Recycling Solutions for End-of-Life Fishing Rope in Newfoundland

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Recycling Solutions for End-of-Life Fishing Rope in Newfoundland

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Executive Summary

Fishing is one of the main industries in Newfoundland and Labrador (NL). Traditionally, fishing rope was manufactured of natural materials, but synthetic plastics (predominantly polyethylene and polypropylene) rapidly replaced these materials as plastic rope was lightweight, more durable and cheaper to manufacture. Unfortunately, end-of-life fishing rope poses environmental, economic and safety hazards.

End-of-life options include re-use, landfilling, incineration and recycling. Many factors can affect the practicality of recycling including storage space at ports, heavy contamination, low quality of degraded plastics, transport and processing costs, inconsistent supply, necessity of specialized equipment, seasonality of waste disposal, and missing end markets. However, the Government of Canada has identified the fishing and aquaculture industries as priority areas in Phase 2 of the Canada-Wide Action Plan of Zero Plastic Waste, so solutions are needed.

Most plastic recycling is mechanical (primary/ secondary). Despite increased interest, there is very little commercial application of tertiary recycling (also known as chemical or feedstock) of polypropylene and polyethylene. Mechanical recycling of end-of-life fishing rope is a multi-step process including identification and sorting of materials, shredding, decontamination, separation of polymers, drying and extrusion. Strategies to support recycling end-of-life fishing gear internationally include landfill tax, extended producer responsibility programs, deposit refund schemes, reward schemes and indirect fees. Extended producer responsibility programs are considered the most effective and should be explored for potential implementation in NL.

Currently in NL, end-of-life fishing rope in NL is landfilled or incinerated. An analysis in Norway that investigated the environmental, economic, and social impacts of landfilling, incinerating, and recycling of waste fishing gear indicated that recycling was the best alternative, but only when that was done locally. Exporting waste for recycling was found to be less sustainable than landfilling or incineration due to significant adverse environmental and economic impacts.

In Denmark, fishing rope has been successfully recycled into pellets and used to manufacture new fishing rope. Manufacturing of pellets or 3D printing filament are options explored for NL.

Many groups in Atlantic Canada are actively seeking solutions to this problem. Maintaining relationships with stakeholders is recommended to avoid duplication of effort, and to collectively work towards a regional solution.

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1 Introduction

As a coastal province with a fishing industry, plastic waste from fishing poses a potential disposal problem. This desktop study was initiated to better understand, and potentially propose ways to reduce end-of-life fishing gear that ends up in landfills in Newfoundland and Labrador (NL) by investigating how waste might be recycled and manufactured into viable products for the NL market. The Harris Centre MMSB Waste Management Applied Research Fund provided funding over three terms for engineering co-op students to explore this topic. The initial proposal included a literature review, volume estimate, and investigation of waste collection and waste diversion options in consultation with stakeholders. The literature review identified other researchers working on the same problem, namely the Fishing Gear Coalition of Atlantic Canada. This group published a report in June 2021, the scope of which overlapped with the Harris Centre funding in terms of attempting to determine appropriate volumes of waste through stakeholder interviews. We reached out to collaborate with this group and subsequently made changes to the scope of work to avoid duplication, to focus on waste with identified volumes (rope rather than monofilament netting) and to potentially try to advance any processing issues identified by recyclers in Atlantic Canada. Scope change was discussed with the Harris Centre in early July and a Modified Scope of Work was provided on July 23, 2021.

2 Background

Fishing is one of the main industries in Newfoundland and Labrador due the island's abundant natural resources and geographical location. One of the most abundant fishing grounds is the Grand Banks. Here the cold Labrador current mixes with the warm waters of the Gulf Stream. The mixing of these waters and the shape of the ocean floor lifts nutrients to the surface, these conditions help create one of the richest fishing grounds in the world. There are 255 core fishing harbours in Newfoundland and Labrador that range in size from 1-120 fishing vessels. Figure 1 shows these fishing harbour locations.

Mass production of plastics did not begin until the 1950s, but this innovation transformed the world and the commercial fishery was no exception. Before plastics had been used in the fishing industry, fishing gear was traditionally made from natural materials such as willow, wood, linen, and hemp. New synthetic plastics rapidly replaced these materials as it made the new fishing gear light weight, more durable and cheaper to manufacture. It was not long before plastic gear had become the new industry standard for harvesting (Quintana, 2018).

Although the innovation of plastic fishing gear has significantly increased harvesting efficiency and effectiveness, there have been undesirable consequences associated with such gear. This is true with end-of-life fishing gear, as the plastic material used can cause numerous harmful concerns if not handled properly.

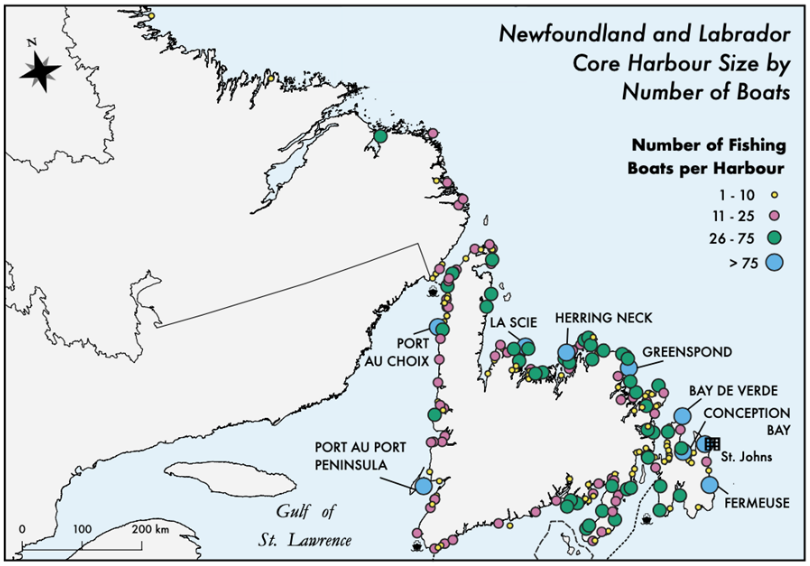

Figure 1 Size of core NL commercial fishing harbours (Dawe et al., 2021)

Plastic products make up an enormous amount of solid waste and takes hundred years to break down in landfills or the ocean (Armentrout, 2021). The extent and impact of the problem have increased significantly over the last 50 years with the increasing levels of fishing effort and capacity in the world's oceans and the increased durability of fishing gear.

It is estimated that between 600,000 and 800,000 tonnes of nets, lines, ropes, pots, and traps used in commercial fishing are lost, dumped, and discarded in the sea every year globally (DFO, 2021). Ghost gear is estimated to make up 10% of ocean plastic pollution (Laville, 2019). Another study estimates that 17.9% of plastic pollution is derived from fishing (OECD, 2021). Comprehensive work done by Liboiron et al. (2020) indicated that in Newfoundland and Labrador, fishing gear accounts for a major source of marine shoreline plastics (37%).

Fishing gear can be accidentally lost due to severe weather conditions, obstacles under water, inability to locate gear and human error (Schneider, 2020; OECD, 2021). Illegal disposal may also occur (Despande 2020). Ghost gear refers to any fishing gear that has be abandoned, lost, or otherwise discarded. It has profound adverse effects including environmental, economic, and even navigational and safety hazards. Ropes, nets, and lines are associated with high levels of marine entanglement. Microplastics, which result from the breakdown of ghost gear through environmental factors, can bind with other harmful chemicals that are often consumed by marine animals, which could have harmful effects (Lusher, 2015). Economic impacts of ghost gear include the forgone catch of target fisheries (Haggert, 2020), risks to navigational safety, delays to shipping and impacts on coastal tourism.

Many factors can affect the practicality and actual recycling of the material including heavy contamination if the gear is left unattended, expensive equipment costs, and even missing end markets. Often, fishing rope and other types of fishing gear end up in landfills as that is the only viable solution at that point in time (Brodbeck, 2016).

2.1 Global and National Perspectives

In 2016, Norway generated approximately 4000 tonnes of plastic waste from commercial fishing (Deshpande et al., 2020a). Of that volume, 55% was exported for recycling, 26% was landfilled and 19% was incinerated. Deshpande et al. (2020b) investigated the environmental, economic, and social impacts of landfilling, incinerating, and recycling the waste fishing gear in Norway using a multi-criteria decision analysis based approach. Results indicated that recycling was the best alternative, but only when that was done locally (within 150-200 km transport distance). Exporting waste (1400-1600 km travel distance) was found to be less sustainable than landfilling or incineration due to significant adverse environmental and economic impacts. This is consistent with the suggestion by MacFayden et al (2009) that the energy and resources required to collect and transport material to a recycling facility may be greater than the benefit derived from recycling it.

Stakeholders in Norway identified transport and the processing cost as barriers to recycling (Deshpande et al., 2020). Stakeholders in British Columbia (BC, 2020) identified low quality of degraded ocean plastics, inconsistent supply, and high labour costs as economic barriers to recycling. Stakeholders suggested that disposal and recycling work was not financially viable without government support.

A study completed for the Government of Scotland (Resource Futures, 2019) found that recycling costs, for example the energy costs of washing nets at approximately £280 ($481 CAD) per tonne, were much higher than landfill tipping fees (approximately £100 per tonne), hence recycling could not compete on purely economic terms. They suggested that the government subsidizing recycling would not be consistent with the polluter pays principle. Space to store the waste in ports until a sufficient volume was collected to justify transport was identified as a barrier by stakeholders. Local, small-scale recycling was suggested as a potential solution to remove costs of storage and transport.

Iceland uses a refund system that resulted in 8400 tonnes of fishing gear being shipped for recycling (90% of waste collected). The success of this program is attributed to sufficient collection points for waste, financial incentive, educated fish harvesters able to sort the material and recyclers able to deal with the material (Tschernij et al., nd).

Ghost nets and end-of-life fishing gear can be handed in for disposal or recycling without costs to the fishermen in Denmark. In Sweden, legislation requires that ports have waste reception facilities, which can be used for disposal of worn out fishing gear or ghost nets (Clean Nordic Oceans, nd).

In West Sweden, 1500 tonnes of end-of-life fishing gear is cleaned and pre-sorted in local harbours each year. Staff of the local fisherman association, FF Norden, divide materials into different classes of materials before sending for recycling. They note that one of the main challenges is waste transportation costs (Marek Press, 2017). In order to make the system financially viable, they cannot handle mixed and entangled retrieved fishing gear due to the extensive separation effort required (Stolte et al., 2019).

Best practices identified for recycling fishing gear (OSPAR, 2020) can be found in Appendix A.

The Government of Canada has a stated goal of zero plastic waste by 2030 (CCME, 2020). The fishing and aquaculture industry was identified as one of six priority areas in Phase 2 of the Canada-Wide Action Plan of Zero Plastic Waste.

3 Plastics Used in Rope Manufacturing

There are seven major fishing gear retailers and manufacturers in Newfoundland and Labrador, four of which sell fishing rope. These retailers include ESL Marine Supplies, Hampidjan Canada, Spartan Industrial Marine, and Vonin Canada. Of the 14 brands of crab and lobster fishing rope sold in Newfoundland and Labrador by retailers, 29% are made from polypropylene, 28% are made from polyethylene, and 43% is comprised of a blend of both materials (Dawe et al., 2021). Figure 2 below represents the percentages of the different material sold and used for rope manufacturing by major retailers in Newfoundland and Labrador.

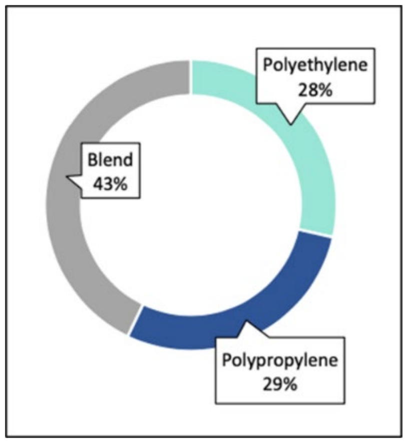

Figure 2 Percentage of lobster and crab fishing rope made using PE, PP and blend (Dawe et al., 2021)

The two main plastics used for manufacturing lobster and crab fishing rope are Polypropylene (PP) and High-Density Polyethylene (HDPE). Both are thermoplastic polymers, meaning they may be formed with heat and re-melted without losing their intrinsic characteristics (melting point, boiling point, density, etc.). What makes this possible is that the polymers found in thermoplastics are strong but feature weak bonds. The polymer chain does not degrade when melted down. The weaker interactions between polymer chains break down at much lower temperatures, allowing thermoplastics to be recycled until the polymers are broken down to the point that the material loses structural integrity (Mayer, 2018). Rope manufacturing is typically done using pelletized thermoplastics.

3.1 Polypropylene (PP)

Polypropylene is a thermoplastic polymer made from the combination of propylene monomers. Polypropylene (PP) is a linear hydrocarbon polymer, expressed as CnH2n (see Figure 3).

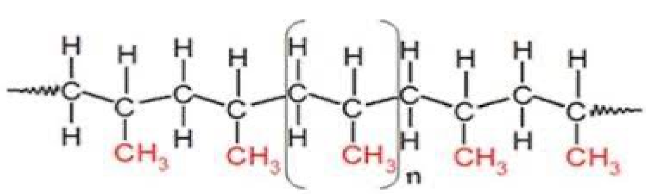

Figure 3: Molecular structure of polypropylene [Omnexus, nd]

It is used in a variety of applications and industries. It is also one of the most common materials used in rope manufacturing. This is because it is relatively cheap to produce and has a wide range of useful characteristics such as its high strength, durability, moisture resistance, chemical and solvent resistance, low density, and it is rot-proof (Ropes Direct, 2020). The table below shows some characteristics and mechanical properties of polypropylene.

Table 1 Properties of Polypropylene (CROW, 2015)

Thermo-Physical Properties		
Property	**Unit**	**Value/Range**
Melting Point	°C	160 - 163
Density	g/mL	0.90 - 0.91 (0.905)
Coefficient of Thermal Expansion x10^{-5}	cm/(cm °C)	8.0 - 10
Heat Deflection Temperature, 0.5 MPa	°C	78 - 122
Thermal Conductivity	W/mK	0.17 - 0.23
Rockwell Hardness, R Scale	n/a	R65 - R110
Mechanical Properties at 23°C		
Tensile Strength, Yield	MPa	31 - 45
Tensile Strength, Break	MPa	18 - 22
Elongation, Yield	%	10 - 12
Elongation, Break	%	50 - 145
Tensile Modulus	MPa	1950
Flexural Modulus	MPa	1350 - 1800
Izod Notched	J/m (kJ/m^2)	35 - 60 (3.0 - 6.5)
Electrical Properties		
Volume Resistivity	Ohm-cm	>10^{16}
Dielectric Strength	V/mm x 10^4	2.3 - 2.5
Dielectric Constant @ 1MHz	n/a	2.1 - 2.6
Dissipation Factor @ 1 MHz	n/a	0.0002 – 0.005
Other Properties		
Processing Temperature	°C	200 - 280
Linear Mold Shrinkage	cm/cm	0.01 0.02
Continuous Service Temp.	°C	90 - 120
Water Absorption, 24hr immersion	%	0.01 - 003

3.2 High-Density Polyethylene (HDPE)

High-Density Polyethylene (HDPE) is a thermoplastic polymer produced from the monomer ethylene. It is one of the most versatile plastic materials. Polyethylene chemical formula is $(C_2H_4)_n$ (see Figure 4).

