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Reduced littering from expanded plastics - Mapping and evaluation of measures

Project report

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Excerpt:
This report was prepared for the Norwegian Environment Agency as a follow up of the Norwegian Plastics Strategy (2021). Littering of expanded plastics (EP), especially in the form of expanded polystyrene (EPS) is a growing environmental concern due to the unique set of properties of these materials and the frequency in which they are found during litter clean-up operations.

This project has mapped central material- and waste streams in Norway containing expanded plastic, mainly EPS, and describes areas of use where EP-littering may occur within each sector. The report also includes a material stream analysis that forms the basis for a simple risk assessment regarding EP-littering from different sectors and areas of use.

Based on an identified set of unwanted incidents a list of measures to reduce EP-littering is presented, including potential areas where EPS can be substituted with alternative materials. From the complete list of 30 measures nine measures are highlighted as especially relevant based on perceived effectiveness of the measure, the size of the material streams that are affected by the measure, and the expected feasibility of implementation.

The report also includes an appendix that contains a short review of selected measures to reduce EP-littering or increase recycling of these materials in other countries than Norway.

The information about material- and waste streams and selection of measures is based on available literature and statistics together with interviews with more than 30 key stakeholders in the EP sector.

Key words:	EPS, XPS, EPP, EPE, measures, import, production, littering mechanisms, risk analysis, life cycle analysis	**Geography:**	Norway
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I. Glossary of terms and abbreviations

EP	Expanded plastics	A lightweight material made by expanding a thermoplastic material.
EPS	Expanded polystyrene	A lightweight material made by expanding polystyrene.
XPS	Extruded polystyrene	A lightweight material made by extruding polystyrene.
EPE	Expanded polyethylene	A lightweight material made by extruding polyethylene.
EPP	Expanded polypropylene	A lightweight material made by extruding polypropylene.
HFC	Hydrofluorocarbons	A chemically stable hydrocarbon compound containing fluorine with a large climate gas footprint.
EPR	Extended Producer Responsibility	
EUMEPS		The association for European Manufacturers of Expanded Polystyrene
HVAC	Heating, Ventilation and Air Conditioning	
	Primary	A primary material that is in its first lifecycle, and has not been recycled.
	Secondary	A secondary material has been recycled.
	Mechanical recycling	Directly recycling of a polymer by remelting it.
	Chemical recycling	Recycling of a polymer by breaking it down to monomers and/or small hydrocarbons.
CCB	Corrugated Cardboard	Lightweight, shock absorbing material made from cellulose fibres
LCA	Life Cycle Analysis	
	Clean-Ups	Events where litter is cleaned and properly disposed to restore natural lands.
	Hotspots	Areas where legacy EP waste has accumulated.

II. Summary

Expanded plastics (EP) are commonly found during litter clean-ups. In this report the storage, use, collection and waste treatment of expanded plastics, and measures which may serve to limit littering from EP are studied. Information was gathered from available statistics, reports and a series of in-depth interviews with more than 30 key stakeholders in the EP sector.

The scope of this report has been expanded polystyrene (EPS) and extruded polystyrene (XPS) in the construction and aquaculture sectors, in floating docks, buoys and pontoons, and packaging.

EPS and XPS are used for:

- Thermal insulation and concrete forms in buildings,
- Light-weight construction materials in roads,
- Shock-absorbing, thermally insulating packaging for seafood and appliances,
- Pontoons for floating docks and filling in mooring buoys and aquaculture pens.

It is estimated that the following products and materials are placed on the Norwegian market annually:

- 5 810 tonnes of fish boxes in EPS,
- 29 460 tonnes of insulation plates and concrete forms of EPS,
- 540 tonnes of lightweight EPS fill for roads,
- 15 350 tonnes of insulation plates in XPS,
- 4 000 tonnes of packaging for packaging of appliances, electronics and other purposes,
- 1 900 tonnes of EPS in pontoons for floating docks,
- 240 tonnes of EPS filling for mooring buoys,
- 130 tonnes of EPS-filling for aquaculture pens.

Products and materials in EPS are mostly produced in Norway, except for packaging for appliances and electronics which is imported with the products. In addition, an estimated volume of 30 250 tonnes of EPS fish boxes is exported annually. There is a high degree (estimated 90 %) of recycling of fish boxes in the domestic market. Infrastructure is being developed for recycling of packaging for appliances and electronics, which is increasingly being recycled, especially in densely populated areas (estimated 50 %). Insulation plates, concrete forms, which represents the largest volume of EPS and XPS, and pontoons are sent to landfills or for incineration, due to contaminants such as gravel, concrete and tar, which renders them unfit for mechanical recycling. High transport costs for non-compacted EPS represent an important barrier for recycling. In total an estimated 25 % of discarded EPS and XPS in Norway is recycled.

Areas of use and substandard practices which may result in littering of EP have been identified:

- Pontoons tear lose during heavy weather and are crushed against shores by waves,
- Pontoons made with open EPS against water and air can result in littering of EPS due to wear from ordinary use, weather and the ocean.
- Cutting and adjusting of insulation plates, construction materials and concrete forms in EPS produces small fragments of EPS which may get transported by wind or water into nature.
- Insufficient fastening of EPS and XPS during transport and outdoor storage, for example from small construction sites or houses to recycling centres may lead to loss of EPS by wind or water into nature.

Important measures which may reduce littering from EP were identified and evaluated as shown in tables a - c.

*Table **a**: List of potential measures to reduce littering of expanded plastics during storage, use and waste treatment.*

Code	Description of measure
A	**Measures related to storage and handling of materials and products containing expanded plastics**
A1	Protection from the weather during storage
A2	Protection of EP during transport
A3	Environmental management Systems
A4	Training programs
B	**Measures to control the scattering of small pieces and particles of expanded plastic**
B1	Measures to reduce spill during use
B2	Air filters in exhaust and ventilation systems
B3	Recovery systems for process and surface water
B4	Fencing and other physical barriers
B5	Regular inspection and collection of spotted littering
C	**Collection of discarded products and materials containing expanded plastic**
C1	Take back schemes for recycling, collection and sorting of EP
C2	Incentives for efficient sorting
C3	Separate EP-waste categories in national waste statistics
C4	Product design for better sorting and recycling
D	**Specific measures for the construction industry**
D1	Use of pre-fabricated building elements
D2	Protecting EPS-insulation in construction to sunlight
E	**Specific measures for the marine and maritime sector**
E1	Eliminate use of floating elements that have exposed EPS-surfaces
F	**Specific measures for the waste treatment sector**
F1	Covering of EPS-containing waste at landfills
G	**Measures to identify and clean up hotspots of EP-littering**
G1	Identification and clean-ups of illegal and/or legacy dumping sites
G2	Marking of EP elements to control sources.

*Table **b**: Measures to reduce littering of expanded plastic: potential material substitutions.*

Code	Description of material substitution
H1	Substitution of EPS and XPS as insulation materials in buildings
H2	Substitution of EPS or XPS-containing materials in road construction
H3	Substitution of EPS packaging
H4	Substitution of EPS in fish boxes
H5	Elimination of EPS in pontoons and buoyancy elements
H6	Elimination of EPS-use during land storage of boats

*Table **c**: Measures to reduce littering of expanded plastics during storage, use, collection and waste treatment.*

Code	Measures that may lead to increased reuse and recycling of expanded plastic
I1	Increased use of compactors that allow for more cost-effective transport of EPS waste
I2	Reuse of discarded EPS elements in new road projects
I3	Reuse of EPS elements in the aquaculture industry
I4	Reuse of floating docks
I5	Reuse of EPS insulation in construction projects.

The different sectors and areas of use that have been evaluated are ranked according to the risk they are considered to represent as a source of EP-littering. Lightweight fill of EPS used for construction of roads and EPS in pontoons are considered to represent a very high risk of EP-littering. Insulation plates from the construction sector, EPS filling from floating pipes and buoys and EPS-waste from scrapping of boats are considered to represent a high risk for EP-littering, while the remaining areas are rated as either medium or low.

Based on the risk assessment for the different sectors and areas of use, the following measures are considered most important for reducing EP-littering from Norwegian sources. The measures are selected out of relevance of the measure, the size of the material streams that are affected and the expected costs and efforts necessary for implementation.

1) Protection of stored EP-material and waste from the weather
2) Measures to reduce spill during handling and use (use of heating knives)
3) Take back schemes that enable both recycling and safe collection and sorting with minimal risk of waste going astray
4) Elimination of use of floating elements and pontoons that have exposed EPS-surfaces
5) Identification of illegal dumping sites with subsequent clean-ups
6) Substitution of EPS or XPS-containing materials in road construction.
7) Substitution of EPS with cardboard shock absorbing packaging
8) Elimination of EPS in buoyancy elements
9) Elimination of EPS-use during land storage of boats on land

III. Sammendrag

Forsøpling fra ekspandert plast er et vanlig funn ved ryddeaksjoner. Denne rapporten utreder lagring, bruk, innsamling og gjenvinning av ekspandert plast, og tiltak som kan begrense forsøpling fra ekspandert plast. Informasjon til utføring av prosjektet ble hentet fra tilgjengelig statistikk, rapporter og dybdeintervju med over 30 aktører fra forskjellige bransjer som håndterer EPS. Rapporten har fokus på ekspandert polystyren (EPS) og ekstrudert polystyren (XPS) i bygg- og anlegg, akvakultur, pontonger og flytebøyer, og emballasje.

EPS og XPS brukes til

- termisk isolasjon og forskaling av grunnmur i bygg,
- lettvekts konstruksjonsmateriale ved veibygging,
- støtsikker og termisk isolerende emballasje både til sjømat, elektronikk og hvitevarer,
- pontonger til flytebrygger og fyll i fortøyningsbøyer.

Det er estimert at følgende mengder produkter og materialer settes på markedet årlig:

- 5 810 tonn fiskekasser i EPS,
- 29 460 tonn isolasjonsplater og forskaling til grunnmur i EPS,
- 540 tonn lettvekts konstruksjonsblokker i EPS til veiarbeid
- 15 350 tonn isolasjonsplater i XPS,
- 4 000 tonn emballasje til møbler, elektronikk m.m. i ekspandert polystyren,
- 1 900 tonn pontonger i EPS til flytebrygger,
- 240 tonn EPS fyll til oppdriftsbøyer
- 130 tonn EPS fyll til oppdrettsmerder

Produktene og materialene produseres hovedsakelig i Norge, bortsett fra emballasjen til hvitevarer, elektronikk m.m. som for det meste importeres. I tillegg produseres 30 250 tonn fiskekasser i EPS som eksporteres med fisk.

Det er relativt høy materialgjenvinningsgrad (estimert 90 %) på fiskekassene som ikke eksporteres fra landet. Det utvikles infrastruktur for å resirkulere emballasjen til møbler, elektronikk med mer, som resirkuleres i varierende grad, spesielt i områder med høy befolkningstetthet (estimert 50 %). Isolasjonsplater og forskaling, som utgjør de største produktgruppene, og pontonger går til energigjenvinning eller deponi ettersom materialene typisk er tilgriset med grus, tjære og betong og derfor er uegnet for mekanisk resirkulering. I tillegg er prisen for transport av ukomprimert EPS høy målt per tonn, og infrastruktur for komprimering av EPS mangler. Det er estimert at 25 % av kassert EPS og XPS resirkuleres årlig.

Praksis og bruk som kan føre til tap av ekspandert plast ble identifisert:

- Pontonger i EPS kan slites løs i hardt vær og ende i fjæresteinene eller stranden hvor de raskt brytes ned til forurensning
- Pontonger av EPS med åpne sjikt mot vann og luft kan føre til utslipp grunnet slitasje fra bruk, vær og sjø,
- Tilpasning med sag av isolasjonsplater, konstruksjonsmaterialer og forskaling i EPS produserer små perler av EPS som kan blåse eller renne ut i naturen.
- Utilstrekkelig sikring av EPS og XPS ved lagring og mellomlagring kan føre til at materialene tas av vind og regn.
- Utilstrekkelig sikring av EPS og XPS ved transport, for eksempel fra små byggeplasser eller husstander til gjenvinningsstasjonen, kan føre til tap av EPS under transport.

Viktige tiltak som kan redusere forsøpling fra EP ble identifisert og evaluert og inkluderer følgende tiltak som listet i tabell **d** - **f**.

*Tabell **d**: Liste over aktuelle tiltak for å redusere forsøpling av ekspandert plast ved lagring, bruk og avfallsbehandling.*

Kode	Beskrivelse av tiltak
A	**Tiltak knyttet til lagring og håndtering av materialer og produkter som inneholder ekspandert plast**
A1	Beskyttelse av lagret EP mot vær og vind
A2	Sikring av EP-holdig last under transport
A3	Miljøstyringssystemer
A4	Opplæring i prosedyrer som forebygger EP-forsøpling
B	**Tiltak for å kontrollere spredning av små biter og partikler av ekspandert plast**
B1	Tiltak for å redusere spill og søl av EP under bruk
B2	Luftfilter i avtrekk og ventilasjonsanlegg
B3	EP-renseprosess for prosess- og overvann
B4	Inngjerding og fysiske barrierer
B5	Regelmessige inspeksjoner med tilhørende oppsamling av synlig EP-søppel
C	**Innsamling av kasserte produkter og materialer som inneholder ekspandert plast**
C1	Returordning for utvalgte EP-produkter, materialer og emballasje
C2	Insentiver til effektiv sortering av EP-avfall
C3	Rapportering av ekspandert plast som egen avfallskategori i nasjonalt avfallsregnskap og statistikk
C4	Produktdesign for enklere sortering og mer effektiv gjenvinning
D	**Spesifikke tiltak for byggenæringen**
D1	Bruk av prefabrikkerte byggelementer
D2	Beskyttelse av EPS-isolasjon mot sollys (UV-stråling)
E	**Spesifikke tiltak for marin- og maritim sektor**
E1	Utfasing av flyteelementer med åpne EPS-flater som er direkte eksponert til omgivelsene
F	**Spesifikke tiltak for avfallsnæringen**
F1	Tildekking av EP-holdig avfall på avfallsdeponier
G	**Tiltak for å identifisere og rydde opp i historisk EP-forsøpling**
G1	Identifisere villfyllinger og andre kjerneområder for historisk EP-forsøpling med påfølgende opprydding
G2	Merking av EP-elementer som muliggjør kildesporing.

*Tabell **e**: Tiltak for å redusere forsøpling av ekspandert plast: mulige material substitusjoner.*

Kode	Mulige materialsubstitusjoner
H1	Substitusjon av EPS og XPS med alternative isolasjonsmaterialer i bygninger
H2	Substitusjon av EPS og XPS med alternative vegbyggingsmaterialer
H3	Substitusjon av EPS med papp som støtabsorberende emballasje
H4	Substitusjon av EPS med alternative materialer i fiskekasser
H5	Eliminering av EPS i flyteelementer og pontonger
H6	Eliminering av EPS som støttemateriale ved lagring av båter på land

*Tabell **f**: Tiltak for å redusere forsøpling av ekspandert plast ved økt gjenbruk og resirkulering.*

Kode	Tiltak som kan føre til økt gjenbruk og materialgjenvinning av utvidet plast
I1	Økt bruk av komprimatorer som gir mulighet for mer kostnadseffektiv transport av EPS-avfall
I2	Gjenbruk av kasserte EPS-elementer i nye vegprosjekter
I3	Gjenbruk av EPS-elementer i havbruksnæringen
I4	Gjenbruk av flytebrygger
I5	Gjenbruk av EPS-isolasjon i byggeprosjekter

De ulike sektorene og bruksområdene som er evaluert er rangert etter risikoen som de anses å representere som mulig kilde til EP-forsøpling. EPS-blokker og XPS-plater for bygging av veier og EPS i flytebrygger vurderes å representere en svært høy risiko for EP-forsøpling. Isolasjonsplater fra byggenæringen, EPS-elementer i flytekrager og forankringsbøyer og EPS-avfall fra opphugging av båter anses å representere høy risiko for EP-forsøpling, mens de resterende områdene er vurdert til å utgjøre enten middels eller lav risiko.

Basert på risikovurderingen for de ulike sektorene og bruksområdene vurderes følgende tiltak som de mest vesentlige for å redusere EP-forsøpling fra norske kilder basert på tiltakets relevans, størrelsen på materialstrømmene som tiltaket berører og forventede kostnader og innsats som vil kreves ved gjennomføring av tiltaket.

1) Beskyttelse av lagret EP-materiale og avfall mot vind og regn.
2) Tiltak for å redusere søl under håndtering og bruk (bruk av varmekniv).
3) Returordninger som muliggjør både resirkulering og sikker innsamling og sortering med minimal risiko for at EP-avfall kommer på avveie.
4) Utfasing av flyteelementer som har eksponerte EPS-overflater.
5) Identifisere ulovlige dumpingsteder med påfølgende opprydding.
6) Substitusjon av EPS eller XPS-holdige materialer i veibygging.
7) Substitusjon av EPS med papp i støtdempende emballasje.
8) Eliminering av EPS i flytekrager og flytebøyer og andre flyteelementer.
9) Eliminering av EPS som støttemateriale ved lagring av båter på land.

1. Introduction

Littering and pollution of plastics is one of the great environmental challenges of our time, rapidly increasing in severity as plastic consumption continues to grow. Expanded polymers, especially those based on styrene, place in the top-5 of plastic litter by number found in Norwegian clean-ups [1].

The objective of this report is to identify and evaluate measures which may reduce littering and pollution of expanded plastics. This is done by identifying products or materials affiliated with a high risk of resulting in littering, describing the mechanisms which may lead to the littering and proposing measures to reduce the risk of littering. The market and waste management of the products are described.

Expanded polystyrene (EPS) and Extruded polystyrene (XPS) are emphasized in the report, while the expanded polyethylene, EPE, and expanded polypropylene, EPP are investigated briefly.

Expanded polymers are used in a great variety of products. The following groups of products are emphasized in this report:

- Insulation plates of EPS or XPS,
- Insulated concrete forms of EPS,
- Low-density construction materials of EPS for roads,
- Frost protection of EPS and XPS for roads and tunnels,
- Pontoons for floating docks,
- Floatation cage filling and buoys for aquaculture
- Packaging for seafood and consumer products.

The report was prepared by Norwaste AS, Bergfald Miljørådgivere AS and SALT Lofoten AS for the Norwegian Environment Agency as a follow up of the Norwegian Plastics Strategi (2021) [2].

1.1. About expanded plastics

Expanded plastics (EP) are produced by heating plastic with a blowing agent. The evaporation of the blowing agent expands the material into a foam with significant porosity altering physical properties. The densities of common plastics are typically close to 1 000 kg/m^3, while expanded plastics have densities closer to 20 kg/m^3.

Pentane is used as a blowing agent for production of EPS, while supercritical carbon dioxide is used for extrusion of XPS. In some countries hydrofluorocarbons (HFCs) have been used as a blowing agent for expanded plastics, but this practice has not occurred in Norway in many years[1]. In 2020, HFCs were banned as a blowing agent for XPS in the EU and European Free Trade Association, and are set to be banned for all expanded plastics by 2023 [3].

[1] Pers. com., environmental protection group, Nov. 22, 2021.

EP has a unique combination of properties: Minimal density, minimal thermal conductivity, decent compression strength, high shock absorption, and they are easily shaped and moulded into complex shapes. They are used as thermal insulators and structural materials in constructions, shock-absorbing packaging for electronics and furniture, insulating packaging for seafood and pharmaceuticals, low-density construction materials, as structural materials in pontoons and flotation elements and much more.

The transport costs for expanded plastics per metric tonne are high due to its low density. EPS is therefore produced as close as possible to the end user. There are 4 major EPS producers in Norway: Brødr. Sunde, Vartdal Plast, Jackon and Bewi, with factories in every part of the country.

Expanded plastics are usually mono-materials, ideal for recycling (Described in-depth in attachment C in the appendix.

Table 1: Some properties of the most common expanded plastics. The raw materials may be sourced from recycled, bio-based or fossil feedstocks.

Property	EPS	XPS	EPE	EPP
Raw material	Fossil Polystyrene pellets	Polystyrene pellets Recycled EPS	Polyethylene pellets	Polypropylene propylene pellets
Blowing agent	Pentane	Supercritical CO_2, HFCs* *		
Possible hazardous contents	Styrene*, brominated flame retardants	Styrene*, brominated flame retardants, hydrofluorocarbons.	Brominated flame retardants	Brominated flame retardants
Recyclable	Given low contents of contaminants	Given low contents of contaminants	Given low contents of contaminants	Given low contents of contaminants
Chemical stability	Degrades in sunlight	Degrades in sunlight	Chemically stable	Chemically stable

* Poorly synthesized polystyrene may contain residues of monomeric styrene.

** HFCs were used as a blowing agent for XPS prior to 2020 in some European countries, Norway not included.

1.2. Why littering of expanded plastics is an environmental issue

Marine littering is a growing environmental concern worldwide and expanded plastics may be some of the most problematic waste types due to its unique set of properties. Like most polymers, expanded plastics are chemically inert and are broken down slowly under natural circumstances. For this reason expanded plastics remain in the environment for a long time. In direct sunlight some degradation of EPS has been shown [4].

The brittle nature of expanded plastics, especially of EPS, results in quick and extensive fragmentation of EPS-litter that create small pieces and particles that are harder to clean up and more likely to be mistaken for food by marine organisms, (see figure 1.1). The shape and size of single beads of EPS is somewhat similar to fish eggs. EPS-particles have been shown to enter the food chain at different levels, and are eaten both by plankton, fish and seabirds [5].

Figure 1.1: Pieces of EPS litter in nature. Photo Left: Snorre Sklet. Photo RIght: Oslofjorden friluftsråd.

When plastic litter sinks to the seafloor it is gradually covered by sediments that limits its exposure to biological organisms. However due to their low density and high porosity EP particles will float on the water surface, continuing exposure to biological organisms. The same porosity also means that an EP-particle may absorb toxins that can later be released in an organism that has swallowed it.

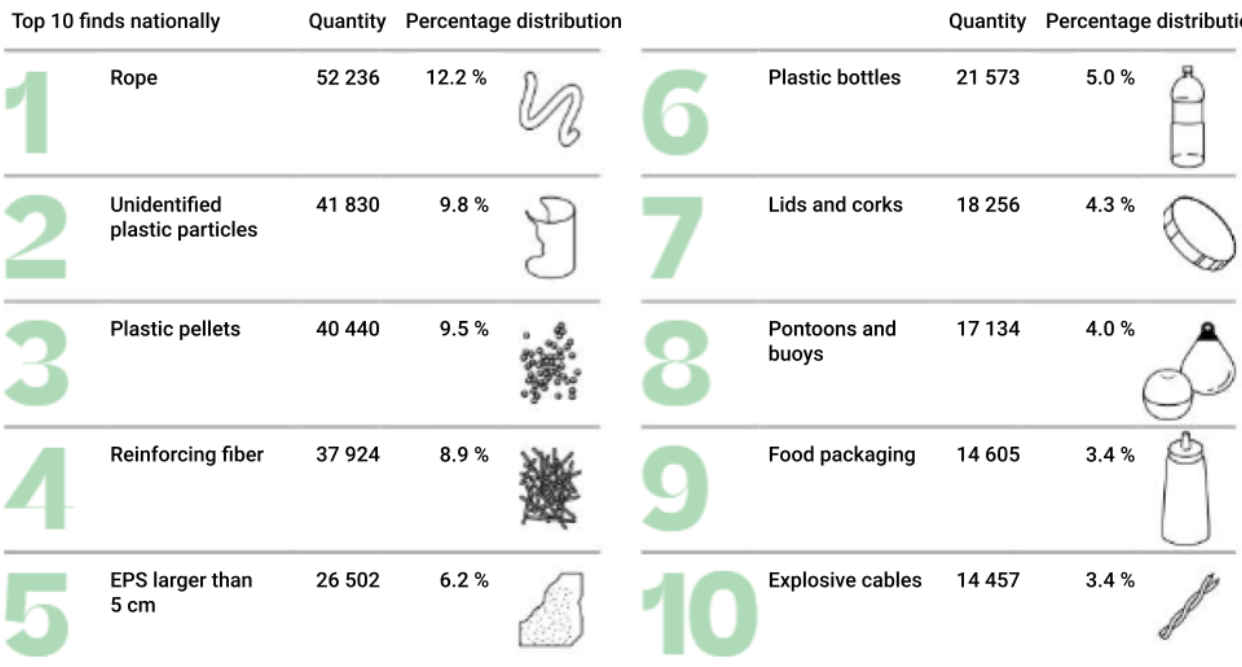
The low density of expanded plastics also means that it occupies a large volume compared to its weight, and is easily caught by wind and may scatter over long distances. EPS is also a littering problem in soil where it accumulates both from activities during road work and other construction projects as well as from illegal dumping sites. The degradation of EPS in soil is slower than in the ocean, and EPS particles in soil will likely remain for hundreds of years, where it may later be liberated and redistributed through erosion and land use change [6].

Sediment samples and observations from excavated soils shows that the extended use of EPS in our society has caused large amounts of soil and sediments around us to be heavily littered with EPS-fragments and smaller particles[2].

Data from registrations of beach litter shows that EPS is commonly placed in the top 5 lists when counting the number of findings. Statistics on findings from national clean-ups published annually by Keep Norway Beautiful (Rydderapporten), shows that EPS pieces larger than 5 cm are number five on the top 10 list of most found plastic littering with 6.2 % of the total number of registered findings [1]. Inlands, EPS is the most common littering item, accounting for 10 % of the total number of findings. Several studies support the findings:

[2] Pers. com., environmental protection group, Nov. 22, 2021.

