Report

Plastics in aquaculture: A circular economy guidebook

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Report

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SUMMARY

This report presents 25 concepts for making plastics from aquaculture more circular. The concepts are based on industry initiatives, circular business models and management principles. Furthermore, the report describes the theory behind circular economy and relevant concepts, as well as the background for plastics in aquaculture, including regulatory context.

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1 Introduction

This report is a deliverable from work package 1 (WP1) in the collaborative and knowledge-building project POCOplast ("Pathways to sustainable post-consumer plastics in aquaculture"). The project is a collaboration between Bellona, Empower, Flokk, Grieg Seafood, NCE Aquatech, NOPREC, Plasto, NTNU and SINTEF. The main objective of the project is to provide new knowledge on how the concept of circular economy (CE) may be applied and to enable sustainable value chain development around post-consumer plastics from the Norwegian aquaculture industry.

This report aims to meet the project objective of providing new knowledge on CE and assessing the applicability of different concepts, from the perspective of participating actors and other stakeholders, with applicable CE concepts and knowledge needs. This report provides an overview of the opportunities to make plastics more circular in aquaculture, in the form of some specific measures that different actors in the value chain could apply in their activities. Furthermore, the report describes the theory behind CE and relevant concepts, as well as the background for plastics in aquaculture, including regulatory context. To make the knowledge as accessible and usable as possible, we have chosen to formulate this report as a guidebook for circularity in aquaculture plastics. Inspired by guidebooks for hikes in the mountain, we wish to help guide the relevant actors and stakeholders on their path to a more circular and sustainable use of plastics in aquaculture.

The concept of a circular economy has received increasing interest from politicians and industry stakeholders around the world. In traditional manufacturing, virgin materials are extracted from nature, manufactured into stocks, utilized, and finally treated as waste. Circular Economy can be regarded as a direct counterpart to this conventional linear economy, representing a shift from the take-make-dispose economy to a regenerative circular economy (Bjørnbet *et al.*, 2021).

As the focus of the POCOplast project is on post-consumer plastics, there is an emphasis on recycling and waste handling. We have chosen to widen the scope to also include measures that can lead to more circular use of plastics throughout the value chain and through the entire life cycle of plastics in aquaculture.

2 A circular economy guidebook for plastics in aquaculture

2.1 User manual / Reading guide

2.1.1 What is this guidebook?

Circular economy is a large topic, and it can come across as vague and hard to define. When wanting to become more circular, it can be hard to know where to start and what to do. This guidebook is here to help you. We were inspired by guidebooks for hiking, which give you a selection of hikes with a description of the route, the level of difficulty, some descriptions of the type of hike, and warnings of relevant dangers. This guidebook provides a selection of measures you can take to make your plastic usage in aquaculture more circular, with a description of the measure, who it applies to, who it affects, and some relevant look-out-alerts. We have called these measures **circular economy concepts** and kept them short and concise to make them as easy to read and use as possible. Where relevant, there is more detailed information in chapter 3. The knowledge needs at the time of writing are indicated, and references to where the concept has been described are listed.

The concepts range from small, simple changes which an actor can implement individually, to large and complex changes involving cooperation between many actors in the value chain. Some concepts will save costs, while other concepts are expensive and may increase costs, yet improve circularity. The guidebook describes this multitude of concepts; hence each actor can choose the most applicable concepts for their situation and level of ambition.

2.1.2 How do I use this guidebook?

The guidebook is organised according to the different activities in the value chain of plastics in aquaculture. Figure 1 shows these different activities, placing them in chronological order of when in the plastics life cycle they take place. The activities in the middle of the figure occur either throughout or unrelated to the life cycle.

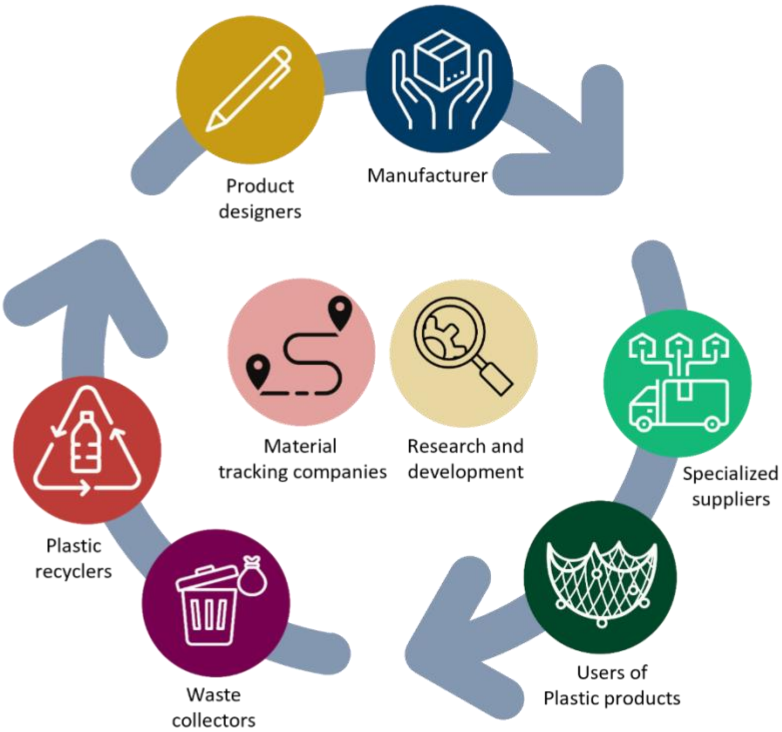


Figure 1 Value chain actors for plastics in aquaculture

Each concept in the guidebook has a dedicated concept card.

Each concept is classified by:

- *Activity for implementation*: This is the activity where the concept is implemented.
- *Level of cooperation needed*: Some concepts require that several actors in the value chain cooperate about implementing it. Other concepts can be implemented by a single actor and does not involve any cooperation.
- *Level of difficulty*: The perceived difficulty level of implementing a concept is a combination of factors and is highly affected by the context of the implementing actor. The evaluated basis for the difficulty level were scored from low to high and combined. The 4 factors were investment size, level of cooperation needed, change in business model, and level of technology development needed.
- *Affected activities*: Most circular economy concepts described here will affect other activities than the implementing ones. For example, if a fish farm implements waste sorting, this will not only affect the fish farm's (user of plastic products) activity, but also the waste collection activity, which will have to collect the new waste fractions, and the recycling activity, which will get sorted plastic to recycle.

Figure 2 shows the layout of the concept cards

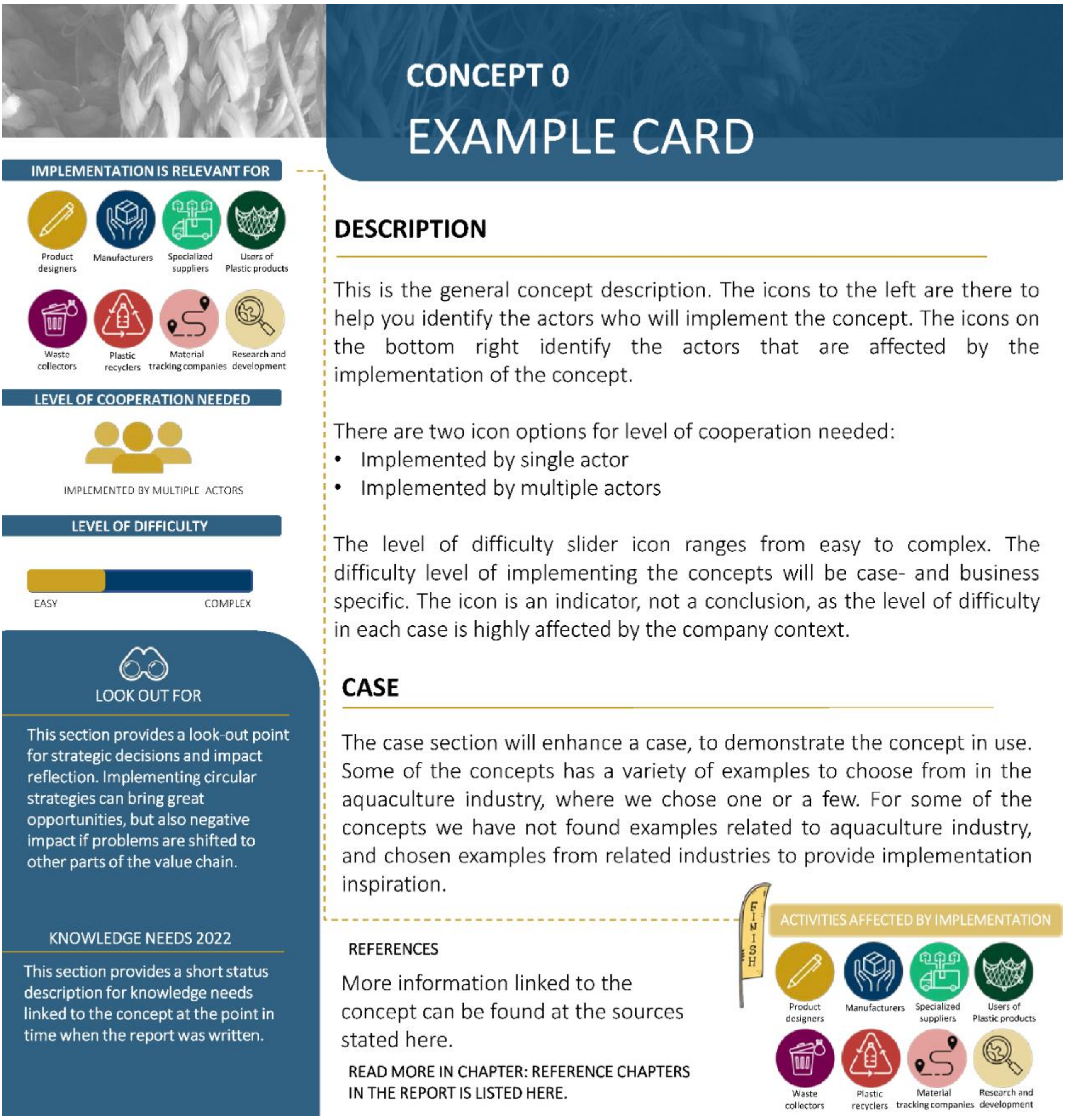


Figure 2 Example concept card.

To make it easy to quickly scan through the guidebook and find what is relevant for you, the classifications are defined by icons, using colour and location in the value chain to easily identify whether the concept is applicable to your activity. Each activity can be relevant for several actors, and in table 1 we have described each activity in greater detail and listed actors who this activity is relevant for.

Table 1 Details about value chain activities

Activity	Details about activity	Relevant actors	Icon
Product designers	Product design of products containing plastic	Product designers, producers who design their own products	
Manufacturers	Production of products containing plastic	Producers of products for aquaculture which contain plastic	
Specialised suppliers	Sale of products to aquaculture operations	Specialised suppliers, complete suppliers	
Users of plastic products	Use of products containing plastic in aquaculture operations	Fish farmers / aquaculture companies, service companies	
Waste collectors	Collection of waste from aquaculture operations	Waste collection companies, either municipal or private	
Plastic recyclers	Recycling of plastics from aquaculture	Plastic recycling companies	
Material tracking companies	Tracking of plastic through the life cycles	Material tracking companies	
Research and development	Research and development, product development, technology development, software development	Research institutes, product developers in e.g. plastic production companies, technology companies, etc.	

The classification of level of cooperation needed has two icon options, described in table 2.

Table 2 Level of cooperation

Icon	Description
	The concept can be implemented by a single actor and does not require cooperation in the value chain.
	The concept is dependent on cooperation in the value chain to be implemented and/or to succeed.

2.2 Concept cards

CONCEPT 1
ROPE CONSUMPTION REDUCTION

IMPLEMENTATION IS RELEVANT FOR

Users of Plastic products

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY HARD

LOOK OUT FOR

Lower rope consumption reduces the amounts for recycling. Implementing routines for reducing rope consumption and marine litter could be a double implementation together with concept 4, organisational routines for circular behaviour.

KNOWLEDGE NEEDS 2022

Best practices need to be shared between companies.

DESCRIPTION

Wear on ropes can be reduced, reducing both the consumption of rope and release of microplastics to nature. Tying ropes are preferred over cutting ropes, as short rope cut-offs are easily lost and is a normal find as marine waste.

Two ways to reduce wear:

(1) A special way of attaching the ropes can reduce chafing.

(2) Using larger dimension ropes to attach bird nets.

Another way of reducing consumption of ropes is to use them more efficiently, like using the same rope to attach both the bird net and the jumping net to the handrail. This can reduce the consumption of rope by 960 meters in an 8-pen facility. In addition, the source claims that this way gives the added benefit of a smaller gap for birds to get into the pen. There are also products designed for reuse that can replace ropes, such as "Hurtigstroppen" from Akvapartner, which sources reported both simplified their work and reduced rope consumption.

CASE

Grieg Seafood changed their rope practice by renaming "cutting ropes" (kappetau) to "tying ropes" (knytetau) with set lengths.

Cut ropes should be secured immediately and temporary storage on boat decks or unsecured at the land base should be avoided.

ACTIVITIES AFFECTED BY IMPLEMENTATION

Specialized suppliers

Users of Plastic products

REFERENCES

(Pettersen and Sæther, 2021)

READ MORE IN CHAPTER: 3.4.4

CONCEPT 2
FEEDING PIPE WEAR REDUCTION

IMPLEMENTATION IS RELEVANT FOR

Specialized suppliers · Users of Plastic products

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY · HARD

DESCRIPTION

Reducing wear in feeding pipes reduces microplastic emissions and prolongs the product life. Feeding pipes wear is concentrated where there is a bend on the pipe. This wear can be reduced by straightening the feeding pipes and avoiding unnecessary bends. When the feeding pipes are being replaced, the fact that the wear is concentrated in points means that the longest pipes can be reused for the closest pens by cutting away the worn points.

When feeding pipes are cut, a pipe cutter can be used rather than a handsaw or a chainsaw, to reduce the production of plastic sawdust.
If using a saw to cut feeding pipes, the sawdust must be collected to avoid release to nature.

CASE

Waterborne feeding is gentler on the feeding pipe, hence reducing wear on the pipes. This also means the release of microplastics to the environment is reduced considerably. In addition, waterborne feeding can enable use of recycled materials in the pipes, as the static tension is lower than with compressed air.

LOOK OUT FOR

Prolonged life might reduce the amount of feeding pipes entering use phase, which reduces the amounts for recycling.

KNOWLEDGE NEEDS 2022

Equipment and technology is commercially available. Best practices need to be shared between companies.

ACTIVITIES AFFECTED BY IMPLEMENTATION

Specialized suppliers · Users of Plastic products

REFERENCES

(Pettersen and Sæther, 2021; akvagroup.no, 2022)

READ MORE IN CHAPTER: 3.3.4, 3.4.2

CONCEPT 3
WASTE SORTING STATIONS

IMPLEMENTATION IS RELEVANT FOR

Users of Plastic products

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY COMPLEX

DESCRIPTION

During normal operations at the work boats, it has been common to discard all waste in the same mixed waste container. By installing a waste sorting system, waste can be sorted directly, and the recycling rate can be increased. Sources say that contrary to common belief, a sorting station is not more space consuming than a mixed waste container.

Always having waste sorting containers easily available, whether on the boat deck or on the land base, means less chance of loss of plastic waste to nature, as well as a higher recycling rate – which can lead to savings in waste fees.

CASE

The Norwegian Retailers' Environment Fund and the Norwegian Fishermen's Association has released 10 tips for reducing littering from fishing vessels. Their tips for waste sorting stations on board is having a waste sorting station available, and secure it safely to avoid waste from being released in rough weather. Available waste sorting stations enables operators to discard waste with sorting at the source.

LOOK OUT FOR

Harmonizing the sorting system with the waste collector in terms of waste types and quality.
Sorted waste usually has a lower delivery fee than unsorted waste.

KNOWLEDGE NEEDS 2022

Best practices need to be shared between companies.

REFERENCES

(Pettersen and Sæther, 2021; Handelensmiljofond.no, 2023)

READ MORE IN CHAPTER: 3.5.3

ACTIVITIES AFFECTED BY IMPLEMENTATION

Users of Plastic products

Waste collectors

Plastic recyclers

CONCEPT 4

ORGANIZATIONAL ROUTINES FOR CIRCULAR BEHAVIOUR

IMPLEMENTATION IS RELEVANT FOR

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY — COMPLEX

LOOK OUT FOR

Some circular strategies are enablers for other circular strategies, while some disqualifies other circular strategies.

