency	Underlag for å utrede produsentansvarsordning for fiskeri- og akvakulturnæringen	2018
19	Ministry of Trade, Industry and Fisheries	The Aquaculture Act	2005
20	NCE Seafood Innovation	Aquaculture's plastic problem	2022

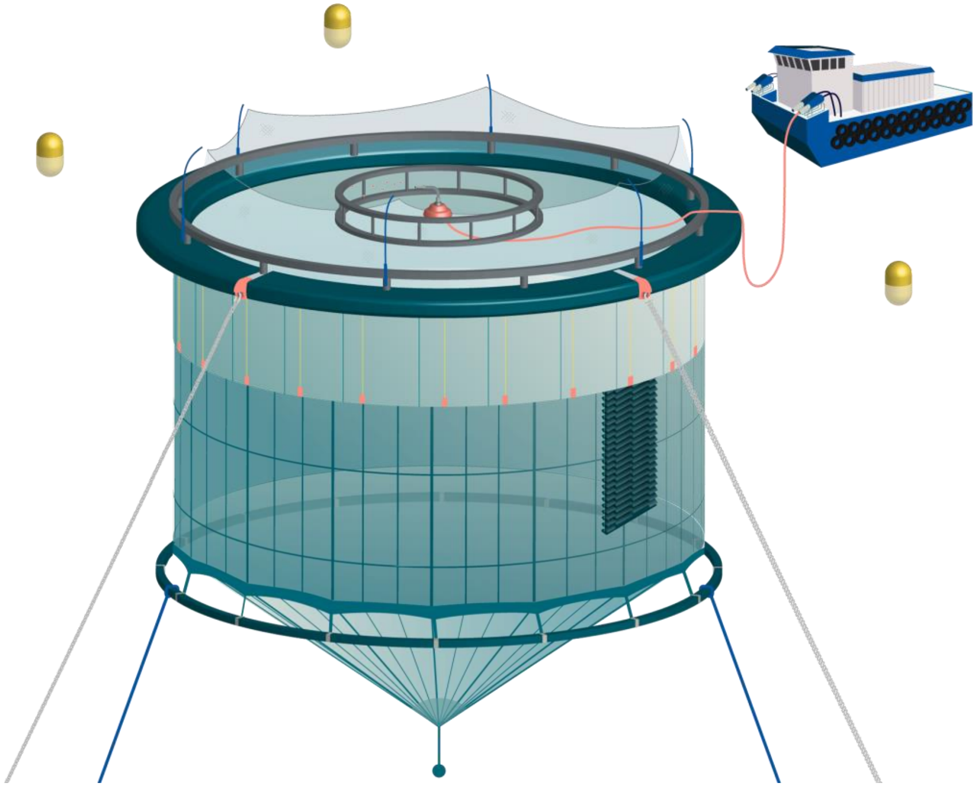
References continued

#	Source	Reference	Year
21	Norwegian Directorate of Fisheries	Laks, regnbueørret og ørret – matfiskproduksjon	2023
22	Norwegian Environment Agency	Videreutvikling av produsentansvaret i Norge	2022
23	Norwegian Seafood Council	Norge eksporterte sjømat for 151,4 milliarder kroner 2022	2023
24	NRK	Vil femdoble lakseproduksjonen	2021
25	Plastics for Change	Which plastics can be recycled	2023
26	Potting et al.	Circular economy: measuring innovation in the product chain	2017
27	SANDS	Nye tekniske krav for akvakulturanlegg I sjø: NYTEK23 og NS 9415:2021	2022
28	SAPEA	Biodegradability of plastics in the open environment	2020
29	Scale AQ	Fish farmer: - Lifetime extension is the best option for pens	2022
30	SINTEF	Avfallshåndtering for sjøbasert havbruk	2017
31	SINTEF	POCOplast (Pathways to sustainable post-consumer plastics in aquaculture)	2021
32	SINTEF	Fra oppdrettsplast til verdi: Drivere og barrierer for sirkulær økonomi basert på hardplast fra norsk havbruk	2022
33	Skirtun, Sandra, Strietman, van den Burg, Raedemaecker, Devriese	Plastic pollution pathways from marine aquaculture practices and potential solutions for the North-East Atlantic region	2022
34	Systemiq / Norwegian Retailers' Environment Fund	Achieving Circularity for Durable Plastics	2023
35	The Norwegian Government	Avgiftssatser 2023	2022
36	Tweede Kamer	Green economic growth in the Netherlands (Green Deal)	2014
37	Zimmermann, Bartosova, Braun, Oehlmann, Völker, Wagner	Plastic Products Leach Chemicals That Induce In Vitro Toxicity under Realistic Use Conditions	2021