- Mepex studied marine litter from 50 beaches in Norway and the work shows that styrofoam pieces under 5 cm count for 20.7 % of the number of findings and styrofoam pieces over 5 cm count for 4.9 % of the total number of pieces [7].
- Results from a study executed by SALT Lofoten AS shows that EPS is a major source of marine litter. In one study in the city of Moss EPS pieces constituted 39 % of the litter [8].



Top 10 finds nationally		Quantity	Percentage distribution
1	Rope	52 236	12.2 %
2	Unidentified plastic particles	41 830	9.8 %
3	Plastic pellets	40 440	9.5 %
4	Reinforcing fiber	37 924	8.9 %
5	EPS larger than 5 cm	26 502	6.2 %

		Quantity	Percentage distributi
6	Plastic bottles	21 573	5.0 %
7	Lids and corks	18 256	4.3 %
8	Pontoons and buoys	17 134	4.0 %
9	Food packaging	14 605	3.4 %
10	Explosive cables	14 457	3.4 %

Figure 1.2: Top 10 most found littering in Norway in 2020, translated, designed by Node Berlin Oslo [1].

1.3. Methodology

To describe the present market, waste management and pollution issues, key stakeholders in every part of the EP value chain have been contacted for short and/or in-depth interviews.

Contacted stakeholders include:

- EP producers,
- Buoy and pontoon producers,
- Aquaculture industry,
- Aquaculture production industry,
- Aquaculture waste management industry,
- Plastic recycling industry,
- Electronics retailers,
- Furniture retailers,
- Hardware stores,
- The building construction sector,
- The road construction sector,
- Building demolition sector,
- Municipal waste management sector,
- Landfill operator,
- Recycling facilities for end-of-life boats
- Marina operators,
- Branch organizations for EPS production, fisheries, aquaculture, marinas, construction,
- Environmental protection groups,

In depth interviews were conducted with 37 different representatives from companies and organizations with questions on the following subjects:

- the market situation, including requests to estimate put-on-market volumes on product level,
- the current status on prevention of littering and increased recycling in their sector,
- trade practices which may results to littering of EP,
- unwanted incidents which may resulted in littering of EP, and
- what measures the stakeholder believes would be beneficial to improve recycling and/or reduce littering of EPS.

The interviews generally lasted 1 hour or more, and were conducted by 1 to 3 project team members. Detailed notes were taken from each interview. See attachment E and F in the appendix for the interview guide and a list of the interviewed organizations. Excursions were made to marinas, a landfill, municipal recycling centre, waste incineration plant and clean-ups.

Not all stakeholders were able to give interviews and feedback to the project. Especially with major corporations. If a key resource in the organization was identified and contacted, useful feedback and data were provided. A lack of feedback and data from important stakeholders may lead to underestimating the risk of EP-littering from their activities.

Estimates of amounts of EPS products placed on the Norwegian market annually are made in chapter 2, and estimates of waste generated and recycled or disposed are made in chapter 3. The estimates are based on the available information and statistics and input from the stakeholders. For some areas of use, the available statistics and data on use of EP is lacking. While the estimates should be of the correct order of magnitude, there is a high degree of uncertainty associated with some of the estimates. Furthermore, many areas of use are undergoing rapid change in associated EPS volumes, for example EPS packaging for electronics and appliances.

The estimates enable a ranking of severity of the different littering risks, and are meant to serve as a starting point for future work. Involved stakeholders have been invited to verify or improve upon the numbers presented in this report. The method and/or source of each estimate is described in chapter 2 and 3.

Within each area of use, unwanted incidents that may lead to littering of EPS were explored through review of literature, interviews with key stakeholders, observations of possible littering sources, and experience from beach cleaning projects. Relevant literature was identified from literature searches, interviews, and general knowledge of relevant literature from other reports. Review of literature gave an overview of possible sources of EPS littering and this information was used to develop the interview guide. Experiences from beach cleaning were also used as background knowledge and input to identify probable sources of EPS littering. Questions about trade practices and incidents were integrated in interviews with key stakeholders in order to identify and describe the mechanisms leading to littering of EPS.

The mechanisms were systematically documented and assessed for each area of use. Based on identified mechanisms that may lead to EP-littering (also referred to as unwanted incidents) an initial list of measures that may both reduce the probability of the incident and reduce the consequence of the incident was set up. This list was then supplemented and edited based on measures described in literature and input from interviews.

2. Production, trade and usage of EP

2.1. EP placed-on-market in Norway

Table 2.1 displays the products and materials of expanded plastics that are studied in this report, categorized by branch sector and estimates of annual put-on-market.

Table 2.1: Rough estimates of amounts put on market in Norway 2020 of products and materials with EPS.

Material	Estimated annual volume placed-on-market
Building and construction	
Insulation plates and concrete forms of EPS	29 460 tonnes
Insulation plates of XPS	15 350 tonnes
EPS blocks as lightweight fill in roads	540 tonnes
Clinker blocks laminated with EPS	5 tonnes
Sum	**45 355 tonnes**
Aquaculture	
EPS fill in aquaculture pens	130 tonnes
EPS filling in mooring buoys	240 tonnes
Sum	**370 tonnes**
Harbours and docks	
EPS-pontoons in floating docks	1 900 tonnes
EPS-pontoons in other floating installations	*Unknown*
Sum	**More than 1 900 tonnes**
Packaging	
Fish boxes*	(~10 million boxes) 5 810 tonnes
Packaging for consumer electronics and furniture	2 000 tonnes
Other packaging**	Estimated 2 000 tonnes
Sum	(Estimated) **9 810 tonnes**
Sum of all product types:	**More than 57 435 tonnes**

* Of 36 000 tonnes of fish boxes, 60 million, approximately 30 250 tonnes are exported, 50 million, and 5 750 tonnes are placed on the Norwegian market. In addition 60 tonnes of fish boxes are imported.

** Other packaging includes packaging for transport, chemicals and industrial products, components, pharmaceuticals, the health sector etc.

Estimates of placed-on-market in table 2.1 are based on the following:

- **Construction materials:** Input from the Norwegian interest group for EPS producers (*EPS foreningen*).
- **Fish boxes:** Input from the Norwegian Interest Group for EPS Producers and Green Dot Norway (Grønt Punkt Norge)
- **Pontoons**: The number of recreational boats in Norway, and assuming each of the 950 000 boats equates to 1.5 m^3 of pontoons in floating docks, and a lifetime of 15 years [9][3].
- **Floatation cage filling** and **buoyancy buoys:** The total number of active aquaculture installations in Norway.
- **Packaging for electronics and furniture**: Calculations done by Green Dot Norway.
- **Other packaging:** Calculation based on EPS packaging waste in *Vartdal Plasts* collection scheme.

2.2. Production and trade of EP in Norway

There are four large producers of EP products in Norway, each producing EPS products and materials. Brødr. Sunde, Jackon, Vartdal Plast and BEWI (see table 2.2). The two former also produce XPS. A total of 19 production facilities have been identified [10]. There are other producers of EPS, such as Glava and PartnerPlast that produce smaller quantities of EPS products. Brødr. Sunde produces polystyrene pellets for expansion, used to produce EPS and XPS. The company has permission to produce 70 000 tonnes of EPS pellets annually. A production of 60 000 tonnes was reported in 2019 [11].

Table 2.2: The EPS producers of Norway. Market share estimated based on gross revenue for 2020.

Producer	Important products	Estimated market share 2020	XPS colour
Brødr. Sunde	EP pellets, EPS fish boxes, insulation plates of EPS and XPS, concrete forms of EPS	23 %	Light orange
Vartdal Plastindustri	EPS Fish boxes, insulation plates of EPS, concrete forms of EPS	28 %	Light green
Jackon	EPS Fish boxes, insulation plates of EPS and XPS, concrete forms of EPS	24 %	Light purple
Bewi	EPS Fish boxes, insulation plates of EPS, concrete forms of EPS, EPP packaging*, HVAC components in EPP*, automobile components in EPP*.	25 %	Pink

* EPP produced outside of Norway.

[3] Pers. com., plastic product producer, Oct. 15, 2021.

EP-containing products consumed in Norway are either produced in Norwegian production facilities or imported. Products are distributed to different industry sectors and serve their functions before they are disposed of and recycled, incinerated or landfilled.

There has been a shortage of polystyrene pellets in the global market due to problems in polystyrene production in the USA[4]. Prices of fossil polystyrene pellets have increased, reducing the price gap between fossil polystyrene pellets, and renewable polystyrene pellets produced from recycled petrochemical products or bioplastics.

Fish boxes are typically produced in close proximity to the fish processing factories and sold directly from the manufacturer to the customer. Construction materials are sold either directly to the customer, or through hardware stores. There are numerous hardware stores in Norway, but a few national actors control a large share of the market: XL-bygg, Maxbo, Optimera and Byggern.

Due to high transport costs of EPS it is assumed that all construction materials and fish boxes made from EPS are produced in Norway. This allows estimation of import, production, export and use of EP products in Norway as shown in table 2.2.

Table 2.3: Estimated import, production, export and use of EPS materials, products and packaging in 2020, in tonnes.

Material	Import	Production	Export	Placed on market
Polystyrene pellets for expansion	**47 600**	***70 000**	**38 230**	**79 370**
Products and materials	**12 708**	**79 370**	**36 300**	**57 435**
Insulation plates and concrete forms of EPS	0	29 460	0	29 460
Insulation plates of XPS	9 400	12 000	6 050	15 350
EPS blocks as lightweight fill in roads	0	540	0	540
Clinker blocks laminated with EPS	5	0	0	5
EPS filling for aquaculture pens	*unknown*	*130*	*unknown*	130
EPS filling in mooring buoys for aquaculture	*unknown*	*240*	*unknown*	240
EPS in pontoons**	***248*	*unknown*	*unknown*	1 900
Fish boxes made of EPS	60	36 000	30 250	5 810
EPS Packaging for electronics and furniture	2 000	0	0	2 000
Other EPS packaging	1 000	1 000	0	2 000

** The production allowance of the sole producer of polystyrene pellets in Norway.

* Identified import of pontoons.

[4] Pers. com., EPS-producer, Oct. 05, 2021.

The mass flow is visualized in figure 2.1 and the volume of a production of 78 000 tonnes of polystyrene and expanded polystyrene is visualized in figure 2.2.

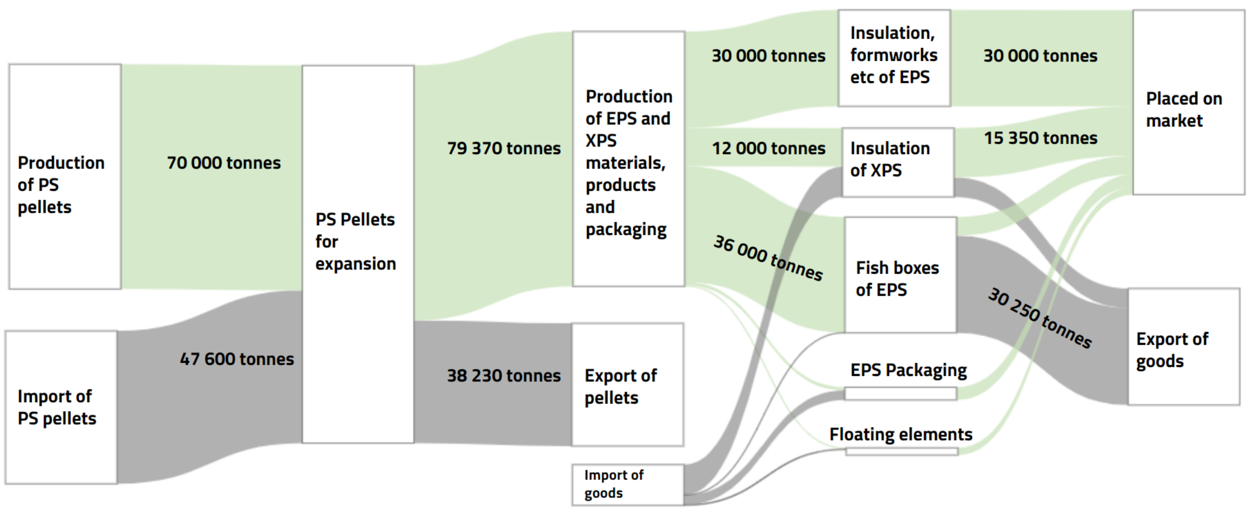


Figure 2.1: Illustration of the volume of PS and EPS usage in Norway in 2020.

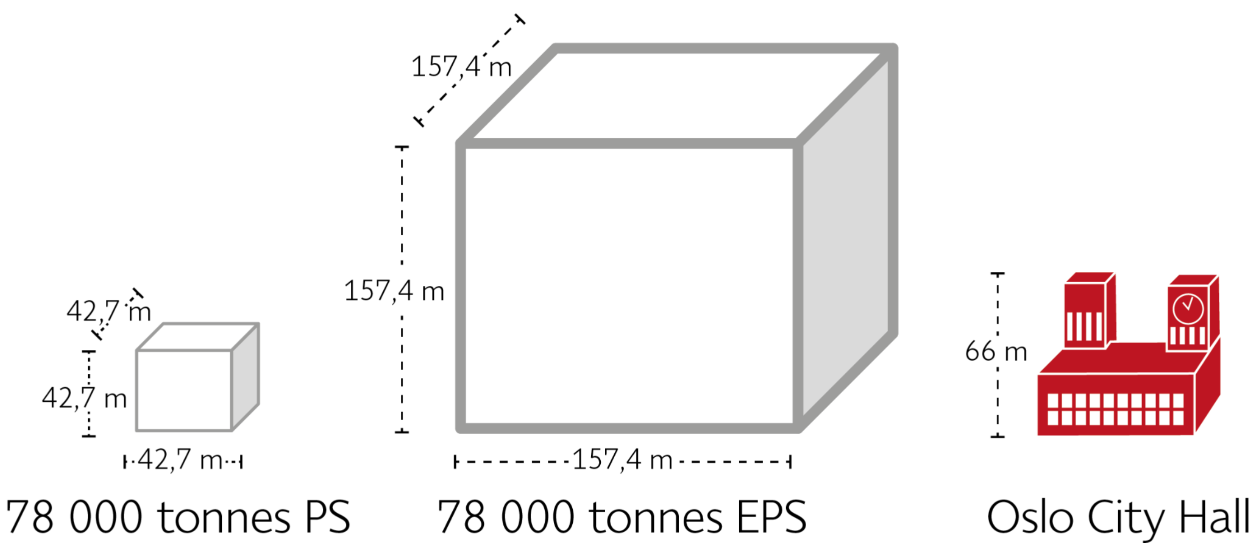


Figure 2.2: Illustration of the volume of 78 000 tonnes of PS and EPS.

2.2.1. The growing demand for recycled expanded polystyrene

There is a growing demand for recycled polystyrene. Entrepreneurs use recycled materials to reduce the environmental footprints of their constructions, which is becoming increasingly important in public tenders. According to the EPS producers, the demand for recycled materials for production of

EPS and XPS cannot be met[5]. Collected EPS waste is recycled into XPS, as the supercritical CO_2 is easier to inject in production sites. The producers would ideally like to also produce their EPS from recycled materials[6].

Over the last 50 years the use of EPS in buildings and roads has increased significantly. Today more EPS is placed in buildings and roads than is generated as waste from demolition of buildings and roads annually. The waste is contaminated with char, tar, gravel and concrete etc., and unsuitable for mechanical recycling. Products like floating docks with uncovered EPS surfaces are also typically contaminated and unsuitable for mechanical recycling. These volumes represent the vast majority of products placed on the market today, most if not all of them non-recyclable[7].

Chemical recycling processes for EPS have been developed in the USA that may recycle these materials, but such processes are not yet available in Europe[5].

2.3. Statistics on production and trade of EP

2.3.1. Development of trade in the EU

Detailed data on production and trade of EPS products and raw materials were requested from each EPS producer but the producers were unable to supply this data.

No reliable sources for global production of EPS were identified in the project. The production in the European economic area (The member states of the EU, and the members of the European Free Trade Association) and Turkey is estimated to be 1 700 000 tonnes in 2021, approximately 75 % of which goes to the construction sector, and 25 % to packaging[6]. In 2000 the production capability in the same region was 972 000 tonnes.

Some statistics from 2011 to 2020 of the domestic EP market are examined in section 2.3. When using import statistics, there are several sources of uncertainty:

- Some goods will be incorrectly declared or not declared at all.
- Some goods are imported as components and assembled in Norway.
- Most goods contain EP as part of the product.
- Many groups of products are imported under singular commodity codes.
- The import of many commodity codes is shown as ‘0’ for unknown reasons.
- The import statistics are updated regularly and subject to change.

These uncertainties may result in underestimations of actual trade volumes.

[5] Pers. com., EPS-producer, Oct. 05, 2021.
[6] Pers. com., interest group, Sep. 28, 2021.
[7] Pers. com., waste management company, Nov. 29, 2021.

2.3.2. Import of polystyrene pellets

Polystyrene pellets, the raw material of EPS and XPS, are imported from European and American markets and imports are shown in Figure 2.3. From 2011 to 2020, import of polystyrene pellets increased from 39 600 tonnes to 47 600 tonnes, an increase of 20 %, approximately 2 % or ~890 tonnes per year. Statistics on production and export of polystyrene in the same period are unavailable.

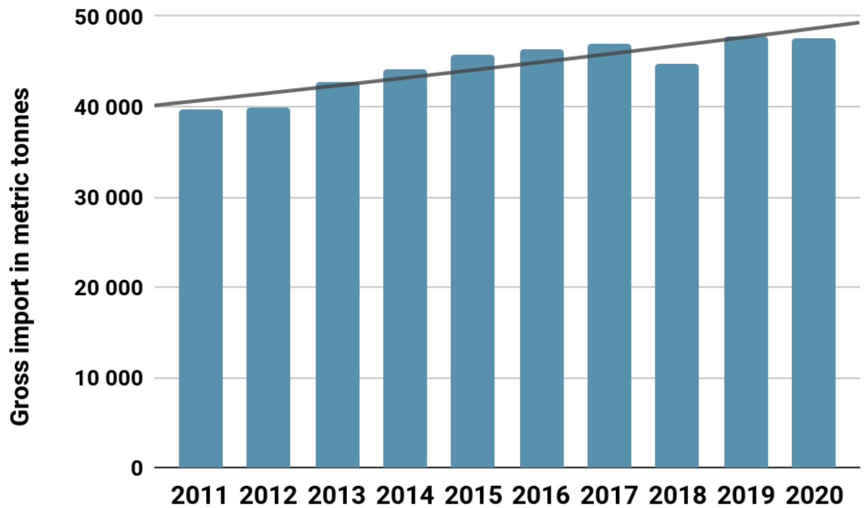


Figure 2.3: Historical net import of polystyrene pellets to Norway [12].

2.3.3. Revenue from sale of EPS and XPS products

From 2011 to 2020, the net revenue of the EPS producers increased by 78 %, adjusted for inflation, see Figure 2.4.

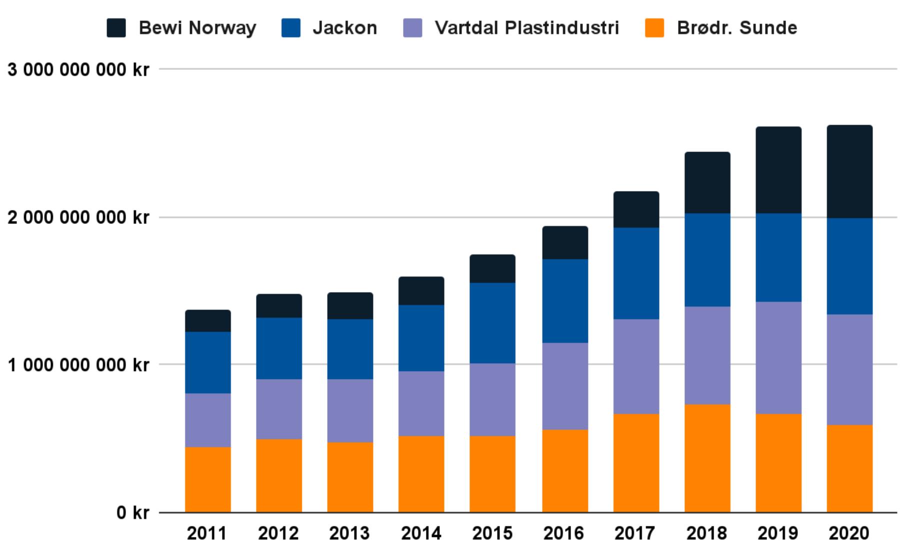


Figure 2.4: Net revenue from sales of EPS products of Norwegian EPS producers from 2011 to 2020. Numbers of Brødr. Sunde and Bewi adapted to exclude sales of other polymers or expandable polystyrene [13].

2.3.4. Export of fresh seafood and fish boxes

The seafood nation Norway exported 1.1 million tonnes of fresh seafood in 2020, corresponding to 30 000 tonnes, or approximately 50 million units of fish boxes, each box of 600 grams containing 22 kg of fresh seafood, see figure 2.5. Between 2011 and 2020 the export of seafood increased by 13 % from 0.97 to 1.1 million tonnes, with a corresponding increase from 26.4 to 30.3 thousand tonnes of packaging. Each 600 gram fish box can hold 22 kg of fresh seafood.

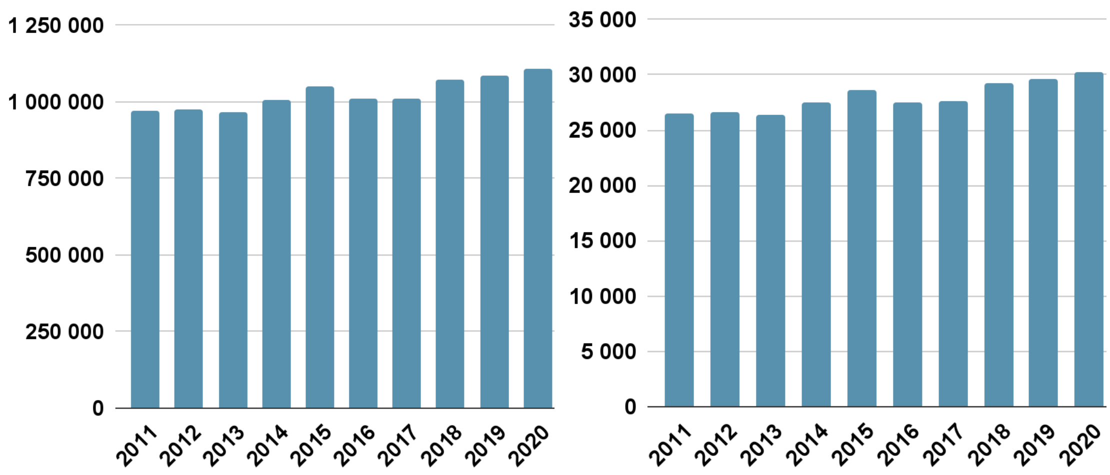


Figure 2.5: Import and export of fresh seafood (left) and fish boxes (right), in tonnes[12].

2.3.5. Import and export of XPS

XPS has a higher price and density than EPS, and is therefore traded across borders in larger volumes. On average since 2011, 9 400 tonnes were imported, and 6 050 tonnes exported, with an average difference of 3 350 tonnes of XPS, see figure 2.6.

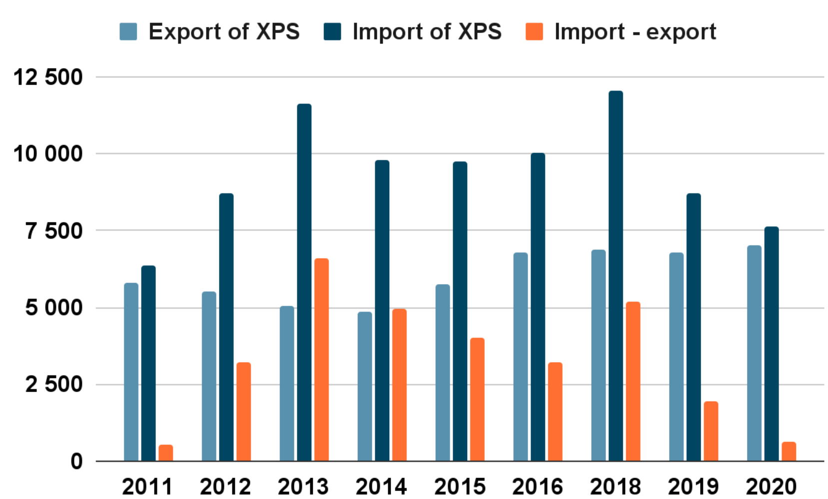


Figure 2.6: Import and export of XPS [12] in tonnes.

2.3.6. Import of floating docks

Import of floating docks is reported under a category for non-inflatable floating vessels. From 2011 to 2020, 11 800 metric tonnes of floating vessels were imported annually. In 2020 ocean farms were imported to Norway under the same commodity code resulting in a sharp rise of imported volume [12]. Given a buoyancy requirement of 1.5 tonnes of buoyancy per 1 tonne of floating vessel, 8 250 tonnes of floating vessels contain 248 tonnes of EP[8]. A significant amount of this would be floating docks, but the exact distribution is unknown.