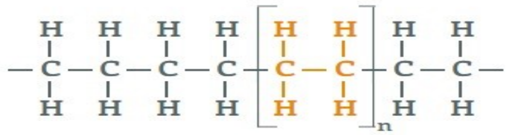

Figure 4: Molecular structure of polyethylene [Omnexus, nd]

Properties and characteristics of polyethylene include low co-efficient of friction, excellent chemical resistance, good impact resistance, resistant to many solvents (HDPE), good fatigue and wear resistance (HDPE), zero water absorption (HDPE) (omnexus, nd).

HDPE plastic is used in a variety of applications including plastic bottles, milk jugs, shampoo bottles, bleach bottles, piping and even rope. It is known for its outstanding tensile strength and large strength-to-density ratio, which makes it excellent for fishing rope. HDPE plastic also has a high impact resistance and melting point (Albers, 2017). HDPE characteristics and mechanical properties are shown below.

Table 2: Thermo-Physical, Mechanical, Electrical, and other Properties of HDPE (CROW, 2015).

Thermo-Physical Properties		
Property	**Unit**	**Value/Range**
Melting Point	^{o}C	126 - 135
Density	g/mL	0.955 - 0.961
Coefficient of Thermal Expansion x10^{-5}	cm/(cm ^{o}C)	12.5 - 18.0
Heat Deflection Temperature, 0.5 MPa	^{o}C	64 - 77
Thermal Conductivity	W/mK	0.35 - 0.49
Shore Hardness, D Scale	n/a	55 - 67
Mechanical Properties at 23^{oC}		
Tensile Strength, Yield	MPa	23.0 - 29.5
Tensile Strength, Break	MPa	30.5 - 33
Elongation, Yield	%	9 - 18
Elongation, Break	%	600 - 1350
Tensile Modulus	MPa	900 - 1550
Flexural Modulus	MPa	970 - 1380
Izod Notched	J/m (kJ/m^2)	71 - 159 (20)
Electrical Properties		
Volume Resistivity	Ohm-cm	6 x10^{15}
Dielectric Strength	V/mm x 10^4	2.1 - 3.5
Dielectric Constant @ 1MHz	n/a	2.2 - 2.4
Dissipation Factor @ 1 MHz	n/a	0.0001 – 0.0005
Other Properties		
Processing Temperature	^{o}C	180 - 205
Linear Mold Shrinkage	cm/cm	0.017
Continuous Service Temp.	^{o}C	-73 - 82
Water Absorption, 24hr immersion	%	0.01 - 0.03

4 Fishing Rope Lifecycle

Although the innovation of plastic fishing gear has significantly increased harvesting efficiency and effectiveness, there have been undesirable consequences associated with such gear. This is true with end-of-life fishing gear, as the plastic material used can cause numerous harmful concerns if not handled properly. The life cycle of fishing rope is depicted in Figure 5 below. Accidental loss of gear in the ocean can have profound adverse effects including environmental, economic, and even navigational and safety hazards. It is reported that intentional disposal at sea of end-of-life gear has significantly decreased over the last two decades (Ackman, 2016). Land-based solutions for end-of-life rope include reuse, for example small scale industry creating door mats, baskets etc; disposal including landfilling and incineration; and recycling, ie. reprocessing into new products.

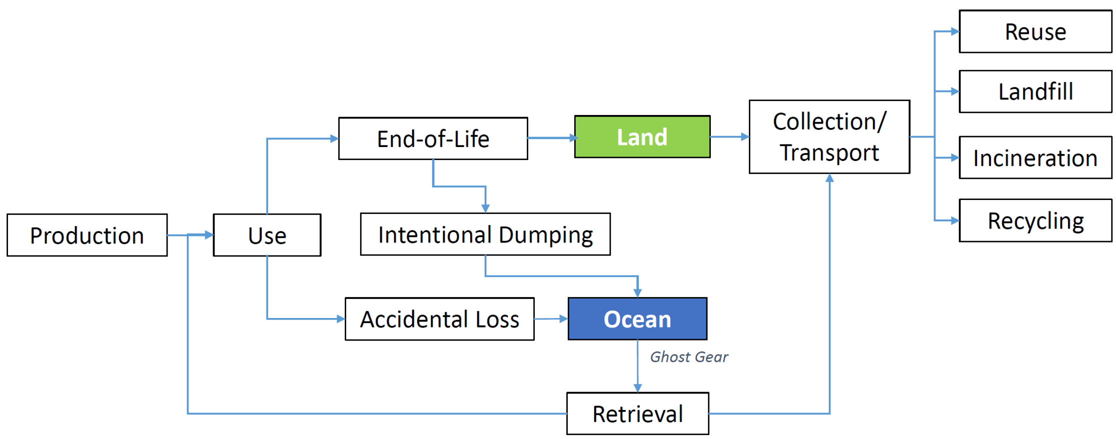

Figure 5 Life Cycle of Fishing Rope (modified from Brodbeck, 2016; Deshpande, 2020)

A distinction needs to be made between rope that is recovered from beach cleanups or the sea (so- called derelict fishing gear or ghost gear) and end-of-life fishing gear. Re-use and recycling of ghost gear poses additional challenges as the rope may be intertwined with other materials and heavily encrusted with salt, sand, algae, crustaceans etc. (Stolte and Schneider, 2018). Ghost gear would require additional pre-processing steps compared to end-of-life gear. This work focuses on mechanical recycling in comparison to landfill disposal.

5 Current End-of-Life Strategies in NL

According to work compiled by the Fishing Gear Coalition of Atlantic Canada (Dawe et al., 2021), none of the 82 fishing harbours in NL have collection programs for end-of-life fishing gear, and harbours do not allow storage of gear on the wharf for extended periods of time. Burning has been reported as a common means of disposal. Twenty-five waste facilities accept fishing gear; 21 landfill it and some allow for the re-use by community members. See Appendix B for details. Fourteen sites indicated that they had stockpiles of old rope or gear that they did not know what to do with. It was suggested that a closer drop off for fishing gear would be beneficial. Derelict fishing gear is primarily dropped of in the spring and the fall. It was noted that NL fish harvesters are good at maintaining their gear for longer periods of time, and on the northeast coast, some fish harvesters sell rope that is no longer useful for their purposes to mussel farms (reuse).

6 Estimate of End-of-Life Rope in NL

The predominant fisheries that use polypropylene and polyethylene ropes are the inshore fisheries and offshore crab fishery. One case study conducted by the FGCAC (Fishing Gear Coalition of Atlantic Canada) estimated that inshore fish harvesters replace an average of two coils of rope each year, and those fishing crab replace approximately nine coils of rope a year. Based on this data, it was estimated that 4,372 coils of rope would be replaced by the inshore crab and lobster fishery and approximately 3,754 coils are replaced in the offshore crab fishing, equating to a total of 8,126 coils of rope replaced annually. This number is equivalent to about 202 tonnes each year and considering the length of a coil, it represents 2,974 km (9,750,900 ft) of rope that is replaced in the province each year (Dawe, et al., 2021). In comparison, it is estimated that 164 tonnes are replaced annually in New Brunswick (Kendall et al., 2021) and 1150 tonnes in Nova Scotia (Dawe et al, 2021).

Current projects being undertaken through the Government of Canada's Ghost Gear Fund, such as gear retrieval programs by the Fish, Food, and Allied Workers Union, Newfoundland Aquaculture Industry Association (NAIA), Torngat Joint Fisheries Board, and Petty Harbour Fisherman's Cooperative create a one-time source of derelict rope. In 2020, 63 tonnes of fishing gear was recovered in Atlantic Canada. It is not known what percentage of this was rope. As this is not a consistent supply of feedstock for any system, it is not considered in the analysis. Also, as previously discussed, rope retrieved from the ocean as part of clean-up efforts may require additional pre-processing steps. Correspondence with the NAIA suggest that the amount of end-of-life rope generated each year from the aquaculture industry is minimal (personal communication, 2022), however efforts to confirm with individual companies were unsuccessful. The 202 tonnes (202,000 kg) is considered a minimum, consistent input. To put this number in perspective, total annual waste generated in NL is estimated as 474,264 tonnes (MMSB, 2022).

7 Landfilling

Landfilling is one of the most common options when discarding end-of-life fishing rope. When landfilling rope in Newfoundland, often fish harvesters are responsible to collect their own rope and transport it to local landfills to be discarded. Figure 6 shows Newfoundland and Labrador Waste Resource Management Facilities with location buffers with respect to core harbour locations for fishing vessels. Seventy percent of commercial fishing harbours are further than 10 km from a waste resource management facility, 71% located within 25 km and 97% within 50 km. In interviews conducted by the FGCAC (FGCAC database), not all facilities indicated that they accepted rope, hence the transport distance to responsibly dispose of rope may be further.

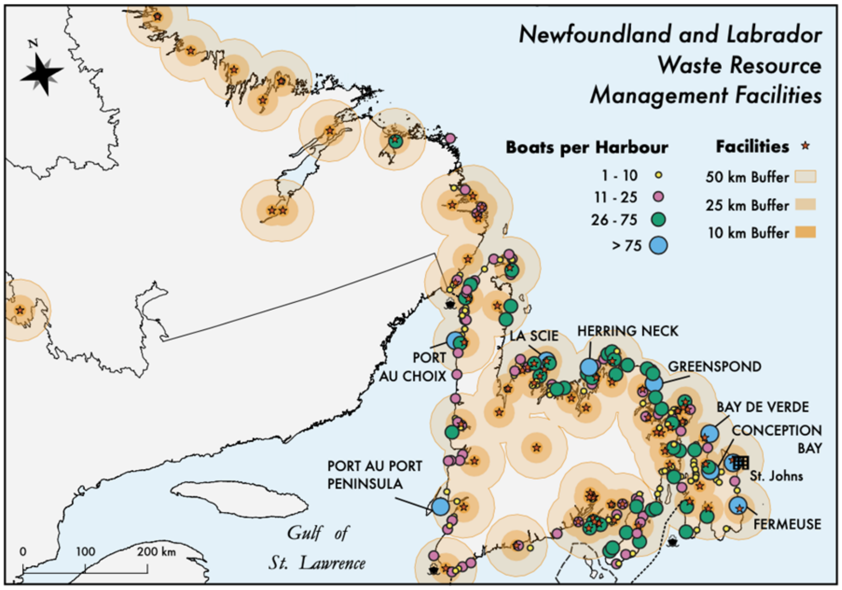

Figure 6: Newfoundland and Labrador harbours and waste management facilities with 10, 25 and 50 km buffers. Not all facilities accept or receive fishing gear (Dawe, et al., 2021).

One safety issue that may occur from discarded rope near landfills, wharfs and fish plants is the problem of the fishing gear entanglement around machinery, such as forklifts, dump trucks, dozers, excavators, and loaders. The ropes and nets can become tangled in the tracks and wheels of the machinery and create a problem with the functionality of the equipment and be extremely difficult to remove once caught (personal communication, Robin Hood Bay, 2021). Figure 7 below show the problems faced with heavy equipment entanglement.

Figure 7: Image of piles of fishing gear being handled by heavy equipment. It is very possible for this gear to become entangled in the wheels, tracks, or arms of various equipment (Clean Nordic Oceans, 2021).

At most waste resource management facilities fishing rope that is received is landfilled within the confines of the facility. Instead of dumping the fishing rope into piles and allowing it to accumulate and create problems with equipment, space, and safety issues, pits are dug, and the fishing rope is buried underneath the ground. This eliminates the safety issues associated with equipment entanglement and potential fire hazards if the rope is left in piles above ground.

7.1 Costs

When the material arrives at the facility, the fishermen are charged a tipping fee per metric tonne of material. Based on interviews conducted by FGCAC (2021), tipping fees for rope range from $0 to $164. As an example, the Robin Hood Bay Waste Management Facility located in St. John's considers fishing gear as "regular waste" (personal communication, Robin Hood Bay, 2021). The tipping fee is $82 CAD/metric tonne (Robin Hood Bay, 2021). If $82 CAD/metric tonne is taken as the average price to landfill fishing rope, and 202 tonnes of rope are replaced by fishermen each year, hypothetically 202 tonnes of rope would be brought to landfills annually. This equates to a cost of $16,564 CAD annually to landfill this material excluding transportation costs. However, this cost does not capture the value of space in the landfill and the costs of siting and building a landfill. If this material was not going to the landfill, it would extend the life of the landfill, which has associated value.

8 Plastic Recycling

The recycling of discarded fishing rope is a possible solution to divert plastics from the oceans, coastlines, beaches, fishing communities and landfills to recirculate the rope's valuable material back into the economy. However, the recycling of this material can be difficult at times since derelict fishing rope can be heavily contaminated, in disrepair, contain a mixture of plastics (blended PP and PE), can be lengthy and difficult to handle without proper processing techniques and machinery. In terms of societal factors, recycling derelict fishing rope removes the plastic pollution from harbour and fishing communities, creates employment opportunities, and creates a safer environment for the public.

Plastics recycling can be classified as primary, secondary, tertiary etc as outlined in Figure 8. At the moment, most plastic recycling is mechanical (primary/ secondary) (ECCC, 2019; Dogu et al., 2021), which consists of re-melting and reforming used plastic. It is noted in the literature (Thiounn and Smith, 2020; Ignatyev et al., 2014.), that as polymers are reprocessed, there may be an effect on the mechanical properties of the recycled product. Tertiary (also known as chemical or feedstock) recycling includes processes such as pyrolysis, hydrolysis, gasification, and cracking.

PRIMARY	**SECONDARY**	**TERTIARY**	**QUATERNARY**
Mechanical reprocessing of polymer waste into a product that has properties equivalent to the original product	Mechanical reprocessing of polymer waste into a product that has properties lower than the original product	Processes to recover chemical constituents from polymer waste	Waste to energy processes

Figure 8: Plastic Recycling Classification, modified from Sahajwalla and Gaikwad, 2018

Despite increased interest, there is very little commercial application of tertiary recycling of PP and PE. A recent review (Thiounn and Smith, 2020) indicated that, as of 2019, there was only one successful commercial tertiary recycling of PE noted (BioCellection, Inc.) and only PureCycle Technologies has been successful in recycling PP (using tertiary methods) to give a recycled product whose mechanical properties are the same as virgin PP.

Dogu et al. (2021) suggest that pyrolysis is the tertiary recycling technique with the most potential. Polyolefins (eg PP and PE) are well suited to it, and it has the potential to be efficient at small-scale or even mobile units. However, tertiary recycling is reported to have higher capital and energy costs (Hopewell et al, 2009; Rahimi and Garcia 2017). Schneider (2020) examined mechanical recycling, chemical recycling, energy recovery and landfilling of ghost fishing gear through a life cycle analysis in terms of environmental impact and feasibility. Based on his scenarios, chemical recycling was too energy intensive to be environmentally competitive.

