Report

21st January 2016

Finfish Mortalities in Scotland

Project Code: 3RP005-502

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Executive Summary

Overview

Aquaculture is a growing industry in Scotland with farmed salmon being the largest food export from Scotland, accounting for around 40% of total value[1]. A natural consequence of finfish farming is fish mortalities (morts). Morts are normally classed as Category 2 animal by-products (ABPs) and must be disposed of in a safe and environmentally responsible manner in accordance with the Animal By-Product (Enforcement) (Scotland) Regulations 2013 (ABP(E)(S)). Examples of suitable disposal options are incineration, rendering, in vessel composting (IVC) or anaerobic digestion (AD), all of which must take place in plants approved under the ABP(E)(S) regulations or the Waste Incineration Directive.

In 2013, the Scottish Government implemented a derogation that allowed the disposal of ABPs by burning or burial on site or by other means under official supervision in remote areas. This meant that both terrestrial and aquatic mortalities generated within these ABP remote areas could be disposed at suitably supervised landfill sites. Since almost all fish farms in Scotland fall within these remote areas, some have taken the landfill option. However, the interpretation of this derogation has recently changed, and from 1st January 2016 it applied only to terrestrial livestock. Under this policy, the aquaculture industry now need to ensure that fish farms located within the ABP remote areas are disposing of their waste in accordance with ABP legislation i.e. it can no longer be disposed of in a landfill site. Although this may present some immediate logistical challenges to the aquaculture sector, it should also present a number of opportunities through valorization of aquaculture wastes.

This report:

- Provides evidence for suitable ABP compliant disposal routes for Scottish finfish farming waste
- Reviews the capacity already existing in Scotland to receive and utilise this material and the logistics involved for the individual solutions identified
- Identifies other options for adding further value to this waste

This report focuses on finfish farming and does not include aquaculture as a whole i.e. does not include molluscs, crustaceans or seaweed. It also does not include waste from fish processing facilities (usually Category 3 waste). The full report details each section more fully, however a summary of the research is provided below.

The Fish Farming Industry and the Scale of Mortalities

The marine aquaculture sector (fish farming industry), this has consolidated in recent years leaving only a few larger farmers: there are only 6 companies operating more than 10 sites and these together operate 89% of all the active sites. The majority of the farms produce Atlantic salmon, many together with cleaner fish (wrasse and lumpsuckers) which act as a biological control for sea lice. There is some marine trout production and there are 2 farms producing halibut. The freshwater rainbow trout sector has 33 operators and 46 active sites i.e.it is a highly unconsolidated industry.

As in other forms of animal production, aquaculture suffers stock mortalities (commonly referred to as morts). Since the majority of Scottish fish farm production is in the marine sector, this contributes the majority of the morts (Figure 1 below). On average, there are around 10,000 tonnes of morts from an average annual production of around 150,000 t, i.e. about 6.7%.

Marine trout production is ca. 1% of salmon production and has an average mortality rate of 5.6% of production. No data is collated and published on mortalities for freshwater production of any species.

[1] http://scottishsalmon.co.uk/exports/

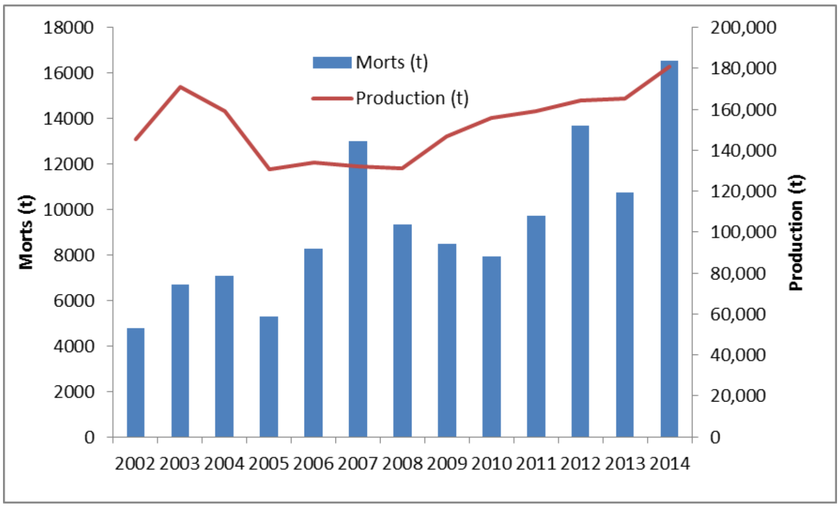

Figure 1 - Annual Scottish marine fish farm mortalities & production (Atlantic salmon & rainbow trout).