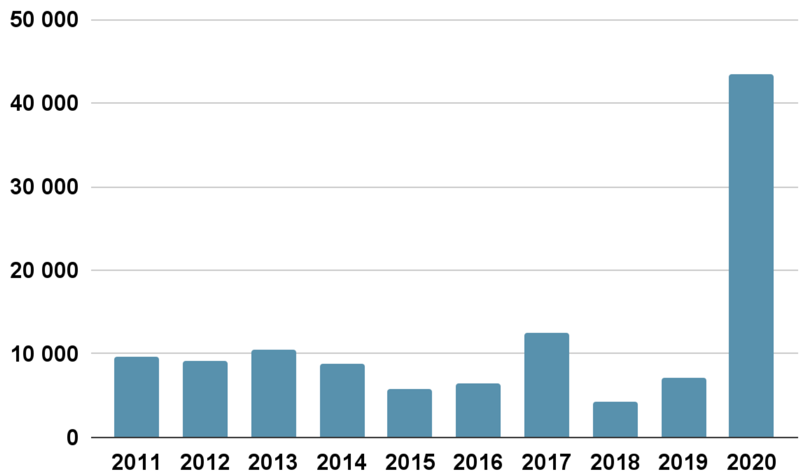


Figure 2.7: Import of floating material, such as floating docks and buoys, in tonnes.

2.3.7. Import of motor vehicles and boats

EP is used in cars as insulation and shock absorbing material [13]. While EPS may be used for insulation, EPP may be used for several structural and shock-absorbing components in the cab of the vehicle. Assuming that 0.1 m^3 of both EPS and EPP is used in a typical car this corresponds to 2 kg of EPS and EPP. As shown in figure 2.8 approximately 230 000 motor vehicles were imported annually from 2011 to 2020, corresponding to 460 tonnes of both EPP and EPS.

131 348 cars were shredded in 2020, corresponding to 262 tonnes of EPE and EPS [14]. During demolition of cars, lighter materials such as plastics and textiles are separated out as “fluff”, a low-value waste fraction sent to incineration or landfill.

A total of 948 000 leisure boats were in use in Norway in 2017. This included 412 000 smaller motor boats without room for accommodation, 161 000 larger motor boats with room for accommodation and 334 000 smaller boats, kayaks and surfboards [9].

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[8] Pers. com., plastic product producer, Nov. 18, 2021.

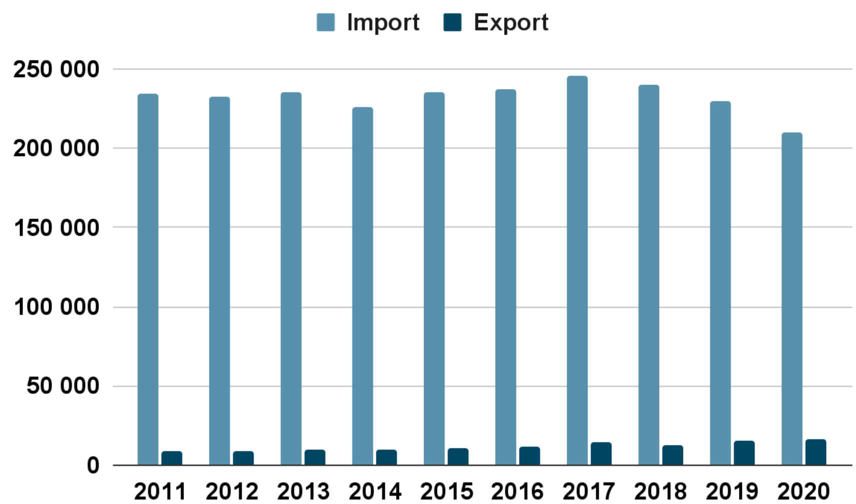

Figure 2.8: Number of imported and exported automobiles, tractors, buses etc. [12].

Boats contain EPS as either insulation or shock absorbing material. Surfboards also normally contain a core of EPS. Assuming that every boat contains on average 1 kg of EPS and that one in twenty boats are sunk each year will mean that 47 tonnes of EPS-waste will be generated. Many boats are sunk or dumped illegally to avoid the costs of scrapping. Only the Oslo fjord is estimated to contain a total of 1500 boat wrecks [15]. If the Norwegian coast line contains 6000 boat wrecks containing on average 1 kg of EPS it equates to 6 tonnes of EPS.

2.3.8. Import of other products containing EP

Estimating total import of EPP and EPE is too complex due to a large number of different items, with different contents of EP. Sales for 2020 for some select items have been estimated [12].

- Car seats for children: 608 000 units, ca 38 tonnes of EPS,
- Helmets for bicycles etc.: 1 000 000 units, ca 38 tonnes of EPS or EPP,
- Life jackets: 300 000 units, ca 25 tonnes of EPE.

3. Waste generation and sources of littering

This chapter describes how EP is used, handled and treated in the many value chains of EP. Unwanted incidents which may result in littering of EP are identified and described for different areas of use. The amount of waste generated is estimated, and the end-treatment is described.

3.1. What causes EP littering?

Unwanted incidents that lead to EP-littering may occur during both production and distribution, use and collection and waste treatment of EP-products, see figure 3.1. EP-particles may escape from entrances to storage facilities or through drains and ventilation shafts. During storage or treatment outside EP-elements may also be blown away or taken away during floods. Unwanted incidents that lead to EP-littering may also occur during transport of EP-products, for example as a result of a container door opening during transit, or from poorly fastened elements that fall off the loading plane.

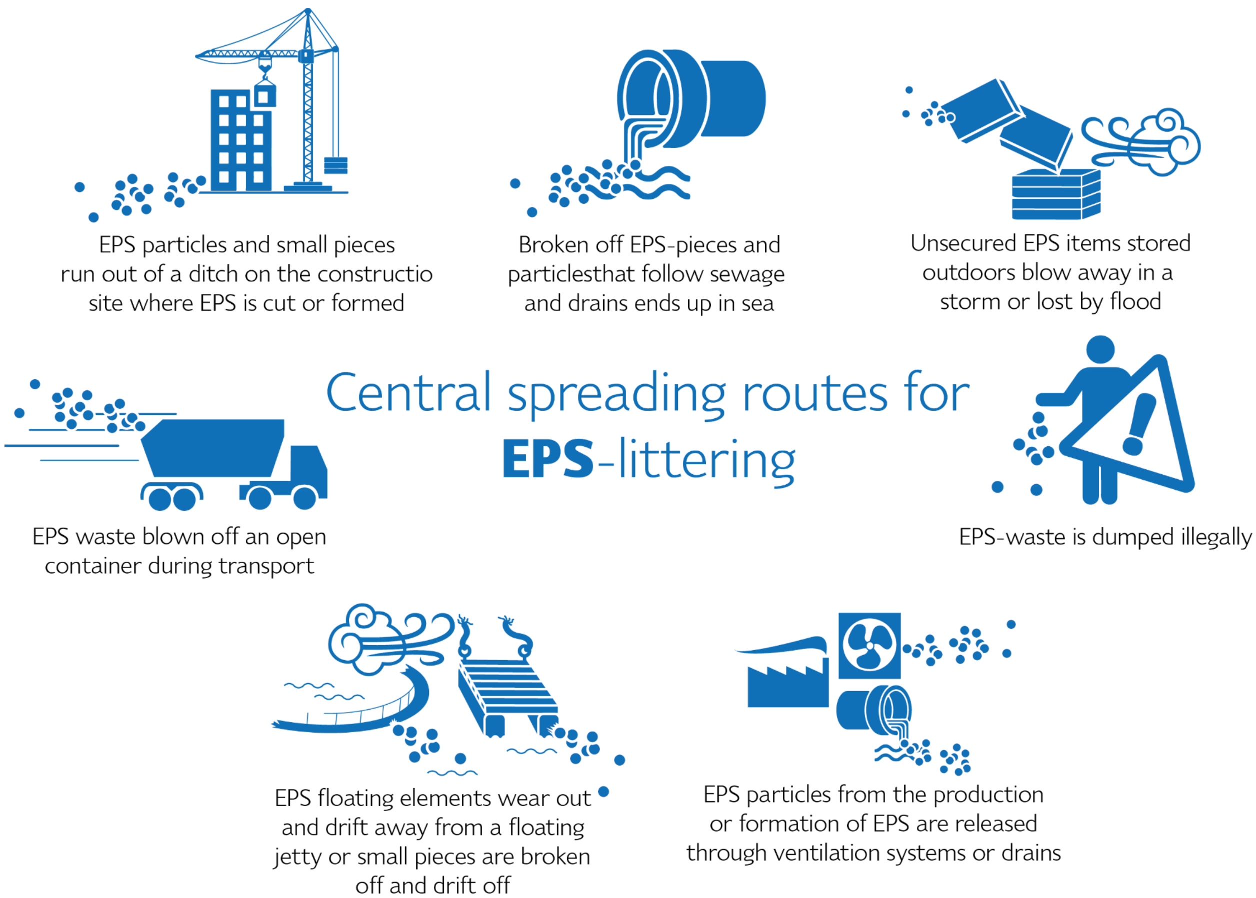

Figure 3.1: Overview of littering streams.

From all these different phases of the product life unwanted incidents may occur that lead to EP-littering. The EP-litter is then spread following a certain route until it ends up in a final recipient that will in many cases be a marine environment as illustrated in figure 3.2.

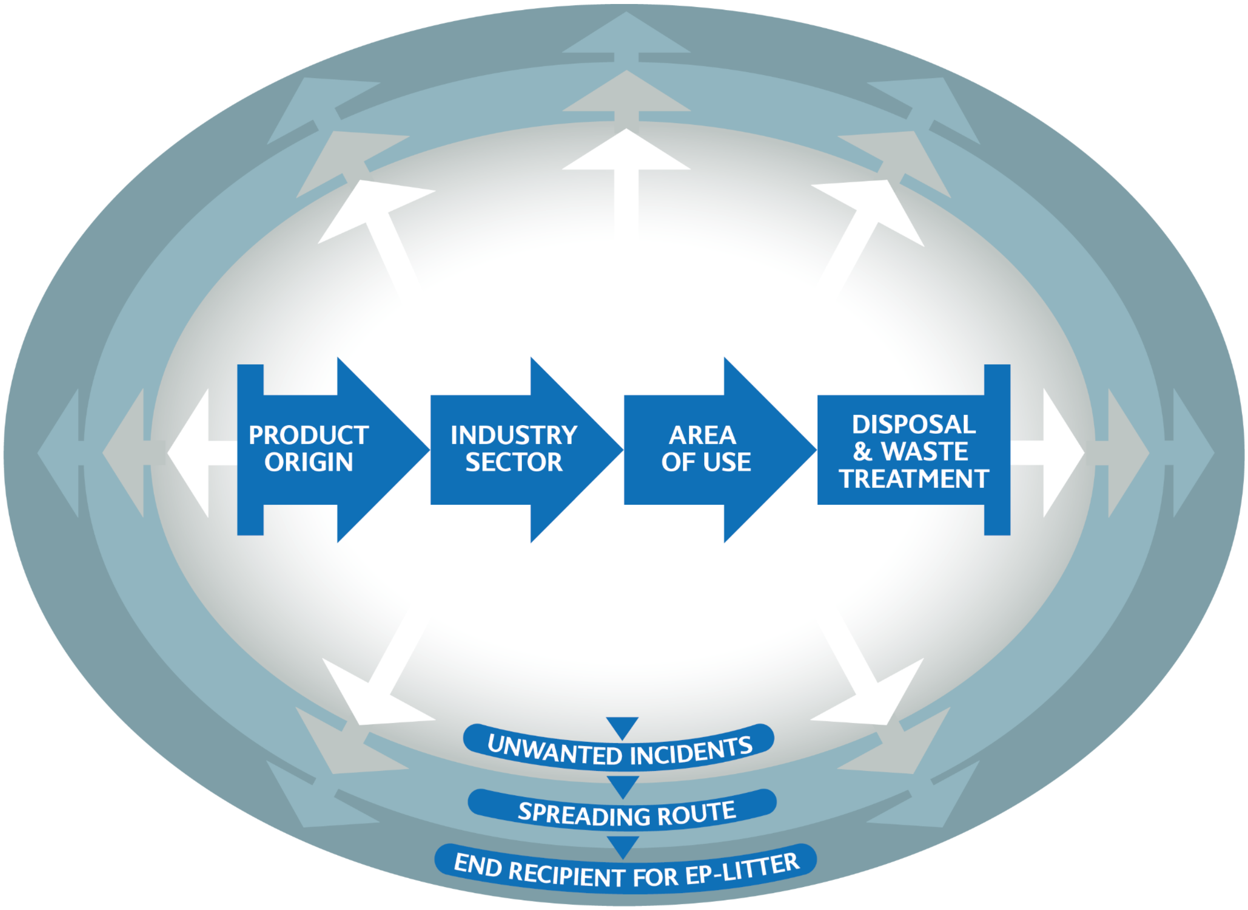

Figure 3.2: Unwanted incidents that lead to EP-littering may occur at all stages of the product life of an EP-product.

An EP-element that is found in a recipient, for example on a beach, may be traced back to its source by identifying its spreading route back to the industry sector or user where it originated. By identifying what area of use and which type of incident that lead to the loss of the EP-material the littering event may be explained. Fragmentation of EP-litter often makes it difficult to identify what use the material has had. Figure 3.3 in section 3.2 shows a more detailed description of material streams that will be discussed in this chapter.

3.2. Waste and littering from handling of EPS

This chapter describes the use, littering and waste generation of EPS in the follow important areas of use:

1. Production of EPS
2. Construction of buildings
3. Construction of roads
4. Aquaculture
5. Floating docks and harbour activities
6. Packaging
7. Recycling centres
8. Other important sources of EPS littering

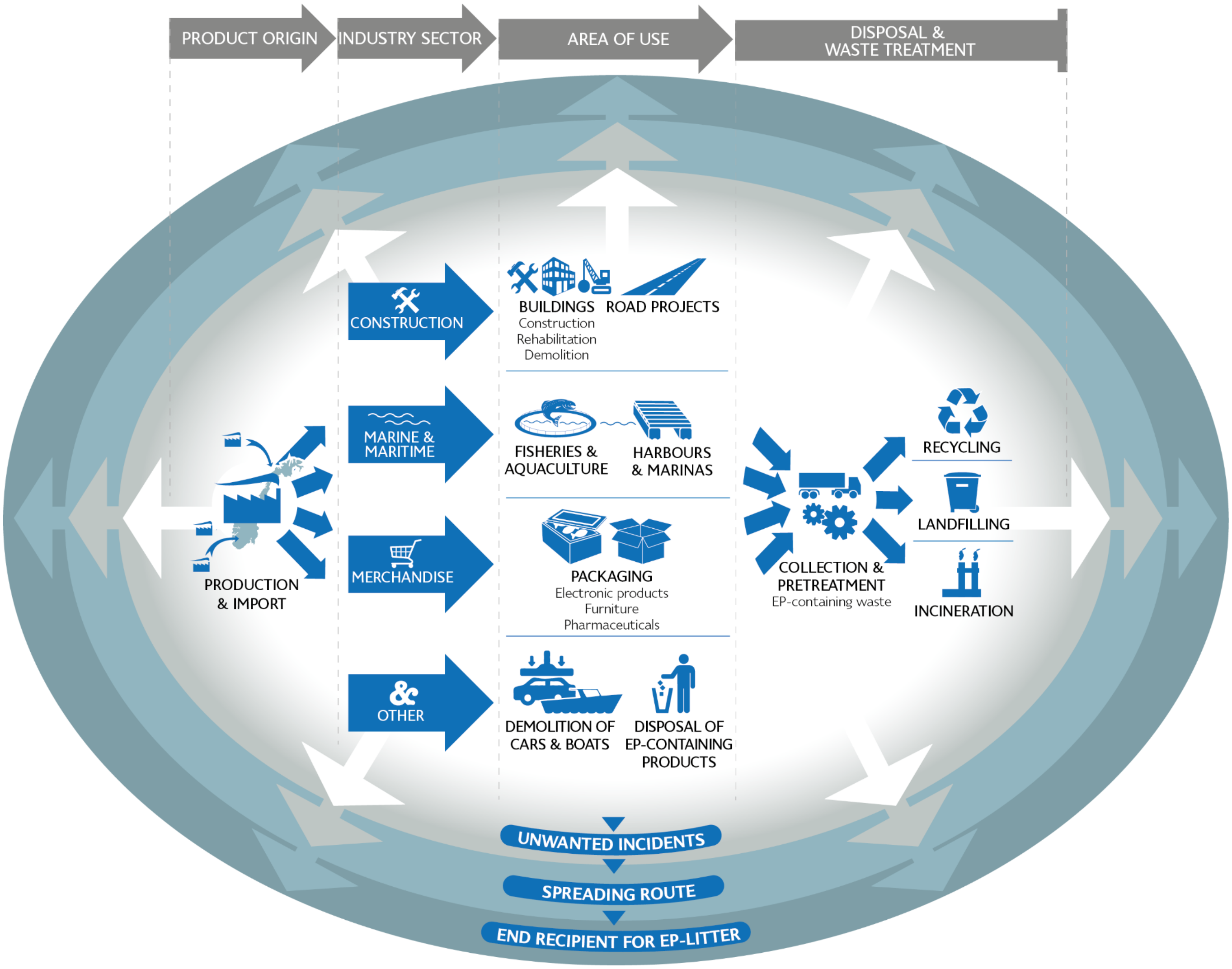

Figure 3.3: Overview over central material streams and waste streams.

Each area of use is described in a subsection headed by a summary of the identified unwanted incidents which may result in littering of EP.

3.2.1. Common unwanted incidents

Some unwanted incidents are common for every area of use described. The incidents are therefore not repeated in subsections 3.2.4 - 3.2.11:

- **Loss of EPS products stored outside due to wind and rain.**
- **Loss of EPS products during transportation.**
- **Loss of EPS waste stored outside due to wind and rain**
- **Loss of EPS waste during transportation.**

The risk of the incidents is varying from sector to sector, due to variations in probability of the incident, the magnitude of EPS used, the possibilities to clean up the littering etc.
Storage and handling of EP-materials and waste is a major source of EP-littering. Due to expanded plastics being very voluminous, it is common to store both unused and discarded EP-materials outside where they may be affected by weather. Having a low density and brittle material structure, EP-materials may easily be carried away by wind or water as whole products or in broken off pieces.

3.2.2. General considerations of waste management

High transport costs represent a major barrier for EPS recycling due to the extremely low density of the material. To reduce transportation costs EPS and XPS is compacted to reduce volume by 20 - 30 times, increasing density from ~20 kg per m^3 to 350 - 400 kg per m^3.

The market value of compacted EPS was 650 to 800 euro per metric tonnes in November 2021[9]. Once EPS is compacted it can be assumed that it will be recycled due to the high market value, and because the current supply of recyclable EPS materials is insufficient to meet the demand in the domestic market. Compacted EPS is generally recycled abroad.

3.2.3. Waste and littering of EPS from production of EP

The domestic EP producers are described in section 2.1. During production of EPS and XPS fragments of EPS are continuously generated through different processes such as cutting and shaping profiles to size, or during storage of raw materials. There is a risk of these fragments being distributed to the environment through open gates, ventilation and drainage systems. Such incidents are expected to occur rarely due to effective procedures and barriers to avoid spills. If they occur they may result in large amounts of EP-litter. Leakage from a storage silo was reported during an inspection in 2008 [16]. No such incidents have been reported in recent years.

The producers store some products outside prior to shipping from the production site. This practice may lead to loss of EPS-material during heavy weather conditions [17].

[9] Pers. com., EPS-producer, Nov. 03, 2021.

Some expanded plastics, especially EPS, are brittle and easily break or crumble into small pieces and particles. EPS-particles are typically generated when EP-materials are cut, filed or otherwise formed by machines. The same can occur if EP-materials are granulated, pelletized or moved. For this reason production, storage, use or other treatment run the risk of creating EP-particles that may be spread to the environment. Typical distribution systems are ventilation or water discharge.

Assumption of potential littering rates

No data has been found to quantify total EPS-littering from an EPS-producing facility. The following estimates are just meant as examples to illustrate possible littering contribution from Norwegian EPS-production, as no case history with quantitative data has been identified.

Assuming one incident each year per facility where 10 kg EPS is lost, this will lead to a total loss of 0.19 tonnes of EPS from the industry. Ten occurring incidents each year correspondingly lead to a loss of 100 kg of EPS this will mean a loss of 1.9 tonnes.

Most, if not all EP waste from production of EPS and XPS is recycled on site. Waste management for EP production is therefore not discussed in depth[10].

Summary of unwanted incidents specific to the production of EPS

- **Spread of EPS particles from open gates, windows, ventilation and water drainages.**
- **Spread of EPS from old, illegal dumpsites in close proximity to the production site.**

3.2.4. Waste and littering of EPS and XPS from building construction

EPS and XPS are used during construction of buildings to insulate the foundations, ring wall (through EPS concrete forms that remain in place after hardening), and roofs.

In 2015 - 2020 approximately 30 000 buildings were constructed annually, corresponding to about 400 000 square meters of floor space. An estimated 29 460 tonnes of EPS and 15 350 tonnes of XPS were used in 2020.

XPS is used where the insulation must bear significant weight, whilst EPS is used where the mechanical properties of the insulation is less important. Recently grey EPS with graphite that further improves the insulation properties have been introduced to the market.

Clinker blocks lined with EPS are used for some ring walls, but after the introduction of concrete forms in EPS, the product is mostly used today as a niche product in larger construction projects to improve fire safety.

EP-materials used for building insulation are known to be stored at the construction site in large quantities. Clean-up operations around construction sites have identified increased levels of EP-littering that may be traced back to these sites[11].

[10] Pers. com., interest group, Sep. 28, 2021.
[11] Pers. com., environmental protection group, Nov. 22, 2021.

Another challenge is that many construction sites are located on a gravel cover or other kinds of unpaved surfaces that may leak EP-particles that are generated through cutting and other treatment of EP-materials or make it difficult to recover the particles during clean-up operations. Uncovered EPS exposed to sunlight for longer periods of time will become more brittle and discoloured. The degradation in some cases becomes so severe that the elements must be replaced or modified through scraping off the outer layers that have been degraded, producing EPS particles in the process.

Many construction sites have area limitations that limit the possibility of erecting indoor storage facilities or the number of containers that waste may be separated into. This may create challenges when it comes to implementing necessary protection of EP-containing products and waste against the elements. Road projects come with an additional challenge due to not having a permanent construction site.

Figure 3.4: Marine litter most probably from a construction site (Salt, 2021) [8]. Photo: SALT Transport of EPS without proper protection. Photo: Snorre Sklet, SALT.

Management of EP waste from the building construction

EP-waste from the construction industry is generated during construction, rehabilitation and demolition of buildings. During construction (and rehabilitation) EPS- and XPS-waste arises both from cut-off and unused EPS-insulation and EP-packaging. The content of EPS in construction waste is reported to be 0.2 % to 0.3 % of waste per weight during construction consists of EPS, this number being slightly higher for smaller houses than for apartment blocks[12].

Construction sites vary in size and longevity. For larger construction sites, waste management can include separate containers for fractions like wood and cardboard. There may also be dedicated tents for cutting materials such as EPS.

[12] Pers. com., construction company, Oct. 25, 2021.

Recently, some contractors in Norway and Sweden have started separating out the EPS waste during construction, in agreement with EPS producers who collect the waste[13]. This practice is being introduced in Norway[14].

When the producer retrieves EPS waste from a construction project they supply, they maintain control over the contents of pollutants such as brominated flame retardants.

There may be several reasons for inadequate collection of EPS on construction sites:
- EPS is included in other waste fractions
- EPS is not sorted correct
- EPS waste are filled over
- Narrow construction sites with lack of space for waste containers

From demolition and rehabilitation of buildings EP-waste is generated from discarded insulation. During demolition EPS is sorted into mixed fractions destined for landfilling or incineration. Contaminants such as concrete, gravel and tar adhere strongly to the materials and are difficult to separate out. The materials may also contain brominated flame retardants, rendering the EP unsuitable for mechanical recycling. These materials could be recycled chemically, but due to lack of a down-stream process, current end-treatment is energy recycling or landfilling.

Around 29 460 tonnes of EPS-insulation and 15 350 tonnes of XPS-insulation is used in construction each year, in total 44 810. An estimated 18 400 tonnes of EPS- and XPS-waste is generated annually from construction, demolition and rehabilitation, as shown in table 3.1.

Table 3.1: Waste from construction, rehabilitation and demolition of buildings [18].

Material type	Yearly tonnage (2019)	Estimated EPS content per weight	Estimated EPS- and XPS waste generated
Construction waste	658 000 tonnes	0.3 %	1 970 tonnes
Rehabilitation waste	495 000 tonnes	*0.9 %	4 460 tonnes
Demolition waste	796 000 tonnes	*1.5 %	11 940 tonnes
Sum	1 949 000 tonnes	0.9 %	18 370 tonnes

* The content of EPS waste in demolition waste is assumed to be significantly higher than in construction waste, whilst the content EPS in rehabilitation waste is assumed to lie in the middle.

Based on these estimates 26 410 tonnes of EPS accumulated in the Norwegian building volume in 2020. The requirements for energy efficiency have increased in the previous years, increasing the amount of EP used as insulation in buildings. The use of EPS as insulation in buildings began increasing in the 1970s. When these buildings are demolished the amount of EPS-waste in the demolition waste is expected to increase until it equals the EPS used in construction of new buildings.

[13] Pers. com., EPS-producer, Oct. 05, 2021.
[14] Pers. com., waste treatment company, Nov. 29, 2021.