KNOWLEDGE NEEDS 2022

No technical barriers, some «best practice»-examples are being spread.

DESCRIPTION

Policy and operating routines can be a tool for “nudging” or requirements for employees and contracted service providers towards circular behaviours. Businesses are required to have internal control according to Norwegian law, usually including business internal routines and instructions. These can be designed to include requirements for work procedures that are supporting chosen focus areas like waste management, preventing littering, purchasing repairable, recyclable and/or recycled products etc. The routines can facilitate circular development in the business they are implemented, or support circular measures in other parts of the value chain.

CASE

Several of the concepts in this report are examples of organizational routines for circular behaviour, like “knytetau” (concept 25) and waste sorting stations (concept 24) . Internal system design, training schemes and management standards can be used to improve motivation and change behavioural patterns for increased circularity.

REFERENCES

(Schyns and Shaver, 2021; Damman et al., 2022; POCOplast workshop interviews, 2022)

READ MORE IN CHAPTER: 3.5.3

ACTIVITIES AFFECTED BY IMPLEMENTATION

CONCEPT 5
EXPERIENCE BASED IMPROVEMENTS

IMPLEMENTATION IS RELEVANT FOR

Users of Plastic products

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY COMPLEX

DESCRIPTION

During use and maintenance phase, the users might discover or develop alterations for improving usability of the fish farming equipment and installations, prolonging the product lifetime.

This experience-based knowledge should be communicated back to the product designers and producers, to enable improvement in future products.

CASE

An example can be fastening walkways with additional screws. Unfastened, the walkways were causing a risk of detachment and subsequent loss to nature. This experience-based knowledge should be communicated back to the producers, to enable improvement in future products.

LOOK OUT FOR

Risk of introducing materials or objects contaminating the waste downstream, like non-magnetic metal screws.

KNOWLEDGE NEEDS 2022

Best practices needs to be shared between companies, and especially communicated to the designer/installer of the products if there are opportunities for redesigning for prolonged product life

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers, Manufacturers, Specialized suppliers, Users of Plastic products

REFERENCES

Pettersen and Sæther, 2021

READ MORE IN CHAPTER: 3.4.2

CONCEPT 6
WASTE PRE-PROCESSING

IMPLEMENTATION IS RELEVANT FOR

Plastic recyclers

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

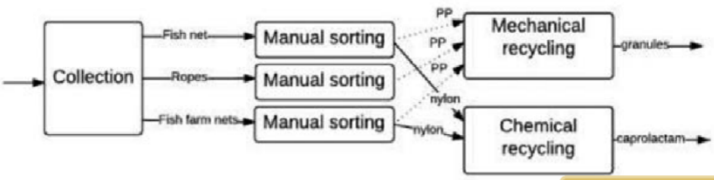
EASY COMPLEX

DESCRIPTION

Most plastic wastes need some form of pre-processing before recycling. Dismantling, shredding or compression for efficient transport, and cleaning to remove contamination are common processes. Pre-processing is an important step for identifying risks and correct handling of the waste in the following recycling process. Pre-processing activities can happen at the aquaculture facility or at specialised waste handling companies.
Mixed plastic and other complex materials complicate recycling, and calls for more advanced pre-processing. This can be mixes of different types of plastic, a mix of plastic and other materials such as metal reinforcements, coatings etc. Some ropes can be coated in PU (polyurethane), and nets are traditionally coated with copper or other antifouling and waxed.

CASE

In the figure below, pre-processing activities of nets and ropes of the Norwegian company Nofir is described with manual sorting. There are currently no industry standard technologies to automate this sorting and cleaning of tangled nets and ropes. After pre-processing, the PP is sent to mechanical recycling. PA/nylon is sent to chemical recycling at Aquafil in Slovenia, where it is processed into caprolactam. The caprolactam is used to produce new nylon yarn (trade name Econyl).



LOOK OUT FOR

Beneficial pre-processing can increase the value of plastic waste and simplify the recycling process. Bad pre-processing like incorrect sorting or mixing unwanted plastic combinations can complicate recycling and reduce the value of the materials

KNOWLEDGE NEEDS 2022

Sorting technology is under constant development with the goal to improve purity of sorted fractions. Sensors are used to differentiate between different types of plastic, making the machines able to sort the plastic by polymer type (TOMRA, 2022). Development of automated processes for aquaculture plastics can become an alternative to manual sorting.

REFERENCES

(Brodbeck, 2016; Sundt et al., 2018; Schyns and Shaver, 2021)

READ MORE IN CHAPTER: 3.5.2

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers · Manufacturers · Specialized suppliers · Plastic recyclers

SINTEF

CONCEPT 7

TREATMENTS FOR NON-CIRCULAR PRODUCTS

IMPLEMENTATION IS RELEVANT FOR

Waste collectors

Plastic recyclers

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY COMPLEX

LOOK OUT FOR

More circular options might appear due to change in plastic waste composition and technology development over time. Alternatives should be assessed regularly.

KNOWLEDGE NEEDS 2022

The evaluation of environmental benefit of the transitional concepts, technology development for mitigating emissions

DESCRIPTION

Moving from linear to circular business models, there will be a transitional phase where products designed for the linear economy are being phased out. Reasons might be challenges for recycling like mixed or polluted waste mass, complex material compositions, long transport distances to recycling facilities etc. The circularity strategies for extended lifetime like repairs and repurposing are preferrable before end-of-life using the recovery strategy. Energy recovery from plastics enable high-temperature incineration and can fuel high-temperature industry as a substitute for coal.

CASE

NORCEM is receiving shredded copper-coated aquaculture nets from Containerservice Ottersøy through their processing partner Renor, to fuel high-energy combustion for cement production. This reduces NORCEM's coal consumption, in line with national goals of reducing fossil fuels. The consistent quality and amounts of shredded nets makes it a valuable source for high-temperature energy recovery.

ACTIVITIES AFFECTED BY IMPLEMENTATION

Waste collectors

Plastic recyclers

REFERENCES

(Hognes and Skaar, 2017; Adresseavisen, 2021; Heidelbergmaterials.no, 2022)

READ MORE IN CHAPTER: 3.5.3

CONCEPT 8

MECHANICAL RECYCLING

IMPLEMENTATION IS RELEVANT FOR

Plastic recyclers

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY COMPLEX

LOOK OUT FOR

Recycling unwanted chemicals and substances from outdated or unknown material compositions and use contamination. Sorting, pre-processing and source information are important barriers.
Experience shows a significant drop in quality after about 4-5 life cycles.
Recycling recycled materials needs to be done with care

KNOWLEDGE NEEDS 2022

Mechanical recycling is technology in use, knowledge- and development needs are quality enhancing measures, standardizing documentation and upscaling for increasing recycling capacity.

DESCRIPTION

Mechanical recycling of plastics involves the shredding and re-melting of material at 'end of life' and is a substantial part of plastic waste management along with chemical recycling. In terms of economic and ecological performance, single material plastics and mixed plastics with defined composition and low levels of impurities (e.g., unwanted chemicals, organic materials) are best suited for mechanical recycling. In this case, the recyclate has almost the same functional properties as the comparable virgin material. Material properties of the recyclate are assessed with analytical measurements to determine the material properties of the recyclate and documented in material data sheets. Measures to increase the quality of recycled plastics are available e.g adding new stabilisers and antioxidants.
Heavily degraded plastics, where reasonable mechanical properties cannot be expected from the recyclate, or the effort required to regain sufficient properties is not cost effective, will not typically be recycled mechanically. These are typically contaminated plastics or plastics where high sorting and purifying efforts are necessary. Alternatives for end of life are chemical recycling or incineration with energy recovery.

CASE

An example of mechanical recycling in aquaculture are HDPE pipes and rings from pens. The plastic material will typically be dismantled and shredded, and sent to recyclers such as NOPREC who recycle these materials into granules. These will then be used by companies like Plasto to produce new aquaculture products.

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers · Manufacturers · Specialized suppliers · Plastic recyclers

REFERENCES

(Sundt et al., 2018; POCOplast interviews)

READ MORE IN CHAPTER: 3.5.2

CONCEPT 9
CHEMICAL RECYCLING

IMPLEMENTATION IS RELEVANT FOR

Plastic recyclers

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY COMPLEX

DESCRIPTION

Chemical recycling is a process using heat, chemicals, or solvents to recycle plastics. Chemical recycling has a higher tolerance for impurities and mixed plastic fractions than mechanical recycling. Using solvents, often at elevated temperature and pressure, can 'purify' the secondary plastics. This enables removing contaminants, pigments, and additives and rebuild virgin like recyclates. Nowadays, dissolution-based recycling is used in industrial scale for the recovery of PVC (known as the Vinyloop® process) and for expanded polystyrene (EPS) (known as the Creasolv® process). When using heat, the two main chemical recycling routes for polyolefins (HDPE, LDPE, PP) are the thermal and catalytic degradation of these polymers. In thermal degradation (pyrolysis), the process produces a broad range of products, such as hydrocarbon gases, liquids, oils, and waxes. This requires high operating temperatures, typically up to 900°C. Catalytic technologies have been proposed which work at lower temperatures, resulting in reduced energy consumption and higher conversion rates. Traditional plastics producers such as Dow, Borealis, and Lyondell Basel are heavily involved in developing chemical recycling technologies for using secondary plastics as feedstock in their production.

CASE

Chemical recycling of PA from aquaculture nets is an established practice, an example is the collector NOFIR and the recycler Aquafil.

Quantafuel currently has a commercial pyrolysis and purification plant in Skive, DK. In their chemical recycling process, they use special purification steps and can handle mixed plastic waste (primarily polyolefins) which can contain impurities, such as PET and PS. The products of this process will then be used by BASF as feedstock for new plastics or other chemicals.

LOOK OUT FOR

Chemical recycling processes consume large amounts of energy, with life-cycle GHG emission limits to be considered as sustainable industry by the EU Taxonomy.

KNOWLEDGE NEEDS 2022

Chemical recycling technologies are in use. However there are knowledge needs connected to good catalysts and up-scaling to process large quantities.
Chemical recycling of plastic-containing waste is not yet a common practice although the commercialization of these methods has been pushed forward in the recent years.

REFERENCES

(Punkkinen et al., 217AD; S. et al., 2012; Krogstad, 2021; Quantafuel.no, 2021b, 2021b; EU Taxonomy Navigator, 2023, shiftplastics.no, 2023)

READ MORE IN CHAPTER: 3.5.2

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers
Manufacturers
Specialized suppliers
Plastic recyclers

CONCEPT 10
ECO-LABELS

IMPLEMENTATION IS RELEVANT FOR

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY COMPLEX

LOOK OUT FOR

Reporting is currently voluntary. There might be little motivation for going beyond the minimum requirements

KNOWLEDGE NEEDS 2022

Several certification bodies are working on circular economy-related certification updates

DESCRIPTION

Eco-labelling provides information necessary to make more sustainable choices. Eco-labelling of plastic products is voluntary and mainly focuses on packaging and consumer products.
Labels like the Norwegian "Svanemerket" and German "Blue Angel" target products and services in a wide range of product segments.
Compliance with different requirements, including material choices, is necessary to get the certifications with these labels. Some requirements involve plastics. For example, to be awarded "Blue Angel", a plastics product needs to contain 80% of recycled plastics.

CASE

Recyclers can document their circularity work through certifications. For example, the Norwegian recycler Norfolier GreenTec is certified through Blue Angel and EuCertPlast.
•EuCertPlast is a certification scheme that helps plastic recycling industry with quality management and standardization of recycling processes.
•RecyClass is a certification organ that helps to document recyclability of the materials.

REFERENCES
(Plastforum.no, 2022; EuCertPlast.eu, 2023; Norfolier GreenTec, 2023)

READ MORE IN CHAPTER: 3.6.1

ACTIVITIES AFFECTED BY IMPLEMENTATION

CONCEPT 11
TECHNICAL STANDARDS

IMPLEMENTATION IS RELEVANT FOR

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY MULTIPLE ACTORS

LEVEL OF DIFFICULTY

LOOK OUT FOR

Too narrow scope of the standard can be misleading for other sustainability and circularity targets.
Implementing several standard sets increase compliance costs and complicate organizational routines.

KNOWLEDGE NEEDS 2022

Technical standards demand documentation that might be hard to provide for recycled materials. New initiatives might require new forms of collaboration for documentation and create new knowledge demands.

DESCRIPTION

Technical standards set requirements for materials and products quality, as well as organizational routines. Standards can be a branch specific (NS9415) or apply to the businesses across the value chain (ISO14001, ISO9001).
The technical standard NS9415 sets, among other, requirements for mechanical load resistance like stress and strain on the installation. The standard aims to ensure fish welfare and prevent tears leading to fish escapes. Aquaculture installations and their components in the Norwegian industry must comply with this standard. Products containing recycled plastics need to be certified with the same standard.

CASE

Collaboration between AKVAgroup, Grieg Seafood, Plasto and OCEANIZE enabled using recycled plastics in walkways for fish farming cages. These companies later started a new joint project on the use of recycled plastics to develop a whole fish farming cage. The goal is also to certify the cage in accordance with the technical standard NS 9415 and document the quality of the products.
The feeding pipe producer Arges have also initiated recycling of aquaculture gear.

REFERENCES
(Arges.no, 2019; Ilaks.no, 2021)

READ MORE IN CHAPTER: 3.6.2

ACTIVITIES AFFECTED BY IMPLEMENTATION

CONCEPT 12

EXTENDED PRODUCER RESPONSIBILITY SCHEMES (EPR)

IMPLEMENTATION IS RELEVANT FOR

Product designers · Manufacturers · Specialized suppliers · Users of Plastic products

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY — COMPLEX

LOOK OUT FOR

The need for documentation and reporting might increase. It could also strengthen collaboration in the industry regarding reporting and more sustainable use of materials. Requirements on reporting can increase the amounts of data and create basis for materials overview. An overview of the materials can, in turn, increase predictability of the access to the resources.

KNOWLEDGE NEEDS 2022

The Norwegian Environment Agency has recommended establishing EPR for plastic products in aquaculture and fisheries. If implemented, the new regulations will state the terms for the industry.

DESCRIPTION

EU suggests focusing more on the reduction of the impact of certain plastic products on the environment. Changes in the EU policy influence Norway due to its membership in the EEA agreement. EPR is one of the instruments to achieve this reduction of the impact of certain plastic products on the environment, and equipment from fisheries and aquaculture that contains plastics is among the focus products.

CASE

The Norwegian Environment Agency is currently working on the review of its EPRs to accommodate the necessary changes. The Agency will investigate how further development of the EPR can contribute to support a transition to circular economy. Their preliminary findings point at the need for more precise goals for waste treatment, reporting and documentation, as well as more precise geographic scope.

REFERENCES

(EU, 2019; Regjeringen.no, 2020; Damman et al., 2022; Miljødirektoratet, 2022)

READ MORE IN CHAPTER: 3.6.1

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers · Manufacturers · Specialized suppliers · Users of Plastic products · Waste collectors · Plastic recyclers · Material tracking companies · Research and development

SINTEF

CONCEPT 13
PRODUCT SPECIFIC WASTE SERVICES

IMPLEMENTATION IS RELEVANT FOR

Waste collectors | Plastic recyclers | Material tracking companies

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY — COMPLEX

DESCRIPTION

There are several examples of service development targeting a specific product with a goal of improving circularity within the aquaculture industry. This can ensure material streams separated by plastic type, product type, user or value chain origin history etc. The service can include introducing new equipment, logistic services or cooperating with other service providers to achieve a separated material stream suitable for reuse, remanufacturing or recycling.

CASE

An example from the POCOplast value chain is the OCEANIZE fish farming cage waste management service. By moving a mobile shredder to the customer location, their team of operators dismantles and pre-processes the fish farming cages. The discarded fish farming cages are managed outside of ordinary waste management streams, and OCEANIZE has information about the waste source, sorting and processing. This information and value chain control is an enabler for product quality documentation for the recycled materials and is reducing the risk of pollution from other plastic waste types in conventional waste management value chains.

LOOK OUT FOR

Establishing specialised treatment systems demands a certain product mass, and might depend on high market share to to be viable.

KNOWLEDGE NEEDS 2022

Implemented for a number of products. Future development of tracking services and processing equipment can enable upscaling.