<u>Alternatives to landfill</u>

<u>Anaerobic Digestion and In Vessel Composting Capacity</u>

AD and IVC sites processing ABP material to European standard and approved to do so by APHA can accept and process Cat 2 fish mortalities. It is the duty of the fish farm to produce commercial documents that comply with the ABP legislation ensuring the haulier receives a copy and the original is supplied to the destination premises, the haulier should ensure that the documentation is in place. However, it should be noted that Cat 2 fish mortalities that are produced as a result of notifiable disease will need to be disposed of in compliance with the legislation that applies for that disease in addition to the ABP legislation. During the course of this report, questions have been raised that current pasteurisation processes used in AD and IVC facilities for Category 2 fish morts, may not meet the requirements of European regulations and from a hazard/risk assessment perspective may not be sufficient for managing the risks associated with fish pathogens. This has been discussed in detail with the Scottish Government which is content with its current position and interpretation.

In terms of managing fish farm morts, all seven operational ABP registered AD facilities in Scotland were contacted, suggesting that there is existing capacity to take the annual 10,000 tonnes of morts. One large AD facility stated that it could accept the entire annual tonnage of morts, whilst others stated that they could each accept a proportion. The Western Isles dry AD facility is currently unable to process morts, but this may change in the future. The Northern Isles face more of a challenge, and although AD options are actively being considered, these will take some time to come to fruition. On Shetland, the Energy from Waste (EfW) facility is reducing the quantity of fish farm waste that it takes, and this means that in the short-term morts from both Shetland and Orkney will need to be hauled to the mainland for disposal.

For IVC facilities, it is not clear whether there is capacity to take the annual tonnage of morts. Although five facilities indicated they had capacity to take additional waste, two were not able to quantify this spare capacity, whilst three facilities collectively could absorb 4,460 tonnes within their existing capacity.

<u>Incineration and Rendering Capacity</u>

Suitable incineration infrastructure in Scotland is extremely limited, with only one small-scale incinerator in Livingston able to take morts at the current time. This facility has not historically accepted fish mortalities, however has the necessary licences and capacity required to treat routine mortalities at what is understood to be very low levels. The potential associated with the energy from waste facility on Shetland is increasingly diminishing.

In addition, there are a number of smaller-scale, local options currently going through the planning process and recently (2015) permission has been granted for an incinerator on Benbecula capable of processing up to 10 tonnes / day, set up specifically to deal with the problem of processing fish mortalities close to source.

Cross-industry feedback suggests that significant quantities of fish farm morts are sent to Widnes for incineration, even where there are potentially lower cost options in Scotland (see Table 1 below). In the case of one haulier, the inability of two AD facilities in Scotland to confirm that they could accept Category 2 ABP (specifically, morts) led to Widnes being identified as the compliant option for processing this waste. The vast majority of fish mortalities currently being incinerated are transported to the SecAnim facility in Widnes, and this facility's operators have stated that it can process all of the fish farm morts produced in Scotland.

One rendering plant in Scotland has just begun to process Category 2 fish, and if the current trial is successful the rendered volumes will expand.

Haulage Capacity

As noted above it is the duty of the fish farm to produce commercial documents that comply with the ABP legislation ensuring the haulier receives a copy and the original is supplied to the destination premises, the haulier should ensure that the documentation is in place.

Transporting fish morts did not appear to pose a problem, although significant mass mortality events clearly put all parts of the supply chain under pressure. However, several hauliers could offer a service for mass and routine mort transport in the future, including a number of road hauliers that already haul routine morts.

Johnson Marine already provide a range of services to fish farms in Scotland, and are interested in developing services involving bulk haulage of fish farm mortalities by boat. Calmac may also be interested in diversifying their business model, to incorporate the haulage of fish farm mortalities.

Hordafor are able to offer a complete haulage service by boat, although they do not currently operate in Scotland, and infrastructure would need to be set up in order to offer a viable solution. Scanbio are in a similar position, but already have appropriately licensed storage infrastructure in Inverness. There could be potential for both Scanbio and / or Hordafor to pick up by boat from individual fish farms, with the boat making multiple stops.

