Study to Quantify Pellet Emissions in the UK

Report to Fidra

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Report for Madeleine Berg, Fidra

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Disclaimer

Executive Summary

This study set out to estimate the quantity of pre-production plastic pellets lost each year in Scotland and elsewhere in the UK. To achieve this, the authors reviewed the published research on pellet loss and attempted to bridge information gaps by speaking with industry representatives and stakeholders, including those with first-hand experience of spills and losses.

E.1.0 Key Findings

The analysis undertaken for this research shows that pre-production pellet loss to the environment in the UK is likely to be at least 105 tonnes, and possibly as high as 1,054 tonnes each year. These tonnages equate to 5 billion and 53 billion pellets per annum respectively.

The study also estimates the number of pellets lost at each point in the plastics value chain, as shown in Table E-1. Due to a lack of more detailed evidence, it is assumed that all points in the value chain exhibit equal percentage rates of pellet loss, and so the difference in the number of pellets lost is driven by the tonnages handled at different points.

Table E-1: Estimates of Annual Plastic Pellet Loss from UK Industries

	Low pellet loss estimate, billion pellets	High pellet loss estimate, billion pellets
Producers	1.3	13
Transport and Other Facilities	1.6	16
Processors	2.4	24
Waste Management	0.0	0.2
Total	5.3	53

It is not known precisely what proportion of the UK plastics industry is located in Scotland. However, mirroring the distribution of the chemicals industry as a whole, for the purposes of illustration, we assume that 15% of the industry is in Scotland. **Pellet loss in Scotland is therefore estimated to be in the range of 15.8 to 158.1 tonnes each year, equal to 0.8 to 8 billion pellets**.

E.2.0 Recommendations

The study recommends that Fidra:

- **Works with the plastics industry** to establish the effectiveness of the pellet loss reduction measures contained in Operation Clean Sweep (the industry's best practice approach to addressing pellet loss); and
- **Works with the plastics industry and other stakeholders to address information gaps** to improve the estimates of pellet loss to determine how best to focus further action. This could in part be achieved through establishing the effectiveness of OCS measures as noted above.

Noting the experience of enforcement work in California, this study recommends that Fidra engages with SEPA, the EA, and NRW in the first instance to:

- **Establish a means for enforcement and prioritising resources for enforcement.** Enforcement can be part of the solution to addressing pellet loss but it may require legislative tools and resources. A shorter term approach would be industry funded self-regulation, involving third party measurements and spot checks on facilities

It is also recommended that Fidra should work with organisations currently conducting largescale beach litter surveys to gather further evidence on pellet loss:

- **Other ways to quantify pellet loss** such as including pellet counts in national beach surveys can help understand the scale of the issue, which can then be communicated to stakeholders and used to raise the profile of this type of pollution.

Finally, the study recommends that Fidra should consider conducting further research:

- **Flakes, powder and related sources of plastic emissions** are not included in the pellet loss estimates presented in this study and further research would be needed to determine how much is lost to the wider environment each year.

Contents

Glossary

Billion - One thousand million = 1,000,000,000

BMP – Best Management Practice

BPF – British Plastics Federation

Compounder – a large scale producer of pre-production plastic, preparing plastic formulations by mixing and/or blending polymers and additives into process ready pellets

Masterbatch maker – a small scale producer of pre-production plastic (a masterbatch) prepared with a high concentration of pigments or additives to be blended with other compounds

OCS - Operation Clean Sweep

Producer / Plastics producer - A compounder or masterbatch maker

Processor – a manufacturer that uses plastics in the process of manufacturing a product; also termed a plastics converter or goods producer

Tonne or T - Metric tonne = 1,000 kg

1.0 Introduction

This study set out to estimate of the number of plastic pre-production pellets, known as nurdles, entering the wider environment each year from the UK plastics industry. Current research on pellet loss focusses on pellets entering drains at or near plastics facilities. We are aware that other losses can occur, such as pellets lost in grassy areas and at the perimeter boundaries of plastics facilities. However, we conservatively only include the losses to drains in this report due to a lack of published research on losses in other areas. Lost pellets entering drains may be transported to the marine environment, but the proportion of these pellets that reach the marine environment is outside the scope of this study.

This study does not look in depth at other forms of plastic raw material such as powders and flakes. Nor does the study investigate the damage caused to the environment from these pellets, which is well documented in other research.

Throughout this report we use the shorthand term 'pellet loss' to refer to pellets which are spilt and not cleaned up. This refers to uncontained pellets that enter the wider environment. This does not refer to all pellets 'lost' from the manufacturing process, which would include pellet waste that is properly contained and disposed of and therefore poses little threat to the environment outside of the issues of resource wastage.

The British Plastics Federation (BPF) is an industry body that represents about 75%-80% of the UK plastics industry by turnover. Plastics Europe is a European-wide industry body. Both organisations were interviewed in the course of this work, to obtain further detail on the structure and operational practices of the industry. However, both BPF and Plastics Europe were limited in terms of the information they could impart for reasons including commercial confidentiality.

We therefore sought information from a broad range of stakeholders including those with first-hand experience of spills and losses. It is therefore hoped that this study will further understanding of the issue and help the industry move towards zero pellet loss. The calculations and reasoning used are explained in detail to provide a framework for calculating the quantity of pellets lost.

This report is laid out as follows:

- The background to the issue of pellet loss is described in Section 2.0;
- Section 3.0 considers where the pellets are lost, including:
    - Particular points of loss at plastics processors,
    - Whether some types of facilities lose a greater proportion of pellets than others, and
    - The diminishing returns to cleaning up pellet spills;
- Section 4.0 presents a calculation of how many pellets are lost each year using the best available information;
- A summary of the report findings is provided at Section 5.0; and

- Conclusions and recommendations are presented in Section 6.0.

2.0 Background

Pellets are often described as lentil-sized plastic particles. These can vary somewhat in size and weight depending on the polymer type and the intended use. However, they tend to be *roughly* the same size and weight and so we use standard conversion rates for all data found on pellets throughout the report, namely:[1]

1 kg of pellets = 50,000 pellets

The BPF reports the following figures on the UK plastics industry:[2]

- 4.8 million tonnes of material are processed;
- 2.5 million tonnes of plastics material are produced;
- 7,500 companies;
- 3,000 primary processors; and
- £19 billion turnover.

To date, a great deal more research and action to deal with pellet loss has been undertaken in the US than in the UK and a lot of the sources used in this study are from the US.

2.1.1 Operation Clean Sweep

The US EPA undertook an investigation into plastic pellet loss, which was published in 1992 and identified a number of areas where pellet loss can occur.[3] This led the US plastics industry to develop a manual of Best Management Practices (BMPs) for facilities to follow to prevent pellet loss, and a pledge to sign, collectively called Operation Clean Sweep (OCS). The OCS manual is largely based on the findings of the US EPA study. OCS has since been adopted by plastics industries in other countries including the UK. Both BPF and Plastics Europe operate a version of OCS for their members.

Growing concern in the state of California led to Assembly Bill 258 being passed in January 2008 establishing the "Preproduction Plastic Debris Program", which applies to facilities in California that manufacture, handle, or transport preproduction plastics - the raw materials used to produce plastic products.[4] This led to inspection of some sites and enforcement, with pellet losses cited as violations of industrial storm water discharge permits. In 2004 Algalita was commissioned to evaluate the effectiveness of the BMPs in OCS by monitoring pellet spills and pellets entering storm drains before and after the BMPs were adopted. Some sites co-operated in adopting the recommendations for BMPs whereas others did not

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[1] Data provided by the BPF

[2] *About The British Plastics Industry*, accessed 28 January 2016, http://www.bpf.co.uk/industry/default.aspx

[3] U.S. EPA - *Plastic Pellets in the Aquatic Environment: Sources and Recommendations*, http://yosemite.epa.gov/water/owrcCatalog.nsf/e673c95b11602f2385256ae1007279fe/26ff1ab41c46a40d85256b0600724785!OpenDocument

[4] *Preproduction Plastic Debris Program*, http://www.waterboards.ca.gov/water_issues/programs/stormwater/plasticdebris.shtml

participate but were still monitored. The findings were inconclusive but the authors commented that: [5]

> *It is interesting to note that the monitoring activities around the non-co-operating facilities resulted in an awareness by management of the goals of the project and improvements at these facilities were roughly the same as those at facilities who agreed to participate. Improvements, though apparent, were not sufficient to prevent significant pellet and production scrap losses to the storm drain system. In all cases, facilities were unable to retain pellets on site during significant rain events.*

3.0 Where Are the Pellets Lost?

3.1 Points of Pellet Loss

Pellets are lost when spills are not completely cleaned up. These pellets can be washed into drains by surface water runoff if the spills occur outside. It is widely recognised by the few studies conducted on pellet loss that there is an opportunity for pellets to be spilt and lost whenever they are handled. This means that pellets may be lost at any point in the plastics value chain: at compounders, masterbatch makers, distributors, resellers, storage locations, processors, recyclers, during waste management, at ports and when being transported between each of these points. The greater the number of points at which pellets are handled, the greater the opportunities for loss.