ACTIVITIES AFFECTED BY IMPLEMENTATION

Users of Plastic products | Waste collectors | Plastic recyclers | Material tracking companies

REFERENCES

POCOplast interviews

READ MORE IN CHAPTER: 3.5.3

SINTEF

CONCEPT 14
PRODUCT DESIGN WITH RECYCLED MATERIALS

IMPLEMENTATION IS RELEVANT FOR

Product designers · Manufacturers · Research and development

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY — COMPLEX

LOOK OUT FOR

Changing the design might require additional production equipment investments and change production cost factors.
Products might need re-certification due to the material source change

KNOWLEDGE NEEDS 2022

Design with recycled materials is a concept in use. Standards for design and material documentation is not updated for most product groups.

DESCRIPTION

Mechanically recycled plastic often has altered mechanical properties than comparable virgin material. In addition, recycled materials generally have bigger variations of their properties from batch to batch. Some recyclers minimize these variations by mixing in a certain percentage of virgin material. However, it might still not be feasible to replace virgin with recycled material without adjustments in production parameters or product design. To use a high percentage of recycled material, one could compensate by changing the product design. These design changes could be for example having thicker walls or additional ribs in areas which will experience a high mechanical stress during use.

CASE

The Norwegian furniture manufacturer Flokk has been using recycled plastics in their chair designs for years, and a recent example is their HÅG Capisco Puls chair made from recycled «snow plough markers». Due to the waste material colour composition, each production series will have a slight colour variation.

ACTIVITIES AFFECTED BY IMPLEMENTATION

Manufacturers · Specialized suppliers · Material tracking companies · Research and development

REFERENCES

(Gemini.no, 2021; Flokk.no, 2022)

READ MORE IN CHAPTER: 3.6.2

CONCEPT 15

MULTIFUNCTIONAL PRODUCTS

IMPLEMENTATION IS RELEVANT FOR

Product designers

Research and development

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY — COMPLEX

LOOK OUT FOR

One product covering several functions will increase vulnerability as several functions are affected if the product breaks.
Multifunctional products mean suppliers will sell fewer products.
Even though the multifunctional product is usually more expensive, this is unlikely to cover the loss in revenue from consumption reduction.

KNOWLEDGE NEEDS 2022

Sector-specific knowledge about which functions and how they can be covered by a multifunctional product, i.e. product development.

DESCRIPTION

Rethinking products and using the same product for several functions reduces the need for materials. The perhaps most obvious example of this is the smart phone, which replaces not only a mobile phone, but also camera, calendar, alarm clock, photo album, newspapers etc. To achieve good multifunctional product design, it is important to work in dialogue with the users, to ensure products are not designed with unnecessary functionality making the product larger than necessary, which would have the opposite effect and increase material use.

CASE

An increasing number of activities and functions are camera-based in aquaculture. Cameras and sensors are combined in control units. An example is ScaleAq's underwater camera units with sensors for temperature, depth, O_2 and compass. The video stream is also enabling several analyse functions like estimating bio mass, monitoring fish health and lice counting.

REFERENCES

(Imenco.no, 2023; Scaleaq.com, 2023)

READ MORE IN CHAPTER: 4.4.2

ACTIVITIES AFFECTED BY IMPLEMENTATION

CONCEPT 16

PRODUCT TRACKING

IMPLEMENTATION IS RELEVANT FOR

Product designers · Manufacturers · Specialized suppliers · Research and development

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY MULTIPLE ACTORS

LEVEL OF DIFFICULTY

EASY — COMPLEX

LOOK OUT FOR

Equipment that is cut (e.g. ropes or tubes) may not be suitable for this type of tracking, as the tag could be cut off. Depending on the tracking technology, plastic products containing tracking devices might be classified as electronic waste.
If the tracking technology chosen provides location information, productivity and use levels of non-stationary equipment can be identified, revealing potential for increased use efficiency.

KNOWLEDGE NEEDS 2022

Product development and system integration is needed, but the technology is mature and solutions for other applications exist.

DESCRIPTION

Adding a tag that can be read digitally, such as a QR code or a microchip, allows a product to be tracked through the value chain. This type of technology is called Automatic Identification and Data Capture (AIDC) technology, and has several purposes in a circular economy context:

1) easily identify correct components and mechanics to repair or refurbish the product
2) exchange information about material composition of the product
3) provide documentation for resale or reuse of the product.

Both non-electronic tags, such as bar codes and QR codes, and electronic tags, such as radio frequency identification (RFID), have been used with great success and large benefits for business. AIDC technologies can give simple readable information (e.g. bar codes), have read-write possibilities (e.g. using RFID), and include technology that can give location information (using e.g. GPS).

CASE

Most, if not all, products sold today are tracked using some kind of AIDC technology. Plastic products in aquaculture are most likely already tracked to the point of sale. The goal would therefore be to continue tracking the product for the rest of the life cycle, adding relevant information if needed. This might require a different tracking technology than what is currently used.

ACTIVITIES AFFECTED BY IMPLEMENTATION

Waste collectors · Plastic recyclers · Material tracking companies · Research and development

REFERENCES

(Hill and Cameron, 2017; Elaskari et al., 2021; AIM, 2023)

READ MORE IN CHAPTER: 4.4.5

SINTEF

CONCEPT 17

MATERIAL TRACKING

IMPLEMENTATION IS RELEVANT FOR

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY MULTIPLE ACTORS

LEVEL OF DIFFICULTY

LOOK OUT FOR

Implementing a material tracking system can be complex, depending on implementation levels. An overview of purchases and material accounting is an enabler for circular economy and can give a competitive advantage.

KNOWLEDGE NEEDS 2022

Some systems are commercially available, but still immature. Large components are registered more often than consumables, such as ropes..

DESCRIPTION

To be able to increase the circularity of plastic, the industry must know where the plastic is, how much there is of it, and the characteristics of the plastic. To get this information, the plastic must somehow be tracked and logged. Tracking and logging of plastic can be done in a variety of ways. By assigning value to the material, it is less likely to end up as waste, and more likely to be recycled. Tracking enables characterization, quality- and risk analysis of waste sources for recycling companies.
This can give a competitive advantage by documenting circularity and sustainability, and telling the story of the material's journey.

CASE

Aquaculture companies generally use systems and software to register all equipment that needs to be certified and have a maintenance plan. Software examples include AKVA group's Fishtalk Equipment and Havbruksloggen. This is the first level of tracking, a business internal registry.

Companies like Empower specialise in tracking plastic materials through the value chain, by using blockchain technology and making it possible to both document and monetise the plastic flow. They provide material passports, so the customer can see where the materials in their products come from and what has happened to them.

ACTIVITIES AFFECTED BY IMPLEMENTATION

REFERENCES

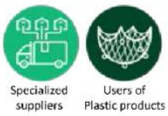
(Hognes and Skaar, 2017; akvagroup.no, 2021; Havbruksloggen.no, 2021; Empower.eco, 2022)

READ MORE IN CHAPTER: 4.4.5

SINTEF

CONCEPT 18
PRODUCT SPECIFIC SERVICE AGREEMENTS

IMPLEMENTATION IS RELEVANT FOR



LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY MULTIPLE ACTORS

LEVEL OF DIFFICULTY

LOOK OUT FOR

Repair solutions can introduce other materials in the plastic components, or non-compatible plastic components in recycling processes. Impact on the value chain processes and product lifetime should be assessed when establishing routines for repairs.

KNOWLEDGE NEEDS 2022

Product specific service agreements exist for many installations and equipment for aquaculture industry. Knowledge needs exist for optimizing the circular potential in all of these product categories.

DESCRIPTION

Product specific service agreements encourages prolonged use phase of plastic constructions and products through repair and refurbish services. In addition, the service operations can be standardized and executed in a way that incorporates other circularity factors like using recycling-compatible plastic materials for repairs and securing proper waste management of discarded parts and materials.

CASE

Product specific service agreements is an eligible circular business model extension for both retailers providing repair services for their own products and general operations service providers.

Product specific service agreements are well established in the aquaculture industry, for several types of equipment. Operation service providers like Frøy Akvaservice and AKVAgroup Egersund Net are examples of businesses marketing repair- and maintenance solutions for cage nets.

ACTIVITIES AFFECTED BY IMPLEMENTATION

Waste collectors

REFERENCES

(Akvagroup.no, 2022; Froygruppen.no, 2023)

READ MORE IN CHAPTER: 4.4.2

SINTEF

CONCEPT 19
DESIGN FOR CIRCULARITY

IMPLEMENTATION IS RELEVANT FOR

Product designers

Research and development

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY — COMPLEX

LOOK OUT FOR

It is important to assess the value chain impact of design for circularity measures to optimise the positive impact and avoid negative impact in other parts of the value chain.

KNOWLEDGE NEEDS 2022

Design for circularity is a concept in use. As other technologies and concepts are adapted, new requirements and possibilities within design for circularity unlocks.

DESCRIPTION

The initial design of a product determines a lot of the circular potential of the product. Within the professional field of product design, design for circularity is a part of the eco-design approach.

Design for circularity enables circular strategies like repair, remanufacture, repurposing, or recycling. For plastics in aquaculture this can be specific like not using glue or other joining methods that are not possible to undo without breaking the product. For repairs, it can be design that allows for wear parts to be replaced by spare parts, and that spare parts are available for the consumer or repair shops.

For remanufacture and repurposing, the designer can consider making parts in a way that they can be used as spare parts if they are not worn out at the end of the product's lifetime.

CASE

An example of this is AKVA group designing pens without polystyrene filling, reducing the number of plastic types within the product. This reduces the amount of contamination from polystyrene in pre-processing and recycling of the rest of the installation.

A Study on Circular Design of the Fishing Gear for Reduction of Environmental Impacts were published by the European Commision in 2020, and is an example of circular design studies for similar industries.

REFERENCES

(Akvagroup.no, 2022a, Feary et al., 2020)

READ MORE IN CHAPTER: 4.4.2

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers, Manufacturers, Specialized suppliers, Users of Plastic products, Waste collectors, Plastic recyclers, Material tracking companies, Research and development

CONCEPT 20

SMART TECHNOLOGY FOR PREDICTIVE MAINTENANCE

IMPLEMENTATION IS RELEVANT FOR

Product designers

Manufacturers

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY SINGLE ACTOR

LEVEL OF DIFFICULTY

EASY — COMPLEX

DESCRIPTION

Adding sensors into products makes it possible to register what happens to the product, which can enable maintenance based on need rather than a set time interval. Equipment that is more exposed to the elements can get the maintenance needed to achieve a longer lifetime, while for more protected equipment unnecessary replacements can be avoided.

CASE

An example is adding sensors into the floating pipe, mooring system, or the brackets holding the walkways in aquaculture pens, which can give information about the mechanical stress the pen has been exposed to, hence give information on how far the construction is from the fatigue limit.

LOOK OUT FOR

Inclusion of sensors can make the product be categorized as electronic waste, depending on how the sensor is attached. This can make it more complicated to recycle.

KNOWLEDGE NEEDS 2022

Technology exists. Research and implementation is linked to "Industry 4.0" data processing and analysis development.

REFERENCES

(Triple-s.no, 2021)

READ MORE IN CHAPTER: 4.4.5

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers

Manufacturers

Specialized suppliers

Plastic recyclers

SINTEF

CONCEPT 21
CIRCULAR SUPPLIES

IMPLEMENTATION IS RELEVANT FOR

Product designers · Manufacturers

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY MULTIPLE ACTORS

LEVEL OF DIFFICULTY

EASY — COMPLEX

DESCRIPTION

Circular supplies is the concept of providing resource inputs that are completely renewable, recyclable, or biodegradable and support circular production and usage processes. Companies may use this to replace linear resource methods, phase out the use of finite resources, cut waste and eliminate inefficiencies.

Plastics from renewable sources and biodegradable plastics may serve as a more sustainable solution to conventional fossil-based and non-biodegradable plastics. Plastics that biodegrade can contribute to reducing plastic littering if used in the right conditions and applications.

CASE

In aquaculture, plastic strips are frequently used for temporary attachments, for example when changing nets. By replacing plastic strips with biodegradable alternatives, the environmental stress may be lower than with traditional plastics. However, biodegradable plastics may as well take several years to degrade (depending on the environment) and are thus still a pollutant and will generate microplastics when degrading.

LOOK OUT FOR

In aquaculture, bio-degradable plastics are not suitable for components that demand high resistance and durability (e.g. floating pipes and walkways).
A naturally biodegradable material does not automatically mean a sustainable material. Resource consumption in production should be assessed and compared like any other material. Not all bio-based plastics are bio-degradable.

KNOWLEDGE NEEDS 2022

There is currently substantial research capacity focused on circular and bio-based materials, with knowledge needs for new materials, product development, degradation conditions and environmental effects etc.

REFERENCES
(Lacy and Rutqvist, 2015; Pettersen and Sæther, 2021; EC, 2023)

READ MORE IN CHAPTER: 4.4.4

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers · Manufacturers · Specialized suppliers · Users of Plastic products · Waste collectors · Plastic recyclers · Material tracking companies · Research and development

CONCEPT 22

REUSE OF COMPONENTS

IMPLEMENTATION IS RELEVANT FOR

Product designers
Manufacturers
Specialized suppliers
Users of Plastic products
Research and development

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY MULTIPLE ACTORS

LEVEL OF DIFFICULTY

EASY COMPLEX

LOOK OUT FOR

The concept should be applied in combination with other circular strategies following reuse, e.g ensure proper waste management.

KNOWLEDGE NEEDS 2022

Development of automated processes for large scale reuse, remanufacturing and repurposing is a current R&D topic for several industries. Projects target a wide range of development areas, including technical solutions, business models and logistics.

DESCRIPTION

To avoid exploitation of new virgin material and to keep the existing extracted resources in loop, we need to reuse the equipment and components already produced. In order to do this, strategies such as remanufacture, refurbishment and repurposing of the equipment can be applied. A case example of reuse is to buy beverages in returnable containers, reuse wrapping paper, plastic bags and boxes, or to reuse pens from aquaculture and create a floating jetty.

Design for reuse is important, how to develop materials in equipment and components that can easily be reused and maintain its strength and properties without downgrading the materials.

CASE

Nofir (Norsk fiskeriretur) has successfully remanufactured fishnets into volleyball nets. The existing net structure is kept, while the nets are cut in smaller pieces and re-sewn to become volleyball nets.

Inseanergy is reusing aquaculture pens as the main construction base for floating solar energy production plants. The solar panel installations are utilized within aquaculture industry to power fish farms, combining circular strategies and energy transition measures.

REFERENCES

(Abdul-Rahman, 2014; E24.no, 2022; Inseanergy.no, 2022)

READ MORE IN CHAPTER: **4.4.4**

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers
Manufacturers
Specialized suppliers
Users of Plastic products
Waste collectors
Plastic recyclers
Material tracking companies
Research and development

CONCEPT 23
PRODUCT AS A SERVICE

IMPLEMENTATION IS RELEVANT FOR

Specialized suppliers

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY MULTIPLE ACTORS

LEVEL OF DIFFICULTY

EASY COMPLEX

LOOK OUT FOR

Making changes to a business model may demand large organizational changes within an established value chain.
The product-as-a-service model would be most attractive to firms whose products' operational costs are high (e.g. the car industry).

KNOWLEDGE NEEDS 2022

Examples of this business model are existing in the aquaculture industry, in several forms.

DESCRIPTION

Product-as-a-service is a business model focusing on the performance of products, where selling the function of products replaces the ownership of products. This includes rental, leasing and maintenance on equipment. Providing service solutions for a part of the business model is becoming increasingly common, also in the aquaculture industry. Including such services to the business model creates new cash flows while simultaneously increasing the total life span or use intensity of products.

CASE

The concept is far from new: In the car industry, leasing services has existed for decades where the amount you pay reflects the miles driven (today known as "Power by the hour" trademarked by Rolls-Royce). An example within aquaculture industry of such equipment rental is with AKVA group, where the rental agreement includes transport of the rental equipment, installation and start-up, training in use, service and support, free repairs and replacements, a fixed price for the rental period, no front-end fee, and free access to support. Examples of equipment that can be rented are feed systems, feed accessories, camera systems, environmental sensors, infrastructure, dead fish systems, underwater lights, washing systems and subsea feeders.