The Norwegian System

In the future, there may be the potential to implement the Norwegian System as an alternative approach to haulage, or variations on this e.g. at a smaller scale to enable bulk pick-ups and possibly storage (ensiled) infrastructure for mass events. This system takes both Category2 and 3 fish waste and incorporates the following:

- Collection of dead fish on a daily basis
- Ground / chopped and mixed with formic acid pH≤4
- Storage pH≤4 at least 24 hours
- Particle size of less than10 mm (after filtration or maceration)
- Heat treatment: at least 85^{o} Celsius for at least 25 minutes

A variation on the Norwegian system could involve the continuation of sea haulage and road transport, but with the latter involving the movement of fish farm mortalities to a central treatment facility (rather than using a bulk carrying, sea-going vessel). The use of bulking and ensiling stations located at either Ullapool or Oban may present a more economically feasible means of hauling ensiled fish morts down to facilities in the central belt of Scotland, and dependent upon ensiling capacity, may offer an interim solution for mass events.

The Impacts on Rural Landfill Operators

Ten remote landfill site operators were contacted (using the most recent, SEPA, 2013 database) to quantify the economic impacts that will result from the change in regulations, prohibiting the landfilling of fish farm waste. The tonnages identified amount to approximately 23% of the estimated arisings of fish mortalities in the country, with the loss of income for Scottish landfill sites as a whole, shown to be £228,149.

The Costs to Fish Farmers Associated with the Loss of Landfill as a Disposal Option

The data generated from engagement across the haulage and treatment industries indicates that where companies are landfilling fish farm waste at licensed landfill sites, they are already able to secure lower cost contracts with more sustainable processes – and will be able to continue doing so once the landfill prohibition is in place. This applies to both routine mortalities and mass mortality events. The potential to reduce cost even includes hauling to the Widnes incinerator, with the exception of fish farm waste currently landfilled on Shetland. In this case, on the basis of currently installed infrastructure, a lower cost option would be dependent on the mainland AD and IVC infrastructure being able to take Shetland's fish farm waste. For the fish farms in all of the regions identified, lower cost options than hauling to Widnes for incineration are available, if the infrastructure is able to accept the waste.

Innovative Business Development Opportunities

A number of innovative technologies have been identified, as having potential for development in the future, as summarised below:

- Biodiesel production - the maximum amount of oil that could be produced from fish farm mortalities, from Scotland as a whole, would be 1,500 tonnes per annum (based on 10,000 tonnes of waste generated per annum).
- Alkaline hydrolysis – reduces biological material into a sterile aqueous solution,
- Dehydration – not currently used for morts, but a technology is being developed by Tidy Planet targeting this.
- Flymeals – Stirling University lead work in Scotland on incorporating fly larvae into animal feed. They are currently piloting insect-based approaches to deal with morts. Their trials utilise flies to break-down whole fish arising from routine mortalities, thereby removing the need to ensile fish and / or transport off-site.
- Small-scale niche markets: fish-skin leather, synthetic hydroxyapatite, vermiculture, mass seaweed culture.

Recommendations

1) A number of potential opportunities for the movement of fish farm waste more cost effectively (than is currently the case) have been identified. These involve establishing consolidation centres at different locations across the country. Cost-benefit analyses, business planning and pilot / demonstration projects could all be carried out to describe in detail the extent of the opportunities, issues and risks associated with such developments. There may be value in considering whether financial support to assist in taking forward such projects is a possibility.

2) There may be value in work being carried out to collate data currently being collected on smolt mortalities. Although the tonnages are considered to be significantly lower than the fish farm mortalities given in this report, they may also represent significant tonnages at a very local level, which could make a contribution to otherwise small-scale, resource efficiency projects.

3) Confirmation from the European Commission regarding the current treatment of fish farm mortalities in Scotland.

1 Introduction

Aquaculture is a growing industry in Scotland with the finfish sector being composed almost entirely of farmed Atlantic salmon (a member of the finfish family) which is the largest food export from Scotland, accounting for around 40% of total value[2]. A natural consequence of finfish farming is fish waste (mortalities). These fish morts are normally classed as Category 2 animal by-products (ABPs) and must be disposed of in a safe and environmentally responsible manner in accordance with the Animal By-Product (Enforcement) (Scotland) Regulations 2013 (ABP(E)(S)). Examples of suitable disposal options are incineration, rendering, in vessel composting or anaerobic digestion, all of which must take place in plants approved under the ABP(E)(S) regulations or the Waste Incineration Directive.

In 2013, the Scottish Government implemented a derogation that allows the disposal of ABPs by burning or burial on site or by other means under official supervision in remote areas. This meant that both terrestrial and aquatic mortalities generated within these ABP remote areas could be disposed at suitably supervised landfill sites. Since almost all of the fish farms in Scotland fall within these remote area, some have taken the landfill option. However, the interpretation of this derogation has changed, and from 1st January 2016 it applied only to terrestrial livestock. Under this policy, the aquaculture industry now need to ensure that fish farms located within the remote areas are disposing of their waste in accordance with ABP legislation i.e. it can no longer be disposed of in a landfill site. Although this may present some immediate logistical challenges to the aquaculture sector, it should also present a number of opportunities through valorization of aquaculture wastes.