Of the studies that have observed spills and losses of pellets at plastics facilities some specific locations are reported as especially problematic. The OCS manual emphasises that pellets may be lost whenever they are handled and suggests BMPs to tackle spills and losses. These can be summarised as follows:[6]

- **General handling**
  - Weak packaging breaks or develops punctures leading to pellet loss into the environment
  - Pellets are spilled during filling process
- **Pellet transport**
  - Cleaning vehicle - Pellets carried away in water used to wash vehicle
  - Loading/Sealing vehicle - Pellets are spilled from loading equipment
  - Storage at intermediate sites - Vandalism leads to pellet spillage
  - Unloading bulk containers - Surges in unloading lines cause pellets to be vented into the environment
- **Shipping**
  - Loose pellets are swept straight into ocean

[5] Moore, C.J., Lattin, G.L., and Zellers, A.F. (2005) Measuring the effectiveness of voluntary plastic industry efforts: AMRF'S analysis of Operation Clean Sweep, 2005, http://www.algalita.org/wp-content/uploads/2014/05/Measuring-Effectiveness-of-Voluntary-Indust.-Efforts2.pdf

[6] Operation Clean Sweep, http://www.opcleansweep.org/Standalone-Content/Operation-Clean-Sweep-Manual-PDF-Version.pdf

    - Containers lost at sea
    - Bags of pellets are damaged during transit and pellets leak from containers onto deck and into the ocean
    - Spillage of pellets due to packaging damaged during transit
- **Waste Disposal**
    - Pellets are disposed of with mixed residual waste
    - Pellets are blown away from bins stored outside

To inform this study, we contacted Dylan Seidner, who currently works at the Office of Enforcement, State Water Resources Control Board. From 2009-2011, he worked on the Preproduction Plastic Debris Program, and personally inspected at least 30 or 40 facilities. Mr Seidner considered the most common points of pellet loss to be:

- **Loading bays**, especially if dealing with large quantities of material from rail or big road trucks;
- **Storage for use**. Big facilities use large silos which can have a lot of leaks when connecting or disconnecting pipes or cleaning out. These are also typically areas of poor housekeeping; and
- **Storage for disposal**. Lots of facilities throw waste plastics into a dumpster which is not water tight or not designed to store this material. Pellets are disposed of as a result of cleaning up spills, an incorrect mix, or an irregular product that cannot be used. If it rains then this can fill up and overflow into storm water drainage. Inspectors have often found pellets around dumpsters and even seen a trail of plastic on the ground from where the waste hauling company has collected the waste.

These three areas were also highlighted by the Operations Manager of a Scottish plastics processor who was contacted for this study, and who considered disposal of waste pellets the biggest risk. This stakeholder currently works at a processing facility making high-spec telecoms equipment, with a turnover of £70million. The individual has over 30 years' experience in the industry working for different manufacturers and has visited numerous other processors and compounders. He provided further insight into how plastic pellets are handled at processing facilities in the UK.[7]

Pellets arrive at sites in 3 different types of packaging container:

1) Bulk tanker delivery - a sealed unit of 30T transferred into a large silo on site.
2) Boxes on a pallet - from 500 kg to 1.5T in a lined, sealed box.
3) 25 kg bags stacked on pallets.

The bulk tanker looks like a shipping container placed on the back of a lorry. To unload the pellets into the silo the tanker has a large diameter hose (6-8 inches) fitted to the rear end and the container tips up so material falls down to the bottom. A vacuum system is then used to transfer the pellets from the tanker to the silo through the hose. The most common point for spillage to occur is when connecting or disconnecting the pipework to the tanker or the silo. Both the tanker and the silo are typically in an outside area.

[7] Personal communication with the Operations Manager of a Scottish plastics processing facility.

Bags and boxes are transferred from the delivery lorry into a raw materials warehouse for storage. It would be unusual to store those materials outside. Boxes and bags are handled with forklift trucks, either on pallets or moved individually, so there is a much greater risk of spills and loss than when pellets are delivered in a tanker. For example, the packaging can rip if a forklift penetrates the bag or box. The chance of this happening particularly is high when loading and unloading the material.

Bags are typically made of polyethylene but some materials absorb moisture and these are packaged in a tin foil bag to prevent moisture. The tin foil bags are typically constructed to make them as strong as the polyethylene bags. The greatest risk is of spills from bags damaged during transportation and handling.

There are two types of boxes. One type of box can only be accessed from the top and so it is transported to the point of use, the lid removed, plastic liner cut, a hose inserted into top and the material is physically sucked out using a vacuum. When removing the hose from the top of the box there will be some pellets left in the hose which can be spilt. Bottom dispensing boxes and bags are mounted on a frame and emptied from the bottom. A funnel is put below it to feed into a hopper and gravity feed on demand. When accessing material from the bottom there is a risk of spillage.

The basic handling of pellets at a processor can be described as follows:

1) **Unloading.** The typical unloading and storage procedures for the different pellet packaging containers, as described above.
2) **Transferring to point of use.** Facilities handling a high volume of pellets will typically invest in a silo for storage and can then receive pellets in tankers, as described above. However, it is likely that they will also receive smaller volumes of pellets (compounds or masterbatches) in bags and boxes. Pellets are transferred from the external silos to the point of use via a piping network using a vacuum. Unless there is a failure or breakage in the piping system it is very uncommon for pellets to be lost in this step as it’s a sealed system from start to end. Often the base material is packaged in a large box, especially at smaller sites that cannot justify the expenditure for a silo, and pellets of pigment are added from 25kg bags, decanted into a smaller container. The operator uses a jug to take the pellets from the small container to the point of use. These are all common points of spillage but are all inside the factory where the risk of pellets escaping and entering a watercourse is minimal.
3) **Use.** The next potential for pellet spillage and loss is at point of use, either when cleaning the machinery or due to a fault on the line. It is common to change the material used, the colour of material or the product on a production line. This requires the operator to clean the machinery to prevent contamination from the previous raw ingredients and this generates loose pellet waste. When pellets are packaged in a large box a pipe and hose is used to suck them out, and some residual pellets are often left in the box, typically a few kilos for a 1 T box. These will be disposed of with the containing box. Boxes and bags are returned to the stores if their entire contents are not used and so they can be handled multiple times. In these cases the way in which they are sealed for storage and reuse is important, as if they are not sealed, and are accidentally dropped, the contents will spill.
4) **Waste management.** If a company is not careful in how it manages waste pellets at point of use some pellets can be spilt and lost. The interiors of most factories don't

have open drains so there is a low risk of pellet loss even if spills occur. Pellets are cleaned up and put in a bin. The risk comes from how the waste material is managed, for example when it is transferred to a larger bin in an external area. Pellet waste is most commonly put into a skip. However, skips are not designed to contain such small waste items and have holes in the bottom to let out water, which is a route by which pellets can escape. Pellets can also be spilt when transferring the waste into the skip. At the facility of the processor in question, the waste boxes and bags are put in a single bag, which is sealed and then put in the skip, and sent to landfill.

A similar process happens at producers, but in reverse: pellets come off the production line, are transferred to storage, and then loaded into a container for transport (either a tanker, box or bag), and put on a lorry. Whilst the two processes are not identical they are similar enough to assume that opportunities for spills and losses are also similar.

3.2 Key Factors in Pellet Loss

Whilst there is not a great deal of research currently available on the causes and circumstances of pellet loss, the published reports and stakeholders contacted for this study identify the following key factors in pellet loss:

- How pellets are packaged for transport – pellets in bags and boxes are easier to spill than tankers;
- Whether pellets are handled inside or outside – spills inside are much easier to contain and clean up;
- Manual vs. machinery handling – greater risk of spillage from manual handling;
- How waste pellets are stored for disposal; and
- Management practices employed – to reduce spills and losses.

3.3 Are Some Types of Facility Worse than Others?

All stakeholders contacted for this study who had seen pellet spills and loss first hand reported that there was no discernible trend to say that producers, transporters or processors were any worse than each other in terms of pellet spills and loss.

Mr Seidner commented that in his experience in California, facilities making food grade or medical grade products would be more concerned about pellet spills and losses as they have better quality controls in their process. Conversely, he commented that if making a low value product then the operator will be less concerned with spills and losses and the raw material will also be cheaper, reducing the incentive to prevent losses. A facility making a low value product with a low profit margin won't invest a lot of money and labour in housekeeping and capture.

Without actually inspecting a representative sample of sites it is hard to determine whether this is also the case in the UK. The BPF do not think this would be the case as facilities see pellet spills as a health & safety issue as well as an environmental one.[8] They also point out

[8] Personal communication.

that even though some plastics have a lower cost per tonne, this material is very valuable to facilities, especially where profit margins are low. We discuss these points and the reasons for pellet loss in more detail in Section 3.4. The BPF also adds that this particular sector is small compared to the scale of the whole industry.

Other stakeholders contacted for this study commented that no one type of facility was more likely to lose pellets than any other.

Although the effectiveness of OCS has never been established, there is a working assumption in the industry and in the literature that facilities that have joined OCS generally lose fewer pellets than those that have not. However, this does not imply that OCS has any impact upon pellet loss. BPF commented that facilities often have BMP in place before signing OCS and only sign OCS to raise awareness of the issue.