Some trials have been conducted on pyrolysis and hydrolysis for derelict fishing gear (Stolte and Schneider, 2018). They concluded that for the heavily contaminated mixed material input (including lead) they investigated, that hydrolysis (steam reforming) was the preferred option.

Based on the above, only mechanical recycling was investigated in more detail in this study. Deshpande (2020) presents a typical process flow diagram for mechanical recycling of end-of-life plastic fishing gear and ropes in Norway, as shown in Figure 9.

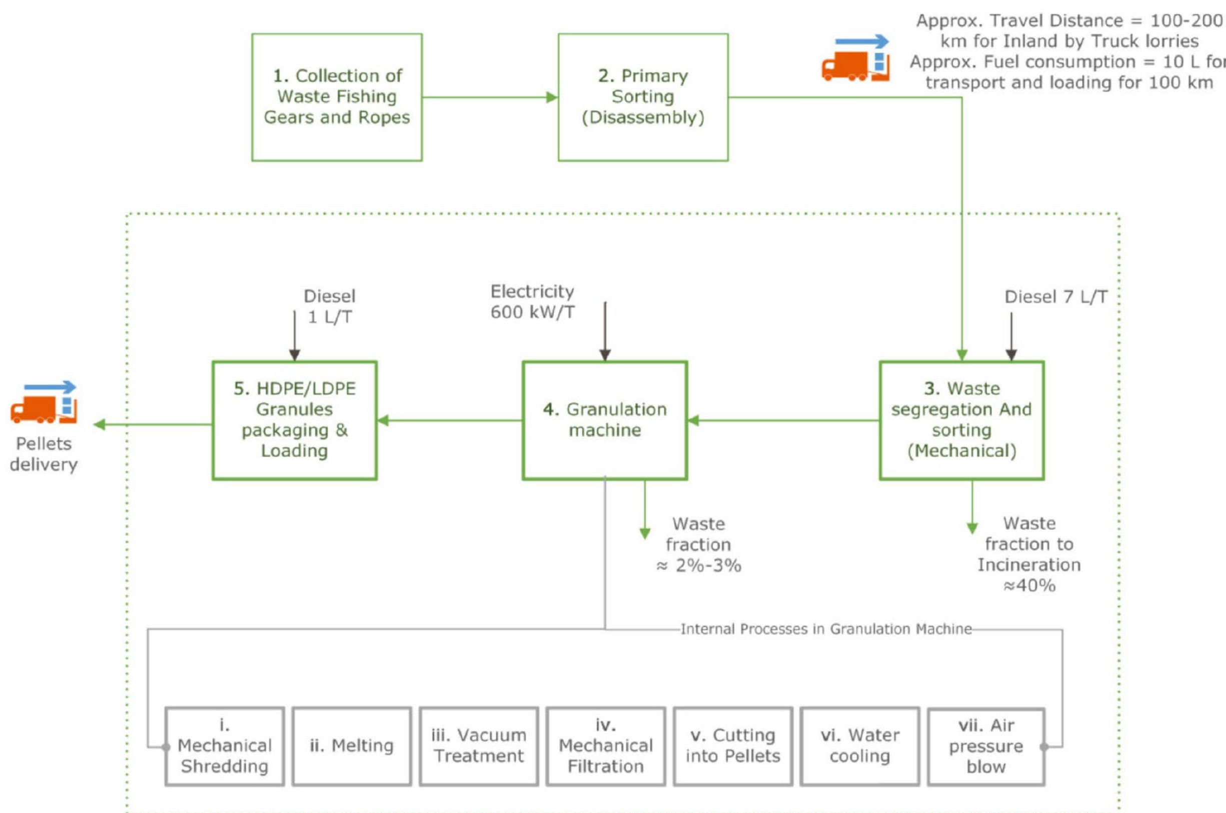

Figure 9: Process flow diagram for mechanical recycling of EOL plastic fishing gear and ropes in Norway, from Deshpande, 2020.

The following equipment and processing steps are necessary when mechanically recycling rope.

1. **Material & Contamination Identification**

   To identify rope material, internal marker tapes can be used. Some ropes have a marker tape buried within a strand. Typically, these markers contain the name of the manufacturer, the type of material, and the year it was manufactured. The marker tape is a conclusive way of identifying a rope's material when it can be found. In unspliced rope, the marker can be found by untwisting the end of a strand. In broken or damaged rope, it can be found by careful disassembly of the rope. Other manufacturers identify their ropes by various color marker yarns that can vary based on the region and manufacturer (TensionTech, 2021).

   If there are no identifiable solutions to determine the rope's material through manufacturer tape and color markers, another solution is to use a method known as Infrared (IR) Spectroscopy, also known as Vibrational Spectroscopy. This method measures the interaction of infrared radiation with matter by absorption, emission, or reflection. It is used to study and identify chemical substances or functional groups in solid, liquid, or gaseous forms. IR spectroscopy exploits molecules and functional groups tendencies to absorb specific frequencies that are characteristic of their structure. These absorptions are resonant frequencies which match the frequency of the bond or group that vibrates. The energies are determined by the shape of the molecular potential energy surfaces, the masses of the atoms, and the associated vibronic coupling (LibreTexts, 2020). Not only can this method be used for plastics such as polypropylene and polyethylene, but it can also be used to identity contaminants in rope such as salts and algae. The identification of plastic occurs in the near-infrared (NIR) spectrum, which corresponds to a wavelength range from 780 to 2500 nm. The NIR range is dominated by overtone and combination bands of C–H, N–H, O–H, and C–O functional groups.

   The identification of plastics is mainly based on the stretching vibration modes of CH, CH_2 and CH_3 groups between about 1.1 and 1.25 µm (1100 and 1250 nm) which correspond to the second overtone, the first overtone ranging from 1.65 and 1.7 µm (1650 and 1700 nm). The main limitation of plastic identification with NIR spectroscopy is that black plastics cannot be detected. The soot they contain absorbs all light in the NIR range and no detectable signal can be evaluated for material separation (Becker, Sachsenheimer, & Klemenz, 2017). Most brown algae (most common form of algae found in the ocean) show reflectance peaks around the 580, 600 and 650 nm wavelengths separating the reflectance troughs (absorption bands) around 670–675 nm, 582–596 nm and 630-635 nm (Olmedo-Masat, et al., 2020). For salt (NaCl - where chloride and sodium make up over 90% of dissolved ions in seawater) an infrared wavelength range of 700-2500 nm may be used to identify the salt (Laub-Ekgreen, et al., 2018). The IR spectroscopy method is currently being used by company by the name of PureCycle to identify rope material and contaminants. The specific model used is a mobile handheld device manufactured by a company called trinamiX which has a wavelength range up to 3 µm (3000 nm). *Figure 10* below shows the device below. The intensity levels of plastics, salts, and brown algae respectively, at different wavelengths using IR spectroscopy are presented in Appendix C.

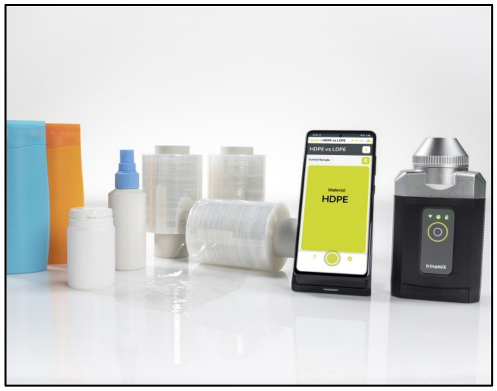

Figure 10: Mobile NIR Spectroscopy Solution by trinamiX (trinamix, 2021).

2. Sorting

Sorting may be necessary if other fishing gear is involved such as weights, pots, traps, or nets (containing nylon or other plastic), these materials would need to be separated from the rope (Stolte & Schneider, 2018). This step can involve strenuous manual labour if there are many types of fishing rope and gear in the recycling feedstock (or what is brought to recycling facility), as shown in *Figure 11* below.

Figure 11: Pile of various types of fishing gear left as stockpile in Cape Breton (Pottie, 2021).

In a study conducted on mixed ghost gear, Stolte and Schneider (2016) found that rough sorting required three person hours for a 783 kg bag of waste and fine sorting required three person hours for an 85 kg bag of waste. The rough sorting resulted in much higher levels of contamination. They recommend that initial sorting be completed at the harbour as fisherman are the most experienced at dealing with fishing materials and this would reduce the weight of the material that would need to be shipped to a processing facility.

3. Size Reduction: Shredding

The next step is to shred the rope down to separate fibers. This would need to be done using a piece of size reduction equipment capable of handling long continuous sections of rope without becoming entangled in the machinery. The cutting principle of a shredding machine is that the blades or cutters are arranged in a misplaced position. The plastic is torn apart from the strain and shearing forces put on the material as the blades or cutters rotate about the shaft, powered by an electric motor. The plastics are reduced to a smaller particle size that varies based on the sieve opening size being used, located under the shredding chamber (Precious Plastics, 2021). One industrial solution for size reduction is LIDEM's rope cutting, chopping, and shredding system: The Rotator. *Figure 12* shows the companies' machine in working order.

Figure 12: LIDEM rope cutting, chopping, and shredding system. The Rotator (LIDEM, n.d.).

One potential concern noted by Stolte and Schneider (2018) is that as fishing rope is designed to perform under harsh conditions, hence the fibers are stable to breaking and cutting. Specially designed machines for fiber cutting are likely required as normal blades may quickly become blunt and require frequent replacement. They further recommended that shredders should have safety stop and back rotation capability to avoid extensive motor heating and machine wear.

4. Decontamination

The decontamination of the shredded rope material involves using several washing techniques and equipment. First, the shredded rope would pass through a sink float tank, preferably a tank with several passes such as a triple row tank. A sink float tank is used to clean and separate plastic from contaminants such as salts and rocks. This tank relies on the specific gravities of various materials processed in the tank relative to the specific gravity of the base solution in the tank. Those with higher specific gravity than that of the base will float (polypropylene & polyethylene will float in water). The specific gravity of the base solution can be changed as necessary through the addition of chemical additives. A motor drives the augers within the tank, which push the material forward and de-aerate the plastic. The auger or drag conveyor is used which continually sweeps the bottom surface to convey the material to an above-water discharge. The triple row tank allows for more residual time in the tank which ultimately allows for more separation and washing. The separated float and sink components are discharged at a common end location so either component can be easily routed to another processing unit (ASG, 2020). An example of a triple row sink float tank is depicted in *Figure 13*.

Figure 13: Triple row sink float tank used to wash shredded plastics (ASG, 2020).

After passing the first washing system, the rope fibers were then pass through an additional decontamination unit known as a friction washer. This machine is comprised of a drum, auger, a fast-rotating shaft, and mesh screens. The washer is accumulated on an inclined frame. The fast-rotating shaft and auger/paddles transport the material upward while also forcing the material against the screens in the drum while water is also fed into the system. The centrifugal forces created from the rotating shaft and the friction forces between the plastics themselves is what cleans the material, along with the water used for a very good cleaning effect. It separates any residual rocks, salts and algae left on the rope fibers. This system operates similar to how a laundry machine works. *Figure 1*4 shows a typical friction washer unit (REGULUS, 2021).

Figure 14: Regulus plastic washing unit. Friction washer (REGULUS, 2021).

5. **Separation of Polypropylene and Polyethylene**

If blended PP and PE rope is being recycled, then a separation process is necessary to isolate the two materials. A baffled oscillation separation system can be used for this purpose. In this system two materials are separated in water, rather than a controlled density solution. The material mixture is introduced into a vessel filled with a segregation media (water). This media can be chosen to circulate from top to bottom or vice versa. The direction is chosen to apply a counter current, which aids in the separation of materials. A centrally located baffle structure inside the vessel will oscillate. The baffle structure is comprised of a central shaft with multiple disks, which contain one of more pathways for the vessel contents. This allows the disks to induce movement to the mixture and allow the materials to move to either end of the vessel. The oscillating baffle will cause "shuggling" or shaking within the vessel which results in the separation of the two materials by density and buoyancy (Impact Solutions, 2021). The shaking causes the lighter material to move upwards while the heavier material moves downward inside the vessel (which is suitable for PP and PE as they have different densities). *Figure 15* represents the typical set up for a baffled oscillation system. *Figure 16* displays the unit the company Impact Solutions uses for the separation of PE and PP plastics.

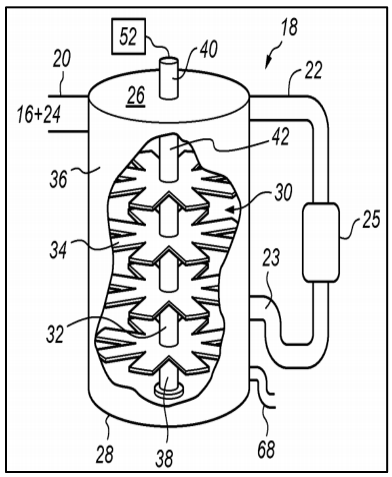

Figure 15: Diagram of a typical baffled oscillation separation unit. A central shaft contains multiple disks which contain space for material to pass through. The shaft oscillates and shakes the vessel to separate two types of material based on density and buoyancy (Vesavkar et al., 2016).

Figure 16: Baffled oscillation separation system by Impact Solutions (Impact Solutions, 2021).

6. **Dewatering & Drying**

After the material is separated, it is often dewatered using screens or by running it on a belt system for the water to leak through. Drying is then done to ensure the material is absent of moisture before moving on to further processing. Thermal dryers are used to achieve this, these dryers use hot air to dry the plastic material. The dewatered material is vacuumed out by a transport blower and mixed with hot air travelling through a long set of metal tubing that winds back and forth. As the material mixes and spins as it travels through this path, moisture is effectively dehydrated. The system usually ends with a cyclone separation apparatus where cool air is mixed in. The cyclone separator removes any dust or fine contamination within the material stream. *Figure 17* shows this type of system.

Figure 17: Plastic thermal drying system (MoogeTech, 2021).

7. **Extrusion**

The extrusion process may not be necessary based on the intended purpose of the recycled material. The extruder machine is used to melt and form plastic into a continuous profile. Shredded and cleaned plastics are fed from a hopper into the barrel of the extruder. The plastics are gradually melted by mechanical energy generated by a turning screw/auger and heaters arranged along the length of the extruder barrel. The molten plastic is then forced through a die which shapes the plastic extrudate (RobotDigg, 2021). *Figure 18* shows this piece of equipment.