This report focusses on finfish farming and does not extend its remit to include aquaculture as a whole i.e. does not include molluscs, crustaceans or seaweed. It also does not include waste from fish processing facilities (usually Category 3 waste). This report:

- Provides evidence for suitable ABP compliant disposal routes for Scottish finfish farming waste
- Reviews the capacity already existing in Scotland to receive and utilise this material and the logistics involved for the individual solutions identified.
- Identifies other options for adding further value to this waste.

In recent years there have been a number of significant developments in infrastructure in Scotland for the processing of animal by-products, delivering added value and potentially allowing fish farm waste to be managed higher up the waste hierarchy. These include the processes below:

- In-vessel composting – the aerobic, controlled processing of waste within an enclosed vessel to produce nutrient-rich compost which can substitute for more carbon intensive, imported inorganic fertilisers.
- Anaerobic digestion – the anaerobic (absence of oxygen) processing of waste to produce biogas (methane) which can either be used as a fuel or burned in a combined heat and power (CHP) plant to produce electricity and heat. The resulting digested material (digestate) can be used to substitute for imported, inorganic fertilisers.
- Rendering – the conversion of animal by-products into stable, value-added materials e.g. into purified fats like lard or tallow.
- Incineration – the thermal treatment of waste materials converting them into ash and gases, with useful heat and electricity produced.
- Biodiesel – the production of fuel from organic wastes and by-products from other industries.

To access fish farm mortalities for processing in the above technologies, the logistics have to be in place in terms of haulage, and a number of opportunities have been considered relating to road and ferry haulage and bulk movements by seagoing vessels.

[2] http://scottishsalmon.co.uk/exports/

2 The Finfish Aquaculture Industry in Scotland

2.1 Industry Overview

Farmed salmon is now one of Scotland's main export commodities and aquaculture contributes substantially to the country's economy. The long coastline of Scotland with its many inlets and islands are ideal locations for fish farms and Scotland is currently the largest producer of salmon in the EU and the third largest globally, producing 179,022 tonnes in 2014. Rainbow trout (5,882 tonnes), brown trout (48 tonnes) and halibut (66 tonnes) are also farmed in smaller quantities (Scottish Fish Farm Production Survey 2014). The estimated value of salmon was £677 million at farm gate prices (2013 data).

Scottish Government figures (2014) show mortality rates for salmon put to sea in 2012 at 14.6% by number (~6 million fish)[3]. Fish mortalities are normally classed as Category 2 animal by-products and must be disposed of in accordance with the Animal By-Product (Enforcement) (Scotland) Regulations 2013. On 1st January 2016, the Scottish Government amended the regulations to remove a previous derogation that had allowed the disposal of aquatic mortalities arising within ABP remote areas to be disposed of in suitably supervised landfill sites. Due to this amendment, alternative disposal and recovery options which move the material up the waste hierarchy needed to be considered, and form the basis of this report.

2.2 Active Marine Farms

The marine aquaculture sector has consolidated in recent years leaving only a few larger farmers: there are only 6 companies operating and these together operate 89% of all the active sites[4]. The majority of the farms produce Atlantic salmon, many together with cleaner fish (wrasse and lumpsuckers) which act as a biological control for sea lice. There is some marine trout production and there are 2 farms producing halibut which are land-based).

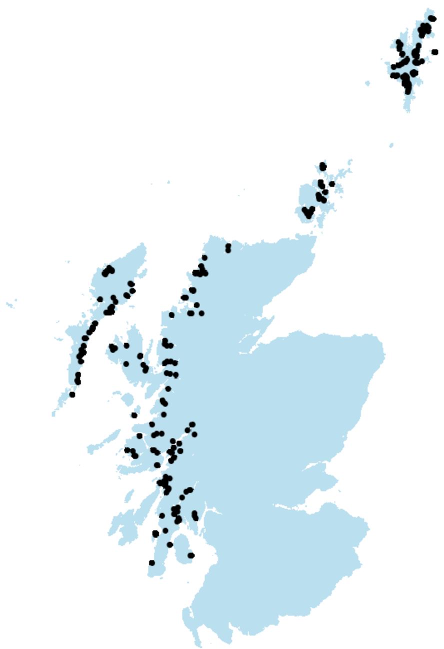

Figure 2: Distribution of Active Salmon Fish Farms in Scotland (2014)[5].