3.4 Diminishing Returns to Cleaning up Pellet Spills

In the course of an interview, BPF representatives reiterated the point that plastics processors will want to prevent pellet spills and recover any spilt pellets, in order to avoid the loss of valuable feedstock. With feedstock costs, in some cases, reaching £2,000 per tonne, this argument would seem compelling.[9]

However, closer consideration of the matter leads one to the conclusion that while the feedstock may, on the face of it, be valuable, there will be a limit to what a company might reasonably spend on preventing pellet loss. There will inevitably be a point where cleaning up spills no longer makes economic sense to the processor (even accounting for health & safety concerns).

3.4.1 Illustrative Scenarios

Take the example of a 25kg sack splitting as it is unloaded from a pallet, and the contents spilling over a wide area of factory floor. Employees will use the relevant equipment at their disposal to gather up the spilt pellets. The majority of pellets may be in a pile close to where the sack split, while a smaller number will likely be scattered in all directions. Every minute spent clearing up pellets in the pile, where the concentration is high, will yield a greater return than each minute of staff time gathering the more widely dispersed pellets. To hunt down each individual pellet from the spill, with pellets perhaps having ended up in difficult-to-access areas, could be prohibitively costly. In simple terms, the value of the few remaining spilt pellets is low, relative to the cost of finding and retrieving them.

This is shown graphically in Figure 1. The y-axis features the marginal cost of recovering each pellet, which is indicated by the blue line. The x-axis shows the cumulative percentage of pellets spilt. Moving from left to right along the blue line, it can be seen that most pellets can be collected at a low marginal cost. That marginal cost, however, increases as the more widely dispersed pellets are gathered. At some point the marginal cost of recovering the remaining pellets – those that have been most widely scattered, and are perhaps difficult to access - increases above the red line. This represents the point beyond which it costs so much to collect each pellet that it is not worthwhile.

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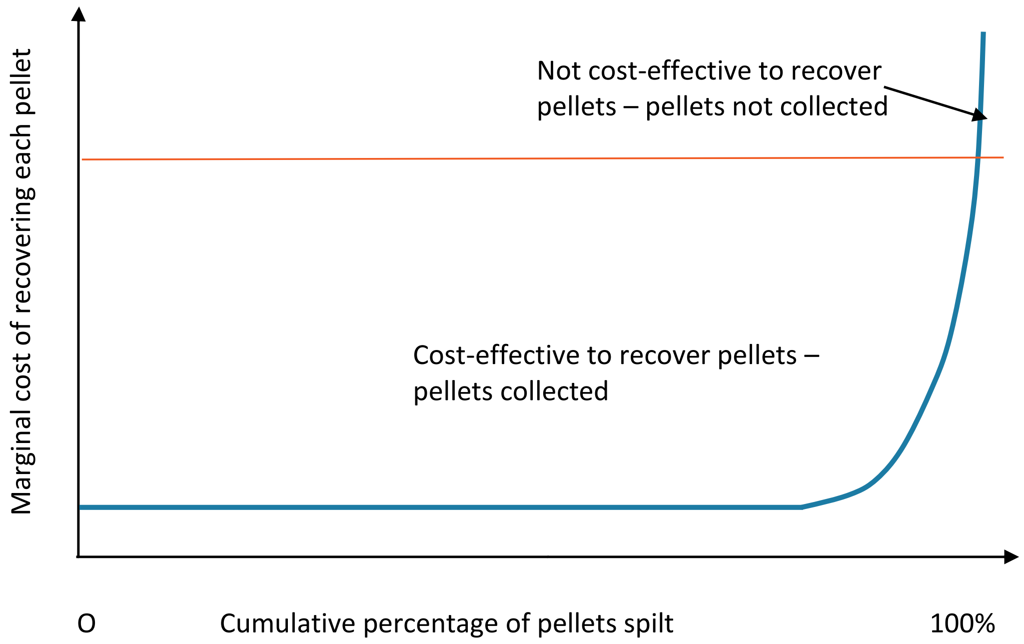
[9] Typical material prices provided by a Scottish processor.

Of course, within an individual factory, this will not necessarily mean that the pellets are lost. Instead, if appropriate measures are in place, they will be retained within the building and gathered at a later date. The point that we are making with Figure 1 is simply that it may not be cost-effective to clean up every individual pellet immediately after it is spilled.

Figure 1: Diminishing Cost-effectiveness of Pellet Recovery within a Factory



Please note that the red and blue lines are illustrative of an effect, and should not be interpreted to suggest an actual proportion of pellets that remain uncollected after an individual spill

This effect becomes considerably more important for spills *outside* a factory, particularly in a yard with a rough surface, such as gravel or tarmac, or perhaps spills where some pellets go into a grass verge. In such a case, illustrated in Figure 2, it can be seen that the marginal cost of recovering even the easiest to collect pellets is likely to be considerably higher than if the spill occurred within the factory itself, and the point at which collecting pellets becomes prohibitively costly will occur sooner. This is shown where the blue line crosses over the red line, which in Figure 2 occurs further to the left than in Figure 1. It is also likely that the red line itself, representing the point beyond which it costs so much to collect each pellet that it is not worthwhile, will be lower than for spills inside the factory. This is for two reasons:

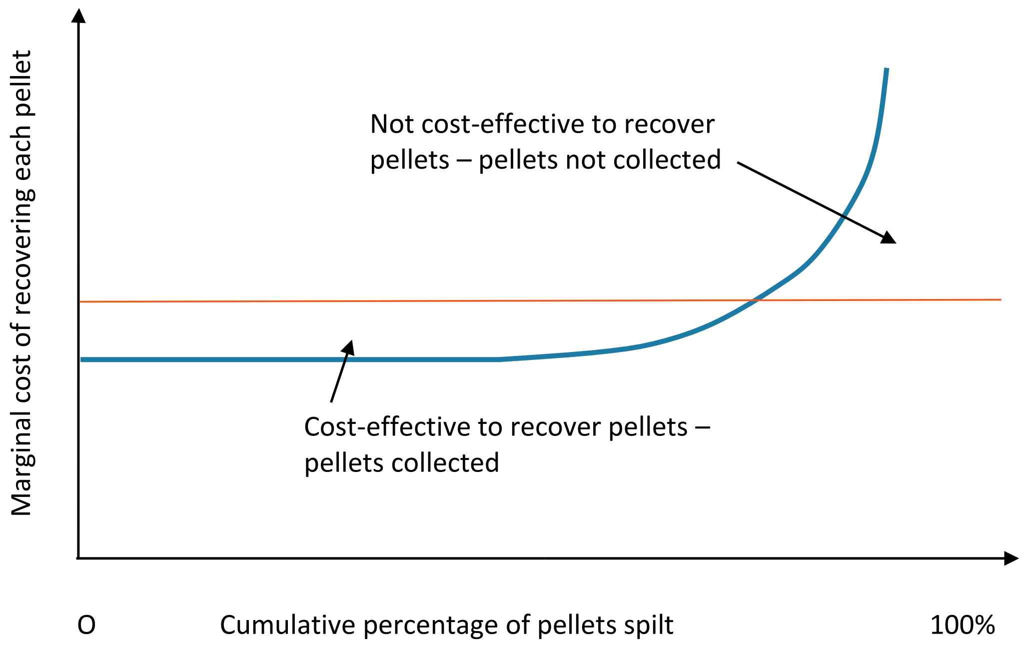
1) Firstly, the health and safety concerns related to the possibility of staff slipping on spilled pellets will be considerably less significant on an external, gravel or indeed rough concrete or tarmac surface, than on a smooth factory floor; and
2) Secondly, pellets spilt outside are far less likely to be suitable for processing, due to contamination, than those spilt within the factory.[10] In such a case they will have lost

[10] Albeit we note that even where spilt *within* a factory, firms may choose to discard such pellets rather than risk contamination of their product.

their value as a feedstock, and would instead have to be appropriately discarded as waste.

It is therefore considerably more likely that a larger proportion of pellets spilt outside will remain uncollected compared to a spill that takes place within a factory.

Figure 2: Diminishing Cost-effectiveness of Pellet Recovery outside a Factory



Please note that the red and blue lines are illustrative of an effect, and should not be interpreted to suggest an actual proportion of pellets that remain uncollected after an individual spill

3.4.2 Feedstock Value

Even in the case where spilt pellets are not considered too contaminated for inclusion in processing, and thus retain their potential value as a feedstock, it is worth reflecting a little on the scale of that value.

Taking the headline figure of a feedstock price of £2,000/tonne, on the basis that there are 50,000 pellets per kg, a tonne would contain 50 million pellets. This means that 25,000 pellets are worth £1, and thus 250 pellets are worth 1 pence. It is therefore clear that the feedstock value itself does not present a significant incentive to recover all individual pellets, particularly when spilt outdoors.

In summary, the feedstock, in overall terms *is* a costly input for processors, and does have some considerable value. Systems will therefore be designed to seek to minimise loss of pellets, but the rational firm will incur expenditure on such effort only up to the point just before the marginal costs of doing so start to exceed the benefits (which will of course include consideration of health and safety aspects plus feedstock value). The estimates calculated later in this report suggest that losses may only represent a hundredth to a tenth of a percent of the total tonnage handled at each site, but as so much plastic material is handled across the whole industry this equates to billions of pellets.

However, staff time is also a costly input, and as illustrated in the examples above, there will be a point at which the marginal costs to the firm of cleaning up pellets exceed the marginal private benefits.