Summary of unwanted incidents specific to building construction

- **Spread of EPS dust and particles from scraping off degraded EPS from materials exposed to sunlight**
- **Spread of EPS particles from cutting and customizing with saws and rough handling of EPS products and materials due to wind, rain and surface water.**
- **Spread of EPS particles from destruction of low-density concrete with EPS.**
- **Spread of EPS particles from building waste fractions from demolition of buildings during handling, transport and temporary storage.**

With a consumption of 38 820 tonnes of EPS and XPS materials annually and a corresponding waste stream of 18 370 tonnes bringing the total amount of EPS/XPS-materials processed up to the sum of 57 190 tonnes, the following statements can be made about potential littering effects:

- Loss of 0.1 % of all EPS and XPS utilized in construction of buildings corresponds to littering of 57 tonnes of EP for 2020.
- Loss of 1 % of all EPS and XPS utilized in construction of buildings corresponds to littering of 570 tonnes of EP for 2020.

3.2.5. Waste and littering of EPS and XPS from road construction

EPS is used as a lightweight construction material to reduce the weight of roads on unstable foundations. The first road filling made of EPS was constructed in 1972. In 2019, more than 500 road fillings will be constructed by use of EPS. An estimated 540 tonnes of lightweight fill of EPS is used for roads annually The volumes vary depending on the type of projects that are carried out [19].

XPS and EPS are also used for frost protection in the transition zone between roads and tunnels, bridges etc., see figure 3.5 and 3.6[15]. It is also often used inside the tunnels and road sections with challenging ground conditions, except where risk of rising water levels may destabilize the road due to the buoyancy of EPS and XPS.

Some EPS- and XPS-plates are also excavated as waste during reconstruction of road and infrastructure. In the lack of available statistics to this waste stream an estimation of 100 tonnes annually has been made. The conditions during road construction increase the risk of littering of EPS. The construction area is outside of cover exposed to the weather and the local wildlife. Another challenge is that many construction sites are located on a gravel cover or other kinds of unpaved surfaces that may leak EP-particles that are generated through cutting and other treatment of EP-materials or make it difficult to recover the particles during a later clean-up operation. Proper control and infrastructure for correctly cleaning, sorting and disposing litter is difficult to maintain due

[15] Pers. com., EPS-producer, Nov. 03, 2021.

to the temporary nature of the work site. Clean-up operations around construction sites have identified increased levels of EP-littering may be traced back to these specific sites[16].

Figure 3.5: Use of EPS in an interim bridge over E6 at Gimsøyvegen. Photo: Tor Helge Johansen.

Rain and wind spread the EPS fragments that break off during cutting, and general wear and tear of the building blocks. As seen in figures 3.6 and 3.7, the workers often walk on top of unprotected EPS. The exposure to sun can lead to degradation of the EPS, which is increasingly vulnerable to wear and tear, and may need to be scraped off.

Water control is also more challenging and EPS-particles are regularly observed being carried away with wind and draining water from cutting sites and excavation pits[16].

In addition to the use of 540 tonnes of EPS- and XPS-materials in Norwegian road projects each year, it is roughly estimated that 100 tonnes of EPS- and XPS-material are recovered as waste. If 1 % of this material is lost this will represent a loss of 6 tonnes. If 10 % is lost this will represent a loss of 64 tonnes. While the magnitude of use of EPS is much lower for construction of roads than construction of buildings, the risk of littering of EPS will often be greater comparatively.

[16] Pers. com., environmental protection group, Nov. 22, 2021.

Figure 3.6: EPS as lightweight fill. Fragmented EPS litter surrounds the area. Photo: Geir A. Carlsson, Fredrikstad Blad.

Management of EP waste from road construction

EPS blocks removed from roads during construction work will in some cases be in good enough condition for continued use, and could potentially be applied in other road projects. When EPS-road elements are dug up elements on the edges will often be damaged or heavily soiled while elements from the core of the EPS-structure will be in more pristine condition[17].

EPS blocks used in temporary fillings in some projects have been reused in new road fillings, but the practice is rare[18]. Recovered EPS and XPS waste from road projects are reported to be mostly landfilled instead or incinerated[16].

When a road construction is dismantled a significant amount of EPS is at risk to contaminate the soil. The EPS may leach out of these soil mounds during temporary storage, or during landfilling. Leaching of EPS from landfills is described in detail in section 3.4.

[17] Pers. com. Statens Vegvesen, Oct. 18, 2021.
[18] Pers. med, waste treatment company, Nov. 29, 2021.

Summary of unwanted incidents specific to construction of roads

- **Spread of EPS dust and particles from scraping off degraded EPS from materials exposed to sunlight**
- **Spread of EPS particles from cutting and customizing with saws, rough handling of EPS products and materials and walking on EPS materials, due to wind, rain and surface water.**
- **Spread of EPS particles to the environment by leachate from soil mounds.**

In addition to the use of 540 tonnes of EPS- and XPS-materials in Norwegian road projects each year, it is estimated that 100 tonnes of EPS- and XPS-material are recovered as waste.

- Loss of 1 % of this EPS- and XPS materials and waste used in road construction corresponds to littering of 6 tonnes of EP for 2020.
- Loss of 1 % of this EPS- and XPS materials and waste used in road construction corresponds to littering of 64 tonnes of EP for 2020.

3.2.6. Waste and littering of EPS from aquaculture

EPS is used as floating elements in different types of equipment in the aquaculture sector like pens, mooring buoys and floating docks. Usually, at least one of the floating pipes in the pens are filled with EPS-elements inserted into the floating pipe during production, see figure 3.7.

Aquaculture pens consist of nets floating from floating rings. The rings are made out of a hard plastic such as polypropylene filled with EPS. As all other closed, EPS-filled buoyancy elements, the EPS does not actually serve to increase buoyancy, but rather helps the rings maintain their shape. Unfilled rings may begin to deflate. If the rings are punctured the EPS ensures buoyancy is maintained.



Figure 3.7.: EPS blocks collected during beach cleaning. Photo: Inger Unstad Disassembled floating pipe filled with EPS-elements. Photo: Snorre Sklet, SALT Disassembled floating pipes. Photo: Snorre Sklet, SALT.

Loss of EPS from floating rings may occur during both assembly and disassembly of aquaculture installations. Some assembly operations take place at coast bases with indoor storage and operating facilities, while in other cases the assembly takes place on-site with limited infrastructure available. These sites are usually especially exposed to wind, rain, waves and tides.

The mooring buoys must be frequently replaced due to a requirement for excess buoyancy, which results in the buoy floating too tall in the water, oscillating in the waves and reducing lifetime and increasing the risk of rifts through which EPS may leak[19].

There are concessions for operating 3 439 aquaculture pens in Norway. 30 % of pens are kept inactive, meaning there are roughly 5 000 pens in circulation at any given time. Each pen contains 0.35 tonnes of EPS. This corresponds to 2 000 tonnes of EPS in aquaculture pens, with 130 tonnes of EPS waste generated from aquaculture pens in 2020.

In addition, it is estimated that six mooring buoys are used per aquaculture pen; the number depends on how many pens are attached together at each site. If the buoys each contain 4840 L of EPS , and have a lifetime of 5 years, there is 1 200 tonnes of EPS in active mooring buoys with 240 tonnes of EPS waste generated from mooring buoys in 2020 [20].

There are several producers and suppliers of pens, but the market is dominated by a couple of suppliers. The main suppliers of pens to the aquaculture sector are AKVA group and ScaleAQ.

Management of EP waste from aquaculture

Assuming a lifetime of 15 years 130 tonnes were disposed of in 2020 from aquaculture pens. Assuming a lifetime of 5 years for mooring buoys, 240 tonnes of EPS was disposed of in 2020 from mooring buoys. Some EPS (typically 3 kg) is also found in bird net systems in some installations, but this represents most likely less than one tonne of waste each year[20].

After use, the pens are disassembled and the EPS is taken out of the pipes. The disassembling may be carried out either at permanent or temporary sites. Disassembly may also occur on-site.

The materials are recyclable, and there are several companies that receive plastic components for recycling. Some of the main companies collecting discarded equipment from the aquaculture sector are Osterøy Miljø, Noprec, Nofir and Ragn-Sells.

Disassembly involves cutting of floating pipes with either hydraulic knives or chainsaws where EPS-spills may occur if cuts are done through the EPS-elements. The materials may be temporarily stored on such sites. This storage is risky due to uncontrolled environments with shifting weather and the potential for floods and waves. The pens may be towed to waste management facilities where they are disassembled under more controlled conditions[21].

There have also been reports of materials from aquaculture pens being reused to build floating docks. While reuse is inherently positive, this may lead to littering if the EPS elements are placed uncovered

[19] Pers. com., plastic product producer, Nov. 18, 2021.
[20] Pers. com., plastic product producer, Oct. 15, 2021.
[21] Pers. med, waste treatment company, Nov. 29, 2021.

in water. It is not uncommon to find EPS-elements from aquaculture installations during clean-up operations of marine litter.

Summary of unwanted incidents specific to aquaculture

- **Spread of EPS particles from disassembling of aquaculture pens through wind, rain and surface water.**
- **Leakage of EPS fragments from holes in mooring buoys.**
- **Leakage of EPS fragments from holes in aquaculture pens.**

Assuming 130 tonnes of EPS in floating pipes and 240 tonnes of EPS in mooring buoys is replaced each year the following can be said about the littering potential:

- Loss of 1 % of this EPS used in aquaculture during assembly and 4 % during disassembly corresponds to littering of 14.8 tonnes of EP for 2020.
- Loss of 2 % of this EPS used in aquaculture during assembly and 10 % during disassembly corresponds to littering of 44.4 tonnes of EP for 2020.

3.2.7. Waste and littering of EPS from packaging

Fish boxes, packaging for seafood, are produced by the EPS producers, usually in close proximity to fish processing facilities where fresh seafood is packaged and sent to further processing. Historically many fish boxes were found during clean-ups of marine litter. In recent years the amount of fish boxes found in coastal clean-ups seems to have decreased, which may indicate a reduction in littering [22]. Notably most of the fish boxes are exported.

EPS-packaging for consumer products is generated for consumption in both households and businesses and comes in many forms and sizes. Some EPS packaging comes in the form of loose filler beads, although most come as form shaped structures surrounding the product. Norwegian retailers are working to phase out the use of EPS packaging as consumers value environmentally friendly packaging alternatives such as cardboard[23,24].

Littering from packaging may occur due to wear and tear producing fragments of EPS which are transported by wind and water. Some EPS packaging is very difficult to handle without producing EPS fragments, this is remedied by indoor handling which facilitates easier clean-up of the fragments. Entire profiles may also get caught in the wind if stored outside. Once lost the entire profile will end up as littering.

[22] Pers. com., environmental protection group, Nov. 22, 2021.
[23] Pers. com., electronics importer, Oct. 13, 2021.
[24] Pers. com., electronics importer, Nov. 03, 2021.

Figure 3.8: Fish box collected during beach cleaning. Photo: Rune Gaasø.

Waste management of packaging

In general fish processing facilities that generate large amounts of discarded fish boxes will have equipment for compacting the fish boxes. Recycled fish boxes may not be reused as fish boxes due to food safety regulations. Almost all used fish boxes on the Norwegian market are recycled to insulation products.

EPS packaging for the end consumer market normally ends up in the private households. Current municipal sorting guidelines urge the consumer to bring EPS packaging waste to a municipal recycling centre. Smaller amounts may also be disposed of as residual waste. Private transport of bulky waste may lead to losses during transport and delivery to the recycling centres. The risks of littering at the recycling centres are described in section 3.2.9.

Warehouses for electronics and appliances produce significant amounts of EPS packaging waste. Some warehouses have initiated projects with collection and compaction of EPS waste. Once the waste has been compacted to 350 - 400 kg/m^3, it is sold on the open market. The practice remains rare in 2021.

Summary of unwanted incidents specific to use of EPS packaging

- **Spread of EPS particles from wear and tear of packaging during unboxing of goods.**

It is estimated that 5 810 tonnes of fish boxes, 2000 tonnes of EPS-packaging for electronics and furniture, and 2 000 tonnes other EPS packaging including packaging for chemicals, industrial products and components, pharmaceuticals and other medicinal applications.

- Loss of 0.1 % of EPS used in packaging corresponds to littering of 9.8 tonnes of EP for 2020.
- Loss of 1 % of EPS used in packaging corresponds to littering of 98 tonnes of EP for 2020.

3.2.8. Waste and littering of EPS from floating docks and harbour activities

Floating docks are placed both along the coast and in lakes to improve access to the boats and the ocean, used both for trade and recreational purposes (see figure 3.9).

Figure 3.9: Aker Marina in Oslo City Centre.

Most, if not all, floating docks contain EPS. The key function of EPS in these products is to simplify production. The EPS helps cover materials such as hard plastics, wood and concrete maintain their shape through the seasons and changing temperatures. A secondary purpose is to reduce the probability of sinking of the dock if the floating elements are punctured[25].

EPS-free floating docks are technologically feasible at the present, but due to the lack of regulation of floatation elements, EPS-based products dominate as they are cheaper to manufacture[26].

There are seemingly few rules and regulations with regards to standards for floating docks and marinas. Common designs have uncovered EPS below and/or on the sides of the floating docks. These designs result in littering of EPS as waves, ice and boats wear at the EPS. It is not uncommon to utilize damaged or sub-par floating docks with homemade pontoons, see figure 3.10.

There are several large producers of floating docks in Norway. In addition, many solutions are imported from China, Estonia and other countries. It is common for a boat to regularly dock at several different docks or marinas, one at home, one at the cabin, and several destinations for stores, restaurants and the like.

[25] Pers. com., plastic product producer, Nov. 18, 2021.

Figure 3.10: Used EPS blocks used as pontoons. Photo: Oslofjorden friluftsråd. -Right: Pontoons torn during heavy weather.

Floating docks are a major source of EPS litter and pollution, see figure 3.10 and figure 3.11. Uncovered EPS will deteriorate over time, due to exposure to waves, sun, ice and impacts from boats. Covering the top and sides helps mitigate, but does not eliminate the littering.

Figure 3.11: Left: EPS leaking out of a covered pontoon. Photo: Oslofjorden friluftsråd. Figure 3.4. Right: Damaged floating elements picked during beach cleaning. Photo: Oslofjorden friluftsråd.

Floating docks with completely covered EPS can still result in EPS-litter. The shell may be punctured by wear over time, or by high impact with a boat, in which case EPS will slowly leak out of the floating element. Floating docks may also tear loose during storms and rough weather.

This represents major pollution events, where beached 'ownerless' docks quickly deteriorate and leak large amounts of EPS into the environment. There are also reported incidents about floating docks with open EPS-surfaces being pulled over gravel or uneven ground during transit to winter storage resulting in excessive wear of EPS surfaces or hard plastic shells resulting in EP-litter.

EPS has been sold as storage blocks for boats [28]. In recent years the EPS producers have stopped selling these products due to the affiliated environmental detriment. Recent occurrences have not been identified, but it may still be practiced in some locations. This practice is expected to produce large quantities of EPS littering, from significant wear and tear from the boats, and from loss of temporarily stored EPS blocks.

Figure 3.12: Storage of boat on land with EPS.

Experience from beach cleaning and interviews with experienced beach cleaners indicate that littering from floating docks is a major source of EPS littering[26].

Management of EP waste from floating docks and harbour activities

End-of-life treatment of a floating dock is disassembling and recycling of the components. Most, if not all the materials are highly recyclable, and in some cases reusable. In many cases, disassembly and recycling represents high costs for the owner.

There is a sprawling secondary market for floating docks. When a marina retires their floating docks due to old age and wear, they often end up being sold or given away to secondary users. This may be beneficial economically for both parties. The reuse of floating docks however increases the risk of littering and pollution as old and worn out secondary docks are more prone to leakage. Then there is the risk of loss of EPS during transport [21].

Due to the costs of scrapping floating docks, many docks are sunk or dumped illegally or lost to bad weather[27].

[26] Pers. com., environmental protection group, Nov. 22, 2021.
[27] Pers. com., EPR scheme, Oct. 15, 2021.

Summary of unwanted incidents specific to floating docks, marinas and harbour activities

- **Spread of EPS particles from wear and tear of uncovered EPS.**
- **Spread of EPS particles through punctured cover materials due to wear and tear.**
- **Excessive wear and tear due to scraping on rock and gravel during transit to winter storage.**
- **Use of EPS as supporting material for boats during winter storage.**
- **Maintenance of uncovered EPS where filth is scraped off.**
- **Illegal chopping of floating docks, boats, sail- and surfing boards.**
- **Littering of EPS from pontoons and floating docks lost at sea during storms or transit.**

Assumption of potential littering rates

Assuming one in ten of all floating docks that are discarded each year are dumped or lost means that 190 tonnes of EPS is lost. If a third of all docks are lost or disposed of illegally this will mean a total loss of EPS of 633 tonnes each year.

Assuming that 25 % of all docks contain open EPS-surfaces and an annual loss of 10 gram EPS per boat mooring will mean that 1.75 tonnes of EPS-particles are lost to the environment. Assuming that the same amount of EPS-particles are lost during cleaning and maintenance of the floating docks means a total of 3.5 tonnes of EPS-particles are lost from floating docks in operation each year.

3.2.9. Waste and littering of EPS from recycling centres and landfills

Municipal recycling centres will receive EPS waste from private consumers and businesses. Until recent years, most EPS waste was sorted into mixed fractions and sent to incineration. In recent years several schemes and projects have been undertaken to ensure separation and recycling of EPS from recycling centres.

EPS may be collected in containers or bag rack collection systems. The EPS is sometimes compacted on site and sold on the market. Recycling centres report mixed results with compaction of EPS. If unsuitable equipment is used for compaction, low densities of compacted materials are achieved, and the process becomes more labour intensive. Most recycling centres do not have protection against wind in the areas where waste is returned. When disposing of EPS waste at the recycling centre EPS fragments from the discarded EPS could be caught by wind and lost. Bag Racks used to collect EPS may also tilt in strong winds, releasing EPS.

Soil contaminated with EPS from construction waste originating from buildings and roads are often landfilled. EPS may "leak" out of the landfill by wind, surface water and leachate if not preventing measures are in place.

Summary of unwanted incidents specific to disposing of EPS at recycling centres

- **Spreading of EPS pieces during delivery of discarded EPS packaging and materials.**
- **Spreading of EPS due to tilting of EPS bag racks.**
- **Spreading of EPS from landfills through wind, surface water and leachates.**

3.2.10. Other important sources of EPS litter

EP-littering is caused not only by ongoing human activities, but also from legacy waste that has accumulated at specific locations in the environment, and from where it may be redistributed to new locations and recipients through processes like erosion, strong wind and flooding. Typical examples are illegal waste dumping sites. Typically there are several documented cases of illegal landfills in each Norwegian municipality where EP-waste may have been dumped[28]. Hotspots of EP-littering have also been known to form around EP-production facilities, construction sites and the fish processing facilities. Although some of these hotspots are discovered through voluntary clean-up operations no systematic national effort has so far been done to map and remove this littering.

Dominating wind and currents along the Norwegian coast trap much marine litter at specific locations like islets and coves where the accumulated litter forms hotspots and may remain for a long time.

3.2.11. Municipal waste management of EPS

EPS is collected by municipalities either through delivery to recycling centres, or through mixed household waste. EPS was previously collected from households together with other plastic packaging in municipalities with source separation of this stream. After causing severe problems in the value chain due to high volume and static electricity, Green Dot Norway changed their quality criteria around 2015 for waste collection and did not support collection schemes anymore where EPS is commingled with other plastic packaging.

Several initiatives are being implemented to ensure separation of EPS waste in the municipalities. For example Vartdal Plast utilizes the transport capacity of their returning trailers to retrieve EPS packaging from municipalities in regions Trøndelag, Møre og Romsdal and Viken. Other local initiatives exist, per November 2021 systems have been identified in 122 of 359 municipalities see table 3.2.

Table 3.2: Municipals, and the inhabitants of those municipalities, with systems for recycling of EPS [36].

System for recycling of EPS		Municipalities		Inhabitants
With identified system	(34 %)	122	(52 %)	2 807 052
No identified system	(66 %)	237	(48 %)	2 584 317
Sum		359		5 391 369

At recycling centres with systems for recycling of EPS, packaging is generally collected separately from construction materials due to concerns for brominated flame retardants in construction materials and because the existing EPR scheme only targets packaging waste. Collected packaging materials may be

[28] Pers. com., environmental protection group, Nov. 22, 2021.

compacted and sent to recycling, depending on available compression infrastructure. If compression is not available, EPS is sent for incineration.

Assuming on average one recycling centre in each municipality where EPS-waste can be delivered either as a sorted fraction or as part of mixed waste means a total of 359 recycling points in total. If 10 kg of EPS is lost from each recycling centre per year this means a total loss of 3.6 tonnes. If 100 kg of EPS is lost from each recycling centre per year this means a total loss of 36 tonnes.

3.3. Waste-treatment

3.3.1. Landfills

4 973 000 tonnes of waste including slightly contaminated soil was landfilled in Norway in 2019 [22]. Waste streams that typically contain EPS include sludge, concrete and bricks, plastics, car fluff (a fraction of mixed light materials from demolition of cars), hazardous waste, mixed waste and slightly polluted soil. The amount of landfilled waste of waste categories that may contain EPS in 2019 is shown in table 3.3.

Table 3.3: The amount of landfilled waste that may contain EPS in 2019 [22].

Waste category	Landfilled	Waste category	Landfilled
Sludge	45 000 tonnes	Hazardous waste	483 000 tonnes
Concrete and bricks	896 000 tonnes	Mixed waste	303 000 tonnes
Plastic	12 000 tonnes	Other materials	215 000 tonnes
Car fluff	8 000 tonnes	Slightly polluted soil	2 677 000 tonnes
Total			**4 639 000 tonnes**

It is estimated that EPS makes up 1% by weight of residual waste in Norway [23]:

- If a tenth of that amount is found on average in the other waste fractions this means that a total of 4639 tonnes of EPS is landfilled each year.
- If 1 % of this landfilled EPS-waste is lost from wind and drainage this means a loss of 46.4 tonnes of EPS from landfills each year.
- If 0.1 % of this landfilled EPS-waste is lost from wind and drainage this means a loss of 4.6 tonnes of EPS from landfills each year.

3.3.2. Recycling plants

Almost all fish boxes put on the Norwegian market (5 750 tonnes) are recycled. In addition about 25 % of EPS-packaging is also recycled. This means that about 7 000 tonnes of EPS is recycled annually.

- If 1 % of the feedstock for Norwegian EPS-recycling ends up as litter, this will mean that 70 tonnes of EPS is lost.
- If 0.1 % of the feedstock for Norwegian EPS-recycling ends up as litter, this will mean that 7 tonnes of EPS is lost.

3.3.3. Incineration plants

3 211 000 tonnes of Norwegian waste was incinerated in 2019 [22]. A significant part of this waste was exported to incineration plants abroad, especially in Sweden. Waste streams that typically contain EPS include Wood, sludge, electronic waste, concrete and bricks, plastic, textiles, car fluff, hazardous waste, mixed waste, and other materials. The amount of incinerated waste of waste categories that may contain EPS in 2019 is shown in table 3.4.

It is estimated that EPS makes up 1% of residual waste in Norway [23]. If it is assumed an average level of 0,5 % EPS in the total amount of waste incinerated, this will mean that a total of 15 500 tonnes of Norwegian EPS waste is incinerated.

Table 3.4: The amount of incinerated waste of waste categories that may contain EPS in 2019.

Waste category	Incinerated (tonnes)	Waste category	Incinerated (tonnes)
Wood	756 000 tonnes	Textiles	2 000 tonnes
Sludge	28 000 tonnes	Car fluff	27 000 tonnes
Electronic waste	18 000 tonnes	Hazardous waste	433 000 tonnes
Concrete and bricks	0 tonnes	Mixed waste	1 627 000 tonnes
Plastic	166 000 tonnes	Other materials	45 000 tonnes
Total (tonnes)			**3 102 000 tonnes**

Almost all waste for incineration is delivered in closed containers and unloaded in closed bunkers before incineration. Thus only very little EP-litter is expected to arise from this sector. If it is assumed that one part per ten thousand of EPS is lost this will mean a loss of 1,5 tonnes. If it is assumed that one part per thousand of EPS is lost this will mean a loss of 15 tonnes. Estimates of how EPS in waste is treated is shown in table 3.5.

At present compactors are installed at facilities where large quantities of relatively clean EPS waste is produced, for example at fish processing factories that use large quantities of fish boxes, and EPS factories that produce EPS scrap during shaping of their products. The former is usually placed in close proximity to a EPS factory, which offers to recycle the EPS on their behalf.

The two existing producer responsibility organizations for packaging in Norway, Green Dot Norway and Emballasjegjenvinning, report that most of the fish boxes placed on the Norwegian market are recycled. However, some 30 250 of the 36 000 tonnes of produced fish boxes annually are exported and are thus outside the scope of the Norwegian EPR scheme.

Table 3.5: Treatment of EPS from discarded products, materials and packaging in Norway in 2020, based on estimates of products,materials and packaging placed on the market in section 2.