[3] Marine Scotland Science (2014), Scottish Fish Farm Production Survey
[4] The source for all production data in this section is the Scottish Government aquaculture database accessed online in September 2015. http://aquaculture.scotland.gov.uk/
[5] Marine Scotland Science, Scottish Fish Farm Production Survey 2014

2.3 Active Freshwater Atlantic Salmon Farms

Overall 32 companies operate 106 active salmon smolt sites. In general, these produce smolts for transfer to seawater. These fish are much smaller than salmon grown in the marine phase (~100g for a smolt; ~5-6kg for a harvestable salmon) although some of these hatcheries are very large and a disease event could in principle result in a significant biomass of mortalities. All of the major salmon producers also produce smolts and mortality data from freshwater farms is not collated.

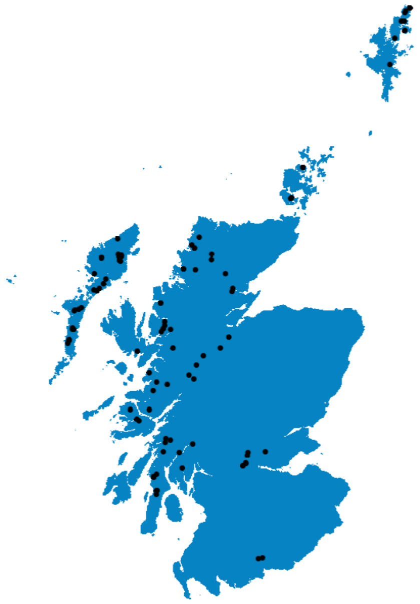

Figure 3. Distribution of Active Salmon Smolt Sites Operational in Scotland (2014)[6]

2.4 Active Rainbow Trout Farms

The freshwater rainbow trout sector has 33 operators and 46 active sites and is a highly unconsolidated industry. There are relatively few rainbow trout farms north of the Great Glen.

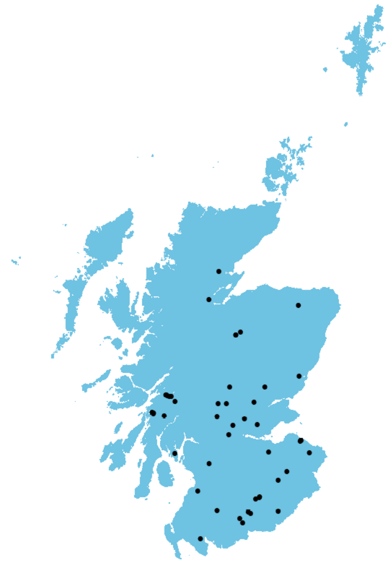

Figure 4. The Distribution of Active Rainbow Trout Sites in Scotland (2014)[7]

[6] Marine Scotland Science, Scottish Fish Farm Production Survey 2014
[7] Marine Scotland Science, Scottish Fish Farm Production Survey 2014

3 Fish Farm Mortalities in Scotland

3.1 Marine Farms

As in other forms of animal production, aquaculture suffers stock mortalities (commonly referred to as morts). The majority of Scottish fish farm production is in the marine sector which consequently contributes the majority of the morts (Figure 5). On average, there has been about 10,000 tonnes of morts from an average production of about 150,000 t, i.e. about 6.7%. Marine trout production is ca. 1% of salmon production and has an average mortality rate of 5.6% of production.