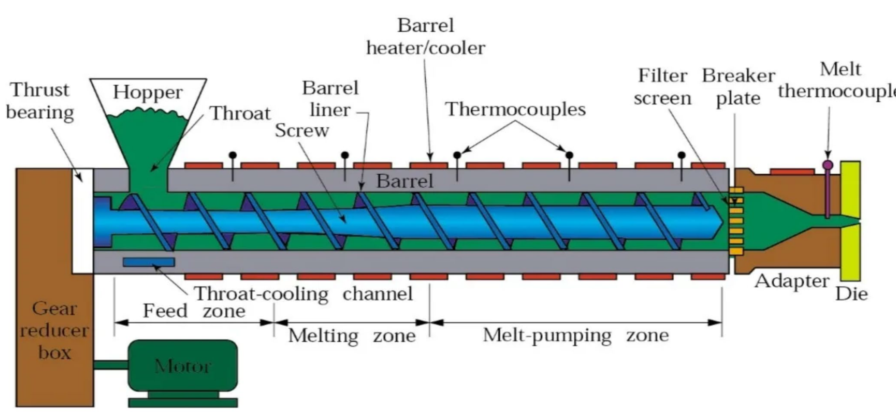

Figure 18: Typical extruder unit (Ranjan, nd)

8.1 Costs

Recycling can be costly due to labour costs to sort materials, the cost of recycling equipment, and the fact that some plastics do not have many buyers; those who are still accepting materials for recycling will only take the highest quality with the least amount of contamination (Jarvis and Robinson, 2019). End-of-life fishing rope can be in poor condition and contain contamination such as salts and algae. Therefore, this fishing rope must be processed and cleaned using industrial equipment if buyers are to pay to recycle this material. Pre-processing of rope may be costly as well, as the required equipment and labour costs can be expensive and take time to achieve the required size and cleanliness. These economic costs vary depending on the type of product processed using rope material.

Some (Resource Futures, 2019; BC, 2020; Marek Press, 2017) suggest that re-directing waste from the landfill requires government intervention, at least initially. Dogu et al. (2021) suggest that mechanical recycling is only economically feasible when costly separation steps are not required, i.e. when the waste is not complex and not contaminated. To put costs into perspective, an attempt was made to estimate the costs for an industrial size recycling plant. Multiple manufacturers (see Appendix D for details) were contacted to obtain quotes for industrial scale recycling equipment. Unfortunately, no quotes were received at the time of writing. Therefore, the cost estimate of an industrial scale recycling facility was done through literature review.

The cost of building a recycling plant depends on what type of material will be processed, and how it will be done. That being said, the cost of starting a recycling plant may remain consistent in terms of what is needed, such as the recycling equipment. Size reduction, decontamination, and dryers are examples of equipment that are common among all plastic recycling processes. There are many upfront costs to consider such as the land requirements, utilities, machinery, and human resources to run the plant. O'Chucks (2021) has estimated the cost breakdown to build and open a recycling plant as $769,000 – $5,130,000, not including permits, with machinery costs ranging from $218,000 to $2,5M. The equipment costs are based on the scale of recycling, large-scale recycling units will cost more than smaller scale equipment. From discussions with recyclers in Atlantic Canada, it was noted that a reliable industrial shredder could cost $1,000,000.

Appendix D shows an example of a recycling line for plastics, this line does not include product production, only the processing to prepare plastics for downstream processing.

8.2 Recycling Challenges

- Fishing rope may be entangled with other forms of fishing gear when received. This requires time and labour to sort the materials from each other.
- End-of-life fishing rope can contain heavy contamination from years of use and may require heavy cleaning. Decontamination is necessary to ensure the recycled material is valuable.
- Often in a marine environment, the plastic is exposed to UV irradiation. Being exposed to UV irradiation for long periods causes the materials' mechanical properties to be negatively impacted with a loss of elasticity and an increase in rigidity. In general, the thermal properties of the polymers are affected, causing a weakening of the material over time. In addition, cracks, flakes, and granular oxidation are common degradation patterns in the chemical weathering of plastics. Salinity, exposure time, UV light, and exposure to oxygen are essential factors affecting the plastic

degree of degradation. This degradation of plastics also makes them difficult to recycle mechanically (Iñiguez et al., 2018).

- Rope material can contain a blend of PE and PP, requiring separation.
- Rope can be difficult to shred and handle due to its length, or knots if proper equipment is not utilized. Shredders are necessary that are capable of handling fishing rope fibers.
- Upfront costs of recycling can be expensive.
- The disposal of end-of-life fishing rope is seasonal, requiring sufficient storage capacity at a recycling facility.

9 Production Examples

9.1 Pellet Production

One option that has been investigated is to use the recycled fishing rope to produce pelletized PE and PP thermoplastics. Pelletizing of plastics is an operation that involves the processing and cutting of a melted polymer to easy-to-handle plastics pellets. Figure 19 shows an image of pelletized plastics. The pellets that are produced are used in further processing operations such as injection molding and extrusion processes to make 3D filament (Core Mini Bins, n.d.) or sold as a product. Pelletized plastics for manufactures create a simple alternative as a feedstock, rather than buy expensive equipment and recycle raw material themselves they can directly buy pellets to use for their production. Thermoplastic pellets sell for approximately \$1 – \$5 per kg (formlabs, 2021).

Figure 19: Image of various pelletized plastics (Core Mini Bins, n.d.).

Pellets could potentially be sold and used to manufacture fishing rope. This would create circular production and lessen the use of raw natural resources. Through a discussion with a representative from Polysteel Atlantic Ltd. (personal communication, 2021) it was learned that both PP and PE pellets are used in their rope making process. An exact combination of both pellets are fed to an extruder where they are melting together and extruded into individual filaments. The filaments are then grouped into yarns are twisted together at high tensions to produce rope (Polysteel, 2021). Recycling end-of-life fishing rope to pellet form then reusing the pellets to manufacture rope or other products may be possible solution to reducing the number of natural resources used for processing plastics.

Plastix Global (Plastix) is a Danish company that transforms used, obsolete, and abandoned fishing nets, ropes, and post-use rigid plastic by mechanically recycling them into high-quality raw pellets (PlastixGlobal, n.d.). The production process involves dismantling, shredding, density separation, washing, drying and extrusion. In 2020, Plastix manufactured 1300 tons of pellets from 2700 tons of post-consumer maritime fibers from 28 input suppliers in 15 countries. They employed 30 equivalent full-time employees and estimate that CO_2 emissions were reduced by 4.5 Mkg by the use of their products compared to virgin plastic (Plastix, 2020). Recently, Plastix successfully processed ghost nets for the first time and had their pellets used to manufacture fishing rope in collaboration with DFS, Randers Reb, and epsotech (Plastix, 2021). An inquiry was made to Plastix to determine whether they currently have any suppliers in Canada, logistics in terms of shipping and what price they receive for their pellets. No response was received at the time of writing.

Based on the experience of Plastix, end-of-life fishing rope in NL could be converted to approximately 100,000 kg of plastic pellets. This could result in revenues of $100,000-$500,000 per year.

In December 2021, Ocean Legacy, based in British Columbia, began commercial sales of pellets generated from ghost gear, under the trade name Legacy Plastic™ (Ocean Legacy Foundation, 2021). The company did not respond to pricing inquiries. The project is funded in part by the Government of Canada Ghost Gear Fund (approximately $2M in 2020/21).

9.2 Injection Molding

Injection molding is one of many methods that is possible with recycled fishing rope material. It is a method to obtain molded products by injecting melted plastic material into a mold using an extruder. After injecting the plastic into the mold, it is then cooled and solidified (Polyplastics Co., n.d.). Injection molding is one of the prime processes for producing plastics articles. It is a fast process and is used to produce large numbers of identical items from high precision engineering components to consumer goods. Once the processed rope is sorted, shredded, cleaned, separated, and dried, it can then be fed directly to a hopper and melted using a heater and shaped using an extrusion device and mold. *Figure* 20 below shows the components of an injection molding device.

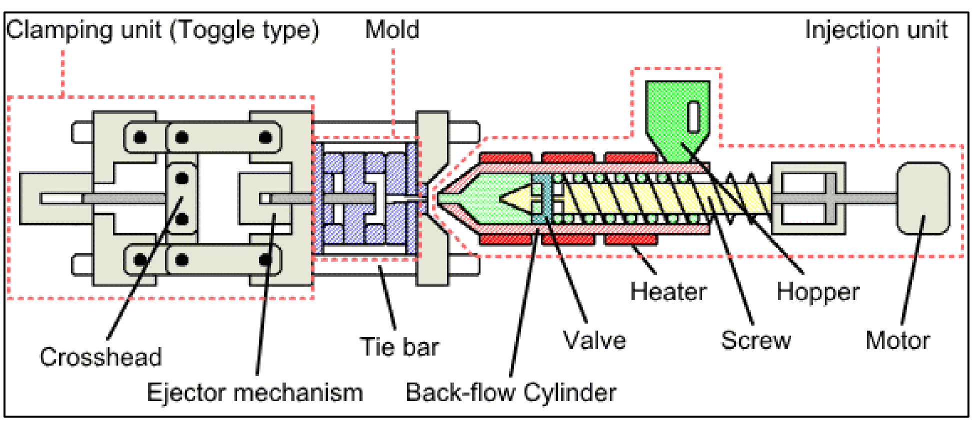

Figure 20: Typical injection molding unit. The function of this unit is to melt plastic by heat and then inject that molten plastic into a mold to cool and shape a final product (Polyplastics Co., n.d.).

The cost of equipment, labour costs or outsourcing, parts, and production vary depending on the scale of production and type of product being produced. Plastic injection molds cost anywhere between $100 for a 3-D printed low-volume injection mold to $100,000 plus for a complex multi-cavity steel mold for high-volume production (10,000+ units). An aluminum mold for mid-volume production of 1,000 – 5,000 units falls within a range of $2,000 – $5,000. A large industrial injection molding machine can cost anywhere from $50,000 to $200,000+ (formlabs, 2021). *Table 3* below details hypothetical production costs with several injection molding production scales. This type of production would be done for a plastic item, such as a small enclosure for an electronic device. This table does not include equipment costs. The product made from injection molding can have a wide range of selling prices. It mainly depends on the demand for the product and what type of product is manufactured.

Table 3: Hypothetical injection molding costs for low, mid, and high volumes (formlabs, 2021).

	LOW-VOLUME PRODUCTION	MID-VOLUME PRODUCTION	HIGH-VOLUME PRODUCTION
Production volume	100	5,000	100,000
Method	In house mold production and in house molding	Outsourced mold production and molding	Outsourced mold production and molding
Mold	3D printed polymer	Machined aluminum	Machined steel
Lead time to final parts	1-3 days	3-4 weeks	4-8 weeks
Equipment required	3D printer, desktop injection molding machine*	-	-
Mold cost	$100	$3,000	$20,000
Material cost	$0.5 / part	$0.5 / part	$0.5 / part
Labor costs or outsourcing cost	$2.5 / part	$1.5 / part	$1 / part
Total production cost	$400	$13,000	$170,000
Cost per part	$4	$2.6	$1.7

9.3 3D Printing Filament

The production of 3D filament from PE and PP material found in fishing rope may be a possible solution as well. 3D filament is a kind of printing material used by the fused filament fabrication (FFF) type 3D printer. The filament is produced into one continuous slender plastic thread that is usually spooled into a reel for purpose of storage and printer feeding. See Figure 21. Filaments are manufactured two standards being 1.75 mm radius and 2.85 mm radius. Most 1.75 mm plastic filaments are in sold in 1 kg spools (Mikula, et al., 2020). FFF printers usually provide a maximum printing temperature of around 260 ^{o}C, which can cover basic filament printing (Raise3D, 2021). The typical selling price of pure polypropylene and polyethylene 1.75 mm radius filaments is approximately $35 – $50 per kg (Filaments.ca, 2021).

Figure 21: Image of 3D filament spools (Raise3D, 2021).

Fishy Filaments is a company based in Cornwall, England who recycles nylon (P6) fishing nets to make 3D printing filaments. They use a washing process that removes both salt and marine algae from the nets before they are re-melted at over 200°C. The nets are graded according to color and wear and are processed separately to maximize their potential. Mechanical tests carried out by an independent ISO accredited laboratory show that their filament is stronger than many unbranded first-use nylons currently on the market (Fishy Filament, n.d.).

Currently, commercial 3D printing filament made from recycled polymers does not include PE or PP, although both have been investigated in the literature (Mikula et al. 2020).

10 Strategies to Support Recycling

Several strategies have been suggested to support recycling end-of-life fishing gear including a landfill tax, extended producer responsibility (EPR) programs, deposit refund schemes, reward schemes and indirect fees (Brodbeck, 2016; Resource Futures, 2019). Of these, EPR programs are considered one of the most effective (Schneider, 2020; CCME, 2020). Under an EPR program, rope manufacturers would be responsible for their end-of-life management. The Norwegian Environment Agency is reviewing a proposal for a producer responsibility scheme for the fisheries and aquaculture industry (Norway, 2017). The Canadian Council of the Ministers of the Environment (CCME) intends to facilitate EPR programs for plastics. The Canada-Wide Action Plan on Zero Plastic Waste: Phase 2 (CCME, 2020) indicates that the CCME plans to assess the best policy options to increase the collection, end-of-life management and reuse, repair and recycling of fishing and aquaculture gear, such as the potential role of extended producer responsibility programs, by 2023.

11 Plastic Waste Initiatives in Atlantic Canada

11.1 ReUsed Plastic

ReUsed Plastic, based in Nova Scotia, plans to convert industrial plastic waste into plastic sheets. Currently, they are not able to accept end-of-life rope, however they are interested in adding this in the future.

11.2 Coastal Action/ Sustane Technologies/ Goodwood Plastics

A collaborative project led by Coastal Action, based in Mahone Bay, entitled the *Collaborative Remediation of Abandoned, Lost, and Discarded Fishing Gear in Southwest Nova Scotia*, has resulted in the installation of rope disposal bins at nine wharves in southwest NS. In collaboration with Sustane

Technologies (Sustane) and Goodwood Plastics Products Ltd. (Goodwood), the project is undertaking a pilot recycling project to convert end-of-life fishing rope to diesel fuel. Trials did not start until late fall 2021 due to regulatory delays, however a trial was completed on a small quantity of rope. The rope was first manually sorted and garbage/ metals removed. The rope was then transported to Goodwood. There the rope is pressure washed, pre-cut and shredded using their high capacity shredder (personal communication, Coastal Action, 2022). The shredded material was then transported to Sustane in Chester, NS. Sustane uses a pyrolysis system to process municipal plastic waste (Strum Consulting, 2018). Sustane has indicated that if the pilot project to convert end-of-life fishing rope is successful, they remain open to the idea of an expanded program going forward (Dawe et al., 2020). The pilot project is funded by Fisheries and Oceans Canada's *Sustainable Fisheries Solutions and Retrieval Support Contribution Program*. Detailed reporting on the project is expected in the spring of 2022.

11.3 PLAEX

PLAEX Building System Inc. (New Brunswick) is a recently founded company committed to building an ecosystem of environmentally responsible, innovative, circular design building materials made from almost exclusively recycled waste materials (90%+). This company is developing a process to manufacture building material mostly from plastic material from the fishing and farming industry in Atlantic Canada. Their product dubbed "PLAEX Bricks" (Figure 22) are a zero waste, mortarless, modular construction block system. The company takes advantage of plastic properties to produce, a durable, heat resistant, watertight, thermal insulating, and inexpensive product (PLAEX, 2021).

Figure 22: PLAEX Bricks made from 90%+ of plastic material (PLAEX, 2021).