Product or material	Estimated yearly waste volume	Estimated recycling	Estimated incineration*	Estimated landfilling*
Building and construction				
Insulation plates and concrete forms of EPS and XPS	18 370 tonnes	**0 tonnes	9 185 tonnes	9 185 tonnes
EPS blocks as Lightweight fill for roads	100 tonnes	0 tonnes	0 tonnes	100 tonnes
Aquaculture and floating docks				
Mooring buoys	240 tonnes	230 tonnes	5 tonnes	5 tonnes
EPS filling for floating pipes	130 tonnes	120 tonnes	5 tonnes	5 tonnes
Floating docks	1 900 tonnes	0 tonnes	950 tonnes	950 tonnes
Packaging				
Fish boxes	5 810 tonnes	5 230 tonnes	580 tonnes	0 tonnes
Packaging for consumer electronics and furniture	2 000 tonnes	1 000 tonnes	1 000 tonnes	0 tonnes
Other packaging	2 000 tonnes	1 000 tonnes	1 000 tonnes	0 tonnes
In total	**30 550 tonnes**	**7 580 tonnes**	**12 725 tonnes**	**10 245 tonnes**
Recycling rates		**24.8 %**	**41.6 %**	**33.5 %**

* For construction materials and pontoons a 50-50 split between landfilling and incineration is used in estimates as the distribution is unknown.

** Recently some cut-off from construction sites have been collected and recycled. It is estimated that at least 60 tonnes of EPS will be recycled in this manner in 2021[29].

[29] Pers. com., EPS-producer, Oct. 29, 2021.

4. Measures to reduce littering of expanded plastics

This chapter describes measures that may eliminate or limit EP-littering. Measures are defined as actions that may be taken by stakeholders to limit littering, while policy tools are defined as governmental instruments to implement or encourage desired measures or other processes that may limit littering. This report does not discuss relevant policy tools for reduced EP-littering.

The discussion of measures is based on the material stream analysis of EPS given in chapter 3. A total of 30 potential measures has been identified as possible initiatives for reducing EP-littering.

These measures are categorized as following:

1) Measures within storage and handling of materials and products containing expanded plastics.
2) Measures to control the scattering of small pieces and particles of expanded plastics.
3) Collection of discarded products and materials containing expanded plastics.
4) Specific measures for the construction industry
5) Specific measures for the marine and maritime sector
6) Specific measures for the waste treatment sector
7) Measures to identify and clean up hotspots of EP-littering
8) Material Substitutions
9) Measures that may lead to increased reuse and recycling of expanded plastic.

4.1. Storage and handling of materials and products containing expanded plastics

Loss of EP during storage and handling of EP-materials and waste is a major source of EP-littering. Identifying and controlling potential sources of littering is essential. The following paragraphs describe important measures to limit EP-littering during storage and handling of these materials.

4.1.1. Protection from wind, rain and surface water during storage

Protection of EP materials from wind, rain and surface water during storage is essential to avoid loss of material. The best way to provide such protection is through indoor storage. Where indoor storage is not possible great care should be taken to secure stored EP-material through fastening with straps or other relevant actions, and to store cut-offs and smaller pieces in closed containers. In cases where outdoor intermediate storage cannot be avoided, it will also be important to store on solid and tight surfaces that enable the collection of small pieces, as well as good security such as preventing

EP materials from blowing away or being carried away by surface water. The weather situation in the surrounding area should be continuously monitored to enable extra security measures in the event of strong winds and heavy rainfall. There should always be readily available equipment for collecting EP spills in the form of sweeping trays, industrial vacuum cleaners or the like as recommended by Operation Clean Sweep [24]. The area where EP intermediates are stored should be adequately secured against theft and vandalism. Relevant personnel including truck operators should receive necessary training in how to limit risk of littering.

Measures to secure stored EP-materials against loss due to strong winds and flooding is considered especially relevant for the following sectors:

- EP-production
- Building and construction
- Marine and maritime
- Waste management and landfilling

EP-production

A measure to reduce risk of littering from EP-production facilities is to construct additional indoor storage capacity that makes it possible to store all EPS-materials indoors.

If implemented, indoor storage of all EPS-products is expected to reduce the risk of EPS-littering due to loss of stored materials significantly. The feasibility of this measure will depend on available areas for the construction of additional indoor storage space, and it comes with significant costs. For production plants that have comprehensive systems for securing products that are stored outside against loss due to wind or flooding the environmental benefits of complete indoor storage may be limited.

Building and construction

During construction projects all EP-materials, both unused products and waste, should either be stored in closed containers or strapped down to prevent loss due to wind or flooding. The doors of the closed containers must remain shut when not operated. The Norwegian and Swedish EPS Association highlight measures to safeguard EPS-elements against wind as important and recommend that cut-offs and unused pieces of EPS are sorted separately in suitable bag solutions [25], [26].

Ideally all storage and treatment of EP-materials should happen on a waterproof and solid surface. Additional challenges can come from winter climate and heavy snowfall that make it more difficult to collect EP-spills.

The use of closed containers for storage of EP-containing products and waste may be expensive. Storage in closed containers and operating on a surface that limits leakage of EP-particles is considered to be an effective measure to limit EP-littering from construction sites. As construction sites are shown to be a significant source of EP-littering, protection against loss due to weather conditions is expected to have considerable effect.

Marine and maritime sector

EPS is used extensively as floatation elements in the aquaculture industry, and loss of such elements is known to happen both during the assembly and disassembly of aquaculture installations. Some assembly operations take place at coast bases with indoor storage and operating facilities, while in other cases the assembly takes place on site with limited infrastructure available.

During the assembly-process EPS-elements must be protected against not only wind and flooding but also waves and tidal currents that may carry unsecured EPS-elements offshore. For this reason all EPS-material both products and waste should be stored indoor or in closed containers.

Waste management

The waste management value chain includes collection, transport, storage, pre-treatment and recycling, incineration or landfilling. During waste treatment EP-waste may therefore be stored at a waste reception or sorting facility, a waste incineration plant or at landfill.

Interviews with several waste operators have confirmed that waste treatment facilities are known to lose EP-material, especially due to wind. For this reason all EP waste should be stored in closed containers, see Figure 4.1[30]. At smaller waste facilities EP-waste is often collected in bag racks that are especially vulnerable to strong wind, and should for this reason always be lidded and secured against being overturned. All full EPS-bags should be collected and stored indoors. The replacement of open outdoors storage solutions with indoor or closed containers will lead to additional expenses.

Figure 4.1: Storage of EPS-waste in closed container, bag racks and outdoor delivery site for EP-containing waste.

[30] Pers. com., waste management company, Nov. 29, 2021.

4.1.2. Measures during transport

EP-containing materials are transported:

- From producer to customer, either directly at location/site of use or to storage,
- From storage to user site,
- From user site to waste management (as EPS-waste),
- From waste management to end-treatment.

Unused products are normally transported in closed trucks and trailers, while EPS waste may be transported in trucks with open containers, on ships or by train. Loss of unused EP-products during transport is rare, while loss of EPS waste during transport seems more common. Spills during transport are usually caused by faulty doors or lack of proper tarpaulin covers of open containers. Properly securing tarpaulins and outlet caps before embarking is an important measure to reduce risk of spilling.

If spills of small pieces or particles are expected when unloading a catch pan or other relevant collection equipment should be applied.

Any spill that occurs during transport must be collected as soon as possible to limit further spread to the environment. All transport should therefore carry readily available equipment for cleaning and collecting of spills, especially when transporting single bales or loose material. For transport at sea, all EP material should be adequately secured against being washed overboard or stored in closed containers, preferably under deck. EP products should also be secured against movements that can crush or damage EP elements during transit. Wastewater from cleaning the cargo hold should be collected and particles should be recovered before the water is discharged.

During unloading of EP-waste care should be taken to ensure that all of the waste material has been removed from the cargo hold. Material collected when sweeping or vacuum-cleaning for remaining leftover particles and smaller pieces should be correctly disposed of.

Transport with leak-proof doors and tarpaulins is considered a feasible measure that does not present huge practical obstacles or high extra costs to implement, and seems to be implemented for most transports already. As is carrying necessary equipment for cleaning up spills. As transport is not considered to be a source of considerable amount of EP-littering these measures are expected to have moderate to limited effect in reducing EP-littering.

4.1.3. Environmental Management System (EMS)

Control with potential sources to EP-littering is one of many important goals that are followed up by an environmental management system, and can most efficiently be followed up as an integrated part of holistic and systematic approach to limiting the total environmental footprint of a business or organization. Many alternative EMS-standards exist. Some are general and can be implemented by many types of businesses, for example ISO 14001 and EMAS for larger businesses and other dedicated certification systems (such as the Norwegian Miljøfyrtårn) for smaller businesses. Some standards are more specialized or limited in scope like Operation Clean Sweep and Good

Manufacturing Practice (GMP). Reduction of EP-littering becomes an integrated part of the day-to-day efforts that follows the implementation of an EMS. The EMS-standard normally includes guidelines for cleaning measures, work and training procedures that may also be crucial for limiting unwanted littering. For EP-production plants the EMS should also include procedures for monitoring and preparedness for handling possible loss of EP waste from silos and storage facilities, conveyor belts, pneumatic transmission systems, loading ramps, etc.

There may be several effects in limiting EP-littering caused by the implementation of an EMS, some more diffuse and indirect, depending on the chosen EMS. It is therefore difficult to assess the net effect when it comes to limiting EP-littering.

4.1.4. Training program

A training program for limiting risk of EPS-littering should promote awareness amongst relevant personnel about potential sources and incidents that may lead to EPS-littering. The training program should also contain drills on how to follow procedures that regulate work with EPS-materials.

4.2. Control of scattering of small pieces and particles

Many expanded plastics, especially EPS are brittle and easily break or crumble into small pieces and particles. EPS-particles are typically generated when EP-materials are cut, filed or otherwise machined. The same can happen if EP-materials are granulated, pelletized or moved. For this reason production, storage, use or other treatment run the risk of creating EP-particles that may be spread to the environment. Typical distribution systems are ventilation or water discharge. The following paragraphs describe measures that may limit EP-littering from these sources.

4.2.1. Measures to reduce spill during use

When cutting of EPS cannot be done in a controlled environment where cutting particles can efficiently be collected, the use of a heating knife or heating wire should be considered, as this equipment allows for cutting with far less particle spill, see figure 4.2. This measure is especially relevant for the construction sector both in buildings and road projects, but can also find use in other sectors for example when customizing floating docks or separating waste. Main use of heating knives is limited to pure EP-materials and can often not be used on complex materials where EP is mixed with other materials.

Construction sector

EPS-insulation for buildings is typically delivered as blocks or plates that are customized size on site. In some projects cutting is performed indoors or in closed containers where small pieces and dust that are generated during cutting can be efficiently collected. Cutting outdoors or without collection equipment typically leads to large amounts of leftover spill that is easily blown or washed away into the surroundings. Use of heat knives in construction projects are recommended by both the Norwegian and Swedish EPS Association [25], [26].

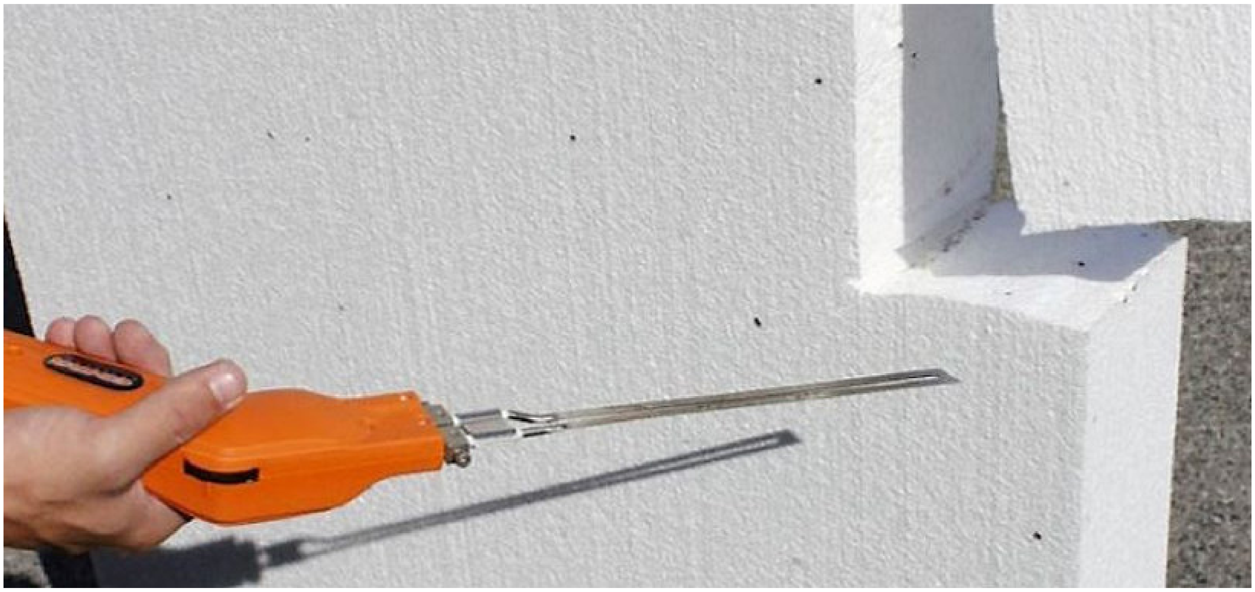

Figure 4.2: Hand-held heat knife for cutting of EPS.

Heat Knives are inexpensive, and are not more time consuming to use compared to mechanical cutting tools. If used indoors or with limited ventilation great care should be taken to avoid exposure to hazardous gases generated during the cutting process. If necessary, protective respiratory equipment should be worn.

Heating knives are not common use in Norwegian construction projects. If utilized in large scale this equipment could potentially reduce the generation of EPS dust and particles from the construction sector to a large degree.

4.2.2. Air filter in all exhaust and ventilation systems

An effective way to limit emission of EP-particles from a production plant or other facility where EP-materials are formed or processed is to install air filters that collect EP-particles before they leave the facility through ventilation or exhaust shafts. Filter systems must be installed with care and take into consideration such issues as necessary capacity and expected particle sizes. Regular and correct maintenance is required for optimal operation of filter systems over time.

4.2.3. Recovery systems for process and surface waters

Both process water and surface water that is drained from the area around a facility or plant that produce, store or use EP-materials may contain EP-particles that should be recovered before the water is allowed to enter external drainage systems. Several alternative recovery technologies exist including grates, sand traps, sludge filter, flotation chambers, cyclones etc. Installation of grates will often be the simplest measure, and will only recover large particles. Material that accumulates in grates must regularly be removed to avoid clogging of the grate. Large amounts of material may end up in grates in a short time during periods of heavy rainfall.

The use of grates that ensure that plastic granules cannot get through are included as an important measure by Operation Clean Sweep. Recovery of EP-particles from discharged water is a relevant measure for both EP-production plants and waste treatment facilities. It may also be considered as a measure for sewage treatment plants that experience a high run through of EP-particles. An additional issue is EP-particles trapped in snow that may be released during melting. If the melting water from removed snow clearing of roads is collected and led through a treatment system for other surface water, this can remove these particles. There are also treatment systems specially designed for snow water cleaning [27].

4.2.4. Fencing or other physical barriers

Fencing the area around a facility where EP materials are produced, used or stored will often capture blown-away EP-elements that would otherwise escape and be spread over a much larger area, enabling collection of the lost EP-material. Walls and vegetation may serve the same purpose. A fence that is meant to hold back litter must have mesh openings small enough to stop typical EP-pieces. Use of physical barriers to stop littering also requires regular clean-up rounds where captured litter is collected.

4.2.5. Regular inspection and collection of spotted littering

Area surrounding EP-production plants and old construction sites are known to sometimes contain littering hotspots where the litter in some cases dates back many years. Regular inspections and collection of spotted littering should be carried out around all facilities from where EP-littering can occur. Inspections should be carried out both on site and in the surroundings of the facility.

During clean-ups off site an assessment of the collected litter should be done to evaluate what parts that may be traced back to its own operations. Relevant equipment that should be used during litter clean-up can include broom boards, industrial vacuum cleaners, sweeping cars etc.

4.3. Collection of discarded products and materials containing expanded plastics

Efficient collection and treatment of discarded EP-products and materials is essential both to avoid littering and ensure optimal resource utilization of these waste streams. The following paragraphs describe important measures to organize collection of EP-waste.

4.3.1. Take back schemes for recycling, collection and sorting of EP

Establishing an effective return scheme that enables both recycling and safe collection and sorting with minimal risk of waste going astray is important regardless of sector. Important elements in the scheme will normally include a system for sorting of EP-waste at its point of origin before being transported to a waste treatment facility. As waste EP-materials are often not desired as input neither in a waste incineration plant where its high energy content may create process challenges, nor at a landfill where the waste is known to blow away and cause littering problems in the surroundings high gate fees are often put on EP-waste[31].

Due to its low density the transport costs of uncompressed EP-waste per tonne and km are significantly higher than for other waste which limit how far the waste can be transported. A common way to collect uncompressed EPS-waste is in big bags. A 1 m^3 bag typically contains 8.6 kg of EPS [28]. Although delivering EPS for recycling does not entail the high gate fees that incinerators or landfills often demand, and normally instead pays a premium, the high costs of transport uncompacted EP-waste will most often make the recycling option less cost effective due to long transport distances to relevant recycling plants, see figure 4.3.

Figure 4.3: EPS-compressor and pressed bars of EPS.

To make the transport more cost efficient the EPS-waste should be compacted. A EPS-compactor granulates the EPS-material and presses it into bars with much higher density that can be transported more efficiently (preferably to densities of 350 kg/m^3 - 400 kg/m^3). Both uncompressed and compressed EP-materials should be stored indoors or in closed containers before transport to recycling and other end treatment.

Feeding EPS-compressors is normally done manually and it may take several hours to feed a container with unpressed EPS into the compactor. The treatment costs of handling of EPS through such a system may run as high as 800 EUR per tonnes EPS [29]. The total costs of compaction may be greater than the income from delivering EPS to recycling, especially when poor compaction is achieved.

[31] Pers. com., waste management company, Nov. 29, 2021.

An intermediate solution for handling EPS after collection, especially for smaller recycling centres with limited EPS-waste could be to have installed crushers that crush the EPS into smaller pieces/grains ready for compacting. If plastic bags (1000-1400 litre) are used to collect the output from the crusher, more EPS will be collected per bag compared to uncrushed material. The amount of EPS ready for transport to compacting facilities would be significantly increased and the machinery cost for the waste disposal sites would be limited[32].

A return scheme that ensures recycling of EPS-waste that meets necessary quality requirements and at the same time eliminates potential sources of littering will create additional costs compared to the current practice.

Production of 1 kg of EPS raw material based on fossil feedstock causes an estimated CO_2 emission of 2.5 kg, while production of 1 kg of recycled polystyrene causes an estimated CO_2 emission of 0.735 kg of CO_2, and combustion of 1 kg of EPS will have a CO_2 emission of 3.3 kg CO_2 [29].

When recycled EPS raw material is used for the production of circular EPS materials, this will therefore result in a reduced CO_2 emission in the order of 1.8 kg per kg EPS compared with the production of virgin EPS. In cases where recycling replaces combustion, this will lead to a reduction in emissions of 2.6 kg CO_2 per kg EPS.

The impact of increased EPS-recycling in Norway can be illustrated in the following way: If half of all the EPS-insulation that is consumed in the construction industry (27 500 tonnes) is recycled when it is discarded this will reduce national CO_2-emissions by 24 750 tonnes compared to production of virgin EPS-material. If all EPS-packaging (except fish boxes) consumed in Norway (4 000 tonnes) is recycled instead of incinerated, this will reduce national CO_2 emissions by 10 400 tonnes.

Construction sector

The construction sector generates considerable amounts of EP-waste that may or may not be recycled depending on contamination with materials such as gravel and concrete, or additives such as brominated flame retardants. Chemical recycle processes that can recycle contaminated EPS materials are emerging [30]. A return scheme for the demolition projects and other construction projects that may generate EPS-waste streams that cannot be recycled must therefore contain separate treatment of recyclable and non-recyclable EP-waste.

Some vendors retrieve discarded EPS-materials while delivering new products, utilizing the free return-transport to save costs. Discarded EPS-material may include unused products as well as cut-offs. Several pilot projects are already ongoing in Norway. By partnering up and using the main storages of hardware stores as hubs for collecting EPS waste from the construction sites, it could be easier to set up an efficient collection system that allows for full trucks of EPS cut-offs in bags[29].

Marine and maritime sector

The marine and maritime sector generate large amounts of EPS-waste from discarded fish boxes, floating elements from aquaculture installations and floating docks, and EPS that arises from

[32] Pers. com., EPS-producer, Oct. 29, 2021.

dismantling of boats and surfboards that could all be part of a return scheme that ensures possible recycling and eliminates littering. Fish boxes that are part of the Norwegian market seem to already have well working return schemes in place.

As for the construction sector, a potential solution could be for suppliers of new EPS-products to accept discarded EPS-materials when delivering new products. This is considered especially relevant for floating docks.

Discarded EP-packaging from households and businesses

Both households and businesses discard large amounts of EP-packaging when purchasing new products. Electronics and furniture are examples of products that typically come with EP-packaging. EPS may cause electrostatics that disrupts the sorting of other plastic waste, and is for this reason not wanted together with other plastic waste. EPS must therefore either be delivered as part of residual waste or as a separate waste stream. Setting up a collection system for separated EPS may strain the municipal waste disposal system when it comes to finding necessary areas for storing the EPS-waste before collection. EPS-waste may also be separated from mixed waste streams at a sorting facility, but this often leads to lower quality of the EPS-material.

For small volumes of EPS, a bag rack collection system is cost efficient. For larger volumes a container solution will often be better, or if this is insufficient an onsite compactor solution should be considered.

One way to more efficiently collect EPS for recycling is to install return points for discarded EPS-packaging in stores selling EE products, furniture, building materials and other products that typically are packed with EPS-materials. This system can be set up in a similar way to return points that already exist for discarded electronic products. In this way consumers may return discarded EPS-packaging when purchasing new products.

Another option is accepting discarded EPS-packaging when delivering products directly to customers through a store delivery service or for products purchased online. Such a collection system may depend on further storage and transport that may be both costly and have a high energy footprint due to small amounts collected from many different points, and it may be difficult to optimize the logistics.

4.3.2. Incentives for efficient sorting

Due to its low density and other unfavourable properties, uncompressed EPS waste is costly to transport and is often charged with high gate fees when delivered to incineration or landfilling. Its low density also means EPS waste will make up a small fraction of the total waste stream when measured by weight, compared to its volume fraction. Low profitability and small impact in the overall waste statistic gives a weak incentive to single out EPS-waste as a separate waste stream. For this reason other types of performance indicators when measuring EPS-waste treatment should be considered to make the waste stream more visible among other waste streams. One possibility is to measure EPS in volume rather than in weight.

4.3.3. Separate EP-waste category in national waste statistics

With increasing concerns regarding the effects of waste streams with expanded plastics comes increasing efforts to improve the treatment. As long as EP-waste is not recorded as a separate waste stream but instead included in other waste streams it is very difficult to monitor or evaluate effects of the efforts made to improve the treatment of EP-waste. For this reason EP-waste should be recorded and reported as a separate waste stream both in waste reports from a single business and in national waste statistics. Better reporting of EPS-waste streams is also recommended by the Norwegian EPS-association [31].

4.3.4. Product design for better sorting and recycling

Collection and recycling of discarded EPS-materials can be simplified by designing EPS-products in a way that facilitates these processes. In producing EP-materials additives that may disrupt recycling should be avoided as far as possible. Examples of potential additives include flame retardants, pigments, co-polymers that add material strength or additives that increase insulation effects. While additives like brominated flame retardants are banned products may have been placed on the market prior to the ban [32]. When designing EP-containing products, efforts should be made to limit the use of composite materials or components where EP-elements are glued or moulded together with other materials.

4.4. Specific measures for the construction industry

4.4.1. Prefabricated building materials

Use of prefabricated or pre-cut building elements allows for construction of buildings with less cut-offs and particles on the construction site. This may reduce the risk of EPS-littering from the project. This practice may however contain a trade off as pre-cutting means larger cut-offs are generated earlier in the value chain. Prefabricated building elements may also contain integrated EPS-elements that are more difficult to separate from other materials when it is later discarded as waste. The environmental benefits of increased use of prefabricated building elements are also limited by the fact that prefabricated building elements often are harder to stack efficiently and therefore will have a higher energy footprint during transport. The net environmental benefit of this measure is therefore difficult to evaluate.

4.4.2. Protecting EPS-insulation in construction to sunlight

Unprotected EPS-elements that are left exposed to sunlight for longer periods of time will become more brittle and discoloured. The degradation in some cases becomes so severe that the elements must be replaced or modified through filing off the outer layers that have been degraded. For this reason EPS-elements that are stored outside or installed in an uncovered facade for longer periods of time should be covered to protect the material against sunlight.

4.5. Specific measures for the marine and maritime sector

4.5.1. Eliminate use of floating elements that have exposed EPS-surfaces

Many floating docks contain EPS-elements to maintain buoyancy. When these EPS-elements are not clad by a protective cover, physical contact and exposure to sunlight will over time erode the EPS-element and release EPS-particles into the surroundings. Physical contact may be a result of waves, ice during winter, collisions with boats and scrubbings to remove fouling during maintenance operations. For this reason all EPS-elements in floating docks should be built in behind a protective layer of plastic or other resistant material. Used floating docks that contain unprotected EPS-elements should not be resold or given away for reuse, but discarded as waste.

4.6. Specific measures for the waste management sector

4.6.1. Covering of EPS-containing waste at a landfill

When low density waste or waste with large surfaces compared to volume is landfilled this waste may be exposed to wind that may carry it off and cause littering in the surroundings. When landfilling EP-containing waste, this waste should be covered with denser material immediately or as soon as possible. This practice requires that the landfill also have available appropriate amounts of waste that may serve as covering material. Waste that are known to have favourable properties as covering material include bottom ash from waste incineration and lightly contaminated soil.