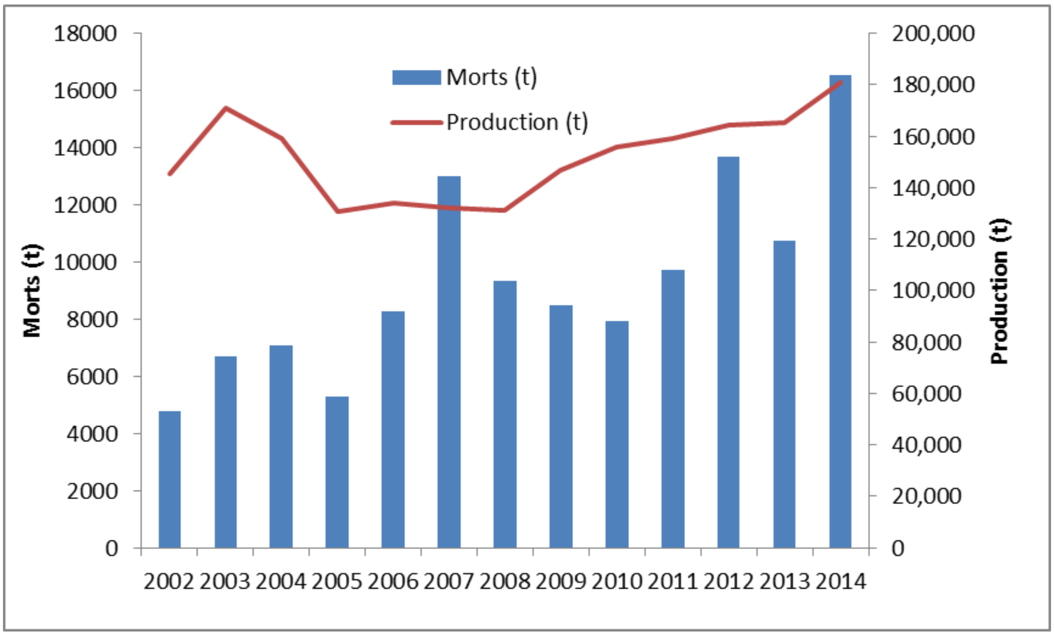

Figure 5. Annual Scottish marine fish farm mortalities & production[8] (Atlantic salmon & rainbow trout).

Another way of considering this is to look at the temporal trends in mortalities and mortalities normalised by production on the same figure. Figure 1 shows that although there is variation, probably caused by years where there were particular issues that caused higher than usual mortalities (e.g. 2007), there seems to be a general trend of both mortalities increasing with time and also with the proportion of production that is lost. In other words, increased production does not necessarily lead to increased mortalities in any one interval but, over the longer term, mortalities do increase both in absolute terms and as proportion of production. This is important given the strategic industry target of increasing the salmon sector to 210,000 t annual production by 2020[9].

However, it is worth remembering that several factors contribute to the mortality data. If all things were equal, we would expect an increase in mortalities with increased production as there are more potential disease hosts in the water. But all things are not equal both in terms of disease factors and improvements to farming that may reduce mortalities. For example, Amoebic Gill Disease (AGD) caused real problems for farmers in 2012 but less in subsequent years at least in part because of collaborative work on understanding the epidemiology and management of AGD (personal communication, industry source). New medicines, vaccines and husbandry practices (e.g. use of cleaner species for removal of sea lice) are introduced to prevent and reduce the impact of diseases on a regular basis. This makes extrapolating weak underlying trends into the future highly problematic.

[8] Production data was obtained from Scottish Fish Farm Survey reports. http://news.scotland.gov.uk/News/Scottish-Fish-Farm-Production-Survey-2014-1cbd.aspx#downloads
[9] http://www.gov.scot/Topics/marine/Fish-Shellfish