Through a discussion with the product developer and founder of PLAEX Building Systems, it was noted that the plastic materials that are possible to recycle for their product are PE (high and low density), PP, nylon, and PET. The key advantage of PLAEX is that they do not require the plastics to be thoroughly cleaned and the only pre-processing needed is shredding. After shredding, the plastic is combined with a dry mix in a mixer (just like a concrete mixer), the combination then moves to an extruding machine that can handle the mix. The material is melted together and extruded into a mold to cool. The company is currently setting up their supply chain under EPR programs, and have started planning a project in NL, partnering with a non-profit and schools. PLAEX are not paying for the materials they are processing in-house. This company creates a possible solution to handle end-of-life fishing rope. For the company to accept the material as a feedstock for their process, they require the rope to be shredded (8 mm or less) with no decontamination (heavy washing) required. The company does not have a shredder yet but are looking on the market for potential opportunities. If a shredding process for rope could be implemented on the Island of Newfoundland, then the material could potentially be shipped to this company for recycling.

11.4 Recycler's Requirements

Several recyclers in Atlantic Canada (ReUsed Plastic, Plaex) and globally (Burgeo) were contacted to determine their particular requirements for accepting plastic feedstock, for example, what form they accepted (eg. raw materials, flakes, pellets etc). Some recyclers require different material, will accept more contamination, and have higher recycling capacity than others. Responses are given in Appendix E.

12 Conclusions

- A multi-criteria decision analysis done in Norway investigated the environmental, economic, and social impacts of landfilling, incinerating, and recycling of waste fishing gear. Results indicated that recycling was the best alternative, but only when that was done locally (within 150-200 km). Exporting waste for recycling (1200-1400 km) was found to be less sustainable than landfilling or incineration due to significant adverse environmental and economic impacts.
- Other jurisdictions identified storage space at ports, heavy contamination, low quality of degraded plastics, transport and processing costs, inconsistent supply, and high labour costs as barriers to recycling end-of-life fishing gear.
- There is increased interest in tertiary recycling of PE/PP, although very little is done commercially at this point. Depending on energy sources, high energy requirements may make these processes less appealing from an environmental perspective.
- Based on the experience of Plastix, end-of-life fishing rope in NL could be converted to approximately 100,000 kg of plastic pellets. This could result in revenues of $100,000-$500,000 per year. Based on the literature, the cost to establish an industrial scale plant range from $769,000 – $5,130,000.

13 Recommendations

- Maintain relationship with PLAEX, encourage the establishment of a pilot plant in NL.
- Establish relationship with Sustane Technologies, if their pilot process becomes viable, investigate potential to pre-process rope in NL and ship to their facility for chemical recycling or encourage setting up of a facility in NL.
- Investigate/design of a mobile unit that could go to the harbours and complete processing to the shredding phase there.
- Evaluate extended producer responsibility (EPR) programs for fishing rope.
- Follow-up with equipment suppliers to determine specific equipment costs for a recycling line with throughput of approximately 200 kg/hour, with shredders capable of dealing with rope. Complete a detailed cost estimate.
- Investigate potential government assistance to make recycling of fishing rope more economical, either by way of grants or as purchaser of end products.

- Establish a laboratory scale plastic recycling line at Memorial University to educate future recycling entrepreneurs and for public outreach.
- Continue to collaborate with the FGCAC to seek regional solutions.

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Appendix A

Best Practices for Recycling Fishing Gear

D.1 Best practices for recycling of fishing gear

4.1 Plastix Global A/S, Lemvig, Denmark

Contact person: Hans-Axel Kristensen (CEO), Peter Buhl (Technical lead)
Country/region: Lemvig, Denmark

This best practice is related to:

☒ recycling ☐ design for more environmentally friendly gear ☐ design for more circular gear

And aims at solving the following issue:

Recycling of waste from the fisheries sector, including fishing gear (nets, ropes, floats) and fish boxes made from polyethylene (PE) and polypropylene (PP).

For this type of fishing gear:

☐ dredges ☒ bottom trawls ☒ pelagic trawls ☒ traps ☐ rods and lines
☐ long lines ☒ seine ☒ nets (trammel net / gill net / drift net)
☐ FADs ☒ other, namely fish boxes, floats

Region of implementation

Fishing gear and fish boxes are collected from North European fisheries, including Sweden, Norway, Iceland, among others. End-of-life FG was also collected from Canadian harbours and shipped in unused sea containers for economic viability.

Project description

Description of Best Practice

Plastix recycles plastics from fishing gear, including nets, lines, ropes, and trap netting, and from fish boxes and floats. The pre-requisite for processing is that the base materials are pure PE and PP, and that materials are moderately clean and pre-sorted by polymer type. Mixed plastics cannot be processed because this would compromise the material properties and the quality of the marketable recyclate. The aim of Plastix was also to establish a market around fishing gear recyclates.

In order to process netting and ropes, Plastix had to develop a highly specialised technology with dedicated machinery that allows for fibre washing, sediment and organic matter extraction, shredding, agglomeration and granulation (extrusion). This process allows Plastix to provide >95% pure HDPE, LDPE and PP recyclates for the pellet market. Because the process is technically challenges, fishing gear according to Plastix cannot easily be mixed with other waste streams.

Products range from packaging materials and water pipes to cosmetic jars. The comparably high purity of the output recyclates, which follow strict REACH standards, allow for a wide range of uses. Recently, Plastix has developed the technology to produce monofilament line from netting and rope fibres, which demonstrates that the overarching aim of a circular economy for fishing gear can, in principle, be reached.

4.1 Plastix Global A/S, Lemvig, Denmark

Involved stakeholders, organisations and other parties

Fisheries associations and fishing harbours worldwide, including FF Norden in Smögen (Sweden), Nofir collection in Norway and dismantling in Lithuania, Fisheries Iceland, Stevenson Harbour (Canada) and others for the collection and pre-processing of end-of-life fishing gear.

Scale

3000 tonnes of fishing gear processed in 2019, with the aim to double the amount of recycled fishing gear by 2021.

Funding

Initially project and private funding, e.g. through the EU project reTRAWL. Today, funding from selling the recyclates to the recycling market.

Process

Plastix was founded in 2012. Since then, processing strands for three polymer types were developed: High-density polyethylene (HDPE), low-density polyethylene (LDPE), and polypropylene (PP). The process consists of mechanical dry spinning to remove sediments, shredding, metal extraction, wet fibre washing and density separation, and finally granulation.

Outcomes

The granulates from fishing gear netting, ropes, floats and fish boxes are sold as OceanIX and NordIX. Material fact sheets and a description of the process are available on the Plastix Global website.

Further information

Website: https://plastixglobal.com
Contact: info@plastixglobal.com

4.2 Aquafil/Econyl yarn recycling

Contact person: -

Country/region: Italy, Slovenia

This best practice is related to:

☒ recycling ☐ design for more environmentally friendly gear ☐ design for more circular gear

And aims at solving the following issue:

Recycling of nylon fibres, including polyamide 6 fibres from fishing gear.

For this type of fishing gear:

☐ dredges ☒ bottom trawls ☒ pelagic trawls ☒ traps ☐ rods and lines
☒ long lines ☒ seine ☒ nets (trammel net / gill net / drift net)
☐ FADs ☐ other, namely …

Region of implementation

Polyamide 6 (nylon) fishing gear, in particular monofilament netting, is collected worldwide with a focus on the European Economic Area and the USA. Aquafil headquarters are located in Italy, fibre/yarn and carpet production plants are based in Slovenia and USA.

Project description

Description of Best Practice

Aquafil is a globally operating company producing, among others, polyamide fibres for carpets. Carpets are produced for the European and the US American markets. Chemical recycling of polyamide 6 fibres was developed to enable carpet recycling. Aquafil's recycling yarn "Econyl" consists of 50% pre-consumer and 50% post-consumer polyamide, with pre-consumer nylon originating from their own carpet production plants. Post-consumer PA6 is composed of carpet fibres mixed fishing gear fibres. The fraction of PA6 from fishing gear as compared to carpet fibres is not provided. Chemical recycling is used to split PA6 polymers into the caprolactam monomer, which forms the basis of nylon. PA6 nylon yarn is then re-extruded from caprolactam, which gives the material a virgin quality. Econyl is used for textile and carpet production, e.g. for outdoor sports wear. A fraction of the revenue is used to support Aquafil's NGO "Healthy Seas", which coordinates lost fishing gear retrieval campaigns in collaboration with trained diving teams of ghostfishing.org.

Involved stakeholders, organisations and other parties

Nylon nets, monofilament and twisted netting, and ropes are collected from harbours worldwide. Input materials have to be clean and pure PA6 in order to be accepted into the recycling process. Aquafil Slowenia sources, e.g., from the Nofir dismantling plants in Lithuania and Turkey, from Fisheries Association Norden in Smögen (Sweden), from the Icelandic fisheries recycling scheme and from other harbours and fishing associations operating with nylon netting. Material has to be pre-dismantled or will not be accepted for further processing. Aquafil states that the collection of end-of-life fishing gear initially started around the North Sea in The Netherlands, Belgium, and the UK, with sourcing extended to Greece and Italy in subsequent years.

4.2 Aquafil/Econyl yarn recycling

Scale

According to a 2016/2017 report, a total of approximately 20,000 tonnes of Econyl yarn was produced in 2016 from recycled fibres. The amount of fishing gear recycled since the industrial development of the recycling process in 2011 over the first 4 years was 300 tonnes, or less than 1% of the total production, such that the dominant source of Econyl yarn has to be assumed carpet fibres. Production rates appear to have increased significantly from year to year. The extensively marketed product has a high visibility on the sports clothing market, which demonstrates the attractiveness of recycling products created from fishing gear for consumers.

Funding

Aquafil is a profitable company, and the Econyl process generates revenues because of the high market value of the "fishing gear yarn" product.

Process

Chemical recycling of polyamide by splitting into the base monomer caprolactam is a known recycling process for nylon. The advantage in comparison to mechanical recycling is that disturbances are removed and the output is a highly pure polyamide 6 granulate or yarn. The process requires a high level of purity in the input fraction, which might not contain substantial levels of disturbances or be mixed with other polymers. Dismantling implies extraction of PA6/nylon netting or monofilament from fishing gear and pre-cleaning before material is fit to enter the washing and chemical recycling process in the Slowenian facility. The ability to process fibres as an input waste stream is exceptional in Aquafil's Econyl production. The output purity allows yarns in clothing quality to be produced.

Outcomes

Econyl yarn for the recycling yarn market, predominantly used in sports and outdoor clothing.

Further information

Website: https://www.aquafil.com/
https://www.aquafil.com/assets/uploads/ENG_Aquafil_RS2016_DEF_20170919.pdf
https://www.aquafil.com/assets/uploads/20181206_RS_Aquafil_ENG_2017_def.pdf
https://www.aquafil.com/products/Econyl-2/
https://www.Econyl.com

Contact: info@Econyl.com

4.3 Nofir Recycling of end-of-life fishing gear

Contact person: -

Country/region: Norway, Lithuania, Turkey

This best practice is related to:

☒ recycling ☐ design for more environmentally friendly gear ☐ design for more circular gear

And aims at solving the following issue:

End-of-life and smaller amounts of retrieved fishing gear is collected from Norwegian and other European fisheries, dismantled, cleaned and sorted for recycling.

For this type of fishing gear:

☒ dredges ☒ bottom trawls ☒ pelagic trawls ☒ traps ☐ rods and lines
☒ long lines ☒ seine ☒ nets (trammel net / gill net / drift net)
☐ FADs ☒ other, namely metal parts

Region of implementation

Started initially in Norway, but material is now collected from fisheries throughout Europe.

Project description

Description of Best Practice

Nofir is a Norwegian company that started with the motivation to collect the large amounts of fishing gear discarded by the intensive Norwegian fishing and aquaculture industry each year and enable material recycling. As a smaller percentage, lobster traps retrieved from the sea during yearly retrieval campaigns coordinated by the Norwegian Ministry of Fisheries (Fiskeries Direktorat) are also recycled. According to their webpage:
"Nofir was founded in 2008 with the purpose of establishing a nationwide system for collecting discarded equipment in Norway. 15 000 tons of plastic equipment from the fishing and fish farming industry is discarded each year in Norway alone. In 2012 Nofir were granted support from European Union through the Eco Innovaton scheme. Since then we have collected material all over Europe."

Nofir sustains two dismantling facilities, one in Lithuania for material collected in Northern Europe and one in Turkey for material collected from Mediterranean fisheries. In both facilities, metals are extracted for regional scrap metal recycling, and plastic materials are sorted and pre-cleaned to facilitate chemical or mechanical recycling with as much nets, ropes and hard plastics as possible. PE and PP polymers are then shipped to Plastix in Denmark for mechanical recycling. Predominantly, Nofir operates in close collaboration with Aquafil in Slowenia and collects nylon (PA6) fishing gear to be chemically recycled in Aquafil's fibre regeneration plant. The process requires a high level of material purity and cleanliness, which is achieved in the dismantling plants before shipping to Aquafil. At the Slowenian Aquafil facility, fishing gear fibres are mixed with post-production industrial carpet residues along with some post-consumer carpet fibres to be recycled into Econyl yarn (see Aquafil/Econyl best practice).

The initially Norwegian system established by Nofir is now well-known worldwide and receives materials e.g. from the UK, Swedish (see Smögen best practice), Canadian (Steveston Harbour), Dutch, Belgian and other fisheries and is hence likely the most extensive fishing gear collection system worldwide.

4.3 Nofir Recycling of end-of-life fishing gear

Involved stakeholders, organisations and other parties

Nofir Norway, with facilities in Lithuania and Turkey, Aquafil and Plastix as recycling partners, fishing harbours and fisheries associations worldwide for end-of-life gear collection, regional scrap metal dealers.

Scale

For the starting years of the international collection project, Nofir states that from 2011 to 2019, 41 634 tonnes of end-of-life fishing gear were collected from fisheries in 17 countries on four continents. Of these, 37 000 tonnes were collected from Norway alone.

Funding

Partially by EU innovation grants, furthermore self-sustaining from revenues of sold recyclable materials.

Process

The dismantling process involves substantial manual labour, which is likely the major reason for the process to have been established in Lithuania and Turkey, where manual labour is substantially less expensive than in Norway. The process is well-established and delivers recyclable metals and plastics to recycling companies, which provides sufficient revenue to be self-sustainable. The collection and dismantling/cleaning steps taken on by Nofir are crucial prerequisites to achieve significant recycling rates for fishing gear.

Outcomes

End-of-life, and to a lesser extent retrieved, fishing gear can be recycled on an industrially meaningful scale.

Further information

Website: https://nofir.no
Contact: post@nofir.no

4.4 PECHPROPRE

Contact person: Mathilde Gueguen

Country/region: France

This best practice is related to:

☒ recycling ☐ design for more environmentally friendly gear ☐ design for more circular gear

And aims at solving the following issue:

PECHPROPRE 1: Assess the technical and economic feasibility to set up a national used plastics management system for fishing

PECHPROPRE 2: Create shared responsibility system of used plastic fishing gear (UPFG; a kind of voluntary extended producer responsibility) by consensus

For this type of fishing gear:

☒ dredges ☒ bottom trawls ☒ pelagic trawls ☒ traps ☒ rods and lines
☐ long lines ☒ seine ☒ nets (trammel net / gill net / drift net)
☐ FADs ☐ other, namely …

Region of implementation: France

Project description

Description of Best Practice

The French « Coopération Maritime » (French association defending the artisanal fishing sector), with the support of the French government and the French Plastic value chain, performed a project named "PECHPROPRE" (pêche propre = Fishing activity is clean). The scope of the first project (2016/2018) was to make an inventory of all used plastic fishing gear (UPFG) in the French fishing activity, and of all collection systems in place to collect those products at the end of their life. The goals of PECHPROPRE 1 were to:

- Obtain national reports on the state of plastics used in the fishing sector;
- Present environmental issues and legal constraints with regard to waste treatment;
- Identify different types of fishing waste management;
- Assess technical & economic feasibility to set up a national UPFG management system;
- Work with agents to establish the necessity for an appropriate management of fishing used plastics and propose a national plan for sustainable management.