Figure 4.4 EPS-pieces among other landfilled materials.

In addition to covering of landfilled EP-containing waste additional protection can be gained through construction of wind barriers that screen active landfill sites, loss of waste due to wind can also be minimized. These barriers will typically be constructed from available material that are resistant to wind flight for example excavated soil, see Figure 4.5.

Figure 4.5: Physical barriers against loss of EP- containing waste from landfills.

4.7. Measures to identify and clean up hotspots of EP-littering

Marine EP-littering is caused not only by ongoing human activities, but also from legacy waste that has accumulated at specific locations in the environment, and from where it may be redistributed to new locations and recipients through processes like erosion, strong wind and flooding. Typical examples are illegal dumping sites for waste. In each Norwegian municipality there normally are several documented cases of illegal landfills where also EP-waste is dumped[33].

Hotspots of EP-littering have also been known to form around EP-production facilities, construction sites and fishing industry, and although some of these hotspots are discovered through voluntary clean-up operations no systematic national effort has so far been done to map and remove this littering. Dominating wind and currents along the Norwegian coast trap much marine litter at specific locations like islets and coves where the accumulated litter forms hotspots and may remain for a long time.

4.7.1. Identification and clean-ups of illegal and/or legacy dumping sites

A national clean-up initiative that systematically identifies hotspots of historic waste and collects this for proper treatment has the potential to reduce amounts of historic littering significantly and will prevent remobilization of this litter at a later stage. Identified sites should be recorded in a public database as a basis for planning further clean-up operations.

4.7.2. Marking of EP elements - source control

The form and material structure of marine EP-litter will sometimes give indications of what type of product or use the EP-material derives from, but tracing it back to its owner or user location is often difficult. This makes it difficult to apply the polluter pays principle when it comes to clean-ups for EP-littering. By tagging EP-elements that are commonly found in clean-ups with relevant information like manufacturer, year of production, area of use, owner, project, additives etc., tracing EP-litter back

[33] Pers. com., environmental protection group, Nov. 22, 2021.

to its source may become easier. One major limitation with such a measure however is the fact that the brittle material structure of EPS leads to physical degradation that will quickly make any marking disappear.

4.8. Material Substitutions

The following paragraphs describe applications of ESP where alternative materials may be used. Advantages and disadvantages between the different material options are discussed.

4.8.1. Substitution of EPS and XPS as insulation materials in buildings

Insulation materials are used to limit heat loss or to protect against unwanted heat. Although energy is consumed during production and transportation of insulation materials, reduced energy for heating in insulated buildings means that the energy footprint of the insulation material is often paid back within 3 - 7 years of the user period depending on climate zone [33]. EPS- and XPS-insulation are in widespread use in the construction of buildings, but can in some cases be substituted by other materials. Two important alternative insulation materials are mineral wool and foam glass.

EPS and XPS insulation

EPS and XPS have excellent properties as insulation materials. In addition to having low thermal conductivity (low λ-value) EPS and XPS tolerate high pressures, do not absorb much water and are not affected by mould or other microorganisms [34]. The materials are used for insulation both against concrete and other surfaces, externally, in foundations, flooring, walls and roofs. Both EPS and XPS are combustible and present a greater fire hazard than mineral insulation. For this reason some EPS and XPS-products may contain flame retardants that in some cases have known toxic effects [35]. Most if not all EPS-insulation products produced in Norway today do not contain brominated flame retardants. Yet this may be found in older materials [32]. Recycling of EPS and XPS contaminated with brominated flame retardants is technically feasible as long as the recycler is able to avoid unintentional contamination of other products [30].

Mineral wool insulation

Mineral wool is an insulating mesh of fibres made from either rock or glass. Mineral wool generally does not absorb much water, although odour problems may arise if it does. Mineral wool is fire resistant but may melt at extreme temperatures. Smaller quantities of organic chemicals (typically phenol and formaldehyde) are also used to glue together the mineral fibres, and may leak out in small amounts during the user period [35]. Free mineral fibres are also considered a health risk if inhaled. Unlike EPS and XPS some mineral wool products may be compressed during transport that slightly minimizes the energy footprint associated with distribution [36]. Compared to the footprint from the production process, the transport footprint is normally very low [37]. Mineral wool may substitute EPS as insulation in walls and ceilings and in floors and foundations where acceptable pressure conditions can be met. Hard product qualities of rock wool with higher density are necessary for use in floors and foundations that tolerate higher pressures. As a substitute for EPS in insulation of concrete in foundation walls and ring walls mineral wool is considered less suitable, and therefore not used very much.

Foam glass

Foam glass is a mineral product that typically consists of 20 % glas and 80% air [38]. Foam glass can replace or limit the need for EPS-insulation in foundations, but is normally not an alternative in walls or ceilings. Foam glass is filled into the building pit under and around the concrete foundation where it can replace EPS-filling materials. End of life foam glass can easily be reused in new construction projects. Used foam glass that has been contaminated in its earlier product life may require a cleaning process before reuse. End of life foam glass can also be melted down and re blown into new foam glass products.

Insulation properties compared

Table 4.1 shows typical λ-values for EPS, XPS, Rock wool, Glass wool and Foam glass. The table shows that the thermal conductivity for most products of EPS, XPS and mineral wool lie in the same range (0.03 - 0.04 W/mK), while foam glass has a poorer insulation effect (ca 0.1 W/mK). Thermal conductivity for an insulation product can change due to contact with water, aging and other conditions. If used for other insulation purposes than the product is intended for, the lambda value may drop significantly.

Table 4.1: Typical λ values for different materials [35], [39], [40].

Insulation in buildings:	EPS	XPS	Rock wool	Glass wool	Foam glass
(W/mK) -λ value :	0.035 -0.041	0.033	0.034 - 0.040	0.034 - 0.040	0.097 - 0.11

Comparison of environmental footprint of EPS and mineral wool

Mineral wool differs from EPS and XPS both when it comes to production conditions and recyclability. Rock wool and glass wool are produced from a mineral feedstock (often diabas for rock wool and borosilicate for glass wool) which is heated to 1400 - 1500 degrees Celsius where it melts and is spun into a mesh of fine fibres. Dusting oil and phenolic resin adhesive are added during the cooling process [37]. The high temperature means that much energy is required for producing mineral wool. This energy may however be delivered from renewable energy sources if the design of the production plant allows for this.

PS-polymers are produced from fossil feed stocks and expanded with pentane or CO_2 to either EPS or XPS. Sometimes additional components are added to the products like flame retardants, pigments or insulation improving agents like graphite. Virgin EPS/XPS-production requires fossil feedstock and sometimes also fossil energy inputs although this can be replaced by renewable alternatives. Polystyrene can also be synthesized from CO_2 (CCU), but this route requires significantly more input of energy, and no commercial technology seems so far to be available. For production of equivalent amounts of insulation materials mineral wool generally requires less energy and has a lower climate footprint than EPS and XPS [37]. Compared to XPS, EPS has a lower energy and climate footprint [37].

Both mineral wool and EPS/XPS may be recycled although this option may be limited by the occurrence of additives or contaminants in the materials. EPS can be melted and re-expanded to new material, but this requires high quality waste materials as input that does not contain unwanted contaminants or degraded polymer fibres. Lower quality EPS and XPS waste that are unfit for melting and re expansion may be chemically recycled. Unwanted contaminants may be removed during a solvent treatment [30]. Polystyrene may also be chemically recycled to new polymer from single styrene monomers [41]. Chemical recycling however has a higher energy demand and requires additional input factors. Chemical recycling processes for EPS are also less technically mature, and not commercially available in Europe at the moment beyond smaller pilot projects [42]. Recycling of EPS will in most cases lower the energy- and climate footprint of EPS and XPS significantly, especially for thermic recycling. Chemical recycling of EPS or XPS allows production of secondary EPS/XPS with virgin quality.

In a comparative Life Cycle Analysis (LCA) the environmental footprint from EPS and rock wool insulation was compared in 17 categories [43]. EPS insulation scored better in the categories Fine particulate matter formation (FPM), Freshwater ecotoxicity (FET), Freshwater eutrophication (FE), Human non carcinogenic toxicity (HNT), Ionization radiation (IR), Marine ecotoxicity (MET), Marine eutrophication (ME), Mineral resource scarcity (MRS), Ozone formation, human health (OFH), Ozone formation, terrestrial ecosystems (OFT), Stratospheric ozone depletion (SOD), Terrestrial acidification (TA) and Terrestrial ecotoxicity (TET).

Rock wool scored better in the categories Fossil resource scarcity (FRS), Global warming (GW), Human carcinogenic toxicity (HCT), and Water consumption (WC). The difference in score for Freshwater eutrophication (FE), Marine eutrophication (ME), Ozone formation, human health (OFH), Ozone formation, terrestrial ecosystems (OFT) and Stratospheric ozone depletion (SOD) was very small.

EPS-insulation seems to have a better environmental footprint in terms of human toxicity (except for carcinogen toxicity) and ecotoxicity and mineral scarcity, while mineral wool seems to have a better environmental footprint in terms of climate change and water consumption. The conclusion that mineral wool has a better climate footprint than EPS and XPS is supported by a study [37].

It may come as a surprise that EPS seems to come out better in general when it comes to toxicity when one takes into consideration that polystyrene is made from toxic raw materials and monomers while mineral wool is produced from inert materials. A main reason is that while EPS will most often not contain additives that may be hazardous, mineral wool will more often contain such additives to make the product perform according to its specifications. These chemicals remain inside the product during its use, and may leak out in small amounts over a long time period.

In another Life cycle assessment by Zhu Li et. al. mineral wool board and EPS board were analysed, from the acquisition of raw materials to the production process [44]. The result shows that the life cycle energy consumption of a mineral wool board is 415 MJ per functional unit, approximately twice of the EPS board's energy consumption (220 MJ). Overall, environmental impact indicators caused by mineral wool boards were reported as more serious than EPS.

Cost and feasibility of the assessed insulation materials

The relative price of an insulation element can be expressed as a function of the area that is covered by the element and the thickness of it. An insulation element that covers an area of 2 m^2, has a thickness of 10 mm and costs 100 NOK can for instance be said to have a relative cost of 5 NOK per m^2 and mm thickness. The price of standard rock wool, glass wool and EPS-plates seems to lie in the same price range. A random price check in December 2021 at two different outlets showed EPS-plates to cost around 0.89 NOK per m^2 and mm thickness, while glass wool cost around 0.72 NOK per m^2 and mm thickness and rock wool cost 1.1 NOK per m^2 and mm thickness[34]. XPS-plates had a price of 2.4 NOK per m^2 and mm thickness.

Although the area of use for EPS/XPS and mineral wool insulation overlap somewhat, standard mineral wool products are not considered feasible for use where high pressures must be tolerated. If mineral wool products shall replace EPS or XPS for these uses, specialized products with increased hardness must be used. These products will typically be in a significantly higher price range (sometimes ten times higher), and result in mineral wool not being cost competitive with EPS/XPS. Higher costs of mineral wool products for high pressure purposes was also confirmed during interviews with Rockwool and Glava. Substitution of EPS with mineral wool may also lead to a drop in insulation effect[35]. The same substitution may also lead to adjustments in the use of other construction materials that may affect the overall environmental footprint of the construction project beyond pure insulation material considerations. Insulation with mineral wool does not require significantly more work hours compared to insulation with EPS and XPS[36].

Although there are some areas where EPS and XPS insulation can be substituted with mineral wool, caution should for these reasons be shown when considering this, as reduced insulation performance seems to be a risk.

4.8.2. Substitution of EPS or XPS-containing materials in road construction

EPS and XPS are used as road building material in the form of blocks and plates. EPS-road building products are also available as loose beads packed in sacks, but it is unclear to what degree loose bead products find use in Norwegian road building projects [45]. If loose beads are indeed used, recovery of EPS materials during later excavation will obviously be difficult. EPS and XPS materials are typically used in road projects when light building materials are needed or as frost protection material [19]. Typical uses are on unstable foundations and in tunnels, bridges and connections to such structures. In tunnels EPS or XPS are used both in the road foundation and wall insulation. Recovery of used EPS- and XPS elements during excavation of old roads is reported to be difficult for outer elements in the light weight construction, especially for XPS-plates as these are thinner and therefore easier to

[34] Product prices for selected groups of products sampled from warehouses 'OBS bygg' and 'Byggeshop'.
[35] Pers. com., interest group, Sep. 28, 2021.
[36] Pers. com., insulation advisor, Dec. 07, 2021.

break off in smaller pieces. Pieces of broken materials and particles from cutting are known to often mix with other materials[37].

Foam glass is an alternative material that can replace EPS and XPS in many cases both as lightweight road building material and for frost protection. Interview with a road entrepreneur has confirmed that both glasopor and leca blocks, although more expensive, can technically replace EPS in many cases with no loss of road performance. More detailed information about the cost differences between EPS/XPS and alternative road construction materials was not possible to obtain. Although for projects where extreme lightweight construction materials are required, for instance for stretches of road with very low ground stability, EPS will often not have any realistic material substitutes.

Crushed rock is generally used as frost protection in road building unless technical or practical reasons make EPS or XPS a more attractive or necessary alternative. EPS or XPS is generally used for frost protection in the transition zone between roads and tunnels, bridges etc.[37]. It is also often used inside the tunnels and road sections with challenging ground conditions, although not where risk of rising water levels may destabilize the road due to the buoyancy of EPS and XPS.

Norway has a tradition as pioneer and innovator when it comes to use of EPS and XPS in road building projects, and this practice is reported to be more common in Norway than most other countries [19]. EPS or XPS has been used in Norwegian road projects since the mid-sixties and the extensive Norwegian use compared to other countries may be grounds for assuming that some use is less crucial and can be eliminated or substituted with other materials, although this assumption is speculative and needs verification.

Regardless, replacement of EPS and XPS materials with other lightweight mineral road building materials is considered to be a relevant measure to reduce EPS and XPS-littering . There may also be cases where EPS or XPS used for frost protection frost protection may be substituted with light weight mineral products or crushed stone without loss of road performance.

4.8.3. Substitution of cardboard EPS packaging

Substitution of cardboard EPS packaging

EPS is used extensively as shock absorbing packaging to protect fragile or heavy products against damage. Electronics, furniture and pharmaceutics are examples of products that often are packed in shock absorbing EPS. Corrugated cardboard (CCB) finds increasing use for the same purpose, and several large companies like IKEA and Jernia have either phased out or is considering phasing out EPS for corrugated cardboard as shock absorbing packaging material. Shock absorbing materials can come either as protective components that are formed to fit against the shape of the product or as flowable loose fills in the form of smaller pellets that can fill the void between the product and the container wall. Other materials than EPS and cardboard are also used as void fills like expanded polyethylene or bubble wrap, but only EPS and cardboard are discussed in detail in this section.

[37] Pers. com., road construction company, Oct. 15, 2021.

EPS and cardboard as shock absorbing packaging material

The expanded beads of polystyrene that are glued together in a matrix have excellent properties when it comes to mechanical and thermal protection of products due to the fact that the material is both firm and resists deforming while at the same time being plastic enough to absorb shocks and vibrations.

CCB has a sandwich structure with a corrugated layer inserted between two pieces of smooth board on the outside. This sandwich structure gives significant strength to CCB materials while at the same time maintaining elasticity to absorb shocks and vibrations.

Some suppliers offer specialized cardboard products with improved performance compared to standard cardboard materials. One example of this is the honeycomb-products from Bewi which are delivered as shock absorbing packaging for furniture, lamps and lightning, other electronics, hydraulics, pumps and valves, bottles, glass and ceramics [46].

Comparison of environmental footprint from EPS and CCB packaging

EPS and CCB materials are produced from very different raw materials. While EPS is generated from fossil feedstock CCB is produced from renewable and biodegradable wood pulp. Both EPS and CCB can be recycled to new products. The fibre in CCB can often be recycled up to seven times before the fibre becomes infeasible for new product generations. When EPS is recycled, the new material will have limited use as food contact packaging and other high quality uses, although technologies are emerging that will probably change this situation in the coming years [30].

Although CCB has almost ten times higher material density than EPS (0,15 g/cm^3 compared to 0,02 g/cm^3 for EPS), smaller volumes of shock absorbing material will often be needed due to the fact that CCB elements can be hollow while EPS-elements most times have a more massive design[47]. In total more mass of CCB will normally be required than EPS to cover the same shock absorbing packaging function, illustrated in Figure 4.6 [47]. The value chains from production to waste treatment for CCB and EPS are shown in Figure 4.7.

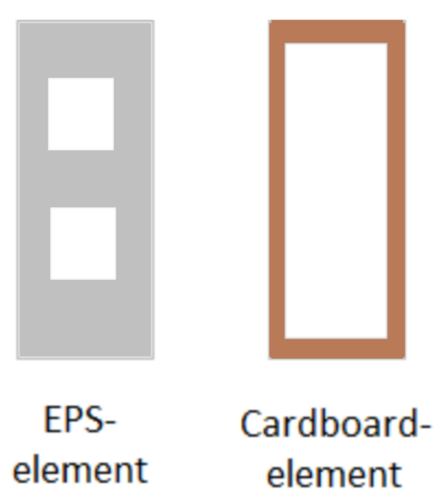

Figure 4.6: Typical design of cardboard and EPS packing elements with a less massive structure for the cardboard element.

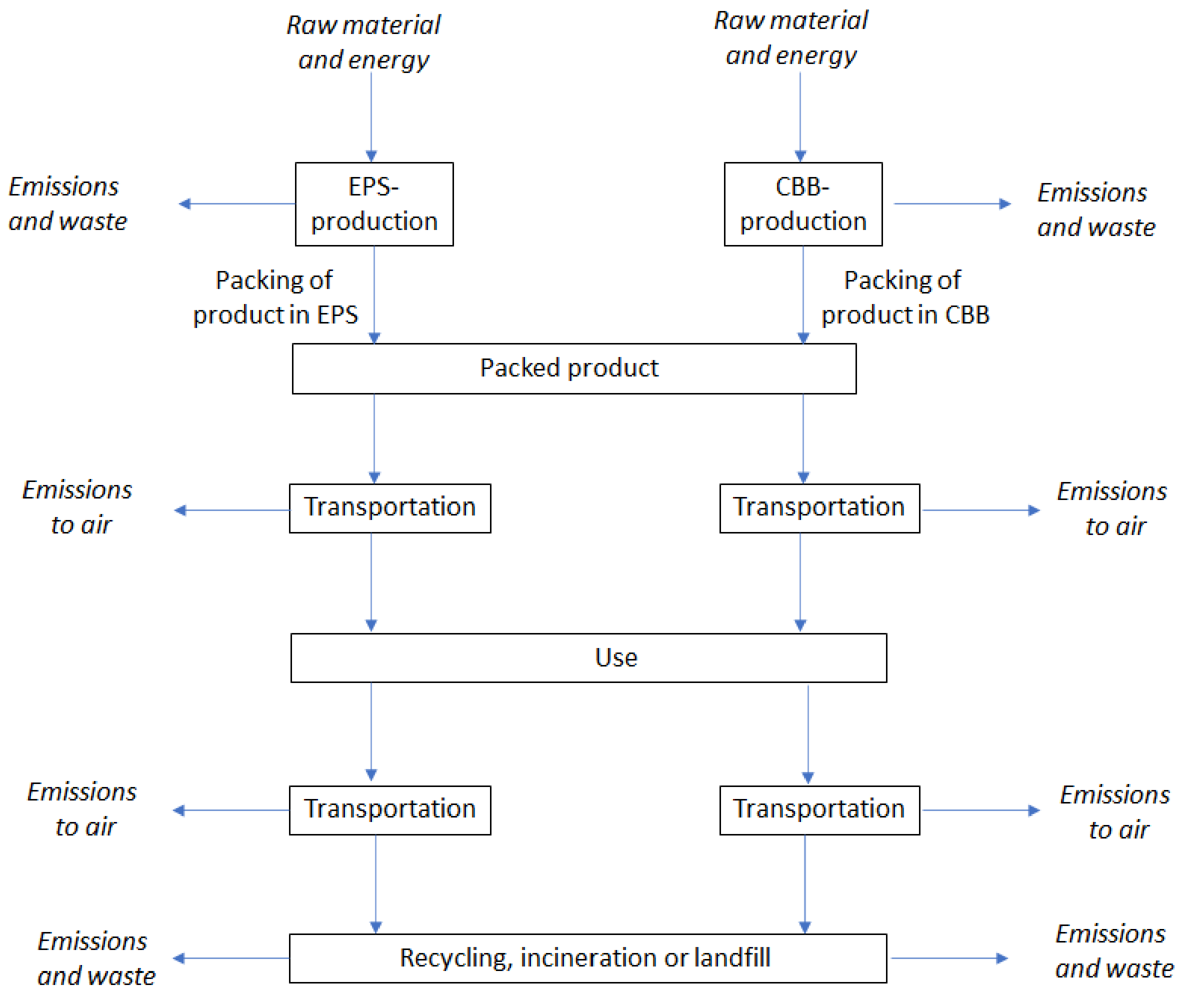

Figure 4.7: System boundaries for a comparative LCA-assessment of EPS vs CBB packaging solution.

In a LCA performed by Reginald B.H. Tan, Hsien H. Khoo in 2005 the environmental footprint of EPS and CCB shock absorbing packaging were compared. The analysis showed higher environmental impact for the production phase for EPS for all categories (climate change, acidification/eutrophication, ecotoxicity, fossil fuels and respiratory inorganics). Due to lower density EPS comes out better than CCB when comparing the footprint during transport. The difference in environmental performance for EPS and CCB packaging for the whole product lifespan is not very large, and which material that comes out with best performance seems to largely depend on the design of the packaging solution. EPS comes out with the lowest footprint of the two alternatives overall when comparing the total cradle to gate footprint [47].

Because CCB is also used extensively as material for boxes and containers, substitution of EPS with CCB as shock absorbing material means a more homogenous waste stream that can more easily be allocated for recycling without additional separation of EPS elements from CCB elements.

As a measure to reduce ESP-littering substituting EPS-shock absorbing packaging with CCB-alternatives seems to be both relevant and effective especially for electronics and furniture.

Pharmaceuticals however often require not only shock protection but also thermic insulation to maintain the products required storage temperature during transport. Because of the superior insulation properties of EPS, phasing out EPS as packaging material in the pharmaceutical sector is considered less feasible than for electronics and furniture.

4.8.4. Substitution of EPS in fish boxes

Transportation of fresh fish and other seafood requires strict control of temperature. For this reason these products are packed in ice and placed in boxes that must protect the product not only against mechanical contact but also against heat from the surroundings. Strict temperature control is critical to maintain the quality of fresh fish. As an example if the fish temperature is raised from 0 degrees Celsius to 5 degrees Celsius the shelf life of the fish is reduced by fifty percent from 18 to 9 days [48]. Packaging solutions that provide optimal temperature during transport are therefore crucial. Packaging with good thermal insulation properties also limits the amount of ice that is needed for packing the fish. Ice typically represents 25 % - 30 % of the total weight [49]. Melting ice during transport is not only a problem for the fish quality but can also leak out of the boxes and cause a problem in the storage compartment. Typical transport time from a Norwegian production site to Paris by truck is 65 hours, while the transport time to Japan or USA by air is 24 hours - 27 hours [49]. Both fisheries and aquaculture have a large environmental footprint, and increased loss of fish product due to less efficient packaging may overshadow any impact difference between different packaging materials.

While EPS-boxes dominate the packaging market for seafood (80 % - 90 % market share in 2011), other material options are also available, including polypropylene and water resistant cardboard [50]. There are also cardboard boxes with both aluminium and polyethylene laminates. The main reason for the market dominance for EPS-boxes is claimed to be superior insulation properties and lower relative weight compared to other materials. This guarantees better temperature control during transport, and also lower total transport weight.

A third party verified comparative LCA-assessment by PWC ordered by the European EPS-association (EUMEPS) in 2011 compared the environmental footprint of EPS-boxes compared to boxes made by polypropylene and water resistant cardboard. The analysis considered the product life from cradle to grave for three different scenarios including one scenario for the Scandinavian market. The analysis only considered transport distances within the EU, and essential conditions for cross continental transport were therefore given little attention. One main concern is that packaging options with lesser insulation effect may not perform to acceptable standards over longer traveling times and when transhipped in warmer climates. Another concern is that the relative environmental footprint may change when the product is transported by air over longer distances where differences in weight may create a larger impact in terms of energy consumption and climate gas emissions during transport.

As shown in table 4.2 both polypropylene and cardboard boxes are significantly heavier than EPS-boxes. The percentage value in brackets show the relative weight of the fish box compared to the weight of the fish it contains. As can be read from the table, EPS boxes are roughly half the weight of PP-boxes while cardboard boxes are 5-8 times heavier than EPS-boxes.

Table 4.2: Typical weight for fish boxes of different material.

Transport of	EPS-box	PP-box	Cardboard-box
4 kg fish	(2.4 %) 96 g	(5.8 %) 230 g	(20.4 %) 815 g
6 kg fish	(2.4 %) 145 g	(5.2 %) 310 g	(17.3%) 1 040 g
20 kg fish	(2.6%) 526 g	(3.7 %) 738 g	(13.3%) 2 650 g

The following flow sheets show system boundaries and central steps in the product life of fish boxes of EPS, PP and CCB.