REFERENCES

(Lacy and Rutqvist, 2015b; AKVAgroup.no, 2017b)

READ MORE IN CHAPTER: 4.4.4

ACTIVITIES AFFECTED BY IMPLEMENTATION

CONCEPT 24
SHARING PLATFORMS

IMPLEMENTATION IS RELEVANT FOR

Specialized suppliers | Users of Plastic products

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY MULTIPLE ACTORS

LEVEL OF DIFFICULTY

EASY — COMPLEX

DESCRIPTION

The Sharing Platforms business model supports a platform for product users, whether people or organizations, to collaborate. These make it easier to share excess capacity or underutilized resources, boosting productivity and adding value to users. The platform can provide solutions for connecting host/owner of shareable units with customers and make profit through a range of organizational setups, like memberships, single transactions, shared ownership etc.

CASE

In other industries, AirBnB and Getaround are examples of successful sharing platforms for housing and transport. Within aquaculture an example can be sharing platforms for service equipment etc, used by several aquaculture locations in the same geographic area.

LOOK OUT FOR

Making changes to a business model may demand large organizational changes within an established value chain.
Be aware that this model does not fit all businesses. This concept, which aids in maximizing use, would be most beneficial to businesses with poor utilization or ownership rates of their products and assets

KNOWLEDGE NEEDS 2022

Digital platforms for other industries exist, can be developed for industry spesific purposes in aquaculture.

REFERENCES

(Lacy and Rutqvist, 2015c)

READ MORE IN CHAPTER: 4.4.4

ACTIVITIES AFFECTED BY IMPLEMENTATION

Product designers | Manufacturers | Specialized suppliers | Users of Plastic products | Material tracking companies

CONCEPT 25

CLOSED-LOOP VALUE CHAINS

IMPLEMENTATION IS RELEVANT FOR

LEVEL OF COOPERATION NEEDED

IMPLEMENTED BY MULTIPLE ACTORS

LEVEL OF DIFFICULTY

LOOK OUT FOR

Closed loop value chains can make the value chain actors dependant on each other for product and service delivery and require close contact between the actors.

KNOWLEDGE NEEDS 2022

Closed-loop systems through value chains are rare and challenging to organize technically and practically for many products. This is why research and innovation is needed on how to establish take-back schemes and reuse of products (including recycling).

DESCRIPTION

A closed loop value chain is where input materials used to create a product, is taken back through return schemes so that the same materials and products can be used again. These used products then become part of the manufacturer's supply through repair, resale or component reuse. In this way, closed-loop supply chains aim at eliminating waste, and these systems are therefore an important part of the circular economy.

CASE

AKVA group, OCEANIZE and Plasto are an example of actors in a value chain joining to create a closed loop system for plastics from pens. In their value chain they are testing recycling plastics from produced pens, and producing new products in the same product category. The most common example is the Norwegian EPR return system for PET bottles.

REFERENCES

(Lacy and Rutqvist, 2015a; Ilaks.no, 2021; Infinitum.no, 2021)

READ MORE IN CHAPTER: 4.5.2, 4.6.2

ACTIVITIES AFFECTED BY IMPLEMENTATION

3 Theoretical framework and background

3.1 Why plastic in aquaculture?

The development of fisheries and aquaculture has relied heavily on plastic use and is likely to continue doing so in the foreseeable future. Ropes and netting made from synthetic fibres offer greater strength and durability at a lesser weight when compared to natural fibres. Plastic components in aquaculture facilities are lightweight, have good mechanical properties and are relatively cheap. Furthermore, plastics are not affected by seawater corrosion. Therefore, plastic materials are used for a variety of components. Ocean based Norwegian fish farms typically consist of a feed raft and several pens. These generally made of metal and plastic, where plastic is particularly important in equipment such as flotation devices, walkways, nets, ropes, buoys, pipes, shielding skirts and wrasse shelters. In addition, seafood packaging and transportation, fish crates and boxes contribute to plastic use.

Plastics can be produced in various forms and can be formed into solid blocks, fibres, and films. Different plastics, also known as polymers, are suitable for different environments, applications, and budgets.

Table 3 shows by polymer how the different plastic materials are used in aquaculture (Huntington, 2019). The main characteristics are explained in more detail regarding their strengths and weaknesses.

Table 3 Overview of different plastics / polymers used in aquaculture and problems that occur during use, recycling, and loss (Huntington, 2019)

Material	Use in aquaculture	Characteristics	
		In use / recyclability	When lost
Acrylic (PMMA)	Incubation jars, containers, laboratory equipment	Lightweight, shatter-proof thermoplastic alternative to glass. Recyclable.	Slow levels of abrasion.
Expanded polystyrene (EPS)	Fish boxes, insulation material, floatation	Extremely light and can be formed into specific shapes. Mainly expanded polystyrene (EPS) used to fill floatation devices (inc. net collars), either by extrusion (within a plastic or metal shell) or as blocks. Is very light and has high insulation properties. Recyclable (see NOWPAP MERRAC, 2015)	Very buoyant, so accumulates on beaches. Easily abrades and breaks into smaller and smaller pieces[4].
Fibre-reinforced plastic (FRP)	Fish transportation tanks, boats, floats, plastic gadgets	Includes glass-reinforced plastic (GRP). Difficult to recycle.	Will splinter in time.
High-density Polyethylene (HDPE)	Floats for cages, twines and ropes, net webbing, monofilament for making nets and hapas, storage tanks, pipes and fittings for water supply, aeration, drainage, pools for water holding, tubs, buckets, trays, basins, and different components of aquaculture implements, laboratory wares	Tough, chemically resistant rigid thermoplastic. Linings 12-100 mm. Commonly recycled.	Will fragment, abrade and weather leading to secondary microplastic formation[5].
Linear low-density polyethylene (LLDPE)	Pond liners	Very flexible, but strong plastic. Linings 0.5 – 40 mm.	Will fragment, abrade and weather leading to secondary microplastic formation.
Low-density polyethylene (LDPE)	Small-scale pond linings, greenhouse canopy poly cover, fish seed transportation carry bags	The most common type of plastic sheeting. It is a flexible sheeting form (0.5 – 40 mm). Due to its flexibility is conforms well to a variety of surfaces but is not as strong or dense as some other types of plastic sheeting. Increasingly recyclable.	Will fragment, abrade and weather leading to secondary microplastic formation.
Nylon (Polyamide, PA)	Twine and ropes, fish nets	Strong, elastic and abrasion resistant.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polyethylene (PE)	Rope, fish transport bags	Cheap rope material.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polyethylene terephthalate (PET) or polyester	Rope	More expensive, strong but inelastic, water resistant rope material. Also used to make plastic bottles. Readily recyclable.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polypropylene (PP)	Twines and rope, crates, feed sacks, tubs, buckets, trays, basins, laboratory wares	Reasonably cheap floating rope but abrades fairly easily. Increasingly recycled.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polyvinyl chloride (PVC)	Pipe and fittings, aeration pipeline, hosepipes and fittings, valves, cage floats, cage collars, drums, jerry cans, prawn shelter, fish handling crates, etc.	Tough and weathers well. Rarely recycled. Should not be burnt as releases toxins.	Will fragment, abrade and weather leading to secondary microplastic formation.
Ultra-high molecular weight polyethylene (UHMwPE)	Ropes and nets	Expensive, very light and strong.	Unknown, but stronger than most materials.

3.1.1.1 Sustainable use of materials

In every stage of the life cycle of plastic – from extraction and transport, refining and manufacture, to waste management; and from plastic lost to nature – greenhouse gas emissions and other environmental impacts occur. The global greenhouse gas emissions from the plastic life cycle in 2019 were estimated to more than 850 million tonnes CO_2 equivalents, which is equal to 189 five-hundred-megawatt coal power plants operating at full capacity. Given the predicted growth in plastic production and incineration, plastic production could eat up 10-13 percent of the remaining carbon budget for keeping within the 1.5°C target (Hamilton *et al.*, 2019; Shen *et al.*, 2020).

The annual production of plastics is currently more than 360 million tons per year (Plastics Europe, 2022). The aquaculture industry is the largest consumer of rigid plastic in Norway, and the volume is expected to grow significantly in the coming years. Only a small proportion of the plastic used in aquaculture is recycled today, which means aquaculture is driving a large demand for virgin plastic. It is evident that the current practices are not sustainable, and we need to find a way to increase circularity in aquaculture plastic consumption – throughout the life cycle of the plastic, and in all parts of the aquaculture value chain. This means (1) reducing the consumption of plastic, (2) extending the lifetime of the plastic used, and (3) increasing the recycling rate.

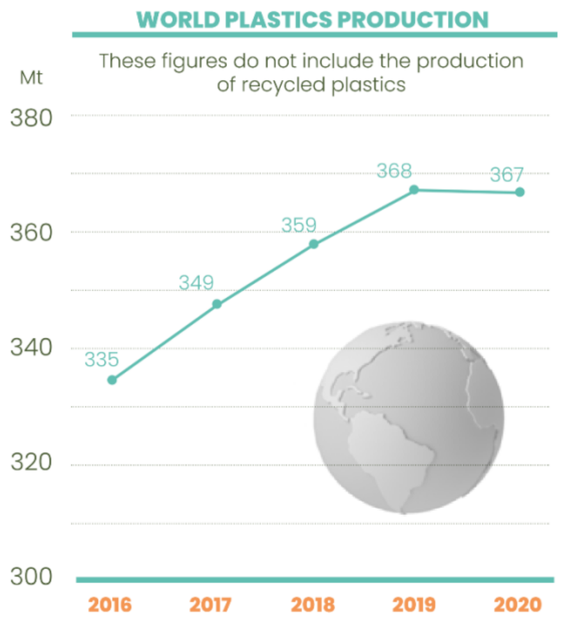


Figure 3 World plastics production (Plastics Europe, 2022).

The aim of the POCOplast project is to increase circularity for post-consumer plastic in aquaculture. We will therefore take a closer look at the plastic once it is in the aquaculture industry. In figure 4 the most circular, and hence desirable, pathways for plastic in aquaculture are indicated by green arrows. The red arrows indicate the undesirable and non-circular pathways that we wish to avoid (Sundt *et al.*, 2018).

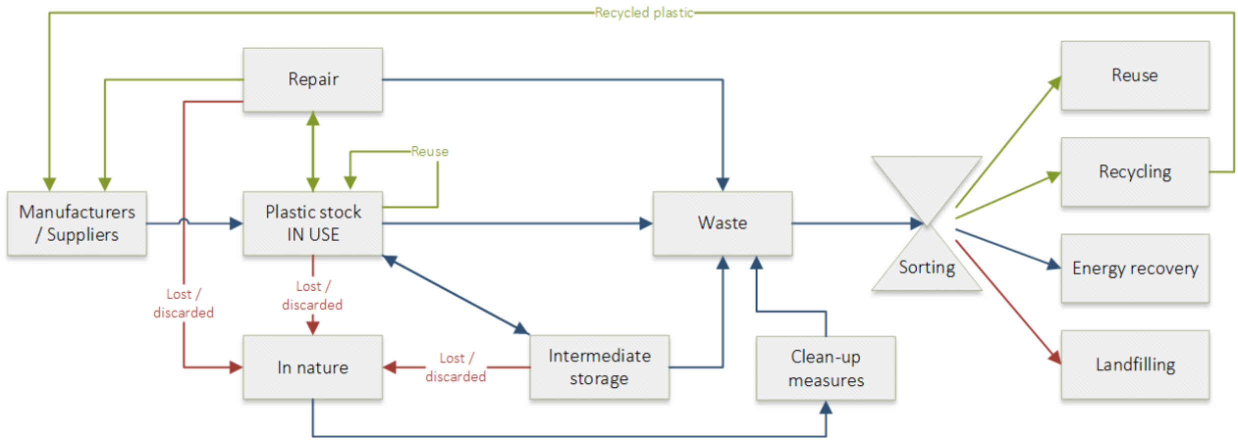


Figure 4 Plastic pathways in aquaculture (Sundt *et al.*, 2018).

3.2 Amounts of plastic in Norwegian aquaculture

Hognes and Skaar (2017) performed a material accounting for ocean-based aquaculture in 2017. Based on a series of assumptions and a limited supply of data, they find that the amount of plastic in ocean-based fish farms in Norway is in the order of 192,000 tonnes.

The data includes:

- Amounts of components in a fish farm with 10 pens and one feed raft
- Weights of anchoring and mooring components from product catalogues
- Weights of floating ring, walkway, bottom ring and hamster wheel estimated with data from AKVA group
- Weights of nets from internal SINTEF projects
- Weights of plastic in feeding system based on AKVA Group product catalogue (only feeding pipes)
- Weights of shielding skirts for lice estimated based on contact with producers
- Weights of wrasse (cleanerfish) shelters estimate based on contact with producers
- Total number of pens used for ocean-based aquaculture in Norway in 2017: 5,500 with average size of 135 meters circumference.
- Total number of fish farms in 2017: 779
- Total number of licenses: 962

The data and material accounting does not include:

- The feed raft
- Boats used in the operations
- Miscellaneous equipment: Cranes, grinder for dead fish, cleanerfish equipment, aeration equipment, generators
- Equipment used in management of lice, except shielding skirts and wrasse shelters
- Other nets than the net enclosure, such as jumping nets or bird nets
- Net cleaning systems (only metal accounted)

Valuable information and assumptions:

- There are large variations in how fish farms are equipped. The material accounting assumes of 10 pens and one feed raft.
- The most common size of pens installed today is 160 meters circumference, despite the average size of existing pens being 135 meters circumference.
- Assume all rings used are plastic rings, and only plastic, as produced by AKVA group. With other producer’s parts may be metal.
- Assume all pens are plastic. (We know some are metal.)
- Feeding systems are assumed to be all metal (except feeding pipes)but are likely to contain plastic.
- The material accounting was done in 2017, but the number of pens in Norway appears fairly stable (Fiskeridirektoratet, 2021). This is confirmed in MEPEX (Sundt *et al.*, 2018), where they indicate that

environmental concerns are limiting the growth in the short term and point out that pens used today have a lifetime of up to 20 years.

- In the longer term, we can expect plastic amounts to grow significantly. This based on the growth in size of pens (Hognes and Skaar, 2017), and on ambitions both in government and the aquaculture industry (Sundt *et al.*, 2018).

Figure 2 and Figure 3 show examples of some of the components in a fish farm (AKVA group, 2017b).

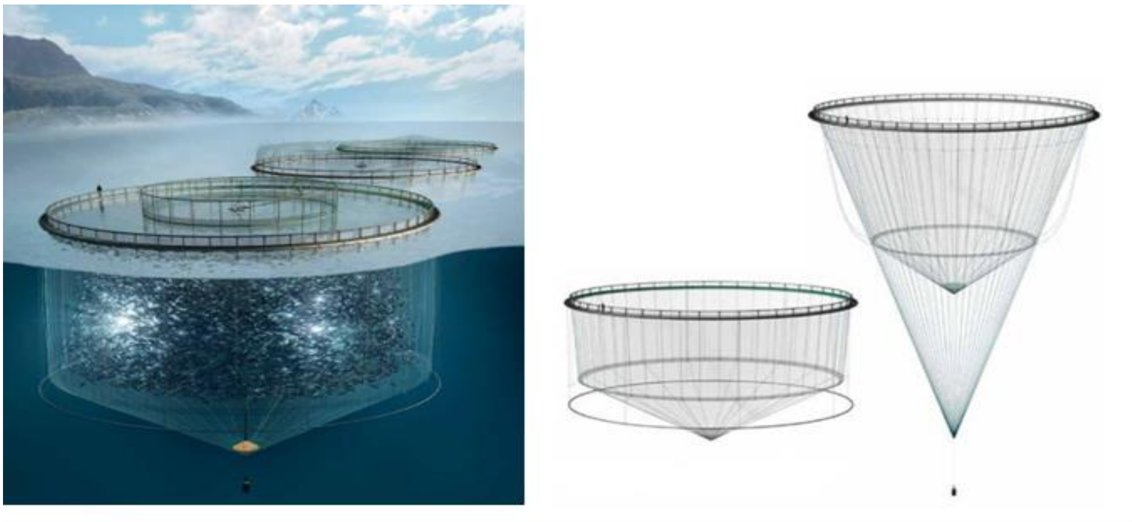


Figure 5 Left: Fish pens with fish inside; Right: Fish pens of HDPE plastic come in different sizes and models (AKVA group, 2017b)

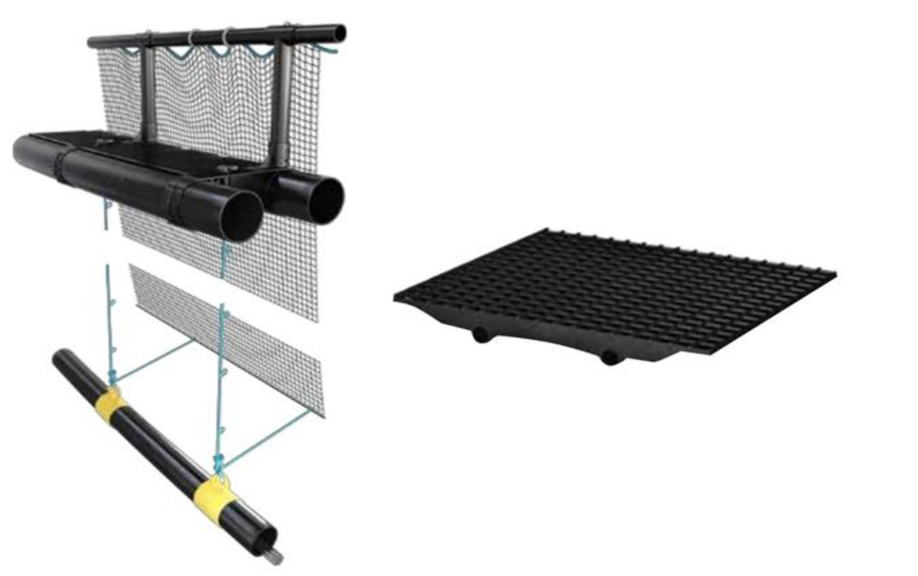


Figure 6 Components of an HDPE pen. Left: Flotation rings on the top, bottom ring with wire inside on the bottom. Right: Walkway (AKVA group, 2017b)

The distribution of the plastic from the material accounting by component is shown in Table 3 (Hognes and Skaar, 2017) with the last column giving more detail on specific components (Sundt *et al.*, 2018).