PECHPROPRE 1 consisted of:

1. A nation-wide survey, aiming to find out the amount, content and destination of waste streams from the fishing sector - both from fishers / fishing harbours and from producers of fishing gear
2. A 5-month pilot study testing a new harbour management regime in 4 smaller harbours in the Mediterranean, with separate collection of different waste streams (PA, PP etc.)

PECHPROPRE 2 (2019/2020) aims to set up a shared responsibility system of UPFG (i.e. like a voluntary EPR), by organising meetings with the fishing sector (harbour masters, fishermen, fishing gear producers) about the SUP directive and the French law against waste and its impact.

Involved stakeholders, organisations and other parties

The aim of the project was to work with all territorial projects in France; a certain number of territories have taken up the subject and have developed local projects with which the PECHPROPRE projects worked in partnership (**Figure 1**). PECHPROPRE 1 was also supported by the French Committee of Plastics in Agriculture (CPA) as experts in plastic and in the plastic waste treatment sector. PECHPROPRE 2 is also working with all French fishing gear producers.

4.4 PECHPROPRE

Scale

The project studied fisheries harbours in seven regions (**Figure 1**); 67 fishing harbours were included, of which 60 gave information. The total budget was over 350.000€ for 22 months.

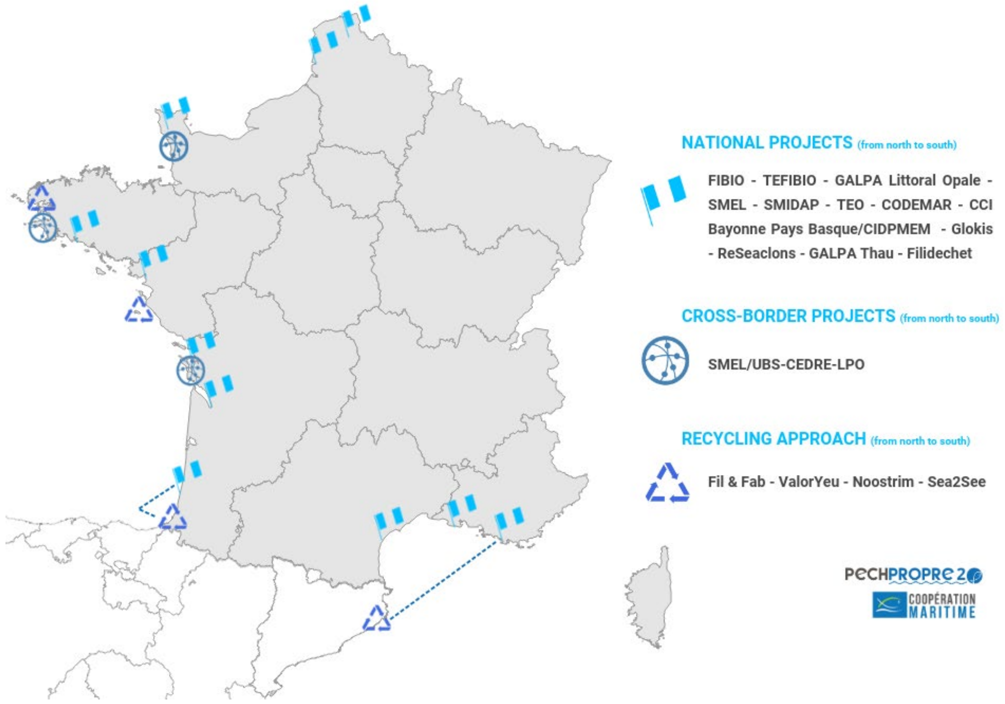


Figure 1*: Regions and local projects involved in PECHPROPRE 1 & 2*

Funding

The French ministry of Environment (MTES) and of Agriculture (MAA) and the Environmental Agency (ADEME) provided most of the funding. Coopération Maritime funded around 20%.

Process

The first project ran from 2016 to 2018. PECHPROPRE 2 began in March 2019 and will be finish in summer 2020.

Outcomes

Conclusions of PECHPROPRE 1 on how to improve collection & handling of UPFG in France were:

- A number of French harbours wishes to be more involved in fishing gear collection, but knowledge on how to organise this is lacking
- Many local project are running already in France, and should be preserved
- Further steps should support all local initiatives; therefore, a bottom-up approach should be taken
- It is important to have everyone in the fishing chain involved / participating
- Next steps should also involve other types of fishing gear. E.g., lines & traps were also studied, but data on these types of gear is lacking, as lines are often disposed of in normal trash bins
- Next step: organise pilot study in a bigger harbour with separate bins for PP / PA nets, lines etc.

Overall, it was concluded that a suitable next step for France would be to introduce a **voluntary** Extended Producer Responsibility (EPR) scheme on all fishing gear containing plastics – similar to the French agricultural sector, where this has proven an effective measure. These conclusions drive PECHPROPRE 2, of which the expected result is a letter of intent signed voluntarily by producers concerned by the SUP directive.

Further information

Website: http://www.pechpropre.fr
Contact: mathilde.gueguen@cooperationmaritime.fr

4.5 Fisheries Iceland return scheme

Contact person: Georg Haney, Icelandic Fisheries Research Institute
Fisheries Iceland

Country/region: Iceland

This best practice is related to:

☒ recycling ☐ design for more environmentally friendly gear ☐ design for more circular gear

And aims at solving the following issue:

End-of-life segments of the Icelandic fishing industry are collected for re-use and recycling, diverting EOL FG from landfill.

For this type of fishing gear:

☐ dredges ☒ bottom trawls ☒ pelagic trawls ☐ traps ☐ rods and lines
☐ long lines ☒ seine ☐ nets (trammel net / gill net / drift net)
☐ FADs ☒ other, namely metal parts

Region of implementation: Iceland

Project description

Description of Best Practice

Fisheries Iceland cooperates with the Icelandic net manufacturer Hampidjan to recover used net materials for recycling. Smaller net segments and trawls on smaller vessels are presumably repaired at sea on the way into the harbour, and net segments are returned to Hampidjan or to the fishing gear collection at the Icelandic recycling facility. The Icelandic fisheries are mostly composed of larger trawlers focussing on pelagic trawling and purse seines. Pelagic trawls last for many years and because of low abrasion only minor repairs are usually required. Purse seines are too large to be repaired on board and are returned for repairs and mending to the net loft. Cut-out material mostly from purse seine and bottom trawl repairs is collected for recycling. The Icelandic industrial fishing fleet is predominantly fishing with PE/PP and PA netting, with about half of the netting send for recycling in 2016 being composed of PE/PP and half being composed of PA6 (nylon). PE and PP nets and ropes are send for recycling to Plastix in Denmark. It is not clear where nylon multifilament netting is send. Each fishing company collects their own materials or the materials are collected at the net loft, but it is likely that the collection facility and the fishing companies and net manufacturers cooperate to fill transport containers. Plastix pays for the transport, but no extra revenue is generated by providing the recycling material to the fishing industry or the collection facility.

The system was set up as a response to new government legislation requiring a recycling scheme for fishing gear which was implemented in 2005/2006. This legislation would require an import tax per each kg of imported net material. The fishing industry opted to set up their own system to take care of fishing gear waste materials. The government supported this approach, yet the legislation would be enacted in case that the recycling system would not function.

The researcher who provided the information suspects that the system operates so efficiently because it is co-ordinated and managed by the fishing industry itself. Hence there are no complaints from the fishing sector, and no additional funding is required to allow for authorities to manage the collection and dismantling. The direct pathways between the fishing companies,

4.5 Fisheries Iceland return scheme

the collection facility, the net manufacturers and the recycler in Denmark are the key to the efficiency, cost-neutrality and success of the Icelandic fishing gear management system. [Information in this section provided by Georg Haney from the Icelandic Fisheries Research Institute and from Fisheries Iceland 2017.]

Involved stakeholders, organisations and other parties

Fisheries Iceland, Hampidjan net manufacturer, sorting and recycling facility in Iceland for collection, Plastix Global in Denmark as the material recycler for PE and PP netting and ropes.

Scale

According to the latest public report by Fisheries Iceland on the Environmental and Economic benefits of the Icelandic fishing fleet from 2016/2017, 8400 tonnes of end-of-life fishing gear was send for recycling during the 10 years since the legislation came into place. In 2016 alone, more than 500 tonnes of PE/PP netting and the same amount of nylon netting were send for recycling. The actual collected amounts since 2017 are not yet publicly available.

Funding

The project operates most likely cost-neutral without direct revenues. Fishers are employed by the fishing companies and carry out dismantling as part of their regular work. Plastix pays for the transport costs, but no revenue is paid for PE or PP nets and ropes. It is not clear whether any revenue is generated from nylon netting. The fishing sector benefits from the positive image generated by end-of-life gear recycling and from savings because EOL FG would otherwise have to be deposited in landfills (incineration or other thermal conversion to energy is not available in Iceland).

Process

According to the Institute of Fisheries Research, smaller repairs take place on the fishing vessels on the way into port. For large purse seines, this is not possible and the nets are regularly returned to the net loft for check-up and repairs. Along the entire value chain, netting and ropes are collected and sorted into individual polymers. Each PE or PP batch is send to Plastix in Denmark for recycling once a container is full.

Outcomes

End-of-life fishing gear of the Icelandic fleet is recycled. The recycling rate by weight is estimated by Fisheries Iceland to be about 90% including metals.

Further information

https://sfs.is/wp-content/uploads/2018/09/Environmental_report_2017.pdf

4.6 GREEN DEAL FISHERIES FOR A CLEAN SEA

Contact person: Ewoud Kuin

Country/region: The Netherlands

This best practice is related to:

☒ recycling ☐ design for more environmentally friendly gear ☐ design for more circular gear

And aims at solving the following issue:

Organising collection and recycling of waste from fishing vessels, to prevent marine litter

For this type of fishing gear:

☐ dredges ☒ bottom trawls ☒ pelagic trawls ☐ traps ☐ rods and lines
☐ long lines ☐ seine ☒ nets (trammel net / gill net / drift net)
☐ FADs ☐ other, namely …

Region of implementation: The Netherlands

Project description

Description of Best Practice

Since 2014, a number of different stakeholders collaborate in the 'Green Deal Fisheries for a Clean Sea' in the Netherlands, with the aim of working together for a cleaner sea. In the Green Deal, parties from across the entire value chain of the fishing sector are involved & collaborate.

Four different waste streams are addressed: dolly rope, Fishing for Litter, domestic waste, and discarded (end-of-life) fishing nets. Fishers can hand in discarded fishing nets free of charge. The waste is collected in harbours and then transported to a number of regional facilities, where it is cleaned, sorted and dismantled by the waste management company Bek & Verburg. From here, materials are forwarded to various recyclers: metals to metal recycling, PA to Aquafil in Slovenia, and PE/PP to a mechanical recycling plant in Vietnam.

Involved stakeholders, organisations and other parties

The Green Deal (one of 3 marine Green Deals out of an overall figure of 180) was signed on November 20th, 2014. In this Green Deal a number of sectors collaborate collectively, including:

- the fishing industry
- port authorities
- waste disposal company (Bek & Verburg); and
- a number of environmental organisations.

The secretarial task is commissioned by Rijkswaterstaat (the Dutch Water Management Office, part of the Ministry of Infrastructure and the Environment), The association of coastal municipalities (KIMO) acts both as secretarial body and project partner.

Scale

The involved parties include most fisheries harbours in the Netherlands, several coastal municipalities, NGO's and the two main demersal fisheries organisations within which most of the Dutch demersal fisheries sector is represented.

Funding

The secretariat,), as well as an annual budget meant for pilots and research, is paid for by the national government (Rijkswaterstaat). Usually other parties (NGO's, fisheries sector) also finance certain projects or initiatives.

Process

4.6 GREEN DEAL FISHERIES FOR A CLEAN SEA

Under the framework of the Dutch Green Deal Fisheries for a Clean Sea, a number of pilots have been run. In 2015/2016, three pilots started:

1. The collection of waste dolly rope in fishing ports:
Dolly rope is a protective layer of tiny fibres that are attached to a net to protect it from wear. Dolly rope is made of plastic and wears out as well, furthermore a lot of old dolly rope ends up in sea, through this plastic microfibers enter the marine ecosystem. By means of the project fishers can hand in dolly rope that has worn out. With the dolly rope project fishers get a small compensation for all the dolly rope they hand in, this compensation is given to the KNRM (the sea rescue society). Meanwhile, another partner is experimenting with the development of an alternative for plastic dolly rope (see best practice DollyropeFree / VisPluisVrij).

2. The collection of domestic waste:
- The normal garbage bags (galley waste) are too vulnerable, both during storage on board as after placement on the quay in the port. Using the infrastructure of the Fishing For Litter project KIMO has started to distribute a smaller type of "big bag" for the purpose of the collection and storage of domestic waste.
- These bags can be attached to a pole on board preventing these to be blown overboard and made of stronger material so the seagulls cannot tear them open.

In 2016 these projects have been integrated in one system and rolled out in the ports of Harlingen and Stellendam. The goal is to develop a system for an integrated way of collection and storage of fisheries related waste in ports.

3. The creation of the "Afvalspoorboekje" (a waste management guide for fishers visiting ports)
Given that every harbour has slightly different customs and arrangements for waste management, and that fishermen at times visit different harbours, a clear overview of practices per harbour could be helpful. In 2016 a project started, involving KIMO and the harbours of Groningen, Den Helder Harlingen, Lauwersoog and Den Oever to create a flyer which presented the waste management facilities per harbour. The idea is that the flyer contains all the information (which containers, where they are, who to contact) a fishermen needs to get rid of his/her waste as efficiently as possible.

Outcomes

Protective bags work well for protecting household waste against the weather and seagulls. In other harbours using closed containers also works. An important lesson here was that every harbour has its own unique characteristics, and therefore also its own ideal solution (e.g., not every harbour has enough space for closable waste containers). Custom made solutions based on best practices therefore seem to be the way forward. The flyer, as mentioned under project 3, turned out to be a useful method to accompany this approach. By 2019 all fisheries harbours in the Netherlands make use of a custom made flyer, representing their waste management solutions. They help raise awareness and increase separately collected waste streams.

Further information

Website: www.visserijvooreenschonezee.nl
Contact: ewoud.kuin@rws.nl

4.7 Fisheries Association Norden, Smögen, Sweden

Contact person: Thord Görling
Country/region: Municipality of Smögen, Sweden

This best practice is related to:

☒ recycling ☐ design for more environmentally friendly gear ☐ design for more circular gear

And aims at solving the following issue:

Collection of end-of-life fishing gear for re-use and recycling.