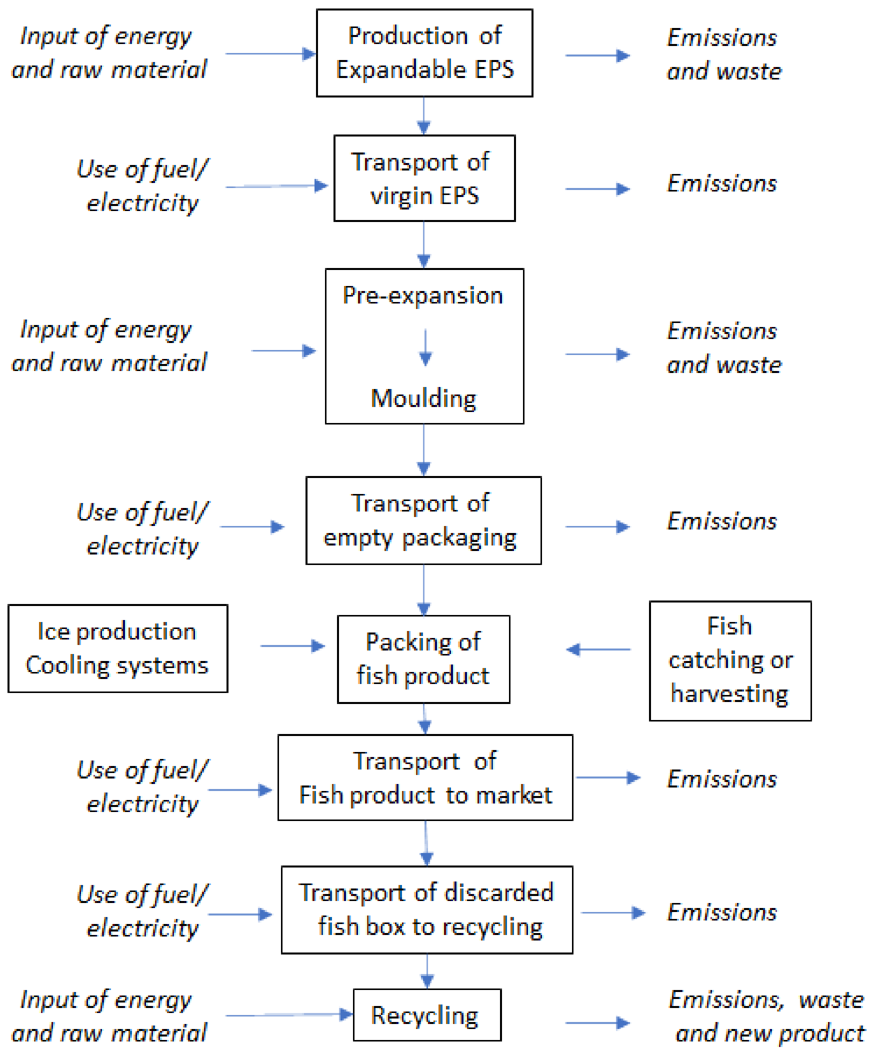

Figure 4.8 System boundaries and central steps in product life of EPS-fish boxes.

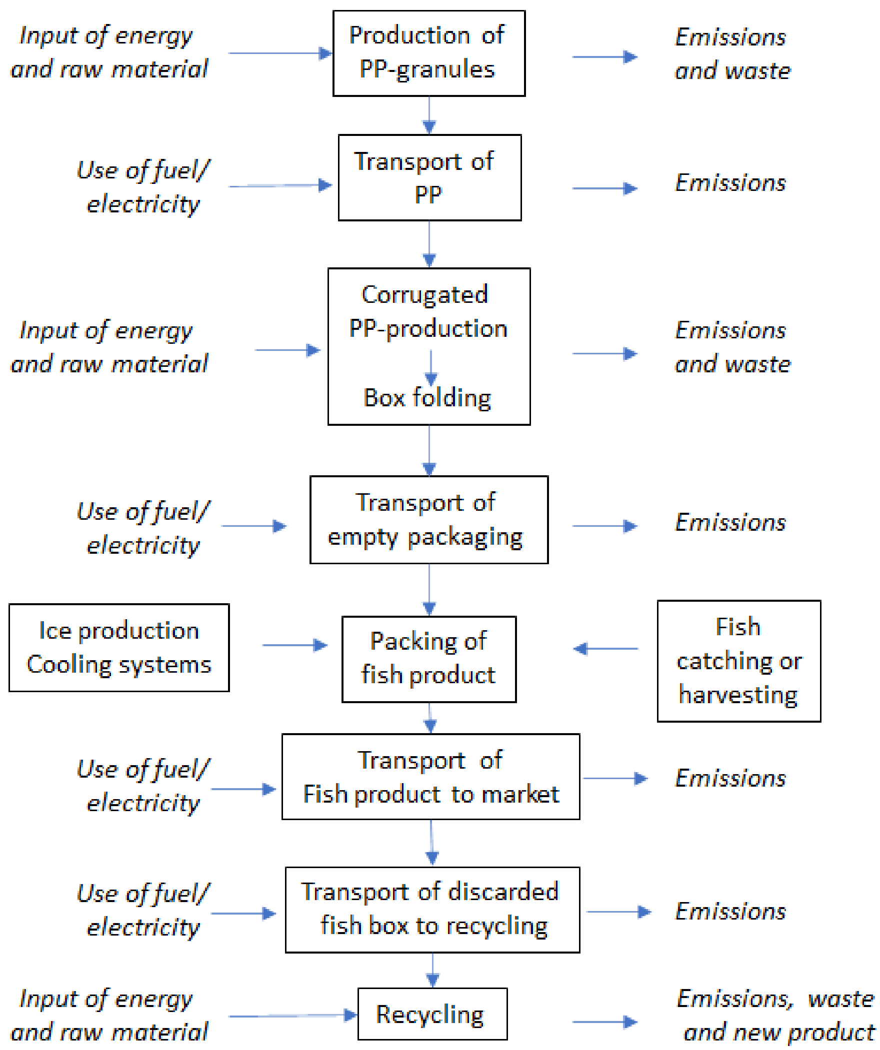

Figure 4.9 System boundaries and central steps in product life of PP-fish boxes.

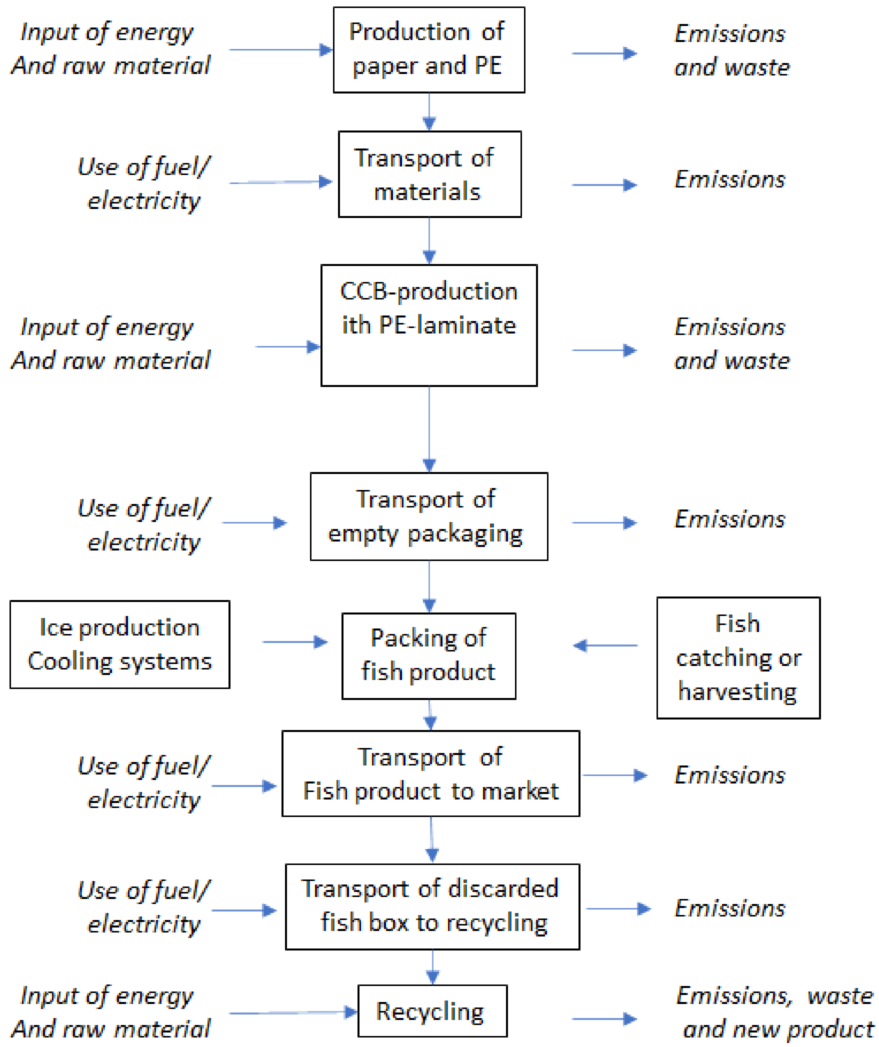

Figure 4.10 System boundaries and central steps in product life of CCB-fish boxes.

As can be seen from the figure 4.7 - 4.9 sheets only the input of raw materials and production process for the manufacture of the boxes differs between the three product descriptions, other steps in the product life are identical.

The results of the LCA study showed that EPS-boxes had a lower or similar environmental footprint compared to PP- and CCB-boxes for two of three scenarios:

- In the first scenario (4 kg fresh fish per box, 300 km road transport to fish market) EPS scored better with the exception of photochemical oxidants.
- In the second scenario (6 kg fresh fish per box, 300 km road transport to Spanish fish market) EPS scored better with the exception of photochemical oxidants and water consumption.
- In the third scenario (20 kg fresh fish per box, 1200 km transport from Denmark to the French fish market),the results were more mixed.

Here EPS and PP performed similarly for 5 indicators (energy consumption, acidification, water consumption and water eutrophication), EPS performed better than PP for waste production but worse for greenhouse gas emissions and formation of photochemical oxidants, and EPS performed better than cardboard for waste production, water consumption and water eutrophication but worse for energy consumption, greenhouse gas emissions and formation of photochemical oxidants. EPS and cardboard performed similarly for acidification.

The impact contribution from transport was very low compared to the production phase for the boxes. No scenario was presented that included Norwegian conditions with longer transport distances and sometimes use of transport by air, and the conclusions drawn from this LCA may there have limited validity for Norwegian fish export.

Considering fish boxes in a littering perspective, all discussed materials have problematic properties as litter, especially in the marine environment. EPS, EPP and cardboard boxes are all lightweight and may easily be blown away and travel far distances due to coastal currents. EPS and EPP are both non degradable and will remain in the environment for a very long time unless cleaned up. Although cardboard is biodegradable the aluminium and polyethylene layers of the laminate are not. What makes EPS stand out as especially unfavourable when it comes to littering compared to the other materials are its brittle material structure and how easily it fragments.

It seems to be a clear perception in the industry that fish boxes in EPS have superior properties when it comes to transport of fresh seafood. Due to limited differences in environmental performance, substitution of EPS with other materials for this purpose does not seem to be advisable.

4.8.5. Elimination of EPS in buoyancy elements

Floating pipes surround the pens in an aquaculture installation and must maintain its buoyancy to prevent the pen from sinking. EPS-elements are inserted into floating pipelines and anchoring buoys to ensure necessary buoyancy even if the structure is punctured. The same effect can be achieved however by compartmentalization where a series of watertight sections keep water that penetrates into the pipe from filling the remaining sections of the hollow interior. EPS-free floating pipes based on this design are available [51].

4.8.6. Elimination of EPS-use during seasonal storage of boats on land

EPS-elements are reported to be in common use as support for storage or leisure boats on land[38]. Metal or wooden cribs may be used instead as shown in the pictures below. Resting the hull against a rubber surface will provide the same protection that EPS gives without the same risk of particle spill.

[38] Pers. com., marine waste company, Nov. 09, 2021.

Figure 4.11: Storage of boats on land without EPS.

4.9. Measures that may lead to increased reuse and recycling of expanded plastics

Better systems for collecting EPS-waste will be beneficial both when it comes to recycling options and reducing littering. Reuse of discarded EPS-elements for new purposes may also limit further littering as an old product serves a new purpose and replaces the need for new EPS-materials. In some cases reuse of old EPS-structures may however lead to increased littering due to faulty function or increased loss of particles from the reused element. For this reason increased reuse of EPS-materials may come into conflict with the goal to reduce EPS-littering. The following paragraphs describe possible reuse of EPS-elements.

4.9.1. Increased use of compactors for more cost-effective transport

When EPS-waste is run through a compactor the material is compressed to a fraction several times of its original volume. Compressed EPS-waste allows for more cost effective transport that may make delivery to recycling plants more economically viable. An EPS-compactor comes with additional costs and will often be more time consuming to operate. Use of EPS-compactors requires a minimum of EPS-waste as an input, and will therefore only be relevant for larger facilities. For optimal operation the EPS-press must have the correct dimensions and a well-designed feeding system as the feeding process is known to be time consuming.

The relative costs of using compaction containers that deliver EPS-bars to recycling compared to delivering uncompacted EPS to incineration or landfilling will obviously vary between different projects and depend on transport distances and other variables. A very rough estimation may still be presented.

For a project that delivers uncompressed EPS-bars to incineration or landfilling, transport costs will typically be 3000 - 8000 NOK per tonne while the gate fee for delivering the waste will typically be around 500 - 800 NOK per tonne [28]. This gives a total treatment cost of 3500 - 8800 NOK per tonne of EPS-waste for this scenario.

For a project that uses a compaction container and delivers compressed EPS-bars to recycling, additional costs for operating the compaction container will typically be around 8000 - 10 000 NOK per tonne [28]. Transport costs will depend on the density of the compacted material, but is conservatively estimated to be one tenth of the transport costs in scenario without compaction (300 - 800 NOK per tonne)[39,40] . Instead of a gate fee, when delivering compacted EPS to a recycler one can expect to be paid a premium between 6500 - 7000 NOK per tonne. This gives a total treatment cost of 1300 - 4300 NOK per tonne of EPS-waste for this scenario.

These estimates indicate that although compaction for recycling of EPS-waste may be profitable for some projects, in other projects the opposite situation will be the case.

In addition to the operation costs, the cost of the compaction system must also be included in the cost calculations. A smaller compactor solution with a capacity of up to 50 kg of loose EPS per hour typically costs $ 18 000 - $ 20 000. Larger compression systems, which can process up to 250 kg of loose EPS pr. hour costs about $ 45 000 - $ 50 000 [28].

Different compaction solutions are available and include systems based on hydraulic, thermic or screw drive compaction. There are also hybrid technologies that combine several of these principles. Suppliers of compaction solutions include [28], [29]:

- Comitec, Italy
- GreenMax (made by INTCO Recycling), Ontario, CA
- Harden Machinery, China
- Hasswell Technologies, China
- Heger, Germany
- KBM, Denmark
- Runi A/S, Denmark
- Avangard Innovative, Houston, TX
- Technical Process & Engineering Inc., Lehighton, PA
- AFPAC Inc., Granby, QC, Canada
- Avangard Innovative, Houston, TX
- Demand Products ("Badger" brand), Alpharetta, GA
- GreenMax (made by INTCO Recycling), Ontario, CA

[39] EPS weighs about 20 kg / m^3 uncompressed, and uncompressed EPS on a typical lorry gives a load of about 1.5 tonnes. Compressed EPS allows you to load about 20 tonnes per truck.
[40] Pers. com., EPR scheme, Oct. 15, 2021.

- RecycleTech Corp, Elmwood Park, NJ
- StyroPower, Knoxville, TN
- StyroSmart Solutions ("StyroGenie" brand), Marietta, GA

Figure 4.12: EPS compactor and EPS-bars after compression.

4.9.2. Reuse of discarded EPS elements in new road projects

Both EPS and XPS elements are used in road construction. They are typically used as road construction material on road sections with unstable foundations or as insulation for frost protection. EPS elements that are removed from roads during construction work will in some cases be in good enough condition for continued use, and could potentially be applied in other road projects. When EPS-road elements are dug up elements on the edges will often be damaged or heavily soiled while elements from the core of the EPS-structure will be in more pristine condition. Reuse of EPS and XPS elements in new road projects may be complicated by long transport distances and challenges in finding acceptable intermediate storage.

4.9.3. Reuse of EPS elements in the aquaculture industry

EPS-elements is used for buoyancy elements in floating collars and surface structures in aquaculture installations. ESP-elements are recovered as part of the disassembly process when an installation structure is decommissioned, and elements in the floating pipes will normally be in a condition that would allow for reuse in new installations. Long transport distance is considered a barrier for such a practice.

4.9.4. Reuse of floating docks

Many floating docks contain EPS-elements that provide the necessary buoyancy. When marinas or piers are closed down or upgraded, discarded floating docks may still be considered usable, and are often sold or given away for reuse. Reuse of defect floating docks or floating docks with uncovered EPS-surfaces is not advised as this can lead to increased EPS-littering.

4.9.5. Reuse of EPS insulation in construction projects

When buildings are demolished or renovated, discarded EPS-insulation can be collected and reused in new projects, see Figure 4.13. Reuse does however come with several challenges. EPS-insulation must be free of other materials and not be glued to other surfaces. Old EPS-insulation may contain flame-retardants that today are banned or contaminated in other ways that make reuse unacceptable. Old EPS-insulation may also have dimensions that do not fit well with the requirements in new projects.

Figure 4.13 : Discarded plates of EPS-insulation that may be considered for reuse.

5. Discussion and conclusions

Expanded plastics are used in a variety of products and materials as summarized in the following illustration.

Figure 5.1 Products and materials that contain EPS or other types of expanded plastic.

5.1. Summary of material analysis

There is no public data and statistics on material- and waste streams for EP. Amounts placed on the market, waste generated and littering from major areas of use have been estimated based on the available data and interviews with key stakeholders, see table 5.1. Assumptions and associated calculations that form the basis for these estimates are presented in chapter 3.

Table 5.1. Summary of estimated EPS-material- and -waste streams in Norway in 2020, in tonnes.

Sector or area of use	Put-on-market	Waste generated	Estimated littering *Low	Estimated littering *High
Production of polystyrene pellets	79 370	0	0.19	19
Products, materials and packaging				
Insulation plates and concrete forms of EPS and XPS	44 810	18 370	57	570
EPS blocks for construction of roads	540	100	9	90
Clinker blocks laminated with EPS	5			
Fish boxes made of EPS	5 810	5 810	5.8	58
EPS Packaging excluding Fish boxes	4 000	4 000	4	40
EPS in pontoons	1 900	1 900	189	626
EPS filling for floating pipes and buoys	370	370	6.4	18
Activities that generate EP waste				
Car fluff from shredding of cars		263	0.26	2.63
EPS-waste from scrapping of boats		6	0.06	0.6
Sum	**57 435**	**30 589**	**271.4**	**1424**
Waste treatment		**Waste processed**	**Litter low**	**Litter high**
Recycling centres		Not calculated	3.6	36
Recycling plants		7 000	7	70
Incineration plants		15 500	1.5	15
Landfills		4 639	4.6	46.4
Sum		**27 139**	**16.7**	**167.4**
Estimated total littering			**288.1**	**1591**

5.2. Risk assessment

As shown in table 5.1 more EPS-litter is expected to arise during use of products and materials than during production or final waste treatment. Based on the size of the material streams and corresponding waste streams, known incidents of littering, reported assessments of amounts of litter found during clean-ups that can be traced back to its source and closeness to the coast, the following risk assessment has been created for selected industry sectors and areas of use, see table 6.1. The following assumptions are made:

- Large material streams or waste streams are expected to represent higher littering risk than smaller streams, other conditions comparable .
- EP-material from sectors with many known cases of littering are associated with higher littering risk than sectors where less cases are known.
- EP-materials handled outside, under bad weather conditions over large distances are more likely to result in littering incidents than materials being handled inside or with good working conditions in a restricted area.
- EP-materials used offshore or close to the coast represent higher littering risk to the marine environment than EP-materials used inland.

Table 5.2. Risk evaluation for littering of EPS from different sectors based on waste stream and results from clean-ups.

Sector or area of use	Risk evaluation for loss and littering
Production of expandable pellets	Medium
Insulation plates	High
EPS blocks for construction of roads	Very high
Fish boxes made of EPS	Medium
EPS packaging excluding fish boxes	Medium
EPS in pontoons	Very high
EPS filling from floating pipes and buoys	High
Car fluff from shredding of cars	Low
EPS-waste from scrapping of boats	High
Recycling centres	Medium
Recycling plants	Medium
Incineration plants	Low
Landfills	Medium

5.3. Summary of potential measures

The following tables summarize the potential measures that have been identified as a way to eliminate or reduce EP-littering. The measures are described in detail in chapter 4.

Table 5.3: Measures to reduce littering of expanded plastics during storage, use, collection and waste treatment.

Code	Description of measure
A	**Measures related to storage and handling of materials and products containing expanded plastics**
A1	Protection from weather during storage
A2	Protection during transport
A3	Environmental management System
A4	Training program
B	**Measures to control the scattering of small pieces and particles of expanded plastic**
B1	Measures to reduce spill during use
B2	Air filter in exhaust and ventilation systems
B3	Recovery systems for process and surface water
B4	Fencing and other physical barriers
B5	Regular inspection and collection of spotted littering
C	**Collection of discarded products and materials containing expanded plastic**
C1	Take back schemes for recycling, collection and sorting of EP
C2	Incentives for efficient sorting
C3	Separate EP-waste category in national waste statistics
C4	Product design for better sorting and recycling
D	**Specific measures for the construction industry**
D1	Use prefabricated building elements
D2	Protecting EPS-insulation in construction to sunlight
E	**Specific measures for the marine and maritime sector**
E1	Eliminate use of floating elements that have exposed EPS-surfaces
F	**Specific measures for the waste treatment sector**
F1	Covering of EPS-containing waste at landfills
G	**Measures to identify and clean up hotspots of EP-littering**
G1	Identification and clean-ups of illegal and/or legacy dumping sites
G2	Marking of EP elements to control sources.

Table 5.4: Measures to reduce littering of expanded plastics: potential material substitutions.

Code	**Description of material substitution**
H1	Substitution of EPS and XPS as insulation materials in buildings
H2	Substitution of EPS or XPS-containing materials in road construction
H3	Substitution of cardboard EPS packaging
H4	Substitution of EPS in fish boxes
H5	Elimination of EPS in buoyancy elements
H6	Elimination of EPS-use during land storage of boats on land

Table 5.5: Measures to reduce littering of expanded plastics by increasing reuse and recycling.

Code	**Measures that may lead to increased reuse and recycling of expanded plastics**
I1	Increased use of compactors that allow for more cost-effective transport of EPS waste
I2	Reuse of discarded EPS elements in new road projects
I3	Reuse of EPS elements in the aquaculture industry
I4	Reuse of floating docks
I5	Reuse of EPS insulation in construction projects.

Not all measures are relevant for all sectors or areas of use. Table 5.6 lists the sectors and areas of use discussed in this report and shows relevant measures for each sector or area of use. The measure is referenced as the code found in table 5.3 to 5.5.

Table 5.6: The Relevant measures for different sectors and areas of use.

Sector or area of use	Risk assessment	Relevant measures
Production of expandable pellets	Medium	A1-A4, B1-B5
Insulation plates	High	A1-A4, B1, B3 ,B4, B5, C1-C4, D1-D2, H1 H2, I1, I5
EPS blocks for construction of roads	Very high	A1-A4, B1, B3, B4, B5, C1-C4, D1-D2, H2, I1, I2
Fish boxes made of EPS	Medium	A1-A4, B1, B4, B5, C1-C3, H4, I1
EPS packaging excluding fish boxes	Medium	A1-A4, B1, B4, B5, C1-C3, H3, I1
EPS in pontoons	Very high	A1-A4, B1, B5, C1-C4, E1, G3, H6, H7
EPS filling from floating pipes and buoys	High	A1-A4, B1-B5, C1-C3, F1, G1, H5, I1, I3
Car fluff from shredding of cars	Low	A1-A4, B1-B5, C1-3, F1, H5, I1, I 3
EPS-waste from scrapping of boats	High	A1-A4, B1-B5, C1-C4, G1, I1
Recycling centres	Medium	A1-A4, B1-B5, C1-C4, I1
Recycling plants	Medium	A1-A4 and B1-B5
Incineration plants	Low	A2
Landfills	Medium	A1-A4, B1, B3, B4, B5, C3, F1, I1

5.4. Conclusion and recommended measures

Based on the risk assessment for the different sectors and areas of use the following measures are considered most important for reducing EP-littering from Norwegian sources based on relevance of the measure, the size of the material streams that are affected and the expected costs and efforts necessary for implementation.

Protection from the elements

A lot of EP-materials are lost due to wind and heavy rainfall. Measures to protect EP-materials against the elements are especially important in the construction sector (building and roads) and marine and maritime sector (aquaculture and floating docks). Indoor storage is the best way to protect against the elements, but if outdoor storage is necessary other actions, as described in chapter 4, should be taken to secure and protect the EP-materials.

Measure to reduce spill during handling and use

Due to the brittle nature of EPS-materials a lot of fragments and particles are formed during cutting and handling of these materials. In all situations where thermic cutting (heating knives or heating strings) can be used, this should be done to limit the generation of spills. Thermic cutting is considered especially relevant for construction projects and road building.