Table 4 Material accounts of plastic in Norwegian ocean-based aquaculture (Hognes and Skaar, 2017; Sundt *et al.*, 2018)

Components	Basis for estimate	Plastic (tonnes)	Uncertainties	Common polymers	Comments and trends (MEPEX, 2018)
Mooring for rings and feed raft, rope/nylon	Estimated by normalising data from fish farm with 10 pens by number of pens and multiplying by total number of pens (5,500). For a fish farm with 10 pens: 18,936 m rope and 31 buoys.	17,201	Lengths and amounts of moorings will vary substantially based on environmental conditions and size of farm. Values are based on data from a small number of fish farms.	Nylon/PA (see Table 1 and (Hognes and Skaar, 2017)), PET, PP (see Table 3)	**Buoys / floats / fenders**: Often several materials in one product. **Trend**: From steel to plastic, lighter and easier, less risk in handling, price. **Rope**: Everything is imported from large suppliers in Asia. Often mixed with misc. materials. **Trend**: Smart ropes (EEE – electrical and electronic equipment)
Floatation rings including walkway	Average circumference 135 m. With 500 mm pipes the weight including walkway is 19,710 kg. A total of 5,500 rings.	108,405	Large variations in thickness of pipes used for the rings. Here all components are assumed to be plastic, but many rings also include components of metal.	HDPE, PVC (see Table 3 and (MEPEX, 2018)), PUR, EPS (MEPEX, 2018)	
Bottom rings	All 5,500 rings have a bottom ring made from 2,856 kg plastic and 4,900 kg wire (metal).	15,708		HDPE, EPS, other plastic (Hognes and Skaar, 2017)	A wire is inserted, often a used wire.
Hamster wheel	All 5,500 rings have a hamster wheel of 1,285 kg.	7,068	How many fish farms use hamster wheels has not been assessed, but similar installations, such as poles for bird nets, are used by most.	Nylon/PA & other plastics (Hognes and Skaar, 2017) HDPE (MEPEX, 2018)	Holds the bird net up, a horizontal wheel made from plastic pipes. 10 % of facilities have this, others have poles on the collar holding the bird nets.
Nets	All 5,500 rings have 3 nets, each weighing 2,156 kg.	35,574	The assumption of 3 nets per active pens is assumed to be a high, but not unreasonable estimate.	Nylon/PA (see Table 3 and (Hognes and Skaar, 2017)) HDPE, PP, UHM w-PE (see Table 1), PA6, HDPE (MEPEX, 2018)	Nylon/PA: Most common materials. Often produced in Asia, requires a lot of manual labour, but designed in Norway. Dyneema: Used as strengthening for nets.

Feeding pipes	All 779 locations have 3,000 m feeding pipes, each weighing 1,900 grams/meter.	4,440	Large variations. Reports about 3,000 to 5,000 meters. A common length of a pipe is 300 m.	HDPE, PEX (Hognes and Skaar, 2017; MEPEX, 2018) FRP, HDPE, PVC (see Table 3), PE (see Table 8)	Normally 90 mm plastic pipe
Shielding skirts	Assume 70 % of pens in Norwegian aquaculture (5,500 pens) are equipped with shielding skirts which are 6 m deep and consist of 276 kg polyester/PVC and 556 kg lead. The circumference of the skirts is set to 3 % longer than the pen (135 m). The weight of polyester canvas/mesh in 270 grams/m^2 and PVC 1000 grams/m^2.	1,063	There is no certain data on how many pens have shielding skirts installed, but most of the interviewed assumed it applied to most pens and would soon be close to all.	Top meter: PVC (900-1200 g/m2); lower part: polyester or similar (240-320 g/m2) (Hognes and Skaar, 2017), PVC, PA, polyester (MEPEX, 2018)	
Wrasse shelters	Assume 70 % of pens (5,500 pens) are equipped with 4 shelters, each consisting of 35 kg PE plastic and 35 kg lead.	770		PE (Hognes and Skaar, 2017), HDPE (MEPEX, 2018)	Different types. Pipes glued together as a shelter, like a kelp forest
Ropes: consumption ropes, not mooring. Rope of 10-30 mm.	Assume that per licence per year 1,632 kg rope is used, at a total of 962 licenses.	1,570	Data is only from two companies. Shows large variations, from just over 200 to more than 1,600 kg (15,600 m) rope per licence per year.	PP, HDPE, nylon/PA, PE, PET, UHMWPE (see Table 3)	

This material accounting only includes the offshore activities. Up to the smolt stage, at the age of approximately one year and size of ca. 100 grams, the fish are bred in a fish hatchery. These are onshore facilities where the fish lives in tanks made with plastics and other materials (Måsøval Fiskeoppdrett AS, 2021; SinkabergHansen, 2021). The plastics used in the onshore tank facilities are not included in the calculations.

Plastic used for packaging and transport of the fish, packaging for fish feed, fish crates and boxes are also not included in this material accounting.

3.3 The environmental impacts of plastic

Plastic production has increased dramatically worldwide over the last 60 years, and is still increasing, with current production at more than 300 million tonnes yearly (Plastics Europe, 2013), rapidly moving closer to 400 million tonnes (Statista, 2021). Exactly how long plastic can remain in nature is difficult to predict as there has been insufficient time to evaluate its true persistence. Further, the degradation of plastic depends heavily on the environmental compartment it ends up in, i.e., soil vs water, warm climate vs cold climate. It is known that most plastics persist in the environment for at least decades. Furthermore, it has been estimated that between 60 and 80% of the world's litter is in the form of plastic (Nerland *et al.*, 2014).

Plastic manufacturing consumes significant quantities of petrochemicals: in Europe, for example, it accounts for roughly 4–6% of all oil and gas use, according to industry group Plastics Europe. Since plastics are interwoven with the petrochemical industry, they are subject to its fluctuations, geo-politics, and contributions to CO_2 emissions (CS3, 2020). Discarded plastic pollutes the natural world, with microplastics and nano plastics being detected in many ecosystems.

Microplastics are also rising contaminants in aquaculture, with microplastics entering the facilities through both water and food (Vázquez-Rowe, Ita-Nagy and Kahhat, 2021; Iheanacho *et al.*, 2023).

3.3.1 Plastic waste in marine environments

Defining the marine litter problem is complex as there are many different sources and forms of litter that can enter the oceans. Plastic items are consistently the most abundant type of marine debris found around the globe and can amount to more than 80 percent of reported debris. Estimates have shown that between 4.8 million and 12.7 million tonnes of plastic waste were released into the sea in 2010. Abandoned, lost and discarded fishing gear (ALDFG) is considered by the fisheries and aquaculture sectors to be the main source of plastic waste, but its relative contribution at regional and global level is not well known (Macfadyen, Huntington and Cappell, 2009, 2009; UNEP, 2016; Huntington, 2019).

Table 5 shows the size definitions of marine plastic litter and common sources.

Table 5 Summary of size definitions of marine plastic litter and common sources (Lusher, Hollman and Mendoza-Hill, 2017)

Size category of marine litter	Longest dimension				
	Nano < 0.1 µm	Micro < 5 mm	Meso < 2.5 cm	Macro < 1 m	Mega >1 m
Source	Primary nanoplastics Secondary fragmentation of microplastics	Primary microplastics Secondary fragmentation of larger plastic items	Direct and indirect: including fragmentation	Direct: lost items from maritime activities	Direct: abandoned gears Indirect: land based waste
Examples	PRIMARY: Industrial applications including pharmaceuticals and the medical device industry SECONDARY: microplastic fragments	Primary: Resin pellets Secondary: fragments and fibres	Bottle caps, plastic fragments	Plastic bags, food and other packaging, fishing floats, buoys, balloons	Abandoned fishing nets and traps, ropes, boat hulls, plastic films from agriculture

3.3.2 Loss from aquaculture

There are several general causes for the loss of plastics from aquaculture operations into the environment. In this context, *three different categories* are described:

1)*the loss of plastic through mismanagement* (e.g. poor waste management, poor placement, installation and maintenance, inadequate recycling, farm decommissioning, and lack of awareness and training),

2)*deliberate discharge* (due to high costs of removal or collection or possible vandalism by poachers or recreational fishermen wanting to release caged stock) and

3)*extreme weather conditions* where large storms cause high winds, large waves and heavy rainfall (lost debris from aquaculture operations, damaged and destroyed cages).

Aquaculture systems in coastal or marine situations are most vulnerable to both chronic, low level plastic loss through poor equipment installation, maintenance, and waste management, as well as possible larger-scale loss from catastrophic, weather-related events.

From 2018 to 2019 the project HAVPLAST was carried out, financed by the Norwegian Seafood Research Fund (FHF) and lead by SALT, a consultancy focused on marine littering in Norway. The project was aimed at identifying sources, amounts and causes of marine plastic littering from fisheries and aquaculture, and contribute to preventing future pollution (Johnsen *et al.*, 2019). For aquaculture they did downstream waste collection and deep dive analysis[1] in five locations to assess amounts of plastic lost from aquaculture. Table 6 gives an overview of the most common objects found, with plausible causes for loss and measures that can be taken to avoid such losses. The causes of loss in the table are based on industry members' assumptions about how the waste ended up in the ocean, and the measures are based on suggestions both from industry and SALT (Vangelsten *et al.*, 2019)

Table 6 Overview of objects often lost, examples of causes of loss and preventative measures (Vangelsten *et al.*, 2019)

Object	Cause of loss	Measures to improve
Pens	Damage due to severe weather	Public database of damages for clean-up and reuse
Pens	Donations of outdated equipment	Deliver outdated equipment to waste treatment companies

Parts of pens: handrails, feeding pipes, walkways and joins for walkways	Lost during transport to shore	Increased focus on securing items during transport
Parts of pens: handrails, feeding pipes, walkways and joins for walkways	Blown to sea during storms, because of inadequate securing of parts	Improve routines for securing parts during storage and use. Loose objects to be stored indoors or in closed storage containers.
Parts of feeding pipes lost	Lost during cutting of blocked pipes	Increased focus on environmental awareness with employees
Pipe cleaning balls lost	Lost during pipe cleaning	Use collection solutions at the end of feeding pipes
Polystyrene lost	Lost during replacement of floating devices and inadequate securing pending transportation to waste treatment	Improve securing of items during transportation and storage
General waste lost	Varying causes	Focus on marking of equipment, attitudes, and routines; securing of waste during transport and operations; good waste solutions at the facilities
Different types of ropes	Varying causes	Focus on marking of equipment, improvement of equipment and replacing equipment before it wears out
Feed bags and bits of feed bags	Lost when bags are cut open at the bottom, and by inadequate securing during transport and at port	Production requirements to suppliers, improve securing during transport and storage on shore

Overall, the HAVPLAST project found that the share of waste from aquaculture was minor compared to the total amount of waste collected (between 2 and 15 %). The exception was one location where there had been recent storms that caused large damage to the pens, and where aquaculture stood for half of the waste collected (Vangelsten *et al.*, 2019). This is in accordance with the study by Hognes and Skaar (Hognes and Skaar, 2017), where they conclude that it is unlikely the Norwegian aquaculture facilities contribute considerably to marine littering. A more recent report from the Norwegian Centre against Marine Litter concludes that a certain proportion of litter from sea-based sources has been registered as fishing-related, even though it originates from the aquaculture industry, due to difficulty in assessing whether fishing or aquaculture is the source. They conclude that the aquaculture industry is probably underrepresented in findings from literature (MARFO, Senter mot marin forsøpling, 2022).

3.3.3 Microplastics

Plastic pollution has serious impacts on our natural environment. In 2012, the United Nations estimated that plastic waste killed roughly one million seabirds and more than 100,000 marine mammals each year. Plastic in the form of exceedingly small particles (<5 mm), called microplastic, can be found in coastal areas and offshore and are of concern as they have a direct impact on marine species.

So-called ”primary” microplastics can originate from industrial products, such as resin pellets, while “secondary” microplastics arise from the fragmentation of larger plastic pieces in the environment due to abrasion or degradation processes (MEPEX, 2014; Nerland *et al.*, 2014; EFSA, 2016; Sherrington *et al.*, 2016; UNEP, 2016; Kalogerakis *et al.*, 2017)

Microplastics can enter aquatic environments via different pathways, and they have been documented in all environmental matrices (beaches, sediments, surface water and water column). They stand for an increasing proportion of marine debris and to date several modelling studies have tried to identify sources, distribution, and accumulation areas (Lusher, Hollman and Mendoza-Hill, 2017).

3.3.4 Microplastics from aquaculture

Aquaculture activities also generate microplastics and in certain field studies it has been possible to source ingested microplastics to fisheries and aquaculture activities. In the HAVPLAST project (Vangelsten *et al.*, 2019) a model simulation was performed to estimate the amount of microplastic generated through the use of feeding pipes. The simulations indicate national emissions of microplastic from feeding pipes to be around 10 to 100 tonnes per year, with the best estimates putting the emissions in the same range as microplastics from laundry (60 tonnes), which is around 1-5 % of the microplastics from car tyres ending up in the ocean (2,250 tonnes) (Johnsen *et al.*, 2019; Vangelsten *et al.*, 2019).

Ropes and other components in a fish farm will be exposed to abrasion and wearing. According to MEPEX (MEPEX, 2014) the amount of micro-plastics produced by abrasion in an aquaculture facility is "in the range of a few kilograms". However, material tests on synthetic ropes and fibres have shown that UV weathering and abrasion of poorly maintained equipment can be significant (Klust, 1991). Biodegradable plastics also form microplastics as a result of weathering, UV-irridation and mechanical forces as a part of the degradation process (Krauklis *et al.*, 2022).

3.4 Circular economy in aquaculture

In this chapter we will take a closer look at a few practices moving us closer to a sustainable scenario: recycling, reuse and rental of equipment, and waste collection.

3.4.1 Circular economy

In tandem with a global expanded emphasis on sustainability, the idea of a Circular Economy (CE) has received increasing interest from politicians and industrialists around the world. In simple terms, a CE can be regarded as a direct counterpart to the conventional linear economy, representing a shift from the take-make-dispose economy to a regenerative circular economy (Bjørnbet *et al.*, 2021). Hence, a CE is generally regarded as a sustainable economic model that intends to provide value to both the society, the economy, and the environment (Ellen Macarthur Foundation, 2013; Lieder and Rashid, 2016; Kristoffersen *et al.*, 2020). CE can be defined as “an industrial system that is restorative or regenerative by intention and design. It replaces the ‘end-of-life’ concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models” (Ellen Macarthur Foundation, 2013)

In traditional manufacturing, virgin materials are extracted from nature, manufactured into stocks, utilized, and finally treated as waste. In strong contrast, a CE aims to “design out” waste by designing and optimizing products for “a cycle of disassembly and reuse” (Ellen Macarthur Foundation, 2013). In other words, the design phase of a product has great importance to make sure that products and materials stay in the circle. Furthermore, a CE intends to replace users with consumers.