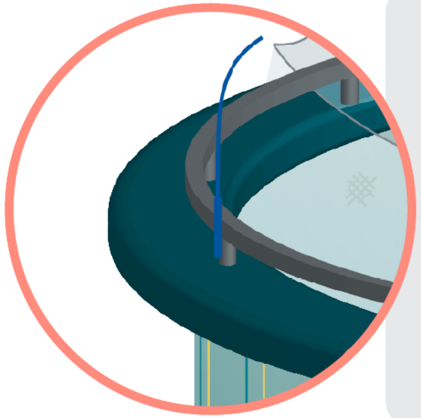
Appendix

Plastic components in detail

Plastic components in detail (1/3)



1. Flotation ring, walkway and railing[18, 30]



Current standing mass:
108 405 tonnes

Portion of total standing mass:
56,5 %

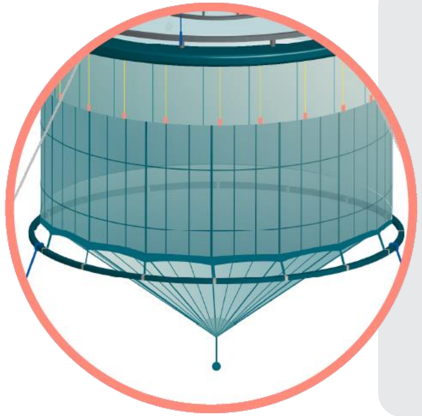
Lifetime:
10 – 20 years

Yearly plastic used:
5 420 – 10 841 tonnes

Yearly material recycling:
3 000 tonnes

Plastic type:
HDPE, EPS

2. Nets[18, 30]



Current standing mass:
35 574 tonnes

Portion of total standing mass:
18,5 %

Lifetime:
5 – 6 years

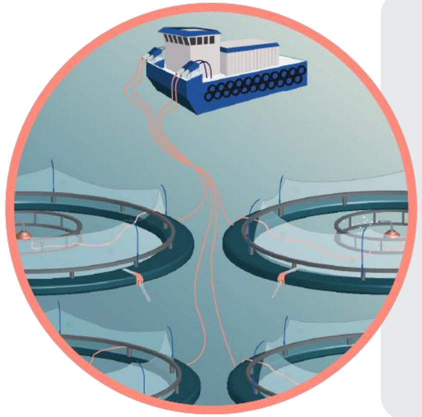
Yearly plastic used:
5 929 – 7 115 tonnes

Yearly material recycling:
3 000 tonnes

Plastic type:
PA6, HDPE

Plastic components in detail (2/3)

3. Mooring rings and feed barge, rope/nylon[18, 30]



Current standing mass:
17 201 tonnes

Portion of total standing mass:
9,0 %

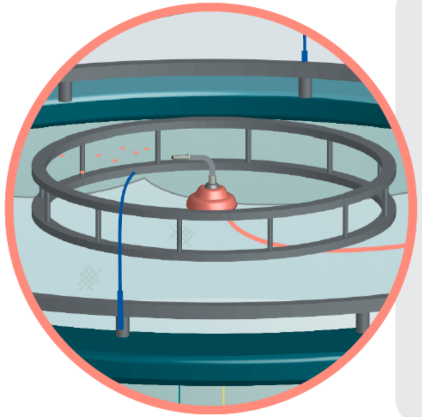
Lifetime:
8 – 15 years

Yearly plastic used:
1 147 – 2 150 tonnes

Yearly material recycling:
2 000 tonnes

Plastic type:
HDPE, PVC, PUR, EPS, PP++

5. 'Hamster wheel' / Poles for bird net[18, 30]