The same applies to measures to *prevent* spills from happening. It is in the interests of the facility to prevent spills, as it can lose valuable feedstock and will then have to spend additional resources on cleaning up the spills. However, there are again limits to what it makes sense to spend on such measures from the firm's perspective.

The argument, therefore, that firms will not want to lose pellets, as they represent 'valuable feedstock', only holds true up to a point. It is beyond this point that additional incentives, such as the threat of enforcement, are required in order to further minimise the amount of pellets lost at each facility.

4.0 How Many Pellets are Lost Each Year?

4.1.1 Summary of Estimates from Existing Studies

Published estimates of pellet loss are reviewed in Appendix A.1.0. Based on this analysis, the figures for pellet loss at processors in a study published by Mepex (0.04%) and the Danish EPA study (0.001% - 0.01%) would appear to be the most reliable. Unfortunately these estimates also have their flaws. The Mepex figure is an estimate from just one processor and was not directly measured. The Danish EPA study is:

- Based on estimates from a handful of processors;
- Not directly measured;
- Is for OCS facilities which may be better performing than most at pellet containment; and
- Because there is no information on the effectiveness of OCS the basis for adjusting this for the average facility is just the author's best guess.

There is only one estimate for losses from transport and as it is derived from data on powders rather than pellets it is not applicable to this study.

4.2 New Data and Analysis

4.2.1 UK Industry Source

The Scottish plastics processor contacted for this study commented that they had seen significant pellet spills at various facilities. They described a 'significant quantity' as a 25kg bag of pellets spread over an area of 30m^2, and that this was the worst that they'd seen. They further commented that if they were to inspect their own yard at any point then they could pick up half a kilo to a kilo of pellets from the ground, and that this is quite a normal quantity to have in a yard area where pellet handling takes place. Indeed, this processor is actively involved in reducing pellet loss, is a signee of OCS, and sustainability is a cornerstone of their USP. They commented that spills inside the facility are contained and cleaned up so losses from these spills are mainly dependent on how the spilt pellets are managed as waste, which could contribute to the spills and losses observed outside the plants.

Whilst this information comes from just one very candid source, they have over 30 years' experience in the industry working for different manufacturers and have visited numerous other processors and compounders. When asked to estimate typical pellet losses at a facility they answered that a 'good' facility handling a similar tonnage of raw plastic to their own would lose 10 kg a year into the drains, based on the drains on their own site and others they have seen. On any day this would mean around 2kg accumulated on the ground and about 50g in the watercourse. A very 'bad' site would typically lose a few hundred kilograms of pellets a year to the drains. The processor then calculated what percentage of raw materials this relates to and was surprised at how low it was, but confirmed that their original estimates were still accurate.

The processor in question handles 3,200 T a year of raw plastic, and only in pellet form. To find a range of pellet loss we assume the highest figure, a few 100 kilograms per year, to be 300 kg per year in the worst case scenario. **The estimates of pellet loss at a facility therefore equate to 0.0003% to 0.009% of pellets purchased**.

4.2.2 Algalita Study

The Algalita study inspected various plastics processors around two watersheds in California with the permission of the owners.[11] The inspections were undertaken during a 'wet season' (greater than 0.25" of rain per day) and 'dry season' (at least two weeks after a rain event of 0.25" of rain). Samples were taken from the grounds where there would be potential for runoff and the debris would have the possibility to reach the storm drain system, as well as from storm drain inserts. No samples were taken inside the facilities. Care was taken to select a range of sites in terms of potential for pellet loss, based on an initial visual assessment of a large number of facilities. All visits to the facilities were unannounced. Samples were taken upon initial contact and some months after the Algalita team suggested some BMPs, mostly taken from OCS, to tackle the specific pellet loss issues at each site. For the purposes of this study we only consider the pre-BMP samples, as most UK facilities have not joined OCS. The results of the 'dry season' measurements are summarised in Table 1.

[11] Moore, C.J., Lattin, G.L., and Zellers, A.F. (2005) Measuring the effectiveness of voluntary plastic industry efforts: AMRF'S analysis of Operation Clean Sweep, 2005, http://www.algalita.org/wp-content/uploads/2014/05/Measuring-Effectiveness-of-Voluntary-Indust.-Efforts2.pdf

Table 1: Summary of Pellet Monitoring at Facilities in California [12]

	Producers (n = 8)		Storage and Transport (n = 2)	
	Pellets found on site	Pellet loss (storm drain insert)	Pellets found on site	Pellet loss (storm drain insert)
Lowest, pellets	8,714	0	16,307	4,145
kg	*0.2*	*0.0*	*0.3*	*0.1*
Highest, pellets	28,049,796	117,969	221,925	65,861
kg	*561.0*	*2.4*	*4.4*	*1.3*
Average, pellets	5,304,876	18,990	119,116	35,003
kg	*106.1*	*0.4*	*2.4*	*0.7*

These measurements represent the stock of pellets that have accumulated since those areas were last cleared.

In the case of the pellets found on the sites it is likely that these represent both recent spills that haven't been cleared up at all, as well as the remains of spills that were previously partially cleaned up. (i.e. where some pellets were overlooked, but were not transported off the site or into the drains).

Pellets found in the storm drain inserts represent pellets that have accumulated since the inserts were last emptied. In storm conditions, all catch basin inserts were either removed to prevent flooding or overflowed into the storm drain system. In the worst case, therefore, these readings would have been taken only two weeks after the previous wet season. The annualised results for this worst case scenario are shown in Table 2.

The processor sites produced a variety of items using a range of processes. One of the storage and transport facilities transported pellets to processors by truck and the other was a trans-shipping and storage facility for pellets, principally coming from abroad via container ship. Far more pellets were found at the transhipping facility than at the trucking company site. **As shown in Table 2, the Algalita study suggests a worst case scenario of 0 to 61 kg of pellet loss per year at plastic processor facilities and 2kg to 34kg of pellet loss per year at storage and transport facilities for the sites sampled.** The report does not state the tonnage of pre-production plastic handled at each site and so a 'rate of pellet loss' cannot be calculated.

[12] Pre-BMP measurements taken during a 'dry season'. Moore, C.J., Lattin, G.L., and Zellers, A.F. (2005) Measuring the effectiveness of voluntary plastic industry efforts: AMRF'S analysis of Operation Clean Sweep, 2005, http://www.algalita.org/wp-content/uploads/2014/05/Measuring-Effectiveness-of-Voluntary-Indust.-Efforts2.pdf

Table 2: Annualised Pellet Monitoring at Facilities in California, Worst Case Scenario [13]

	Processor (n = 8)		Storage and Transport (n = 2)	
	Pellets found on site	**Pellet loss (storm drain insert)**	**Pellets found on site**	**Pellet loss (storm drain insert)**
Lowest, pellets	226,564	0	423,982	107,770
kg	*4.5*	*0.0*	*8.5*	*2.2*
Highest, pellets	729,294,696	3,067,194	5,770,050	1,712,386
kg	*14,585.9*	*61.3*	*115.4*	*34.2*
Average, pellets	137,926,773	493,740	3,097,016	910,078
kg	*2,758.5*	*9.9*	*61.9*	*18.2*

It would be difficult to determine how applicable these results are to the UK. To do so would require that someone familiar with UK facilities either visit these sites or review the inspection reports. Furthermore, the sites that participated in the study are somewhat self-selecting, given that they voluntarily agreed to a third party measuring this pollution at their facilities. However, since these are one of the very few examples of direct measurements of spills and pellet losses at facilities they provide a valuable insight.

4.2.3 Comparison of Results

It is interesting to compare these results to the estimates from the UK processor contacted for this study. The UK processor estimated that a good site would only lose 10 kg a year to the drains, whereas the Algalita results found that one site had no pellets in the storm drain insert. This Algalita study site had a fairly low number of pellets found on the site, and on the return visit, following suggestions for BMPs, only 167 pellets were found in the storm drain insert. The total tonnage of plastic handled by the site over this period is not known, and the conclusions that can be drawn from two ‘snapshots’ of a facility that has volunteered to be inspected are limited; but this result is encouraging in that it suggests that zero pellet loss, or near zero pellet loss, is possible.

The UK processor estimated that a very bad processor site would lose a few hundred kilograms a year while the Algalita results suggest the worst performer in their sample might only lose up to 61 kg a year. In fact, the average pellet loss in the Algalita study roughly

[13] Pre-BMP measurements taken during a ‘dry season’. Moore, C.J., Lattin, G.L., and Zellers, A.F. (2005) Measuring the effectiveness of voluntary plastic industry efforts: AMRF’S analysis of Operation Clean Sweep, 2005, http://www.algalita.org/wp-content/uploads/2014/05/Measuring-Effectiveness-of-Voluntary-Indust.-Efforts2.pdf

matches the UK processor's estimate for the best performing sites – 10 kg losses a year. The reason for this discrepancy is not clear and it is impossible to say which results are most representative of a typical facility in the UK.