3.4.2 R-strategies

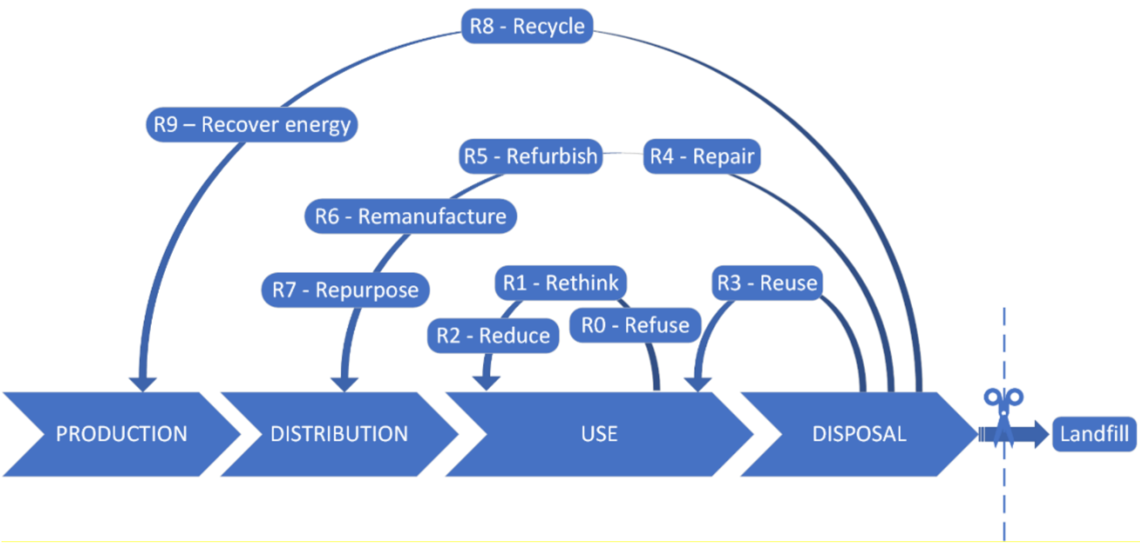
Several authors highlight the 3Rs as the most common principles of CE (Ghisellini, Cialani and Ulgiati, 2016; Lieder and Rashid, 2016; Kirchherr, Reike and Hekkert, 2017). Generally, the 3Rs stand for Reduce, Reuse, and Recycle. However, in recent years, questions have been raised concerning the inconsistencies in the conceptualization of the 3Rs. These questions stem from the fact that various authors refer to dissimilar numbers of the Rs (from 3Rs, 4Rs, 5Rs, and so on), as well as giving the R-terms different meanings (Reike, Vermeulen and Witjes, 2018)).As a result of this uncertainty surrounding the R-strategies, we propose a framework of R-strategies based on the literature review in this research field. The R-strategies we propose are inspired by the R-frameworks of both Reike et al. and Kircherr et al., as both authors propose R-frameworks based on studies of a vast majority of literature.

Combined framework:

Circular strategies		**Description of strategy**
Smarter product use & manufacturing	R0 Refuse	Users are stressed to buy and consume less, whereas producers should refuse to use virgin and hazardous materials.
	R1 Rethink	Rethink your business model and the need for materials.
	R2 Reduce	Reduce the use of virgin and hazardous materials in all stages of a product’s life cycle.
Extend lifespan of products and its parts	R3 Reuse	Increase products’ lifetime by reparation so it can be used with its original function.
	R4 Repair	Consumers are encouraged to buy second-hand products rather than first-hand products.
	R5 Refurbish	Restore old products and bring them up to the state-of-art.
	R6 Remanufacture	Use parts of discarded products in a new product with the same function

	R7 Repurpose	Reuse discarded products or components for another use.
Useful application of materials	R8 Recycle	Convert materials that would otherwise be considered waste, into new materials or products.
	R9 Recover	Incineration of materials with energy recovery
	R10 Re-mining	The extraction of materials and valuable resources from landfills

Source: POCOplast project production, based on Kircherr et al. (2017) and Reike et al. (2018).



Figur 1 R-strategies related to linear value chain, based on (Potting *et al.*, 2017; Geissdoerfer *et al.*, 2020)

3.4.3 Reaching a circular economy for plastics

In a circular economy, the aim is to keep the materials as materials for as long as possible, minimising waste and material outtake. This implies recycling is the only correct way to treat plastic waste. However, in our current system and given some of the previously discussed challenges for recycling, the picture can be more complex. In the case of very long transport distances, such as in the north of Norway or where recycling is unavailable in Norway as is the case for nets from aquaculture, incineration with energy recovery might make more sense than recycling. If there is a local need for heat, then more "short travelled" energy recovery will often give a smaller environmental footprint than recycling. This is the case for COAS, who have found an alternative to exporting the nets from aquaculture for recycling. Instead, the nets are shredded and sent to NORCEM, a cement producer, where it can replace coal. The combustion of plastic for cement production is high-energy combustion, which is more energy efficient than regular incineration of municipal waste for district heating and leaves a smaller amount of ash, and the ash is also used in the cement to further reduce emissions. This means transport emissions as well as the cement production emissions are reduced. This solution will make sense if the plastic waste is replacing coal and as long as there are no recycling options within a reasonable distance. There are no absolute answers for these considerations, and the best options will depend on materials, distances/logistics and systems available and change with changing conditions. It shows how important holistic considerations are in relation to environmental accounting, and it is important to have updated information about waste treatment options and conditions specific to each case. As the recycling industry in Norway develops and expands, net recycling might become possible in Norway, which will change the considerations in the above example, and shows the importance of updated information (Hognes and Skaar, 2017; Lindberg, 2021).

3.4.4 Reuse and rental of equipment

There has been a tradition of aquaculture equipment being donated to local farmers for reuse, e.g. old ropes so they didn't have to buy new, and pipes to use as drainage pipes. Parts of pens would also be donated, such as handrails to be used as fences, flotation rings to be used for boat mooring, or rings and pipes to be used for floating docks. These practices have largely been discontinued, as this type of donation often leads to intermediate storage during which the equipment may get lost to nature, or the storage becomes permanent, both of which cause littering problems (Hognes and Skaar, 2017; Sundt *et al.*, 2018; Vangelsten *et al.*, 2019)). There is one example, also listed in Table 11, of a company, Havretur, that reuses flotation rings for floating docks. According to Havretur there have been several similar companies and initiatives along the coast, but due to the laborious nature and low profitability of such activities, most have given up. This is a general problem for plastic products. In several cases there are options for reuse and possibilities for repair for reuse, but due to the low price of new plastic products, new products are often chosen over good but laborious solutions for reuse. Strict quality requirements also contribute to the choice of new equipment over old, e.g. for ropes (Sundt *et al.*, 2018).

This does not mean there is no reuse of aquaculture components. Some examples of reuse that still happens are (Sundt *et al.*, 2018):

- Flotation collars can be sold to a different aquaculture company, or used in a different location;
- Flotation collars can be chopped up and used as service pipes, floating docks, etc;
- Walkways can be reused in new facilities;
- Wires in bottom rings can be reused in new bottom rings;
- Buoys can be used by others for similar purposes;
- Bird nets can be used for football pitches;
- Ropes can be used by others or retwined.

Collected ropes are often sent to repair for reuse in the form of retwining, often in countries like India, Indonesia and Malaysia. These spliced ropes can then be sold for 80 % of the price of new ropes. The sale of collected ropes for reuse is usually more economically profitable than sale for recycling. The waste collectors estimate that 50-60 % of used rope in Norway is landfilled (Sundt *et al.*, 2018)

One option to facilitate reuse, is by renting equipment rather than buying it – equipment as a service. When the equipment needs replacing, it goes back to the supplier. This means equipment that is not worn out can be reused elsewhere, and at the end of its lifetime it is the one with the best knowledge of the materials that decides how to dispose of the equipment (Hognes and Skaar, 2017). This is beneficial both for reuse and for recycling. An example of such equipment rental is with AKVA group (AKVA group, 2017b), where the rental agreement includes transport of the rental equipment, installation and start-up, training in use, service and support, free repairs and replacements, a fixed price for the rental period, no front-end fee, and free access to support. Examples of equipment that can be rented are feed systems, feed accessories, camera systems, environmental sensors, infrastructure, dead fish systems, underwater lights, washing systems and subsea feeders.

3.4.5 Logging and documentation

The lack of data is also noted by Hognes and Skaar (Hognes and Skaar, 2017). However, they did interviews with aquaculture companies and waste companies and found that there are systems in place for registering data. All the aquaculture companies interviewed used systems and software to register all equipment that needs to be certified and have a maintenance plan. Examples of such programs are AKVA group's Fishtalk Equipment (AKVA Group, 2022) and Havbruksloggen (Havbruksloggen, 2021). Large components are registered, but not consumables such as ropes. No companies had any systems registering all equipment coming to the facilities and going out of the facilities, as waste, for reuse or for recycling (Hognes and Skaar, 2017).

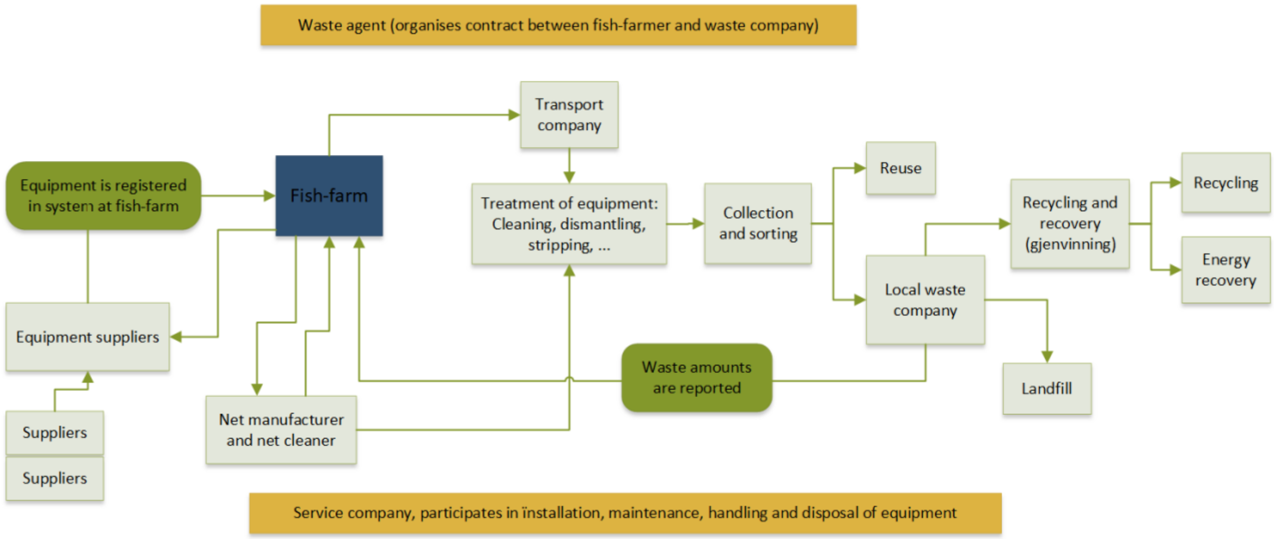


Figure 5 Actors, mass and information flow in the material flows in an aquaculture facility (Hognes and Skaar, 2017)

Waste companies reported that they have data on amounts and types of waste, can easily report this to each customer, and most can aggregate the results for the aquaculture industry (Hognes and Skaar, 2017).

This shows that there is a lot of data out there, but there is no central system gathering this data and making it available to the industry or researchers. This is also one of the concrete points of improvements mentioned in the HAVPLAST final report (Johnsen *et al.*, 2019): logging plastic in the value chain. This is mentioned as a key component to reaching a more sustainable way of dealing with different materials in aquaculture, and must stretch across the value chain, from suppliers to aquaculture operators to the waste companies. By sharing information through the value chain, the different actors can make more informed decisions and put pressure on each other to improve the value chain. Currently, aquaculture operators do not document the waste they deliver, neither amounts, nor sorting or further treatment. Nor do they assess the best options for treatment of their waste but trust the waste companies to make the best decisions (Vangelsten *et al.*, 2019). This way, the aquaculture operators are not able to know what happens to their waste, nor in a position to put any demands or pressure on the waste companies. Recycling companies interviewed for Hognes and Skaar's study (Hognes and Skaar, 2017) referred to aquaculture companies as "easy customers with low demands". Several informants in the HAVPLAST project mentioned that they wish to have a material accounting of their equipment and consumables, i.e., as detailed and thorough a logging of material flows as possible. To measure progress, they must know where they are today, in terms of amounts of plastic produced and recycled (Vangelsten *et al.*, 2019). In practice, this means setting up a material balance of the facility: Registering everything that comes into the facility and register where everything goes when it leaves the facility's control (Hognes and Skaar, 2017). MEPEX (Sundt *et al.*, 2018) indicate that the topic of waste and waste treatment in aquaculture has had a low priority with both the industry and the authorities, meaning that there has been no demand for documentation to drive the documentation development.

How to achieve the necessary documentation is an important question. Government regulations and reporting requirements will play a key role in creating framework conditions that will speed up the transition to more a sustainable scenario. In addition to securing better traceability and documentation, clearly defined goals, requirements, controls and sanctions are important. Experience shows that without this, industry rarely aims higher than the minimum requirements (Sundt *et al.*, 2018). However, it is important such regulations are not too demanding for the aquaculture companies to comply with. In the HAVPLAST project, several measures to integrate logging and documentation into already existing practices and systems were suggested (Vangelsten *et al.*, 2019)

- Logging can be added as a routine in relation to purchases and accounting, registering information about amounts, weight, and characteristics of the plastic together with the economic data.
- Another way is to make logging part of the HSE routines at the facility.
- When delivering waste to a waste company, logging should be integrated into the waste handling routines.

We see similar possibilities mentioned in Hognes and Skaar's study (Hognes and Skaar, 2017):

- Aquaculture operators think the already implemented software and systems for equipment maintenance and certifications could be expanded to include a larger share of the materials, such as consumables. A connection to accounting systems can automate the registration.
- The economic accounts already include data which would make an important part of a material accounting: Purchases of equipment without certification requirements; amounts of waste delivered, as it is part of the invoice from the waste companies; and sales or transfers of equipment, which will be entered as a depreciation of capital or as an income.
- The waste companies have data on amounts delivered and where it goes and should be able to report on this. The construction industry already has such reporting requirements, in addition to requirements to sort at least 60 % of the waste into different waste types, prepare a final report on actual disposal of the waste, and document that waste has been delivered to an approved waste treatment or recycling facility.

In addition to these existing tools, data and practices, standard templates and reports should be established, in cooperation between the actors in the value chain, to facilitate both the reporting and the compilation of the documented data. Industry organisations can contribute with coordination between the actors in the value chain, and templates and efficient routines should be implemented into existing reporting systems. It is essential that the purpose of the logging is communicated to the whole organisation, so the workers in the aquaculture facilities will see it as a valuable tool in the combat again plastic pollution, and not just extra work (Hognes and Skaar, 2017; Vangelsten *et al.*, 2019). Several ongoing research- and development projects in aquaculture are working on documentation- and traceability through the value chain (SirkAQ.no, 2023; *Shiftplastics.no*, 2023).

If reporting is done in a standardised way, making the aggregated data available through a database will be invaluable for research. Such a database on amounts of plastic would also be a great resource for recycling companies to get more predictability for their feedstocks, as well as for authorities to be able to set goals on reduction of plastic use or recycling. Having current stocks of plastic in the system, with estimated lifetimes, will give longer-term predictability of plastic waste flows, which can make it easier to plan and build infrastructure to handle the plastic at the end of its lifetime.

3.5 Recycling

The aquaculture industry is the largest producer of rigid plastic in Norway, and the volume is expected to grow significantly in the coming years. Only a small proportion is recycled today, so the need to increase the recycling rate is great, at the same time as the need for use must also be reduced. The annual production of plastics currently stands at almost 360 million tons per year (CS3, 2020).

In the last years it has become more difficult for Europe to get rid of their plastic waste. China imported two thirds of global plastic waste in 2016, before banning imports of most plastic wastes in January 2018 (Huang *et al.*, 2020). Malaysia, Vietnam, and Thailand have implemented similar bans, and the EU's European Green Deal aims to stop exporting waste out of the EU (Nørstebø *et al.*, 2020). This implies that Norway, the Nordic countries, and the EU should develop and expand their own recycling industry. This is seen as an important part of the circular economy initiatives in Norway and in Europe (Sundt *et al.*, 2018).