Take back scheme that enables recycling and minimizes risk of EP-littering

Take back schemes that ensure that sorted EPS waste is collected and sent to recycling have several environmental benefits. It will reduce the incentive for illegal disposal or dumping of waste that is otherwise very costly to dispose of for example pontoons and boats. It extracts EPS from mixed waste streams where it could otherwise end up at landfills where it may cause littering or create problems in automatic sorting facilities due to electrostatics. It reduces CO_2 emissions from production of new EPS-products. Take back schemes are considered as especially relevant for the construction sector with its large volumes, and the marine and maritime sector where much EPS-littering is caused by illegal disposal and dumping of EPS-containing pontoons and boats.

Eliminate use of floating elements that have exposed EPS-surfaces

Uncovered EPS-surfaces on floating elements leak EPS-particles over time to the surroundings due to contact with waves, ice, contact with boats and scrubbings to remove fouling during maintenance operations. By replacing such floating elements with floating elements where EPS-elements built in behind a protective layer of plastic or other resistant material this leakage will be eliminated.

Identify illegal dumping sites with subsequent clean-ups

A national clean-up initiative that systematically identifies hotspots of historic EP waste and collects this for proper treatment has the potential to reduce amounts of historic littering significantly and will prevent remobilization of this litter at a later stage. Identified sites should be recorded in a public database as a basis for planning further clean-up operations.

Substitution of EPS or XPS-containing materials in road construction

EPS and XPS are used as road building material as either blocks and plates, but can sometimes be replaced by light weight mineral products like foam glass or leca blocks without loss of road performance. Compared to EPS/XPS however, the costs are higher and these materials may not be used where extreme light materials are needed.

Substitution EPS packaging with corrugated cardboard

EPS-littering caused by lost shock absorbing packaging can be eliminated by substituting with cardboard materials. Cardboard materials show acceptable shock absorbing performance, are biodegradable, have comparable overall environmental footprint compared to EPS and are homogenous with other cardboard materials that often make up the container or box that the shock absorbing packaging is inserted into. Cardboard boxes and shock absorbing packaging that follows it can therefore easily be recycled together without further separation or sorting.

Elimination of EPS in buoyancy elements

EPS in floating pipes is not a very large EPS-source compared to for example building insulation. It can however be eliminated by use of compartmentalized floating pipes that are now becoming commercially available [51]. In the future floating elements in other buoyancy products like mooring buoys may also become an option. The same can also be done for floating elements in jetties.

Elimination of EPS-use during land storage of recreational boats on land
Although EPS-material is reported to still be in extensive use as a supporting medium when boats are stored on land, this EPS can easily be substituted by alternative materials like wood or rubber.

5.5. Further work

This report contains an initial survey of current measures to reduce EPS littering, and all conclusions and recommendations are associated with significant uncertainty and viewed through limited data. A more in-depth evaluation where a larger environment of experts with direct industry experience and a deeper understanding of sub-streams of EP-materials and waste participate in the evaluation can be a way to arrive at a more secure assessment basis. Both representatives from production, use and waste treatment of EP-materials should be represented in the work.

No data has been found available for quantifying EP-littering from specific sources beyond rough estimates. A more exact description of the actual contribution of EP-litter from different areas of use and waste streams will require a more detailed study of these sectors than what the framework for this project allows. A more systematic and scientific based method of tracing cleaned up litter back to its source and detailed investigations into specific sectors and areas of use of EP-materials and products could be a way to move forward.

6. Acknowledgements

This report presents information on the use, recycling and disposal of expanded plastics (EP) in Norway, including measures which may serve to limit littering from EP. Information has been gathered from available statistics, reports and a series of in-depth interviews. The report has benefited greatly from assistance and good will from EPS-Foreningen, Vartdal Plast, PartnerPlast, Brødr. Sunde and Grønt Punkt, who contributed with both in-depth interviews and quality control.

Environmental littering is an issue that engages. The individuals and organizations we have been in contact with are committed to help and bring an end to this littering. Many have gone above and beyond for this project. To gather data and knowledge more than 30 stakeholders involved in the value chains for EPS were interviewed. We would like to thank all the contributors who set time aside for us for one or more in-depth interviews (see attachment F in appendix).

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Appendix

A. Examples of measures to reduce littering and increase recycling from other countries

The following paragraphs summarizes measures taken abroad to either reduce EP-littering or increase recycling of these waste streams. The cases are grouped under the following headings:

- Collection initiatives and take back schemes
- Measures to eliminate EPS-littering
- New recycling technology

i. Collection initiatives and take back schemes

Increased collection of EPS-waste in Denmark

Since 1995 the Danish EPS-industry has accepted returned EPS-packaging from customers. From 2020 this return system was expanded to include all spent EPS-packaging regardless of origin together with other EPS-waste that may be recycled[41].

Return points for sorted EPS-waste in the Municipality of Mariagerfjord in Denmark

A return system for sorted EPS-waste was established at five recycling centres in the Municipality of Mariagerfjord. From June 2020 to March 2021 9.12 tonnes of EPS-waste was collected from the 41 800 inhabitants of the Municipality. This represents roughly 1 kg per household. After compression the EPS is sent to BEWiSynbra Circular's factory in Thisted, where the material is remelted into new raw material[42].

Collection scheme for source-sorted EPS waste in Belgium

A collection scheme for separate sorted EPS-waste in 0.5 m3 bags has been tried out in Belgium. The collection scheme is an extension of collection systems for paper/cardboard and other plastics that are already in place, and could potentially reach 20 000 businesses. 70 companies are reported to currently be part of the scheme and include partners like Val-I-Pac, Fostplus, Vanheede, Suez and Shanks[43].

Dutch initiative for overall collection of EPS-waste

Since 2013 a government supported initiative has worked toward an overall system for collection of EPS-waste in the Netherlands. The goal is to combine private and municipal collection in an overall collection and recycling scheme. This scheme is again part of the government initiative and support

[41] https://plast.dk/2020/03/eps-branchen-moderniser-branchens-genanvendelsesordning/
[42] https://plast.dk/2021/02/mariagerfjord-kommune-sparer-co2-ved-at-genanvende-eps/
[43] https://eumeps-powerparts.eu/content/downloads/recycling/eps-waste-in-the-paper-bin-a-pilot-in-belgium.pdf

for collection and recycling for all plastics. The initiative has increased its collection of EPS-packaging waste from 653 tonnes from 104 centres in 2016 to 1 320 tonnes from 200 centres in 2020. The EPS-waste is collected in transparent bags, marked with clear images of EPS for easy sorting, and upon delivery to a recycler a bonus is paid as an additional incentive. The bonus system is attributed as an important driver for the increase in sorted EPS delivered to recycling. There is also a parallel take back initiative that focuses on systems for point of sale for household appliances and white goods. Partners for these initiatives include Stybenex, Municipalities, Cool Blue, Media Markt, Saturn, Expert, BCC etc.[44].

Onsite collection of EPS waste in Germany

Through an Extended Producer Responsibility program that supports onsite collection of EPS waste Germany has managed to recycle 45 % of its EPS post-consumer packaging. The collection and recycling are organised by public-private-partnerships that ensures that collected EPS-waste is recycled into secondary products like lightweight concrete and new EPS-beads. Partners in this initiative include Fischer Recycling, Duale Systeme Deutschland, Industry partners, IK Industrievereinigung Kunststoffverpackungen[45].

UK Polystyrene Recycling Trial Launching in North London

In November 2021 a new initiative was launched by the North London Waste Authority (NLWA) to collect polystyrene at its eight reuse and recycling centres (RRCs) across north London which will then get processed at two main sites equipped with new compactors. The trial happens at South Access Road RRC in Waltham Forest, and Summers Lane RRC in Barnet. It is the result of a partnership between NLWA, LondonEnergy Ltd, the British Plastics Federation and Greenbank Recycling Solutions [46].

Recycling of fish boxes from Billingsgate fish market in London

Billingsgate fish market is the biggest inland fish market in the UK. Fish boxes from this market are collected by the waste management company Regent Hill and compressed into bars before being shipped to recycling[47]. The fish boxes are mostly recycled into insulation plates.

Cross industry project in Spain to increase recycling of fish boxes

Spain has a large fishing industry and for this reason fish boxes represent about 50 % of the EPS packaging in the country. From 2017 to 2019 an EU supported 1,3 MEUR project was run to identify recovery options and bottlenecks in the existing collection systems. The project also looked into recycling options for the fish boxes and evaluated market opportunities for recycled products. Partners in the project included ANAPE, Coexpan, Total, El Corte Inglese, Cicoplast[48].

Nation wide collection of ESP-waste in Italy

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[44] https://eumeps-powerparts.eu/content/downloads/recycling/eps-waste-collection-points-in-nl.pdf
[45] https://eumeps-powerparts.eu/content/downloads/recycling/eps-packaging-scap-collection-in-germany.pdf
[46] https://www.nlwa.gov.uk/news/polystyrene-recycling-trial-launching-north-london
[47] https://eumeps-powerparts.eu/content/downloads/recycling/fish-box-collection-at-billingsgate-fish-market.pdf
[48] http://www.life-eps-sure.com/en/

Since 2003 Italian EPS Industry Association (AIPE) has worked together with COREPLA, Italys national plastic recycling organization, on the selective collection of EPS from post-use packaging in Italy. EPS collection points are set up throughout the country where the waste is received and prepared for transport to specialized recyclers[49]. Much of the collected EPS-waste is recycled to floor underlay for the building industry.

Setting up collection points and compacting services for recycling of EPS in Australia

From 2012 – 2013 a total of 19 government supported projects set up collection points and recycling services for EPS-packaging at different sites in Australia. The projects received government grants that totalled 933 000 AUS$ and included a several businesses including a fish market, NGOs and waste treatment facilities[50]. The project succeeded in diverting 600 tonnes of EPS from landfills in the reporting period[51].

ii. Measures to eliminate EPS-littering

Operation Clean Sweep

Operation Clean Sweep is an initiative to reduce plastic resin loss to the environment including PS and EPS. The initiative is spearheaded by Plastics Division of the American Chemistry Council (ACC) and Plastics Industry Association (PLASTICS) and includes best practices and tools to limit resin littering[52].

When a company signs up for Operation Clean Sweep it commits to set its business in a way that avoids spillage of resin particles and to train staff to always prevent, collect, clean and dispose of spilled plastic. As an Operation Clean Sweep member a business must also audit its own performance regularly as well as to encourage partners to also work on the elimination of plastic littering.

Operation Clean Sweep encourages measures like having grates in the drain that ensure that plastic granules cannot get through and having vacuum cleaners / brooms everywhere in production where spills can occur.

Introduction of bans and adoption fees on EPS products USA

249 local US governments and 2 states (and the District of Columbia) have banned EPS to varying degrees. While most of the bans have focused on EPS food service containers, bans have also included EPS packaging for example deli and food trays, egg cartons mm and other materials for example EPS coolers and packing material and SUP utensils. One goal with these bans has been to facilitate substitute materials that may be either composted or more easily recycled. Adoption of fees

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[49] https://eumeps-powerparts.eu/content/downloads/recycling/epr-collection-system-for-eps-waste-in-italy.pdf
[50] https://www.epa.nsw.gov.au/working-together/grants/business-recycling/australian-packaging-covenant
[51] https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/business-government-recycling/what-can-business-recycle/expanded-polystyrene
[52] https://www.opcleansweep.org/about/

for single-use cups has also been introduced as means to retain customer choice while achieving the goals of reduction and preferable product substitution[53].

Specific bans on single-use plastic foam products, including EPS have been introduced in New York City together with more than 100 other U.S. jurisdictions including Washington, DC, Portland, Maine and San Francisco[54].

EU-ban on trading of single-use plastic

On July 2, 2021, the Directive on Single-Use Plastics took effect in the European Union (EU). The directive bans certain single-use plastics for which alternatives are available. A “single-use plastic product” is defined as a product that is made wholly or partly from plastic and that is not conceived, designed, or placed on the market to be used multiple times for the same purpose. The European Commission has published guidelines, including examples, of what is to be considered a single-use plastic product. (Directive art. 12.)

For other single-use plastic items, EU member states must limit their use through national consumption reduction measures, a separate recycling target for plastic bottles, design requirements for plastic bottles, and compulsory labels for plastic products to inform consumers. In addition, the directive extends producer responsibility, meaning producers of selected products will have to cover the costs of waste-management clean-up, data gathering, and awareness raising. EU member states must implement the directive in general by July 3, 2021, for the different actions to be taken specific deadlines apply[55].

The directive implements the EU’s plastic strategy and aims to “promote the EUs transition to a circular economy.” (Art. 1.)

With the effect of July 2, 2021, member states, including Norway, shall ban:

- food containers made of expanded polystyrene
- beverage containers made of expanded polystyrene, including their caps and lids
- cups for beverages made of expanded polystyrene, including their covers and lids[56]

53 https://digital.detritusjournal.com/articles/policy-instruments-to-reduce-consumption-of-expanded-polystyrene-food-service-ware-in-the-usa/284
54 https://www.nationalwaste.com/blog/eps-foam-regulations/
55 https://ec.europa.eu/environment/topics/plastics/single-use-plastics_en
56 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0904&from=EN

B. New recycling technology

Resource-efficient and environmentally friendly treatment of EPS waste in Denmark

The purpose of the project "New life for post-consumer insulation and packaging in EPS" was to develop and demonstrate a circular solution for end-of-life EPS materials collected on return points.

Part of the project was the development of a container-based compactor solution that can granulate and compact EPS materials into EPS blocks at sites of use. The development of the compaction solution is considered successful and enables more efficient transport in that 46 trucks, each with a load of 130 kg EPS, can be replaced by a single car transport with 6 tonnes.

The project has also demonstrated the recycling of EPS waste into new products using both thermal- and solvent-based technologies.

The project partners included Amager Ressourcecenter I/S, EPS Recycle A/S (Hawfisk), Aage Vestergaard Larsen A/S, Shark Service Center ApS and Teknologisk Institut[57]. The project was also supported by Miljø- og Fødevareministeriets Miljøteknologisk Udviklings- og Demonstrationsprogram (MUDP).

Recycling of EPS with flame retardants in Netherlands

The PolyStyreneLoop Foundation has built a large-scale demonstration plant for recycling of EPS-waste in Ternauzen in the Netherlands. The recycling process is based on a physio-chemical polymer dissolution process CreaSolv® and has a yearly capacity of 3300 tonnes. This technology allows for recycling of bromine resulting in new EPS-materials without residues of bromine-based flame retardants that discarded EPS-insulation foam often can contain which will allow for use in a wider range of new EPS-products. PolystyreneLOPP, Fraunhofer IVV and ICL IP are partners in the project[58].

[57] https://www2.mst.dk/Udgiv/publikationer/2019/08/978-87-7038-094-2.pdf
[58] https://polystyreneloop.eu/

C. Barriers to recycling

The following barriers to recycling expanded plastics were identified through conversations with stakeholders and review of available literature.

i. Barriers across the sectors

Lack of reporting and statistics on EP

There is a lack of accurate and reliable statistics on use, recycling and disposal of EP materials, products and packaging

Better reporting will be helpful to assess the market situation for EP. Statistics Norway yearly publishes statistics on import, export and production of goods such as EP material. The low level of detailing on the commodity codes and prodcom codes used to classify the goods results in low level of detailing. Other commodities are described with more detailed codes. A good example of this is seafood.

Shared recycling requirements and goals for complex products

Targets and requirements, both governmental official and private, for collection and recycling of materials in complex waste streams products are typically measured by the weight of the product. For example there is a general recycling target of 50 % of the total weight of a battery, and 80 % of the total weight of a motor vehicle.

This incentivizes collection and recycling of heavy materials that are easier to collect and recycle, such as concrete and metals. With a target of 80 % recycling of construction and demolition waste, it is generally more cost efficient to first recycle concrete and steel rebar. Thereafter, lighter materials such as aluminium and wood.

In the draft waste battery directive the EU Commission specifies that certain materials must be recycled within a product, e.g. for cobalt, copper, lead, nickel, and lithium[59]. This is a possible way to supplement general recycling targets by weight in mixed waste streams.

ii. Industrial practices that act as barriers to recycling

Use of additives

Additives such as brominated flame retardants, graphite and pigments (commonly added to XPS), and unwanted polymers mixed in through waste fractions polluted with the wrong polymers must be managed while recycling all EP. Some additives such as brominated flame retardants are strictly

[59] V. Halleux, "New EU regulatory framework for batteries," EPRS European Parliamentary Research Service, Brussels, Jul. 2021. Accessed: Oct. 10, 2021. [Online]. Available: https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf

unwanted in most secondary materials to be used in Norway, due to regulations of use of brominated flame retardants[60].

Some Norwegian EPS producers have produced EPS with brominated flame retardants. For example some products are destined for use abroad where the use of brominated flame retardants is more common. Alternatively the products may have been used before the use of brominated flame retardants was regulated. If a waste material is contaminated with brominated flame retardants, it may no longer be suitable for recycling.

Other additives, such as graphite, may be unproblematic in smaller quantities, but result in unwanted properties (such as reduced strength, shock resistance and insulation value) if levels reach certain thresholds.

Methods to overcome these barriers exist. For example pollution may be diluted by mixing in primary raw materials. The materials may be recycled chemically into precursors for production of new polymers, from which the pollutants can be extracted.

Current construction materials in EPS and XPS are not designed for recycling

The EP products used in the construction industries, especially products made of EPS and XPS, are not designed to be recycled. When removed from buildings at end-of-life, the materials frequently can be contaminated with dirt, concrete, glue, cardboard or incorrectly sorted EP. The contaminants are challenging to separate out, making the contaminated EP unfit for mechanical recycling. Contaminated EP may be chemically recyclable.

Approximately four times as much EPS and XPS is placed on the Norwegian market as construction materials compared to packaging materials. Only packaging materials and scraps from cutting of construction materials are recyclable.

Notably, the construction materials may reside in buildings for more than 50 years, whilst packaging materials are usually disposed of within one year.

According to the EPS producers, the demand for recycled materials for production of EPS and XPS cannot be met, yet the vast majority of the products that are placed on the market today, are not designed to be recycled in the future.

Ban on use of recycled EPS in food contact packaging

The use of recycled EPS in food contact packaging such as fish boxes is illegal due to concerns regarding hygiene (food contact regulation). Recycling technologies that sterilize the fish boxes could enable fish box producers to directly recycle old fish boxes into new.

Littering of EP results in loss of materials to be recycled

Littering of materials reduces the available material flow to recycling.

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[60] Forskrift om registrering, vurdering, godkjenning og begrensning av kjemikalier (REACH-forskriften) [Online]. Available: https://lovdata.no/dokument/SF/forskrift/2008-05-30-516

iii. Barriers to recycling of floating docks and marinas

Contamination of EPS-pontoons exposed directly to the ocean

EP exposed directly to the ocean is covered in algae and crustaceans. These contaminants make the materials difficult to recycle.

Reuse of floating docks

While reuse is prioritized above recycling in the waste hierarchy, reuse of floating docks or pontoons may result in littering of EPS, as worn pontoons release increasing amounts of littering and mechanical integrity fails.

Lack of design criteria for floating docks and pontoons

The lack of requirements for the design of floating docks and pontoons results in the use of subpar pontoons and materials with low recyclability and high risk of EPS littering. For example, use of uncovered EPS in buildings is illegal, while it is legal in pontoons.

iv. Barriers to recycling within waste management

Lack of capacity for recycling of contaminated EP waste

There are no operators offering chemical recycling of contaminated EP-waste in Europe[61]. Much of the EP-waste that is currently landfilled or incinerated could be recycled chemically in a tailored process.

Lack of infrastructure for collection and compaction of EPS waste

While systems for collection, compaction and recycling of EPS have been identified in municipalities with 52 % of Norway's inhabitants, a large part of municipalities have no identified system for recycling of EPS. Furthermore, the municipalities that have infrastructure for collection and compaction of EPS may still send parts of their EP waste to incineration, for example if inhabitants are unable to drive to recycling centres with their EP waste.

Separation of EPS-packaging waste and other EPS wastes at recycling centres

As the Extended Producer Responsibility (EPR) -schemes only fund recycling of packaging materials, the recycling centres are instructed to separate EPS packaging waste and other EPS waste. In some recycling centres, other EPS waste is sent directly to incineration. The ERP scheme faces several economic risks if they halt this practice: Not only would there not be funding for the extra materials, in addition, the new material flows may contain brominated flame retardants and contaminations, reducing the value of the entire waste material flow. However this separation of the waste streams is confusing to the inhabitants, and requires increased investments and use of space at the recycling centres. Without EPR schemes for other EPS materials and products means the waste owner or the municipality are taking the costs for waste collection and treatment.

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[61] Pers. com., waste treatment company, Nov. 29, 2021.

D. Unwanted incidents that may lead to littering of EP

i. Unwanted incidents across all sectors

- Loss of EPS products stored outside due to wind and rain.
- Loss of EPS products during transportation.
- Loss of EPS waste stored outside due to wind and rain
- Loss of EPS waste during transportation.

ii. Unwanted incidents from building and road construction

- Spread of EPS dust and particles from scraping off degraded EPS from materials exposed to sunlight
- Spread of EPS particles from cutting and customizing with saws and rough handling of EPS products and materials due to wind, rain and surface water.
- Spread of EPS particles from destruction of low-density concrete with EPS.
- Spread of EPS particles from building waste fractions from demolition of buildings during handling, transport and temporary storage.
- Spread of EPS particles to the environment by leachate from soil mounds.

iii. Unwanted incidents from aquaculture

- Spread of EPS particles from disassembling of aquaculture pens through wind, rain and surface water.
- Leakage of EPS fragments from holes in mooring buoys.
- Leakage of EPS fragments from holes in Aquaculture pens.
- Spread of EPS particles from wear and tear of packaging during unboxing of goods.

iv. Unwanted incidents from floating docks and harbour activities

- Spread of EPS particles from wear and tear of uncovered EPS.
- Spread of EPS particles through punctured cover materials due to wear and tear.
- Excessive wear and tear due to scraping on rock and gravel during transit to winter storage
- Use of EPS as supporting material for boats during winter storage
- Maintenance of uncovered EPS where filth is scraped off.
- Illegal chopping of floating docks, boats, sail- and surfing boards.
- Littering of EPS from pontoons and floating docks lost at sea during storms or transit.

v. Unwanted incidents during waste management

- **Spreading of EPS pieces during delivery of discarded EPS packaging and materials.**
- **Spreading of EPS due to tilting of EPS bag racks.**
- **Spreading of EPS from landfills through wind, surface water and leachates**

E. Interview guide

Dato:	
Aktør:	
Bruksområde:	
Type Aktør:	
Tilstede:	
Tlf:	
Epost:	

Questions:

1. Could you give a brief introduction of who you are, what you do, and how your industry/trade uses EPS today?
2. What are the largest areas of use for EPS and EP in your trade/industry (including packaging)?
3. Does the trade/industry use other kinds of expanded plastics such as EPE and EPP?
4. Who are the largest importers of EPS and XPS products to Norway in this sector?
5. Who are the largest producers of EPS and EPS products in this sector?
6. How large quantities of these products have you used/purchased/imported or produced in 2010-2020?
7. What collection schemes are there for these products?
8. Do you have numbers on how large amounts of these products are sent to recycling, incineration or reuse?
9. What are the most important factors that cause EPS to not be recycled?
10. What are potential sources of unwanted loss of EPS to nature?
11. Why do these losses occur?
12. What use of practice may reduce the risk of spreading expanded plastics or expanded plastics waste in an uncontrolled manner?
13. Are there schemes or practices that you consider especially beneficial or unbeneficial with regards to reducing the risk of spreading EPS to the environment?
14. Do you know of, or have suspicion of, that expanded plastics or waste containing expanded plastics is dumped or otherwise illegally disposed of?
15. What measures or schemes are in place to reduce the risk of losing EPS to the environment?
16. Are there measures that you would consider to reduce the risk of losing EPS or EPS-containing waste to the environment?
17. Are there alternative products or materials that could replace EPS materials used today?
18. Are there cost-related or practically related conditions that hinder efficient handling of EPS waste?
19. Any other comments to our project?

F. Interviewed actors

The following actors were interviewed indepth:

1. Akvagroup
2. Asvo Vestvågøy
3. Bewi Norway
4. BMC
5. Brødr. Sunde
6. Elkjøp
7. EPS-foreningen
8. Franzefoss
9. Glava
10. Grønt Punkt
11. Hold Norge Rent
12. Ineos Bamble
13. IVAR IKS
14. Jackon
15. Jernia
16. Kambo Marina
17. Kongelig Norsk Båtforbund
18. Lofoten Avfallsselskap
19. Mepex
20. Naturvernforbundet
21. Norsirk
22. Norsk Sjømatforening
23. Oceanize
24. Oslofjorden Friluftsråd
25. PartnerPlast
26. Peab
27. Ragn-Sells
28. Scale AQ
29. Skanska
30. Statens Veivesen
31. Svåheia Avfallsanlegg
32. Søre Sunnmøre Reinhaldsverk
33. Vartdal Plast
34. Veidekke
35. Wee Marina
36. Wilfa
37. Ålesundregionen interkommunale Miljøselskap

The following actors were interviewed briefly:

38. Fiskarlaget
39. Fiskebåt
40. Norsk Gjenvinning
41. Sjømat Norge
42. Zero
43. Østriv

The following actors were not able to be interviewed:

44. Byggenæringens landsforening
45. Ikea
46. Lerøy
47. Møbelringen
48. NHP-nettverket
49. Nye veier
50. Salmar