There are only two transport and storage sites sampled, so the findings are less robust. The number of pellets found in storm drain inserts at these two sites falls within the bounds of the best and worst performing processor facilities. **Without better evidence the best assumption may be that a similar number of pellets are lost at transport and storage facilities as are lost at processors.**

A case study on waste reduction measures in a US plastics manufacturer provides some information on spills and losses of plastic pellets.[14] The company reports that in 1992, 248,500 pounds (lb) of resin pellets fell onto the floor while being loaded into process equipment. The company manufactures plastic sheeting and extruded plastic packaging for commercial, medical, food, construction and agricultural purposes, and produces 60 million pounds (lb) of product annually. **The rate of pellet spills when loading pellets into the process equipment is therefore 0.41%.**[15] Some facilities will be able to clean some of the spilt pellets and reuse them in their process, whilst others will not be able to do this due to their quality criteria and so will have to dispose of the spilt pellets. When stored for disposal onsite there is potential for pellet loss, as already identified in Section 3.1. The pellets which are not lost will be taken offsite by the contracted waste management firm, where further pellet loss may occur. The company also reports *up to* 5% of pellets remain in the cardboard boxes (called gaylords in the US) caught under the flaps, which are then stored for waste disposal. The same issue was mentioned by a UK processor contacted for this study. A quick calculation shows that 5% of pellets would exceed the company's total waste reported so the *average* quantity disposed of in this way is likely to be much lower, assuming that, as with the other reports of pellet loss, only a small proportion of these escape the waste container and are lost before the waste is collected and weighed. Comments on this issue presented in Section 3.1 suggest a few kilos of pellets may be left in a 1 T box, i.e. around 0.3% of the box contents.

4.3 Calculating a UK Pellet Loss Figure

4.3.1 Processors

In lieu of actual measurements of pellet loss from UK facilities we use the best information currently available, as reviewed in previous sections and appendices:

- The Mepex study finds pellet loss of 0.04% is measured at one Norwegian reprocessor.[16]
- The Danish EPA study uses estimates from OCS-signatory Danish processors that they lose a maximum of 0.001% of pellets at their facilities, and the study then

[14] *Plastics Manufacturer Reduces Waste through Good Housekeeping and Recycling*, accessed 28 January 2016, http://infohouse.p2ric.org/ref/17/16189.htm

[15] 248,500 / 60,000,000 = 0.41%

[16] Mepex (2014) *Sources of microplastic pollution to the marine environment*, Report for Norwegian Environment Agency, April 2014

multiplies this by 10 to estimate the pellet loss of an average (non-signatory) processor, giving 0.01% loss.

- A UK processor estimated for this study that pellet loss in the UK could range from 0.0003% to 0.009%.
- The Algalita study indicates 0 - 61 kg of pellet loss a year at the facilities inspected.[17] Information from the BPF suggests that UK processors handle 1,650 T of polymer on average. [18] If UK processors exhibited similar amounts of loss, this would equate to pellet loss of 0 to 0.004%.[19]

The estimates for pellet loss at processors that can be derived from the best, but rather limited sources, exhibit a considerable range. Each source has different strengths and weaknesses, and in the absence of actual measurements of pellet loss, all are useful in helping to inform estimates of the true rate of loss.

Some of the companies and organisations engaged in this project are adamant that no pellets are lost in the UK, whereas others report having seen significant pellet spills and some pellets entering drains at facilities, and indeed even at their own site where they say that environmental sustainability is a corporate priority. We assume that there is not zero pellet loss, given some of the reports we have received of pellet spills and losses when engaging those in the UK plastics industry, and that presence of pellets found on beaches and in estuaries is unlikely to solely originate from abroad and transport accidents.

Given this understanding, **the rate of pellet loss at plastic processor facilities in the UK is estimated to be 0.001% to 0.01% of pellets handled by processors.** The lower bound of this range assumes that every facility loses no more pellets than the Danish processors reported that they lost. The Danish EPA study assumes that the *average* facility loses ten times more than the best performing, but this provides the highest rate of pellet loss reviewed that can be used in this study. In lieu of better data we therefore use this estimate for the *worst* performing facility, i.e. the upper bound figure. This is not an unreasonable assumption given that the next largest estimate, provided by a Scottish processor, is very similar in magnitude.

The BPF reports that 4.8 million tonnes of plastic is processed by the UK plastics industry each year.[20] Not all raw plastic material is pellets as some is flake or powder, but it is thought that pellets make up by far the most common form of raw plastic in the UK. We assume that almost all the plastic used in the UK is pellets, and therefore use the BPF figures for plastic use as a proxy for plastic pellet use. Therefore, on the assumed rates of loss presented above **in the region of 48 to 480 T of plastic pellets are lost each year at UK plastics processors, equal to 2.4 to 24 billion pellets**.

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[17] Unfortunately the quantity of pellets handled by the facilities was not reported and so a rate of loss cannot be calculated based on the tonnage handled.

[18] *About The British Plastics Industry*, accessed 28 January 2016, http://www.bpf.co.uk/industry/default.aspx

[19] *About The British Plastics Industry*, accessed 28 January 2016, http://www.bpf.co.uk/industry/default.aspx

[20] *About The British Plastics Industry*, accessed 28 January 2016, http://www.bpf.co.uk/industry/default.aspx

4.3.2 Producers

The Scottish processor contacted for this study covers both processors and producers. No other estimate was found for pellet loss from producers. Given the limited data, and the similarity of handling and storage operations that might lead to pellet loss, we assume that the rate of pellet loss at producers is broadly the same as at processors, i.e. **0.001% to 0.01% of pellets produced**. The BPF estimates that 2.5 million tonnes of plastic is produced in the UK [21], which means that **25 to 250 T of plastic pellets are lost each year at UK plastics producers, equal to 1.3 to 13 billion pellets.**

4.3.3 Transport and Other Facilities

The UK plastics value chain can be complicated and the material can move around between different facilities: compounders, masterbatch makers, distributors, processors, and recyclers, with each movement and transferral of feedstock presenting potential for pellet loss. The number of handling points and journeys the average pellet makes is unknown.

No robust estimates of pellet loss from transporters were found in previous studies. The Algalita study inspected two storage and transport facilities: one supplying processors with pellets by truck and the other a transhipping and storage facility for pellets principally coming from abroad via container ship. Evidence from this very small sample suggests that the quantity of pellets lost at these facilities was very similar to that lost at the processors. Given an absence of better information, **we therefore use the same rate of pellet loss as for plastic processing facilities: 0.001% to 0.01% of pellets handled.**

Comtrade data shows that 3.6 million tonnes of raw plastic material was imported and 1.6 million tonnes was exported in 2014. This gives a net import of 2 million tonnes, which roughly matches the difference between the amount of plastics produced in the UK (2.5 million tonnes) and the amount processed in the UK (4.8 million tonnes).[22] Most, but not all, of the material imported or exported will be contained in large steel tankers, similar to shipping containers. These containers are only likely to cause pellet loss when transferring them on and off the ship if there is a serious accident. We therefore make the conservative assumption that all material exported is loaded into a tanker at the producer's site (these losses are already covered by the producers estimate) and transported straight to the port where they are loaded onto the ship with no further losses.

However, imported feedstock may travel to a compounder, masterbatch maker, processor or other facility, be unloaded or repackaged, processed or stored, and then have several other journeys between facilities before being manufactured into a final product. Subtracting the export tonnage from the amount processed in the UK we find that 3.2 million tonnes may be making these additional journeys, requiring additional handling and therefore producing additional pellet loss not already covered by the previous estimates given in this report.

If the average pellet takes just one additional journey (with associated loading and unloading steps) this results in **32 to 320 T of pellet loss each year by storage and transport**

[21] *About The British Plastics Industry*, accessed 28 January 2016, http://www.bpf.co.uk/industry/default.aspx
[22] *About The British Plastics Industry*, accessed 28 January 2016, http://www.bpf.co.uk/industry/default.aspx

firms in the UK, equal to 1.6 to 16 billion pellets. The number of average journeys taken may be greater than this but we will use this estimate for the remainder of the report.

Catastrophic accidents resulting in large quantities of loss can receive a lot of publicity. The container spill in 2012 off the coast of Hong Kong dumped 150 T of pellets directly into the ocean.[23] However, given that the global trade in raw plastic material was 144 million tonnes that year[24] this only accounts for 1g per T of transboundary raw plastic transport that year, or 0.0001%. This is significant as it directly enters the ocean. However, applying this rate of loss to the tonnage of UK plastic imports and exports contributes very little to the overall estimate of pellet loss from UK industries.

4.3.4 Offsite Waste Management

Even less is known about loss of waste pellets during transport offsite, storage and eventually disposal, as they represent such as small fraction of the waste stream they are never counted or monitored. For the purposes of this study we assume that the facilities' waste may be transported to a waste transfer facility, or directly to a recycling or disposal facility. If taken to a waste transfer facility, straight to a compounder for recycling or to a materials recycling facility (MRF) for sorting then opportunity for further pellet loss is likely to occur in similar ways to those identified at processors and transporters. These facilities will receive the waste, typically outside or in an open but roofed area, unload the waste from the transportation container, possibly into a pile on the floor, or directly into another container or into the facility's process. The waste will be handled over hard surfaces and storm drains will discharge rainwater from the site. **We therefore apply the same rate of pellet loss to these sites as we do to processors, producers and transporters**.