MEPEX (Sundt *et al.*, 2018) compares earlier reports from MEPEX to the current situation, finding that the share of plastic waste from aquaculture and fisheries being recycled is increasing. This is however not well documented.

3.5.1 Amounts for recycling

To develop good recycling schemes, recyclers must know how much and which types of used plastic will be available for them to process. In relation to their material accounting, Hognes and Skaar (Hognes and Skaar, 2017) estimated the amount of plastic that will become waste every year, by using expected lifetimes of the different components. Uncertainties are high, as the reasons for replacing equipment will vary. For some components, such as feeding pipes, experience about wear and tear gives good data on how often they need replacing. For other larger components, strategic decisions such as a desired change in technology or size may decide replacement intervals, making them irregular. Changes in regulations may also lead to major replacements, increasing the waste streams; or the opposite, when limitations of number of fish per pen were implemented (Hognes and Skaar, 2017).

Table 9 shows a range of potential amounts of plastic waste, based on a high and a low estimate on lifetimes. For more details about the assumptions, see Hognes and Skaar (Hognes and Skaar, 2017).

Table 9 Potential plastic waste amounts per year (Hognes and Skaar, 2017)

	Lifetime (years)		Plastic waste (tonnes / year)	
Component	**High**	**Low**	**High lifetime**	**Low lifetime**
Mooring for rings and feed raft, rope/nylon	15	8	1,147	2,150
Floatation rings including walkway	20	10	5,420	10,841
Bottom rings	20	10	785	1,571
Hamster wheel	20	10	353	707
Nets	6	5	5,929	7,115
Feeding pipes	4	1	1,110	4,440
Shielding skirts	6	3	177	354
Wrasse shelters	7	3	110	257
Ropes: consumption ropes, not mooring.	2	1	785	1,570
TOTAL			**15,817**	**29,004**

MEPEX (Sundt *et al.*, 2018) expanded on this estimate, using experience from amongst others waste companies who indicated the amount of rope and feeding pipes were too low, and concluded with an estimate of 25,000 tonnes plastic waste per year. A newer report published by the Norwegian Retailers' Environment Fund includes fishery together with aquaculture, with a total of 31 000 tonnes of durable plastics from the industries per year (Systemiq, Handelens Miljøfond, and Mepex, 2023).

Table 10 gives detail on waste amounts versus recycled amounts, and some comments on recycling possibilities.

Table 10 Estimates for recycled plastic equipment (Sundt *et al.*, 2018)

Component	Plastic waste (tonnes / yr)	Plastic recycled (tonnes / yr)	Comments Recycling vs other disposal
Mooring for rings and feed raft, rope/nylon	2,150	2,000	Estimate based on a total market for ropes of 8,000 tonnes in total (not 2,150). Includes retwining/repair for reuse. A lot of mixed rope still landfilled; smaller items also incinerated.
Floatation rings including walkway	8,100	3,000	Regional differences. Costly collection and treatment. Requires reimbursement for the job. Some goes to reuse / repair for reuse. Still some intermediate storage. Landfilling rare.
Bottom rings	1,200	500	Uncertainty about dumping due to complicated handling.
Hamster wheel	500	200	Accompanies flotation rings.
Nets	6,500	3,000	Uncertainties due to difficult market conditions for PA. Intermediate storage. Other disposal.
Feeding pipes	4,400	2,000	Regional differences. Easy to grind up for recycling. Still some landfilling.
Shielding skirts	250	0	Complex material, landfilled.
Wrasse shelters	200	0	Complex material, landfilled.
Ropes: consumption ropes, not mooring.	1,570	0	Included in ropes above.
TOTAL	**24,670**	**10,700**	

3.5.2 Recycling process

The recycling process for plastic varies depending on the product and the plastic types. For products containing only one type of plastic, such as HDPE pipes and rings, the plastic will typically be cut or ground up, to simplify transport, and sent to mechanical recycling. An example of this is NOPREC, which will receive and mechanically recycle HDPE and clean PP ropes into granules. These granules can then be used directly to produce new products, like Plasto who produce new aquaculture products with the recycled HDPE from NOPREC – an example of a closed loop (Sundt *et al.*, 2018).

Products with several types of plastic must be dismantled, separating the different types. Products with coatings or impregnations must be cleaned before recycling. These pre-processing activities can happen at the aquaculture facility (sorting and dismantling) or at specialised waste companies. For some examples of the latter, see Table 11.

To go into further detail, the process of Nofir is investigated. In Figure 4, these pre-processing activities are summed up as manual sorting, as there are currently no good technologies to automate most of this sorting and cleaning of tangled nets and ropes, and it is therefore done manually. After pre-processing PP-plastic is sent to mechanical recycling, where it is processed into granules, and PA/nylon is sent to chemical recycling at Aquafil in Slovenia, where it is processed into caprolactam. The caprolactam is used to produce Econyl, a nylon yarn used for example in the textile industry (Brodbeck, 2016; Sundt *et al.*, 2018).

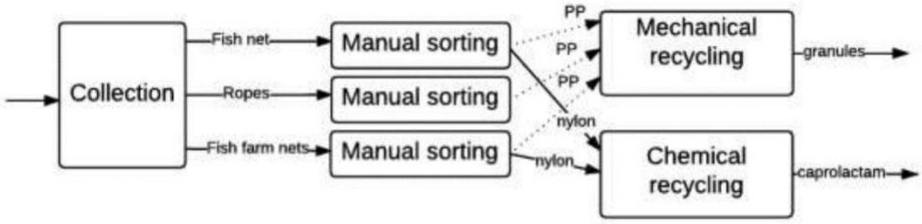


Figure 6 Diagram illustrating how fish nets, fish farming nets and rope can be recycled, based on process at Nofir/Aquafil (Brodbeck, 2016).

Another example is Quantafuel, which has a pilot-plant for chemical recycling of polyolefines (PE, PP) in Kristiansund were they use a multi-step process (pyrolysis, purification, a catalytic process, distillation) to prepare three liquid oil fractions. These oils are then used by BASF in their chemical production to prepare new plastics or other chemical products. Quantafuel built this pilot-plant in the same facility as Replast's mechanical recycling plant, to be able to recycle a higher fraction of the waste, as the recycling process can be chosen based on the most appropriate technology. Mechanical recycling requires the plastic to be clean and in pure fractions, while chemical recycling, as done by Quantafuel, has a higher tolerance for impurities, as well as mixed plastic fractions (Krogstad, 2021; Quantafuel.com, 2021a, 2021b).

3.5.2.1 Improving properties of recyclates

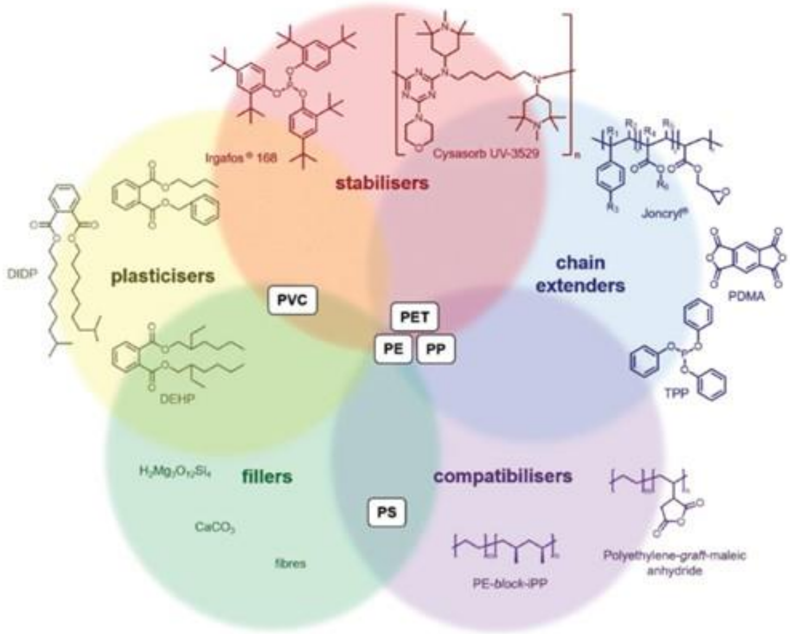


Figure 6 Common polymer additives used to improve polymer recyclates (Schyns and Shaver, 2021)

Mechanically recycled plastic often has a lower quality compared to virgin material. This quality reduction stems from both the use phase of the plastic, with exposure to sun (UV radiation) and the other elements; and from the recycling process itself. The melting required for extrusion causes the polymer chains to shorten and free radicals cause chain branching / cross-linking of chains. In addition, stabilisers and antioxidants present in the plastic are used. Experience shows a significant change of mechanical and rheological properties after about 4-5 life cycles. To increase the quality, new stabilisers and antioxidants can be added. The source, condition of the material, amount of degradation that has occurred during processing, impurities, and targeted application are the main criteria that determine the type and amount of additive(s) added to a recyclate. These different factors make it difficult to provide general guidelines but careful adjustment of the concentration of the various additive components provides the basis for manufacturing tailor-made products. To know better when to use which additives, it would be useful if the plastic materials could be tracked and thus for example one would know how many life cycles it has been through.

3.5.3 Challenges for recycling

In theory almost all plastic can be recycled. However, in practice there are many challenges that reduce recyclability and the amount sent to recycling. Examples are volumes of waste for a successful market, available technologies, need for pre-treatment and the existence of a market for the recycled plastic (Sundt *et al.*, 2018)). Global plastic material flow, strongly differing regional waste management systems and lack of international recycling standards are other systemic hinders for increased recycling (Shamsuyeva and Endres, 2021). We will now look closer at some of these challenges, related to the characteristics of the components or materials to be recycled; to variations in classifications and labelling, attitudes and work practices, and costs in all parts of the value chain; external factors such as (a lack of) regulations; and to insufficient overview and communication in the market.

3.5.3.1 Material specific challenges

Many components contain mixed materials. This can be a mix of different types of plastic, a mix of plastic and other materials, such as metal reinforcements (typically for ropes), different types of coatings and impregnations, or the addition of colour. Some ropes can be coated in PU (polyurethane), and nets are usually impregnated with copper and waxed. These mixes and treatments can make the components either difficult or impossible to recycle,or lead to demanding pre-treatment processes (such as cleaning of impregnated and waxed nets) that make the recycling process complex and costly. The addition of the colourant carbon black is also a known complicating factor, as advanced sorting technology struggles with the black colour (Sundt *et al.*, 2018).

Other examples of challenging plastics are strong plastic types such as Dyneema (ultra-high molecular weight polyethylene (UHMWPE) or high modulus polyethylene (HMPE), used in nets and ropes for mooring), which is difficult to recycle; composites and fiberglass reinforced plastics, which are currently not recycled, but ground up and used in concrete or cement production; biodegradable plastics and PEX (cross-linked polyethylene) used in feeding pipes, which are not recyclable and must not be mixed with plastics (such as HDPE pipes) going to recycling as they can ruin the whole batch of recycled plastic, even at low concentrations (Sundt *et al.*, 2018).

In addition to mentioned challenges for recycling ropes, there is a trend towards smart ropes, with sensors that can measure load on the rope to prevent it breaking and increase traceability. This way the ropes can end up as WEEE (waste electrical & electronic equipment). This adds to a more general trend of equipment becoming increasingly complex to recycle (Sundt *et al.*, 2018).

Continuing with management, labelling and work practices, we see that variations and a lack of standardisation causes problems throughout the value chain. Starting with the suppliers of equipment, an example is how manufacturers of ropes made from PP (polypropylene) have developed many different variants and brand names, with no common standard. Ropes can have different colours, look like other material (such as Hampex that looks like hemp), and be mixed with other materials, such as polyester or metals for strengthening. This is challenging for sorting and achieving clean plastic fractions for recycling (Sundt *et al.*, 2018).

3.5.3.2 Work practice specific challenges

Moving down the value chain, to the aquaculture facilities, we see how work practices and attitudes can affect how much plastic is lost to nature, as well as how much is recycled. Awareness and focus on plastic, both the harmful effects and the value of the material, will influence how plastic is handled. Inadequate maintenance has negative effects, e.g. net cleaning, where too little will make the nets wear faster, increasing the release of plastic to nature, as well as reducing the lifetime. When cutting feeding pipes and ropes and opening feed bags, work practices will affect how much plastic is released to nature through how offcuts and debris from the cutting is handled (whether flushed to sea or collected and disposed of properly). Offcuts, debris and empty feed bags must also be protected from the elements to avoid release to nature, and work practices will decide whether this is sorted properly for recycling or not. Intermediate storage of used feeding pipes and other waste going to recycling can contribute to loss to nature if not done properly, e.g. storage of feeding pipes on the seashore can lead to unnecessary wear and release of microplastics, and outdoor storage of plastic packaging can lead to the plastic blowing or being washed away (Vangelsten *et al.*, 2019)). There are also large variations between aquaculture facilities when it comes to practices for waste sorting. Generally, four different ways of dealing with the waste are described: (1) Waste is collected unsorted, at the facility, (2) Waste is collected sorted, at the facility, (3) Waste is delivered unsorted, to a waste collection point, (4) Whole components are delivered to the waste (Hognes and Skaar, 2017). More waste sorting at source could reduce the amount of plastic waste landfilled, as unsorted equipment can be difficult to handle and costly to sort at the waste plants. At some aquaculture facilities the waste is sorted and the plastic ground up to facilitate transport, while, on the other hand, some waste companies complain that the waste sorting by aquaculture facilities is too bad and a challenge for recycling. Although waste sorting can be challenging on a feed raft, the sorting can be done in the onshore facilities (Hognes and Skaar, 2017; Sundt *et al.*, 2018). This variation shows the importance of work practices and attitudes.

3.5.3.3 Waste actor specific challenges

The next step in the value chain is the waste companies. There are generally four different types of waste companies the aquaculture industry relates to: (1) National waste treatment companies, which are operating in most counties in Norway, (2) regional/local waste treatment companies, with operations limited to one or a few counties, (3) transport companies, which deliver the waste to one or more waste treatment companies, and (4) specialised waste treatment companies, such as Mørenot and Nofir (Hognes and Skaar, 2017). Within these companies, there are also large variations, for instance in terms of competence and technology availability. Many of the aquaculture facilities have a local waste treatment facility with its own landfill or incineration plant. These smaller waste companies will often lack competence on recycling and will only in the cases it is profitable sort and send the recyclable equipment to a more specialised company. Low value for secondary materials in relation to the costs of waste handling and logistics can lead to plastic being landfilled or incinerated (with energy recovery) instead of recycled (Sundt *et al.*, 2018). There are also regional differences, causing areas such as the north of Norway, with large distances and few people, to have extra challenges in their waste management. Long transport distances and complicated logistics cause the aquaculture facilities to have to store their waste for a longer time than they want (which can contribute to more loss to nature, as described previously), before it can be collected. In these areas there is typically also less capacity for collection of discarded equipment and waste, which the aquaculture facilities are requesting (Hognes and Skaar, 2017). In addition, the long distances and few customers gives a higher unit price for the waste companies, as well as a higher transport costs for the aquaculture companies (Sundt *et al.*, 2018; Vangelsten *et al.*, 2019). Finally, it can be challenging to get an overview of the different waste streams from aquaculture, as aquaculture companies claim that the different waste companies use different terms and classifications (Sundt *et al.*, 2018)

3.5.3.4 Regulatory challenges

The authorities can play a key role in how much plastic gets recycled. Currently they are playing a limiting role, through no prohibition against landfilling plastic, no demands or regulations on separation of plastic waste from other waste, nor on reuse or recycling of plastic waste from the aquaculture industry and fisheries. Other industries, such as the construction industry, have strict regulations related to this (Hognes and Skaar, 2017; Sundt *et al.*, 2018). There is also no regulation requiring any form of documentation, neither on use of plastic nor on what happens to the waste after disposal from the aquaculture facility. No tracing of equipment or waste is required, and there are no controls or sanctions from the authorities. And even when waste is sorted and exported for recycling, most of it is not documented, as it is classified as green listed waste (Annex VII), and therefore not reported to the Norwegian Environment Agency. This lack of demands and regulations limits the development and incentives for better technological solutions, slowing down the development of design for recycling and systems for documentation and tracing (Sundt *et al.*, 2018; Vangelsten *et al.*, 2019). The only thing that seems regulated by the authorities related to plastic, is that the facilities should always be tidy, and all equipment must be removed upon closure of the facility (according to the aquaculture management regulations §17) (Forskrift om drift av akvakulturanlegg, 2008; Hognes and Skaar, 2017). For more information on existing regulations, see chapter 7 in the POCOplast report “Fra oppdrettsplast til verdi” (Damman *et al.*, 2022)

There are no national statistics specific to waste from aquaculture (Sundt *et al.*, 2018). Statistics Norway has waste accounts broken down by industry for building and construction, manufacturing industries and service industries, in addition to households, but only sectoral resolution for the primary industries (see chapter 7.1

for more details) (Statistics Norway, 2019). This makes it difficult to get an idea of the amounts that could go to recycling.