Current standing mass:
7 068 tonnes

Portion of total standing mass:
3,7 %

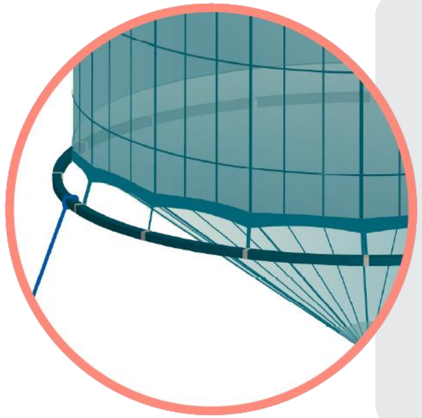
Lifetime:
10 – 20 years

Yearly plastic used:
353 – 707 tonnes

Yearly material recycling:
200 tonnes

Plastic type:
HDPE

4. Bottom ring[18, 30]



Current standing mass:
15 708 tonnes

Portion of total standing mass:
8,2 %

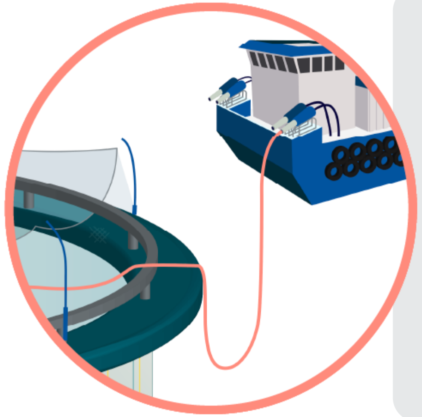
Lifetime:
10 – 20 years

Yearly plastic used:
785 – 1 571 tonnes

Yearly material recycling:
500 tonnes

Plastic type:
HDPE

6. Feed tubes[18, 30]



Current standing mass:
4 440 tonnes

Portion of total standing mass:
2,3 %

Lifetime:
1 – 4 years

Yearly plastic used:
1 110 – 4 440 tonnes

Yearly material recycling:
~2 000 tonnes

Plastic type:
HDPE

Plastic components in detail (3/3)

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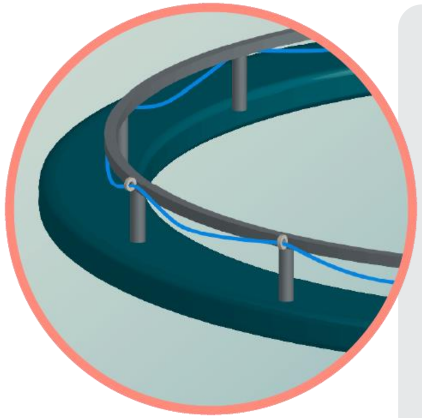
7. Rope, 'consumption', not for anchoring. Rope 10-30 mm[18, 30]