We can estimate the amount of pellets handled by waste management companies more accurately. The Algalita study in California suggests that pellet spills range from 4.5 kg to 14.6 T per annum on the outside areas of facilities inspected, where there would be a potential for runoff and the debris would have a possibility to reach the storm drain system.[25] The large range in these figures is probably related to the sampling method whereby spot-checks represent 'snapshots' of each facility, and may also be linked to differences in tonnages handled – which are not reported in the Algalita study.

Information from the BPF suggests that UK processors handle 1,650 T of polymer on average[26], and so these spills would represent 0.0003% to 0.88% of their raw plastic consumption. Reports from one plant in the US of spills inside the facility when loading pellets into the process equipment suggest such spills may account for 0.41% of pellets purchased. Combining these two key spillage points gives an estimate of pellet spills of 0.41% to 1.30%. In some plants these spilt pellets can be cleaned and reused whereas in

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[23] (2012) *Hong Kong government criticized over plastic spill on beaches*, accessed 10 February 2016, http://www.reuters.com/article/us-hongkong-spill-idUSBRE87306J20120805
[24] Comtrade data.
[25] Pre-BMP measurements taken during a 'dry season'. Moore, C.J., Lattin, G.L., and Zellers, A.F. (2005) Measuring the effectiveness of voluntary plastic industry efforts: AMRF'S analysis of Operation Clean Sweep, 2005, http://www.algalita.org/wp-content/uploads/2014/05/Measuring-Effectiveness-of-Voluntary-Indust.-Efforts2.pdf
[26] *About The British Plastics Industry*, accessed 28 January 2016, http://www.bpf.co.uk/industry/default.aspx

others all will need to be disposed of as waste. We therefore assume that spills may result in 0 to 1.30% of pellets being stored for disposal.

As already discussed, some of these will leak from the disposal storage container and be lost but these losses are also thought to be a fraction of a percent, and so when they are subtracted there remains 0 to 1.30% of pellets which are transferred offsite for waste management. The tonnage of plastic raw material handled is 4.8 million tonnes at processors, 2.5 million tonnes at producers, and 3.2 million tonnes at transport and other facilities, meaning that a total 10.5 million tonnes passes through these companies, all of which may produce waste from spills and accidents. Of these, 0 to 1.30% will be transferred offsite for waste management, and of those 0.001 to 0.01% will be lost by the waste management facilities. The waste pellets will therefore be in the order of **0 to 4 T of pellet loss each year by waste management firms in the UK, equal to 0 to 0.2 billion pellets.**

4.4 Total Pellet Losses in Scotland and the UK

The estimates of annual pellet loss by different parts of the plastics value chain are collated and summed in Table 3 and Table 4, showing that roughly **105 to 1,054 T of pellet loss each year in the UK, equal to 5 to 53 billion pellets.**

Table 3: Estimates of Annual Plastic Pellet Loss from UK Industries, by Weight

	Low pellet loss estimate, T	High pellet loss estimate, T
Producers	25	250
Transport and Other Facilities	32	320
Processors	48	480
Waste Management	0	4
Total	105	1,054

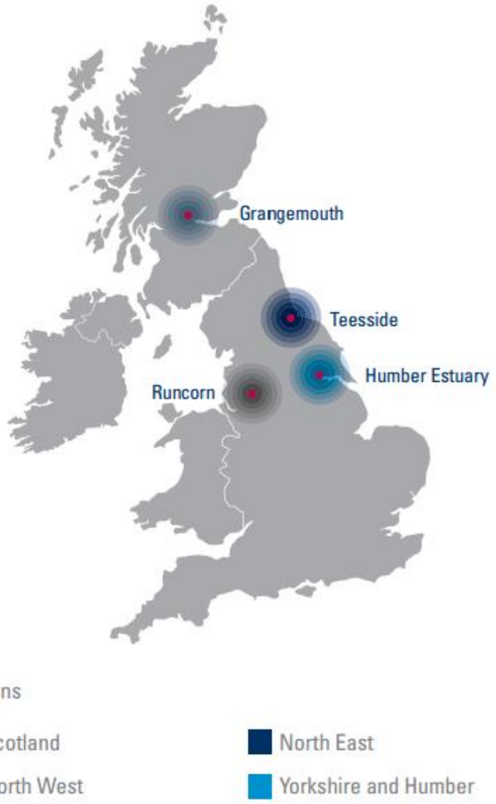
Table 4: Estimates of Annual Plastic Pellet Loss from UK Industries, by Number of Pellets

	Low pellet loss estimate, billion pellets	High pellet loss estimate, billion pellets
Producers	1.3	13
Transport and Other Facilities	1.6	16
Processors	2.4	24
Waste Management	0.0	0.2
Total	5.3	53

The BPF and Plastics Europe were unable to provide details on the size, location and nature of individual plants, reporting that their members typically consider such information confidential. Such analysis may be possible using other sources, such as the companies' SIC codes registered with Companies House, but the reliability of this data would need to be tested first. UK Trade & Investment report that 15% of the UK chemicals industry is located in Scotland and generates £9.3 billion in revenue.[27] One of the four key chemical clusters in the UK, shown in Figure 3, is in Grangemouth in Scotland, located on the banks of the Firth of Forth around 20 miles upstream from the Forth Bridge. It may well be that many of the plastic pellets found in the Firth of Forth originate from the Grangemouth hub.

[27] UK Trade and Investment *Chemicals - the UK advantage*, http://www.cia.org.uk/Portals/0/downloads_pdf_1_Chemicals-Brochure-FINAL-JAN-09.pdf

Figure 3: Four Key UK Chemical Clusters[28]



On this basis we assume that, mirroring the chemicals industry, 15% of plastics industry is located in Scotland. What this means in terms of Scottish pellet loss is shown in Table 5 and Table 6.

Table 5: Estimates of Annual Plastic Pellet Loss from Scottish Industries, by Weight

	Low pellet loss estimate, T	High pellet loss estimate, T
Producers	3.8	37.5
Transport and Other Facilities	4.8	48.0
Processors	7.2	72.0
Waste Management	0.0	0.6
Total	15.8	158.1

28 UK Trade and Investment *Chemicals - the UK advantage*, http://www.cia.org.uk/Portals/0/downloads_pdf_1_Chemicals-Brochure-FINAL-JAN-09.pdf

Table 6: Estimates of Annual Plastic Pellet Loss from Scottish Industries, by Number of Pellets

	Low pellet loss estimate, billion pellets	High pellet loss estimate, billion pellets
Producers	0.2	1.9
Transport and Other Facilities	0.2	2.4
Processors	0.4	3.6
Waste Management	0.0	0.03
Total	0.8	7.9

4.5 Putting the Results in Context

This study finds that between 105 and 1,054 tonnes of pellets are lost to the environment from UK industries each year. This equates to three and a half 30 tonne tanker loads of pellets being lost to the wider environment each year, or in the worst case scenario 35 tanker loads every year. In Scotland alone this equates to somewhere between half a tanker load and five tanker loads of pellets lost each year.

In 2012 the container spill off the coast of Hong Kong dumped 150 tonnes of pellets into the ocean. Many of these pellets were washed onto beaches, resembling piles of white snow as shown in Figure 4. The company that owned the pellets, Sinopec Corp., contributed the equivalent of £820,000 towards the cleanup effort.[29] [30] Each year UK industries lose somewhere between 70% of the amount lost in this single container spill incident, and seven times the amount lost. It is impossible to estimate to a reasonable degree of accuracy the potential cost of cleaning up all pellets lost in the UK each year. The losses are likely to come from a slow trickle of pellets from many sources that are then widely distributed and thus large piles of pellets are not found in one place, as was the case with the Hong Kong spill. This would therefore make potential clean-up efforts significantly more costly per pellet lost than in the Hong Kong example.

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[29] *Hong Kong Plastic Pellets Spill: Sinopec Vows To Clean Up Beaches*, accessed 10 February 2016, http://www.huffingtonpost.com/2012/08/10/hong-kong-plastic-pellets-spill_n_1759119.html

[30] HK$10 million, historic exchange rates for August 2012 obtained from xe.com, costs were not inflated to present day values.

Figure 4: Pellets from the 2012 container spill washed onto Hong Kong's Lamma Island[31]

5.0 Summary

This study finds that there are very few reliable estimates of pellet loss in Scotland and the UK, and no direct measurements at all. Using the best available information we estimate that only fractions of a percent of pellets handled by each company are lost to the wider environment. However, the tonnage of plastic handled is so large that these fractions of a percent result in billions of pellets being lost each year. In the absence of evidence to suggest that the rate of pellet loss is greater at any one type of facility, the total amount of pellets lost calculated for different parts of the plastics value chain depends on the tonnage handled. In the estimates provided, processors are responsible for the greatest quantity of pellets lost, but this could change if, for example, further information revealed that pellets are transported and handled at more points between production and point of use.

We do not attempt to calculate how many pellets then enter rivers and are transported to the ocean, but it is likely that many eventually make their way into the marine environment where they are known to cause significant harm. We do, however, show that pellet spills from catastrophic accidents covered in international news stories, such as the shipping accident near Hong Kong in 2012, are significant when compared with the amount lost by UK industries on land, but portion of this that is related to UK imports and exports is likely to be, on average, very small.