3.5.3.5 Logistical challenges

Finally, logistics and communication appear to be barriers for recycling. A fragmented and widespread waste industry is an expensive and ineffective one. To achieve synergies and economies of scale, the different players in the market should work better together. An example is how the large transport companies, such as DB Schenker and Bring, have a significant direction imbalance, in that they transport much more goods to the coast than from the coast. By taking advantage of the unused transport capacity, the waste collection capacity for the aquaculture facilities could increase which would reduce the waste storage problem (Sundt *et al.*, 2018).

Centralised systems with good coordination of the amounts and between the players in the market, can lower the prices, improve the service, and remove other barriers towards recycling. Good traceability in the system can secure the environmental benefit, by ensuring the sorted waste does not end up in uncontrolled processes in countries where the waste is illegally landfilled or otherwise incorrectly treated (Sundt *et al.*, 2018). Aquaculture facilities are also interested in having their waste sorted by the waste companies, to save space and logistics. Central sorting technology for household waste already exists (Hognes and Skaar, 2017; Nørstebø *et al.*, 2020).

Figure 5 summarises positive and negative drivers associated with fishing gear collection and end-of-life treatment (Brodbeck, 2016). Although it is not the same as aquaculture, there are many similarities, and the figure touches upon topics not mentioned here, such as education campaigns, taxes, different rewards and penalties, and gate-fees for waste.

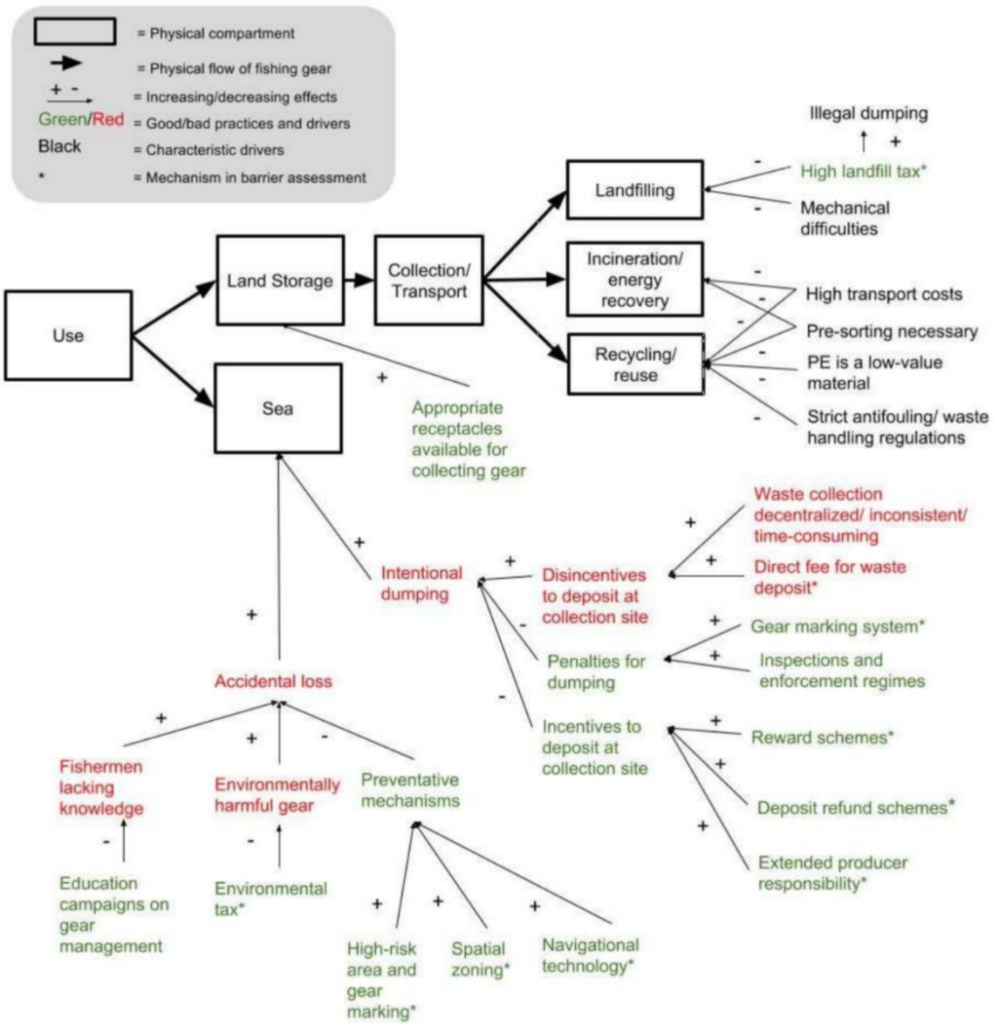


Figure 7 Flowchart summarizing the positive and negative drivers associated with fishing gear collection and end-of-life treatment (Brodbeck, 2016)

3.6 Future developments in aquaculture

3.6.1 Regulatory development

In January 2018, the EU adopted a European strategy for plastics, as part of the EU's circular economy action plan. The first directive to come out of this strategy was the *Directive on the reduction of the impact of certain plastic products on the environment*[4], which is aimed at single use plastics and equipment from fisheries and aquaculture containing plastic; product groups selected based on beach clean-ups in Europe. One of the measures in the directive is EPR for producers of products for fisheries and aquaculture containing plastic, which must be in place by 1. January 2025.

The study by MEPEX (Sundt *et al.*, 2018) frequently referenced in this memo, is a background study for the extended producer responsibility (EPR) policy for fisheries and aquaculture, from when the Norwegian Environment Agency assessed this in 2018/2019. This was not followed up by the Ministry of Climate and Environment at the time, as they were waiting for the EU directive, but it is now back on the agenda. The Norwegian Environment Agency will continue their work on EPR for fisheries and aquaculture while assessing improvements of EPR policies in Norway in general, in relation to several updates in EU Directives on waste, plastic products and circular economy. With EPR policies in place, the producers of the equipment will be responsible for the equipment also when it becomes waste (Miljødirektoratet, 2020b, 2020a, 2021; Regjeringen.no, 2020; EC, 2021c).

In December 2019, the EU presented their European Green Deal, an action plan to make Europe the first climate neutral continent in the world. As a part of the financing of the Green Deal, a common classification system for sustainable economic activities, or an "EU taxonomy" (EC, 2021b), has been created to get a common language and a clear definition of what is 'sustainable' (EC, 2021a).

The taxonomy regulation entered into force on 12 July 2020, and establishes six environmental objectives:

- Climate change mitigation
- Climate change adaptation
- The sustainable use and protection of water and marine resources
- The transition to a circular economy
- Pollution prevention and control
- The protection and restoration of biodiversity and ecosystems

To be classified as sustainable, any economic activity must contribute to at least one of these six, and not cause significant harm to any of the other environmental objectives (EC, 2021c; Store norske leksikon, 2021). The taxonomy will apply to Norway through the EEA.

A *part of the* taxonomy was implemented in January 2022, requiring large European companies to report on technical criteria related to the first two of the six environmental objectives. Technical criteria for the remaining four environmental objectives will be implemented during 2023 (after several postponements). The economic sectors and activities first selected are the ones contributing the most to the relevant environmental objectives, i.e. climate change mitigation and climate change adaption. Fisheries and aquaculture were not selected. There is ongoing development of criteria for remaining economic sectors and activities that are not yet included (EU, 2020a; EC, 2021b)Economic activities that are not included in the taxonomy when it is implemented will not be considered "green" (these activities will be defined as "non-eligible") This has implications for how they can and should communicate around sustainability and may also affect their abilities to achieve financing and secure capital. There is a worry in the aquaculture industry about not being included in the taxonomy, and there is ongoing work to be included (SjømatNorge, 2020; Energi og Klima, 2021; iLaks.no, 2021c). Requirements for plastics from fishery is proposed included in the taxonomy, as a part of the technical criteria for biodiversity. The proposed criteria for minimising marine litter from fishery includes minimising gear loss, implementation of tagging gear, reporting, recovery and recycling, and use of biodegradable materials (EU, 2022).

Several of the waste sector's activities related to the plastic waste from aquaculture are covered by the taxonomy. "Separate collection and transport of non-hazardous waste in single or comingled fractions aimed at preparing for reuse and/or recycling", and "Sorting and processing of separately collected non-hazardous waste streams into secondary raw materials involving a mechanical transformation process[5]" are included. Further, the incineration of waste for cement production is included[6], but incineration of waste for energy recovery is not included. The recycling of plastic is described in the activity *Manufacture of plastics in primary form,* where the recycling covers two (mechanical recycling or chemical recycling with lower emissions than virgin production) of three criteria the manufacturing activity can fulfil to be considered sustainable (EU, 2020b; EC, 2021b).

3.6.2 Industry development in aquaculture

An expected development in the future is more land-based fish farming (Nofima, 2020). Land-based fish farming can have many advantages compared to ocean-based fish farming. Examples are less emissions to water; better control of the fish, to avoid escaping, as well as parameters for growth, such as temperature; year-round production, not affected by seasons; less use of antibiotics, hormones and other chemicals, as the fish is not exposed to illnesses and parasites from the ocean; no threats from predators; and more freedom in terms of location, which gives the possibility of locating production near transport infrastructure, or even the market, which can be inland as well as abroad. Onshore facilities have challenges as well, including high investments costs, a higher degree of complexity, higher energy use, and high risks related to power outages or illness (Svendsen, 2019). In addition, analysts see bottlenecks in the industry such as shortages of expertise in building and operating land-based facilities. There are currently only 5-6 suppliers, or a few hundred people, with the capacity, experience and expertise required to build the most common onshore technology, RAS (Recirculating Aquaculture Systems). This will lead to higher risk for investors, in case projects go wrong, which may lead to challenges to achieve financing for projects, even though financing is currently not a limitation (iLaks, 2021; iLaks.no, 2021a; SalmonBusiness, 2021a, 2021c, 2021b). Developers in Norway are also facing local resistance due to the greater use of area compared to offshore fish farming (iLaks.no, 2021b).

Despite these challenges, there are advanced plans for building onshore facilities with a capacity of 2.2 million tonnes of salmon – a third of which is planned in Norway. The expected global production of farmed salmon in 2021 is 2.7 million tonnes, in sea pens across Europe, America and Oceania, meaning the planned capacity is nearly a doubling. The increase of 700,000 tonnes of salmon in Norway would entail a 50 % increase (iLaks, 2021; iLaks.no, 2021b). The main drivers behind this development are high salmon prices, increased production costs in the sea due to sea lice, a focus on environmental footprints, political bottlenecks and a freeze on new licences. This has led to an explosive interest in such projects, with a more than doubling in 10-11 months (SalmonBusiness, 2021c).

Currently, there are few large-scale land-based salmon farm in Norway, using the RAS technology to farm salmon for food (Fredrikstad Seafoods, 2021). The same technology has until now mainly been used for fish hatcheries where the salmon lives in freshwater until the smolt stage, when it is transferred to sea pens in the ocean. As mentioned in chapter 3.2, the fish hatcheries have not been accounted for in the material accounting. As the onshore activities will increase, the plastic types and amounts will change. There will be more fiberglass (GRP) and composite materials (FRP) used, which are complicated to recycle (Sundt *et al.*, 2018).

Referring to Table 3 in chapter 3.1 (Huntington, 2019), we see that the types of plastic in a tank and inland pond system differ a bit from open-water cages and pens. The use of acrylic (PMMA) in incubation jars, containers and laboratory equipment is an example of a plastic that is not used in the ocean-based systems. As mentioned, fibre-reinforced plastics (FRP) is used in tanks and pipework, and the amounts will increase significantly, going from only spawning and incubation tanks to stock holding tanks for fully grown fish. HDPE (High-density Polyethylene) is also used in tanks and pipework. The amount of pipework is likely to increase, as feeding pipes and feeding systems are required also in onshore systems, but in addition pipes for water supply, aeration, drainage, and for between filters and treatments are needed. Substantial amounts of HDPE are used in the tanks, as popular tank solutions are HDPE tanks and steel tanks with an HDPE liner. Additionally, pools for water holding, tubs, buckets, trays, basins, aerators, pumps, nets, mechanical filters, degassers, and laboratory wares are (partly) made from HDPE (AKVA group, 2017a).

LLDPE (Linear low-density PE) and LDPE (low-density PE) are also used for liners in ponds/tanks, and for greenhouse canopy poly cover; and PVC is used in aeration pipes, hosepipes and fittings, valves, and office and laboratory fixtures and fittings (Huntington, 2019). We can expect an increased supply of these types of used plastic in the future, as onshore facilities are built, and eventually require upgrades and replacements of equipment. As the industry is initiating projects for equipment design for increased circularity (SirkAQ.no, 2023), the design and material choices of products for future construction might change. As seen in Table 9, the lifetime of the components will affect the amount of plastic waste, and several of the listed components, such as tanks, can be expected to have long lifetimes.

4 References from concept cards

1. Rope consumption reduction
   (Pettersen and Sæther, 2021)
2. Feeding pipe wear reduction
   (AKVA Group, 2021; Pettersen and Sæther, 2021)
3. Waste sorting stations
   (Pettersen and Sæther, 2021; Handelensmiljofond.no, 2023)
4. Organizational routines for circular behaviour
   (Schyns and Shaver, 2021; Damman *et al.*, 2022)
5. Experience based improvements
   (Pettersen and Sæther, 2021)
6. Waste pre-processing
   (Brodbeck, 2016; Sundt *et al.*, 2018; Schyns and Shaver, 2021)
7. Treatments for non-circular products
   (Hognes and Skaar, 2017; Adresseavisen, 2021; Sement.heidelbergmaterials.no, 2022)
8. Mechanical recycling
   (Sundt *et al.*, 2018)
9. Chemical recycling
   (Punkkinen *et al.*, 217AD; S. *et al.*, 2012; Krogstad, 2021; Quantafuel.com, 2021b, 2021b; *EU Taxonomy Navigator*, 2023; *Shiftplastics.no*, 2023)
10. Eco labels
    (Plastforum.no, 2022; EuCertPlast.eu, 2023; Norfolier GreenTec, 2023)
11. Technical standards
    (arges.no, 2019; Ilaks.no, 2021)
12. Extended producer responsibility schemes (EPR)
    (EU, 2019; Regjeringen.no, 2020; Damman *et al.*, 2022; Miljødirektoratet, 2022)
13. Product specific waste services
    (POCOplast interviews, 2022)
14. Product design with recycled materials
    (Gemini.no, 2021; Flokk.no, 2022)
15. Multifunctional products
    (Imenco.no, 2023; Scaleaq.com, 2023)
16. Product tracking
    (Hill and Cameron, 2017; Elaskari *et al.*, 2021; AIM, 2023)
17. Material tracking
    (Hognes and Skaar, 2017; AKVA Group, 2021; Havbruksloggen, 2021; Empower, 2022)
18. Product specific service agreements
    (Akvagroup.no, 2022b; Froygruppen.no, 2023)
19. Design for circularity
    (Feary *et al.*, 2020; Akvagroup.no, 2022a)
20. Smart technology for predictive maintenance
    (triple-s.no, 2021)
21. Circular supplies
    (Lacy and Rutqvist, 2015a; Pettersen and Sæther, 2021; EC, 2023)
22. Reuse of components
    (Abdul-Rahman, 2014; E24.no, 2022; Inseanergy.no, 2022)
23. Product as a service
    (Lacy and Rutqvist, 2015b; AKVA group, 2017b)
24. Sharing platforms
    (Lacy and Rutqvist, 2015c)
25. Closed-loop value chains
    (Lacy and Rutqvist, 2015a; Ilaks.no, 2021; Infinitum.no, 2021)

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APPENDICES

Klikk eller trykk her for å skrive inn tekst.