Current standing mass:
1 570 tonnes

Portion of total standing mass:
0,8 %

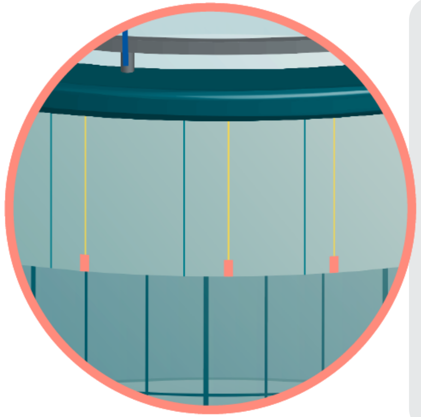
Lifetime:
1 – 2 years

Yearly plastic used:
785 – 1 570 tonnes

Yearly material recycling:
0 tonnes

Plastic type:
PP, PE or other

8. Lice skirt[18, 30]



Current standing mass:
1 063 tonnes

Portion of total standing mass:
0,6 %

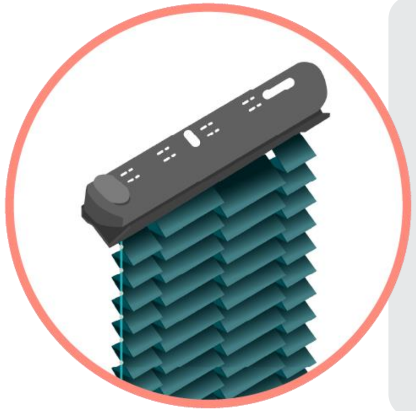
Lifetime:
3 – 6/years

Yearly plastic used:
177 – 354

Yearly material recycling:
0 tonnes

Plastic type:
PVC, PA Polyester

9. Lumpfish shelter[18, 30]



Current standing mass:
770 tonnes

Portion of total standing mass:
0,4 %

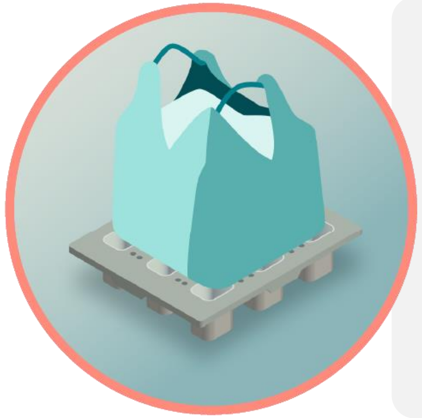
Lifetime:
3 – 7 years

Yearly plastic used:
110 – 257 tonnes

Yearly material recycling:
0 tonnes

Plastic type:
HDPE

10. Big bags[1]



Big bags were not a part of the data basis used for the other equipment components. However, as they are fully made of PP and PE, they also contribute to sea farming operations' plastic consumption. Big bags are used for transportation and storage of feed. They are recyclable but can be leaked into nature as they are not fixed to the feeding barge. In addition, they have a comparably short lifetime. Therefore, they should be included when looking into and developing more circular solutions.

Disclaimer

The focus of this report is on sea-based operations within the salmon farming industry. Consequently, detailed information regarding processes on land, including breeding/ smolt production, transportation, and packaging, is not covered extensively. See slide 23 for more details about the scoping for this report.

The content of this report is based primarily on interviews conducted with industry experts which can be found in the 'Contributions' section at the front of the report. Additional information has been gathered from scientific papers and other selected sources. References are indicated where necessary, even though this report is not expected to fulfill the criteria of a scientific paper.

Given that this report encompasses input from a wide range of different actors from the entire value chain, conclusions drawn by NCE Seafood Innovation based on this research do not necessarily represent each contributor's individual opinion.

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

***Photo** Anders Valseth*

About NCE Seafood Innovation

A collective effort for sustainable seafood growth

NCE Seafood Innovation is a leading business cluster within the seafood industry, with more than 120 partners and members representing the whole seafood value chain. The cluster plays a central role in contributing to the sustainable growth and development of the seafood industry.

Promoting team efforts is a focal point. We believe that mobilizing joint forces is the way forward, and our cluster contributes through sustainable innovation projects and by facilitating interaction across the industry.

We work within five industrial areas of priority, which are defined by the industry, and which reflect the challenges we need to solve together with partners and members to realize opportunities for sustainable growth and development in the seafood industry:

- Climate, environment, and circular economy
- Digital transformation and digitalization
- Fish health and welfare
- Future feed ingredients
- Future competence and talent attraction

This report is part of our ‘Industry Insight’ report series.

Industry Insight

2023 | Climate, environment, and circular economy

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Thank you for your contribution to the production of this report

Financially supported by

Norwegian Retailers' Environment Fund

NCE Seafood Innovation