[31] (2012) *Hong Kong government criticized over plastic spill on beaches*, accessed 10 February 2016, http://www.reuters.com/article/us-hongkong-spill-idUSBRE87306J20120805

This study focuses on plastic pellets lost, and therefore does not include powders or flake in the estimates. Although only a small quantity of these materials are thought to be handled in the UK it is likely that they have a higher rate of loss as they are much smaller particles. These types of plastic may require additional research and should certainly be considered wherever possible in planning measures to reduce plastic losses.

6.0 Conclusions and Recommendations

This study constructs a framework by which pellet losses from UK industries can be calculated. Existing evidence is used to provide reasoned estimates of loss, presented in ranges. However, much could be done to improve the accuracy of these estimates.

6.1 Address Information Gaps

There are many areas where the plastics industry and others can work to provide more accurate information in order to improve the estimates of pellet loss. The key information gaps are summarised in Table 7. We recommend that Fidra works with the plastics industry and other stakeholders identified in Table 7 to fill these information gaps. The priority of the information gaps to address will depend on Fidra’s aims and objectives, for example whether it is deemed more important to improve the accuracy of the pellet loss estimate by country or source, or whether it is more important to include other sources of loss such as pellets not directly entering drains or other types of pre-production plastic such as powder and flake.

Table 7: Summary of Key Information Gaps

Information Item	Uncertainty	How to Improve	Effect on Estimate of Pellet Loss
Number of pellets produced and processed	Uncertain what proportion of pre-production plastics are pellets, flake or powder – although it is known that the proportion that is pellets is 'very high'.	Producers and Importers may be able to provide enough information to derive a Scottish and UK estimate.	In this study we assume that all pre-production plastic is pellets (using tonnages reported by the BPF). Further information would likely reduce the estimates of pellet loss by a maximum of 20%, but as other forms of plastic are harder to handle, the total amount of *all* plastic lost would most likely increase.
Number of pellets lost in road transport accidents	Not known at all.	The road haulage industry or national statistics on accidents may be able to provide the necessary information.	This is not included in the current estimate. However, the quantities are likely to be small.
Rate of pellet loss at processors	There are no direct measurements of sites in the UK. Most estimates are in a similar order of magnitude.	Systematic, independent sampling of facilities.	Direct measurements would vastly improve accuracy and confidence in the current estimate. It is difficult to estimate how different new data may be from current estimates but it is unlikely to be more than an order of magnitude difference.
Rate of pellet loss at producers and other facilities	Most current estimates of loss are for processors only.	Independent, evidence based estimates for each type of facility would be better but direct measurements would be best.	Same as above.
Number of facilities handling each pellet / journeys made on average by pellets	Not known at all.	The road haulage industry may be able to provide the necessary information. The plastics industry is unlikely to be able to provide this information.	This could increase the magnitude of losses at 'intermediary facilities' (i.e. not producers or processors) by several factors. This would make the overall estimate of pellet loss more detailed but also clarify which businesses are handling pellets the most and therefore where the greatest losses may occur.

Information Item	Uncertainty	How to Improve	Effect on Estimate of Pellet Loss
The location, size and nature of plastics facilities in Scotland and the UK	It is surprising how little is known about the location, size and nature of plastics facilities in Scotland and the UK.	A survey of industry, anonymised where necessary, could be conducted of the members of industry bodies and combined with other data sources.	Further research in this area would not only improve the estimates of pellet loss, but also help to engage the industry and steer actions to prevent losses.
Number of pellets lost, but that do not enter drains onsite, i.e. the pellets that are lost into areas such as grasses and public streets	This has been largely ignored by current research, except for occasional reports of finding pellets along fence-lines and kerbs outside facilities.	Direct measurement of this type of pellet loss at UK facilities.	Adding this type of pellet loss would increase the overall figure but it is impossible to estimate the size of the impact it would have.

6.2 Working with the Plastics Industry

The estimates presented in this report show that plastic pellet loss could be considerable and will add to the already rising public concern around this issue. The fact that the plastics industry does not know how many pellets are lost, where they are lost and who is responsible for the losses may not be viewed by many as acceptable. The plastics industry's own programme to reduce pellet loss, Operation Clean Sweep, is increasingly being adopted by some of the larger plastics companies around the world. However, as the plastics industry does not know how effective this programme is at preventing pellet loss it cannot (yet) be considered an effective means of tackling this problem.

Indeed, most of the stakeholders contacted for this study, including some within the plastics industry, commented that in many cases it is *not* effective or that it results in no change of practice in the company joining the programme.[32] This is not to say that the measures contained within the Operation Clean Sweep manual are not effective – but that signing the pledge does not ensure that these measures are effectively implemented. The Algalita study was inconclusive on this point, but raised some serious concerns about the effectiveness of OCS, and Mr Seidner (of the California State Water Resources Control Board) found that of sites inspected in California that had an OCS poster on a wall, only about 60% were following all OCS procedures.[33]

It would be in the best interest of the public and the plastics industry if the effectiveness of Operation Clean Sweep were independently evaluated. This would have a number of far reaching benefits:

- The reasons for OCS being ineffective in some facilities can be addressed.
- Proving the effectiveness of OCS will entice others to join OCS, and for all those signing the pledge to adopt the best management practices to the best of their abilities.
- In evaluating the effectiveness of OCS it is necessary to establish the quantity of pellets lost at a site before a firm signs up to OCS and the quantity they lose after subsequently joining OCS. If this monitoring is designed correctly it can provide the first actual measurements of pellet loss at UK facilities, and can be used to update the estimates of loss in this study. This will provide a much more accurate idea of the scale of the problem and will in turn help to prioritise action to address this issue.
- The monitoring of sites can be designed to determine if certain facilities are likely to lose more pellets than others, determined by their size, process, product or other factors. If this is found to be true then it will help to target pellet reduction

[32] The BPF has responded to this point by indicating that where signing up to OCS results in no change of practice, this will be due to the fact that the signatory already has very efficient systems in place.

[33] The sites inspected by the California State Water Resources Control Board are not a representative sample, but this suggests the BMPs in OCS are often not effectively implemented.

efforts to tackle the biggest emitters first, thereby improving the cost-effectiveness of such actions.

It is recommended that the plastics industry invest in an independent evaluation of Operation Clean Sweep involving direct monitoring of sites with the considerations listed above. It would be best if the evaluation were commissioned and managed by an interested and independent third party, such as Fidra, working in collaboration with the plastics industry to ensure that the validity and impartiality of the results are not called into question. The first logical step in undertaking this evaluation is to review the study of a similar nature undertaken by Algalita in California. Many lessons can be learnt from this study and no doubt Algalita will be able to provide further guidance on how to improve the methodology.

6.3 Establishing a Means for Enforcement and Prioritising Resources for Enforcement

Assembly Bill 258 introduced specific legislation on plastic debris in California in 2008. However, enforcement action for this issue was taken on violations of a site's General Permit for Industrial Storm Water Discharges Associated with Industrial Activities, which wasn't updated to reflect the Assembly Bill until 2015. The existing discharge permits were completely sufficient to allow the water board to inspect sites, issue notices of violation, outline steps needed to correct violations, and if necessary take further enforcement steps. It would be valuable to understand if enforcement action could be taken against facilities in the UK under existing permits and legislation.

The effect of Assembly Bill 258 was to focus attention on the issue of plastic debris, especially plastic pellets, in the waterways. As a result resource was allocated to inspecting sites and following up with enforcement action if necessary. It would be valuable to understand what efforts the EA and SEPA currently undertake on this issue, and what would prioritise the issue enough to allocate the necessary resources to enforcing it.

It may be that the enforcement agencies could work with other parties to share the responsibility and burden of enforcement activities. This might take the form of shared funding for these activities, or a way for the public to report suspected violations and provide information to support enforcement activities.

Funding for independent inspections could in fact come from the plastics industry itself in the form of a voluntary agreement, to show their determination to address the issue.

6.4 Other Ways to Quantify Pellet Loss

Plastic pellets are relatively small and can easily become buried in sand and sediment, making them hard to find. However, they are very easy to identify, and there is only one producer and consumer of plastic pellets: the plastics industry[34]. This is a rare property amongst types of marine debris as, for example, a plastic bottle could come from land or sea, and it could come from beach leisure activities, city litter transported out to sea, a fisher on a boat, or almost any conceivable source.

Fidra supports the public in monitoring plastic pellets found in the environment through the Great Nurdle Hunt programme and the results are presented on an interactive map with more than 220 sites currently represented. This citizen science is a popular way to gather data on marine debris and raise the profile of the issue at the same time. Monitoring of plastic pellets could be made more systematic and widespread by working with other organisations currently engaged in monitoring litter and marine debris.

The major voluntary beach clean surveys are the Ocean Conservancy's International Coastal Cleanup and the Marine Conservation Society's Great British Beach Clean. Both involve large numbers of volunteers to collect, classify and count each piece of debris before disposing of it. Currently neither scheme has a separate category to record the number of plastic pellets found, most likely as they can be buried in the sand and are hard to spot on a beach. However, a standard could be established with these organisations for finding, identifying and recording plastic pellets in a way that allows a direct comparison to other types of marine debris. This would help to further establish the scale of the plastic pellet problem.