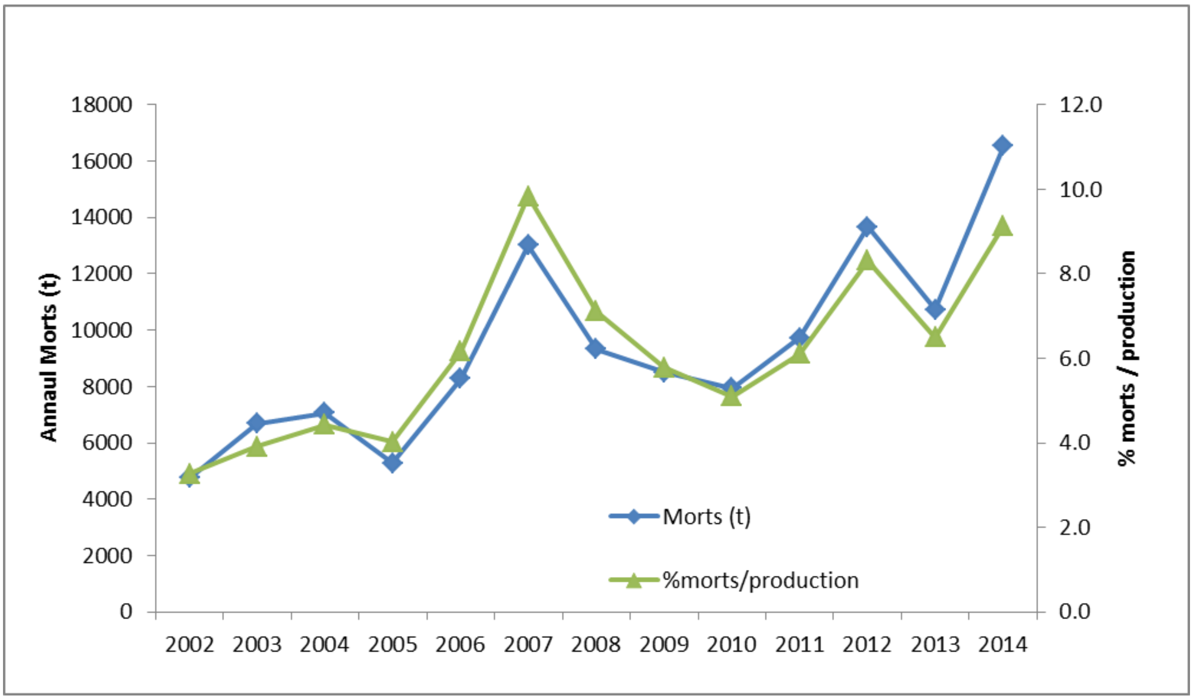

Figure 1. Trends in mortality and mortality normalised by production.

Individual monthly mortality records (2002 – 2015) for each marine farm vary between 565 tonnes and zero with the distribution of records shown in Table 1. The monthly mode is zero, the monthly median is 83 kg, and the monthly mean is 2.5 t. Almost half of the monthly returns are zero and 45,658 records are < 10 t, i.e. 95% of all records, which constitutes 38% of total morts biomass. This leaves the 5% which are >10 t accounting for 62% of morts biomass over the period.

Table 1. Frequency distribution of monthly mortality records for all marine sites in Scotland (2002 - 3/2015)

Monthly morts (t) class	Number of monthly records in class
0	22679
0 - 10	22979
10 - 50	2085
50 - 100	200
100.- 200	93
200 - 300	18
300 - 400	6
>400	3
Total records	**48063**

There is regional variation in average mortalities (2004-14, Table 2) with Highland and Argyll having lowest and Eilean Siar highest morts normalised by either feed or production.

Table 2. Average mortalities (t) by region and normalised by production (2002-14)

	Morts (t)	% of production
Argyll	1662	5.4
Eilean Siar	2252	8.8
Highland	2205	5.3
Orkney	581	8.1
Shetland	3298	8.0

NB Here and throughout, data from Argyll includes the farm in N Ayrshire and is equated with the SW production region in the production data.

3.2 Freshwater Production and Mortalities

Data on freshwater production of Atlantic salmon smolts is available in numbers of smolts only and not in terms of biomass. Trout production in freshwater is however reported as biomass (Figure 7). No data is collated and published on mortalities of freshwater production for any species.

Figure 7 Total Marine and Freshwater Rainbow Trout Production (2002-14). 2014 Data is Estimated.

4 Review of the Potential Processing and Logistics Infrastructure in Scotland for Managing Fish Farm Waste

4.1 Processing Fish Farm Waste through Existing AD and IVC Facilities

4.1.1 Objectives

The objective in this section is to review the potential capacity we have within Scotland to process fish farm waste through existing AD & IVC, considering the following:

- What percentage of the overall input at Scottish AD & IVC plants, could this fish waste represent (on an individual as well as collective basis, listed as a percentage and tonnage)?
- How much is known about processing this material through AD & IVC in a UK context i.e. with a mix of input materials including general food waste and not just co-digested with manures / slurries or crop residues?
- What is the likely inhibiting factor(s) if any?
- What mitigation methods could be employed to alleviate any inhibiting factors (include costs / process modifications and which industry this would impact: fish or organics' recycling)?
- Are there collection services which could undertake the transfer of this material to Scottish AD & IVC plants (volume, geographical location, ABP category etc.) – if not, why not?

The above has been examined through a combination of a literature review Stakeholder Engagement Results – Processing and Logistics Companies and Analysis of Processing and Logistics Infrastructure Data with full findings to be found in Appendix A.

4.2 Processing Fish Farm Waste through Rendering and Incineration Infrastructure

4.2.1 Objectives

The objective is to review the capacity within Scotland to process fish farm waste through incineration / rendering in terms of the following considerations:

- What percentage of fish farm waste could the Scottish incineration / rendering plants take?
- How much do we know about putting this material through incineration / rendering?
- What is the likely inhibiting factor(s) if any?
- What mitigation methods could be employed to alleviate any inhibiting factors (include costs and to which industry this would impact fish or reprocessors)?
- Are there collection services which could undertake the transfer of fish farm waste to incineration / rendering plants in Scotland (volume, geographical location, ABP category etc.) – if not, why not?

The above has been examined through a combination of literature / desk-based Stakeholder Engagement Results – Processing and Logistics Companies and Analysis of Processing and Logistics Infrastructure Data with full findings to be found in Appendix A.

5 Stakeholder Engagement Results – Processing and Logistics Companies

5.1 Overview

The stakeholder engagement aimed to obtain a representative sample of the aquaculture industry. The industry was targeted based on the following groupings, which have been adapted from the Scottish Government groupings, for consistency.