For this type of fishing gear:

☐ dredges	☒ bottom trawls	☒ pelagic trawls	☒ traps	☐ rods and lines
☒ long lines	☒ seine	☒ nets (trammel net / gill net / drift net)		
☐ FADs	☒ other, namely floats, fish boxes			

Region of implementation: Swedish west coast, all fishing harbours participate.

Project description

Description of Best Practice

Fishing gear collection started as a pilot project in 2012 and increased in the collection of end-of-life netting each year. Since 2015, most of the pre-processed material was send to Plastix. In 2018, a marine recycling centre was installed to move operations away from the touristic harbour area. Sotenäs municipality now manages the pre-sorting of collected end-of-life fishing gear with support from FF Norden and organises beach clean-ups.

Fisheries Association Norden has set up a system to collect end-of-life and, to a lesser extent, retrieved fishing gear for re-used and recycling. It started as a system to collect production waste netting for recycling. As of 2018, seven regional fishing harbours and 37 fishing vessels on the West Coast of Sweden participate. The material is either collected by members of FF Norden or brought to the municipality or to Norden harbour for dismantling. Initially, all dismantling took place at Norden fisheries harbour and was carried out by fishers of FF Norden. In 2018, a pilot facility dismantling center was opened at a nearby location in Sotenäs municipality, next to the municipal regular recycling central (RAMBO), where the smell of end-of-life FG would not impact tourism, harbour visitors and personnel.

Collected materials are checked for re-use possibilities and, if re-use is not feasible, are sorted into metals and different plastic types. Polyethylen (PE) and Polypropylen (PP) nets and ropes are send to Plastix in Denmark for mechanical recycling. Polyamide (PA6, nylon) from pots and fishing net is sent to Plastix to at the moment, who then resends this further. Logistics to send the PA directly to other recycling plants are currently under investigation. Metals are recycled at a local scrap metal facility, including steel parts and lead from sink lines, though this is quite rare since gillnets are not that commonly used on the Swedish west coast. Since 2019, however, a collection initiative covering all of Sweden to collect DFG was started, so from areas where gillnets are more commonly used an increased collection is expected.

Some special equipment has been invested in to be able to take care of as much material as possible, such as a wire-cutting machine, a mill to reduce the size of the fishing gear etc. Since 2018, Norwegian lobster traps are also compressed for steel recycling, while energy is generated from the polymer net material. According to FF Norden, 20-30% of fishing gear by weight is fit

4.7 Fisheries Association Norden, Smögen, Sweden

for re-use, mainly creeper balls and rubber chains are re-used. 70-80% of material is prepared for recycling, and 0-10% is incinerated for energy recovery.

Involved stakeholders, organisations and other parties

Fisheries Association FF Norden, Smögen/Norden fishing harbour, municipality of Sotenäs, pilot sorting facility in Sotenäs municipality, Plastix as receptors of recycling materials, local metal recycling plant.

Scale

Seven fishing harbours along the Swedish West Coast, at least 37 fishing vessels participate in regular collection of end-of-life FG. Since December 2019, a national collecting initiative, called Fiskereturen was started by FF Norden, Sotenäs Municipality, Båtskroten and Keep Sweden tidy, to collect DFG from all over Sweden. This is financially supported by HaV, Swedish agency for marine and water management.

Amounts were 1-2 containers per year until 2016, which has risen to 3-4 containers per year, with a weight of 10-15 tonnes of fishing gear in each container. The total yearly turnover depends on the condition and the types of gears collected (pers. communication, Thord Görling).

Funding

Initially, the project started "with enthusiasm and private funding" in 2012. Later, some project/EU/EMFF funding was used to set up the system, and the marine recycling centre is currently also run on a project-funding basis. Although the fishing gear collection and dismantling is not yet operating self-sustainably according to FF Norden, a small revenue is generated by selling especially scrap metal and some of the plastics from fishing gear for recycling. The fishers of FF Norden dedicate a significant fraction of their time and manual labour voluntarily.

Process

The collection and pre-processing/dismantling and sorting system has been in place for several years, and is now self-sustaining, though not financially. Pre-processing and sorting of the materials, and where necessary pre-cleaning, is key to the success: only properly sorted and pre-cleaned materials can be send to the recycling facilities Plastix.

Outcomes

All end-of-life fishing gear and production waste netting and ropes are collected in participating harbours along the West Swedish Coast. This includes waste FG occurring during operations at sea. To hand over fishing gear is at a no-cost for the fishermen, there are no further cost applied to them, which leads to a high participation rate and incentivises collection of end-of-life materials also at sea. It is expected that the system leads to less cut-offs and netting accidentally lost at sea, because of the incentive that all material is brought back to shore, the value of the material given by the project, and the raised awareness through the project. In addition to dismantling and sorting the Fishing gear, a testbed for developing new innovations and products from the resources found in the fishing gear was started in 2020. Hopefully this will lead to that the material is reused more locally and at the same time increases the value of the marine plastic while also raising awareness of the issue.

Further information

Website: http://www.ffnorden.se/
Contact: info@ffnorden.se

4.8 Fiskereturen, Sweden

Contact person: Alexander Hassellöv, Fiskareföreningen Norden

Country/region: Sweden/Smögen

This best practice is related to:

☒ recycling ☐ design for more environmentally friendly gear ☐ design for more circular gear

And aims at solving the following issue:

The purpose of the project is to establish a national system for the collection of end-of-life or lost fishing gear

For this type of fishing gear:

☐ dredges ☒ bottom trawls ☐ pelagic trawls ☒ traps ☒ rods and lines
☒ long lines ☒ seine ☒ nets (trammel net / gill net / drift net)
☐ FADs ☐ other, namely …

Region of implementation

Sweden

Project description

Description of Best Practice

The goal is to create a national system where end-of-life fishing gear is handled according to a quality-assured and environmental friendly process. This reduces the occurrence of degrading fishing gear. Abandoned fishing gear and fishing gear that are degraded by UV radiation or processes in nature have been identified as a significant source of microplastics. The long-term goal is therefore that fishing gear should be taken care of as soon as they have become degraded through the establishment of a recycling system which in turn supports a better circular economy system as described in "Lost and worn fishing gear from a circular economic perspective" (see the report in Swedish).

Procedure

The work is broadly based on informing both recreational and professional fishermen, locating need areas, coordinating the existing system of subcontractors, establishing cost model systems, establishing pre-treatment systems, adapting existing (boat scrapping and professional fisheries networks, possible transports, network transports, computer systems for registration, implementation support and follow-up, investigate the possibilities of environmental certification, establish a quality assurance system and establish information dissemination activities.

Transports go to Sotenäs Marine Recycling Centre for sorting and then on to recycling, material recycling and ultimately energy recycling. Even now, the goal is for at least 80% of the materials to go to material recycling. The collection will take place through six fixed collection sites at strategically selected locations, through campaigns where fishing ports are visited and via collection from reported needs through the End of Life Boat recycling system, Båtretur. There will be campaigns at strategic dates before and after fishing seasons.

Sorting for recycling will be carried out by the municipality of Sotenäs, with the support of the Fisheries Association Norden, FF Norden, with its knowledge of how different types of materials can be sorted and broken into suitable fractions.

Results from all activities will be collected and entered into the IoT hub developed by Sotenäs municipality. The material will form the basis of the final report that will be delivered.

4.8 Fiskereturen, Sweden

Involved stakeholders, organisations and other parties
Fisheries Association Norden, Båtretur and Sotenäs municipality.

Scale
We estimate to collect around 165-200 ton from Dec 2019 to Dec 2020.

Funding
Funded by the Swedish Agency for Marine and Water Management.

Process
We have started to collect and as well established a website.

Outcomes
The outcome so far is positive in the sense that we have collected a lot already.

Further information
More information about the project can be read on www.fiskereturen.se
Fiskareföreningen Norden, Alexander Hassellöv alexander@smogensnat.se

Appendix B

Waste Facilities

From Dawe, N., Kendall, R. A., Smith, S., & Davis, M. (2021). End-of-life Fishing Gear Management in Newfoundland and Labrador. Fishing Gear Coalition of Atlantic Canada (FGCAC). https://fgcac.org/wp-content/uploads/2021/06/FGCAC_Report_End-of-Life-Fishing-Gear_Newfoundland-Labrador.pdf

Table 6. Management of end-of-life fishing rope and lobster traps at Newfoundland and Labrador waste resource management facilities.

Facility Name	Rope	Crab Pots	Wire Traps	Wood Traps
Bay Bulls Waste Recovery Facility	---	---	---	---
Bell Island Waste Recovery Facility	---	---	---	---
Cavendish Waste Recovery Facility	---	---	---	---
Clarenville Transfer Station	---	---	---	---
Harbour Grace Waste Recovery Facility	---	---	---	---
Old Perlican Waste Recovery Facility	✕	✓	✓	---
Placentia Waste Recovery Facility	---	---	---	---
Robin Hood Bay	✕	---	---	---
Renews-Cappahayden Waste Recovery Facility	---	---	---	---
St. Joseph's Waste Recovery Facility	---	---	---	---
Sunnyside Waste Recovery Facility	---	---	---	---

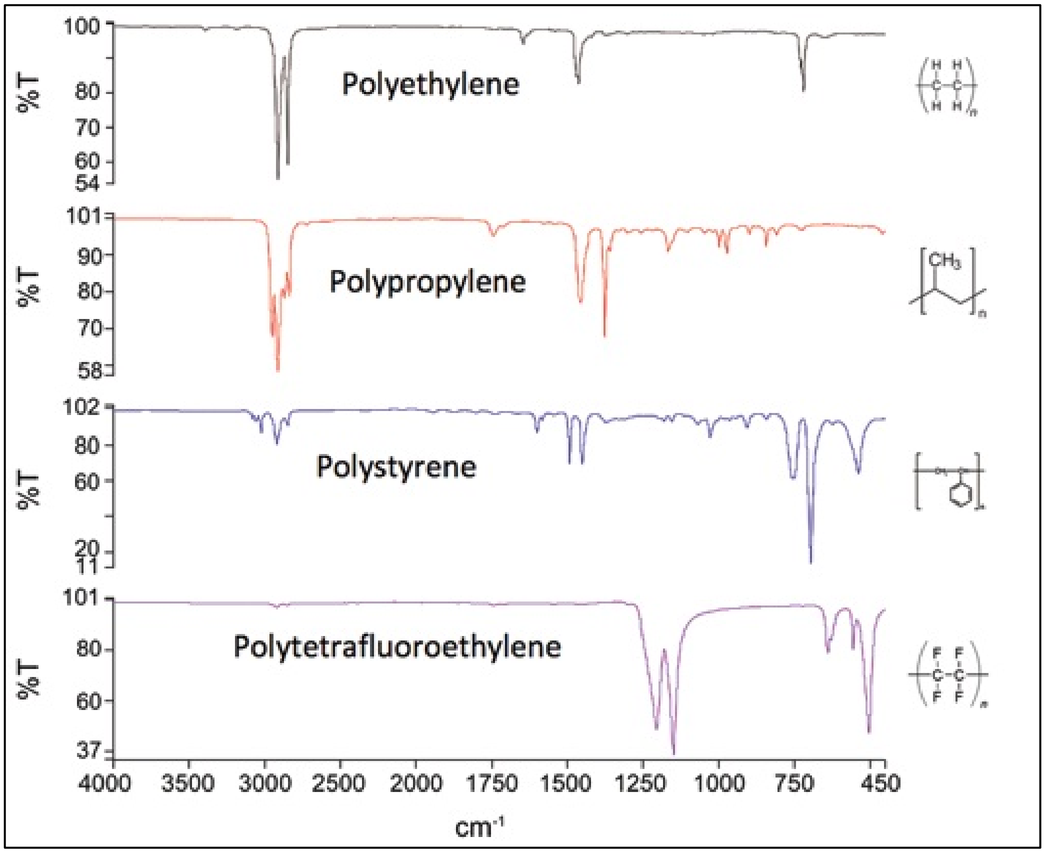
Whitbourne Waste Recovery Facility	---	---	---	---
Central Newfoundland Regional Landfill	✗	✓	✓	---
Buchan's Junction Transfer Station	---	---	---	---
Fogo Island Transfer Station*	✗	✓	---	✗
Gander Bay Transfer Station*	✗	✓	---	---
Indian Bay Transfer Station*	✓	✓	✓	---
New World Island/Twillingate Transfer Station*	✓	✓	✓	---
Point Leamington Transfer Station*	✗	---	---	---
Terra Nova Transfer Station*	✓	✓	✓	---
Bay St. George Waste Transfer Station	✗	✓	✓	---
Burgeo Waste Transfer Station	✗	✓	✓	✗
Long Range Waste Transfer Station	✗	✓	✓	---
Southwest Coast Waste Transfer Station	✗	---	---	---
Wild Cove Waste Transfer Station	✗	---	✓	✗
White Bay South Waste Transfer Station	✗	✓	✓	✗
Eddie's Cove East-Castor River North	✗	✓	✓	✓
Eddie's Cove West-River of Ponds	---	---	---	---
Goose Cove-Boat Harbour	✗	✗	---	---
Main Brook-Englee	---	---	---	---

Burin Landfill	×	✓	✓	---
Baie Verte Landfill*	---	✓	---	---
La Scie Landfill	×	✓	---	---
South Brook Landfill	---	✓	---	---
Trinity Bay North	✓	✓	✓	×
Bonavista	×	✓	✓	×
Port Blandford	---	---	---	---
Port Rexton Waste Disposal Site	×	✓	---	×
Milltown-Head of Bay D'Espoire Landfill	---	---	---	---
Hermitage-Sandyville Landfill	×	✓	✓	---
St. Alban's Landfill	×	---	---	---
Harbour Breton	×	✓	✓	---
Labrador Straits Waste Disposal	---	---	---	---
Labrador City-Wabush	---	---	---	---