Where this is considered too burdensome for a volunteer scheme it could be left out of the survey procedure – but even a handful of reliable surveys each year would be very valuable. Furthermore, searching for pellets could be a fun opportunity for citizen science, as reported by Captain Charles Moore of Algalita when he witnessed the cleanup efforts after the Hong Kong container spill:[35]

> *The young people cleaning the beach had been using colanders to sift the pellets out of the sand, but decided to invent a rotating screen that you put sand in one end and turn and have pellets coming out the other. Kids would turn it for fun for half an hour, so volunteer beach cleanup technology is advancing rapidly.*

6.5 Flakes, Powder and Related Sources of Plastic Emissions

Intuitively the smaller and lighter the particle the more difficult it will be to prevent and contain spills. When spilt, some materials will be transported by the wind, as well as surface water runoff. Inspections of facilities in California by Algalita found dust all around processing plants that handled this material – in the surrounding fields, on the fur of animals and even on the clothes of the inspectors.

[34] Although as discussed in this report, pellets can also be lost by those performing distribution or waste management services for the plastics industry.

[35] C.Moore, Algalita, On the ground at the site of largest plastic pellet spill in history, http://www.algalita.org/on-the-ground-at-the-site-of-largest-plastic-pellet-spill-in-history/

It is much harder to detect flakes and powders in the marine environment and impossible to distinguish them from other sources of microplastics, and so they may go largely undetected. Having smaller particle sizes, they will enter lower levels of the food chain than pellets, and there will be more individual particles per kilogram of plastic. This type of plastic pollution could therefore pose a very serious risk to the environment, even if much less tonnage is handled than pellets, and is worthy of further investigation.

Pellets and other plastic waste are sometimes reused by grinding the material and either producing new pellets, flake or powder or feeding the regrind directly back into the process. This can happen in closed-loop recycling procedures at producers and processors or at specialist recycling facilities. The regrind product, and emissions from the regrind process itself, also warrant further enquiry; and Mr Seidner highlighted regrind recycling facilities as particularly high-risk in terms of plastic emissions. Manufacturing processes also produce small-particle plastic waste, such as powders, flake, punch holes etc. and these can also be lost if not properly contained.

It is likely that the BMP recommended for handling pellets will not be sufficient for handling smaller particle size materials such as flake, powder and regrind. For example, it may be that these materials need to be unloaded and handled entirely indoors due to the difficulty in containing and cleaning up spills, or special management facilities put in place if the material can become airborne.

APPENDICES

A.1.0 Review of Existing Studies

There are no existing published estimates of the quantity of plastic pellets lost in the UK each year.[36].

A number of recent studies have estimated the quantity of pellets lost in other countries. The reports make an estimate of pellet losses based on the best available information but often report a lack of data and that the data that is available is of poor quality. These estimates are summarised in Table 8, and their reliability and suitability for application to the UK are discussed in more detail below.

Table 8: Summary of Estimates of Pellet Loss

Author and Year	Area of Study	Estimate of Pellet Loss	Basis of Estimate
Nova-Institut (2014) [37]	Germany	0.1 – 1.0% of total plastics production	Estimates of resource efficiency comparing how much raw material is needed to make a tonne of manufactured product.
Mepex (2014) [38]	Norway	0.09% of total plastics production, (0.05% from transport and 0.04% from processors)	The transport estimate is based on a previous emission factor for dust emissions from transferring solid powders and an assumption that 10% of this will not be contained by spill control measures. A Norwegian reprocessor provided the estimate of 0.04%.

[36] We asked the BPF and Plastics Europe for an estimate of losses across the industry or in individual facilities. They were not able to provide any such estimates, but noted that losses are "very small".
[37] Roland Essel, and et al. (2014) Sources of microplastics relevant to marine protection, Report for Federal Environment Agency (Germany), November 2014
[38] Mepex (2014) *Sources of microplastic pollution to the marine environment*, Report for Norwegian Environment Agency, April 2014

Author and Year	Area of Study	Estimate of Pellet Loss	Basis of Estimate
The Danish Environmental Protection Agency (2015) [39]	Denmark	On average 0.01% of raw material consumption at plastics facilities. Maximum 0.001% of raw material consumption for processors that have joined OCS.	Estimates provided by processors who have joined OCS in a survey undertaken by the Danish Plastics Federation. The figures represent loss to sewage from within the companies' area (incl. unloading from trucks that deliver raw materials). The authors adjust the potential for bias in the provision of this information by assuming the *average* facility will lose ten times as many pellets.
Boomerang Alliance (2015)	Australia	1% of domestic production, relating to nurdle loss in domestic production and transport.	The source of this estimate is not given in the paper.

[39] The Danish Environmental Protection Agency (2015) *Microplastics - Occurrence, effects and sources of releases to the environment in Denmark*, 2015

Author and Year	Area of Study	Estimate of Pellet Loss	Basis of Estimate
Eunomia (2015)	EU	0.04% losses of domestic production from production, of which 0 – 57% will be captured in waste water treatment. 0.05% losses of domestic production from transport, of which 10 – 50% will be captured in in some way before they reach the oceans.	Both pellet loss figures are taken from the Mepex study. The waste water capture is calculated from 63% of EU population being connected to tertiary waste water treatment. In the best case 90% of microplastics are captured in these facilities and in the worst case, no microplastics captured. Capture of losses from transport is an assumption reflecting the likelihood that pellet spills that occur during transport—especially oceanic—will not be captured in a waste water treatment system

A.1.1 Nova Institut

The Nova-Institut study gives two examples comparing the amount of raw material that plastics manufacturers need in order to make a tonne of manufactured product. One example shows that 0.89%[40] of material is lost, while the other shows a loss of 0.3%[41] during the manufacturing process. Following these examples, the authors assume that pellet loss in Europe is around 0.1% to 1.0% of total European plastics production. The examples are not stated to represent solely pellets lost to the environment and so one must presume that they include:

- Pellets which are spilt, cleaned up and then have to be discarded;
- Inefficiencies in the manufacturing processes including end products failing quality tests and other mistakes; and
- Offcuts and other waste.

[40] The paper states that in 1999 1,009 kg of raw material were needed to make 1,000 kg of manufactured product. Therefore 9kg is lost for every 1,009 kg used; a loss rate of 0.89%.
[41] The paper states that current figures for polypropylene indicate a yield of over 99.7%; a loss rate of 0.3%.

Indeed, the example presented in the paper shows that in 1964 16% of raw material was lost. It would be very hard to imagine that all of this was spilt pellets which are not properly cleaned up. Upon further investigation, the losses in one of the sources cited appears to be primarily due to waste gases from incineration rather than pellet losses. There is no indication that pellet loss has been considered when calculating these resource efficiency figures and so there is no justification for even using them as an 'upper bound' estimate of losses (including other losses such as waste). Whilst it is tempting to think that pellet losses could be measured simply by comparing the weight of the material bought to the weight of the final product it is unlikely this would be done with the precision necessary to capture the likely marginal losses that come about through pellet loss unless this was the specific aim of the monitoring exercise.

A.1.2 Mepex

The Mepex study bases the pellet loss estimate for transport on losses of solid powders given in an OECD report.[42] However, powders handle very differently to pellets and a much greater rate of loss is expected, as corroborated by the experience of Algalita visiting facilities in California.[43] Mepex states that this emission factor is a worst case scenario for what remains, or gets spilt, from transferring material from different transport containers. The authors found no evidence of the effectiveness of spill control measures for the transferral process, but assumed that 90% of spills would be contained and 10% would be lost to the environment. The basis for the estimate of pellet loss from processors appears to be more reliable. This figure is calculated from measurements of pellets found in effluent from a Norwegian polystyrene plant. However, this only represents data from one specific site.

A.1.3 Danish EPA

The Danish Environmental Protection Agency study reports that:

> *Data on spill percentages collected via the Danish Plastics Federation from companies that have joined Operation Clean Sweep indicate that loss to sewage from within the companies' area (incl. unloading from trucks that deliver raw materials) accounts for a maximum of about 0.001% of raw material consumption.*

The report notes that only nine out of 250 plastic processing companies in Denmark have joined the OCS programme. The survey answers are not based on actual measurements but instead represent estimates of losses in the respondents own facilities. As the survey was only answered by OCS signees the results most likely

[42] OECD (2009). EMISSION SCENARIO DOCUMENT ON ADHESIVE FORMULATION
[43] Personal correspondence with Algalita.

represent the better performing facilities in terms of preventing pellet loss. The authors attempt to adjust for this bias:

> *It is unknown to what extent the average emissions of all plastics companies in Denmark exceed this figure, but it is assumed that the average would not be more than 10 times higher than the highest values indicated in the Danish Plastics Federation survey.*

The average rate of pellet loss for all plastics companies used in the study is therefore 0.01% of raw material consumption.

A.1.4 Eunomia Report for DG Environment

The Eunomia report uses the Mepex estimates of pellet loss and is the first to then consider how many pellets may be captured before they enter the oceans, for example by tertiary waste water treatment. The waste water capture is calculated from 63% of EU population being connected to tertiary waste water treatment, in in the best case 90% of microplastics are captured in these facilities. Not all tertiary facilities will be able to provide such a high capture rate and leaching from sludge placed on land may also be a significant issue. On this basis, a worst case lower estimate of 0% capture was used to demonstrate the full range of the possible emissions.