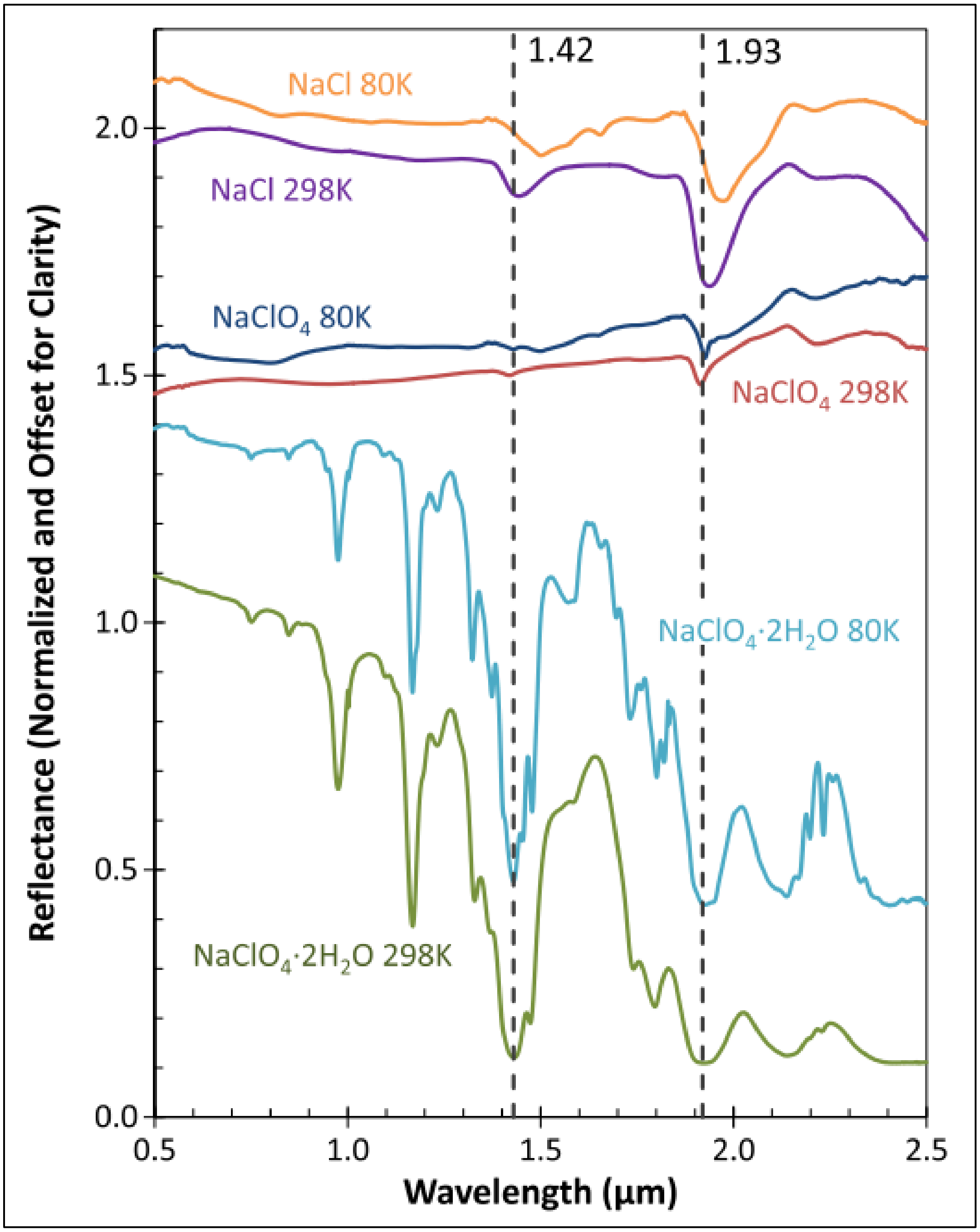
'√' indicates facilities that recycle, stockpile for future recycling or repurposing, reuse fishing materials, or otherwise divert waste from the landfill. 'x' indicates that these materials are landfilled. This table shows facilities that recycle, reuse, or repurpose the above fishing gear materials, but does not necessarily indicate that gear is diverted from the landfill in absolute.

Appendix C

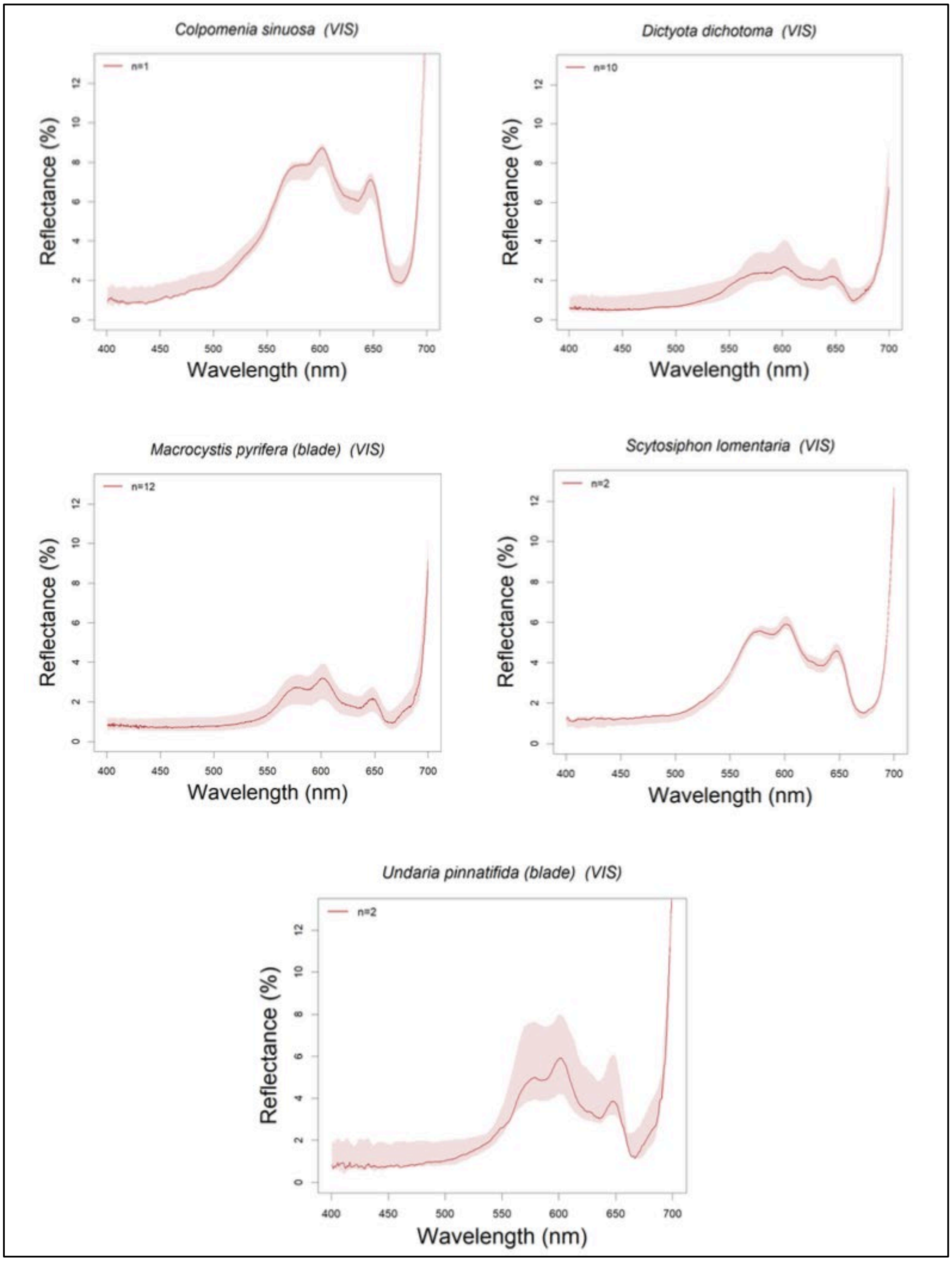
IP Spectra Examples



IR spectra of various types of plastic. The peaks show the percentage of transmittance corresponding to various wavelengths. Most peaks occur at the wavelength ranges discussed previously (PerkinElmer, 2011).



NIR reflectance spectra of anhydrous NaCl and NaClO4, and NaClO4 · 2H2O at 298 and 80 K
(Hanley, Dalton III, Chevrier, Jamieson, & Barrows, 2014).



IR spectra of several brown algae species (Olmedo-Masat, Raffo, Rodriguez-Perez, Arijon, & Sanchez-Carnero, 2020).

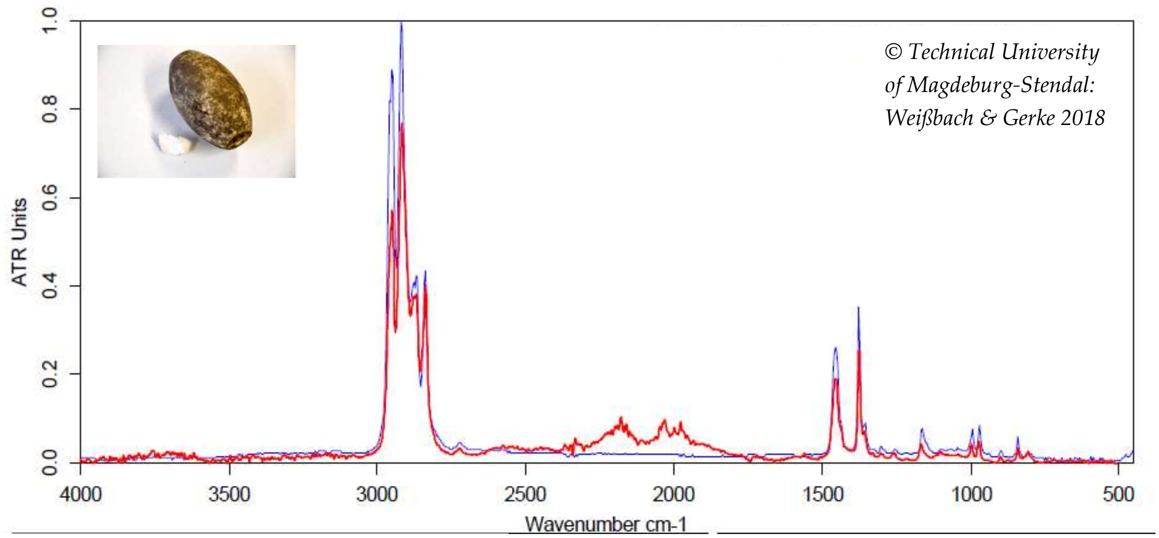


Fig. 6.4: FTIR spectra of floats from the Ahlbeck gillnet sample (red) in comparison to a PP template spectrum (blue, © Sadtler spectroscopic library).

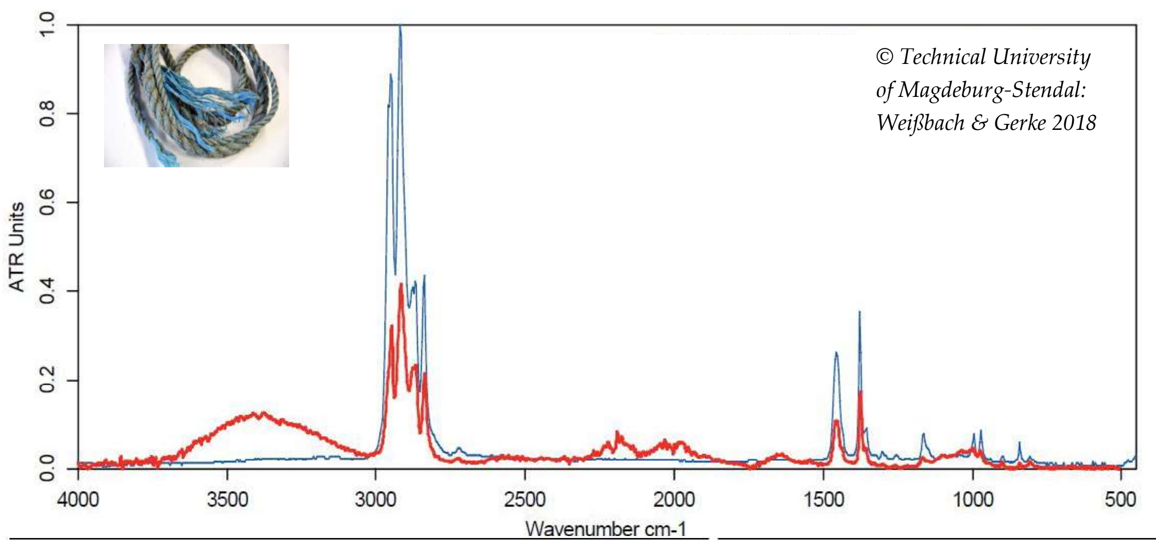


Fig. 6.5: FTIR spectra of blue rope or floatline extracted from the Ahlbeck gillnet sample (red) in comparison to a PP template spectrum (blue, © Sadtler spectroscopic library).

Appendix D

Recycling Equipment

List of Companies/Contacts

Name	Email	Location
Amstar Machinery Co., Ltd. (Branch of ASG Group)	mailto:sales@plasticrecyclingmachine.net sales@plasticrecyclingmachine.net	China
Tecnofer Ecoimpianti SRL	sales@tecnofer.biz	Italy
LABTECH ENGINEERING COMPANY LTD	labtech@labtechengineering.com	Thailand
Regulus Machinery Co., Ltd.	manager@regulusmachine.com	China
General Kinematics Corporation	info@generalkinematics.com	Illinois, USA
Sierra International Machinery, LLC.	info@sierraintl.com	California, USA
Carr Industrial Ltd.	office@carrindustrial.com	Brantford, ON
Lindner RecyclingTech America LLC	office-us@lindner.com	North California, USA
LIDEM. Construcciones Mecánicas. S.L	lidem@lidem.com info@lidem.com	Spain
Wiscon Envirotech Inc.	wiscon@wiscon.com	China

(LINDNER, 2021)

Appendix E

Recycler Questionnaire Response

Questionnaire Table

Company	In what form are you willing to receive the material?	What contaminations are of concern for recycling?	What volume of feed stock is desired?
Reused Plastic Founder, CEO | Spencer Pieczonka Reused Plastic	To create my sheets the feedstock needs to be flakes (8mm or less) or pellets. Currently I do not have a shredder but am pricing one now as I have intent from numerous sign companies, sheet wholesaler, and manufacturers that are offering to give me their plastic waste ASAP or else it gets landfilled. I do have intent from rope and net manufacturers in Atlantic Canada and beyond to incorporate their rope and nets as a shredded feedstock but again it requires a specialized shredder. For the current scope of my organization, it's not feasible to accept rope and nets.	For rope and nets there are a multitude of variables, and I am worried about metals (hocks), dirty, rocks, sand, and more. For other plastic types I'm only acquiring them as post-industrial waste, therefore, they never touched a landfill avoiding multiple forms of contaminants. I plan to implement this same process for my clean rope and net feedstock (if implemented).	I'm in the process now of starting my first run of sheets for basic level testing. I'm seeking 100 lbs of multiple plastic types. In one year, I expect: 20,000 lbs of plastic types to be made into our products; 2nd year 40,000 lbs; and 63,000 lbs in the third year.

Company	In what form are you willing to receive the material?	What contaminations are of concern for recycling?	What volume of feed stock is desired?
PLAEX PLAEX BUILDING SYSTEMS INC.	Disassembled, ideally no metal. Rope bagged separate (mostly our focus ATM). As much type of separation as is possible. We can only use a small percentage of mixed materials as we need to list our ratios for certification.	Metal (thicker than the thin strands which may be in rope), heavy mud or organic matter contamination, and wood.	We will start with the 2 tons for testing, if we can get sufficient quality of material, we may be able to take upwards of 500 tons annually once we scale up next year. There are a few variables to sort out.
Bureo inc. bureo	Nylon 6 or High-Density Polyethylene (HDPE) End of Life Fishing Nets.	Photodegradation, Machine Oil, Heavy Metal Exposure (e.g., lead weights), Anti-Fouling Paint, Non-Nylon 6 or HDPE plastic fibers woven into the nets, Heavy Biofouling.	Minimum supply required is 10 tons (to fill a shipping container) but would typically looking to source a least 60 tons annually to set up in a new location.