- Group 1: Trout
- Group 2: Freshwater Salmon (Smolts)
- Group 3: Seawater Salmon (broken down by region):
  - Group 3.1 Western Isles
  - Group 3.2 Northwest
  - Group 3.3. Shetland
  - Group 3.4 Orkney
  - Group 3.5 Southwest

5.2 Fish Farming Companies

5.2.1 Objectives

The objectives of this engagement were to determine:

- which companies or areas would be most affected by the removal of the derogation allowing landfill of farmed fish mortalities (morts)
- whether companies were likely to incur significantly increased costs as a consequence
- which disposal methods were presently used in the industry and the final disposal destination
- which logistical companies were used
- how mass mortality events were dealt with

5.2.2 Methods

A sample of fish farm companies with significant production share were selected for interview. From the Scottish salmon sector these included The Scottish Salmon Company, Marine Harvest (Scotland), Scottish Sea Farms, Grieg Seafoods and Cooke Aquaculture. From the trout sector, Dawnfresh was included. Although the focus was on the marine sector as this was the largest volume, the companies were also asked about practices at their freshwater sites.

The most appropriate individual was identified from each company by consultation on the basis of their knowledge of their company's activities with respect to morts. In some cases, this involved more than one person from a company. These individuals were then interviewed using a semi-structured method whereby a series of questions were asked to elicit the required information but there was sufficient flexibility to follow fruitful lines of discussion. The results of these interviews are presented below on the basis of general categories derived from both the questions and responses in order to produce a coherent narrative.

5.2.3 Results

5.2.3.1 Present Practices for Disposal of Morts

Farmers presently use a limited range of routine disposal options:

- Ensiling on site (i.e. maceration and acidification) followed by storage either in a tank on site, a tanker vehicle on-site (in Orkney only) or in Intermediate Bulk Containers (IBC) of 1 m^3 volume. Generally, farms have a licence from SEPA to store a maximum of 10 such IBCs on site. There will be occasions when this storage capacity is exceeded (during mass mortality events) in which case whole fish are moved off site as quickly as the logistics can be arranged.

- Storage, un-acidified, in a tanker vehicle at a central site serving several farms (Orkney only). This is then hauled to the mainland e.g. for anaerobic digestion.
- Incineration on-site (either at a land base or occasionally on a barge at sea) using a small scale incinerator. These are generally of less than or equal to 50kg/h processing capacity which falls below SEPA's regulatory threshold, are fuelled by diesel or oil and require. approval only from APHA. The fish farm operators then have a duty to dispose of the ash in an environmentally responsible manner, e.g. at a licensed waste management facility.
- Landfill of morts: presently only used on the Uists, Shetland and parts of Argyll.
- Sporadic utilisation of mainland anaerobic digestion (AD) & and in vessel composting (IVC) of ensiled (macerated and preservation in formic acid) and whole fish.

For mass mortalities companies have few additional options. Typically, morts are placed into harvest bins and removed by suction tanker without ensiling as quickly as possible. Some logistics companies offer large sealed skips for transport of mass mortalities. For one company, in Argyll, mass mortalities are landfilled when ensiling capacity is exhausted. In one case a farmer contracted a (Hordafor) vessel from Norway to remove a mass mortally at one site.

Only a small range of transport logistics and destinations were used across the farmers sampled. The un-ensiled morts produced in Orkney are transported exclusively to an anaerobic digestion (AD) facility. A mainland respondent used this AD option for mass mortalities only. One respondent also used this AD option for disposing of freshwater hatchery mortalities, although in this case the morts were ensiled and stored prior to transport. In all other cases (of fish farmers engaged with), ensiled and un-ensiled mortalities that are not incinerated on site or landfilled were described as being transported by tanker to the Widnes incinerating facility. The exception to this is in Shetland where a small proportion of the mortalities are taken by the Lerwick community waste heat recovery plant (this is described later in more detail).

5.2.3.2 Consequences of the Removal of the Derogation Allowing Landfill

The consequences of removal of the derogation fall only on those companies that operate in areas where landfill is presently a major disposal option. This applies especially to the Uists and Shetland but also to parts of Argyll.

In the Uists it would appear that the majority of mortalities are presently disposed of to landfill. The respondents operating on the Uists are considering ensiling on-site, followed by transport off the islands to Widnes. They are also considering on-site incineration, with one technology provider indicating that there were currently plans for the installation of a number of their plants (six units) on the Uists. On Benbecula, planning permission has been given (2014) for what is classified as a small-scale thermal treatment facility (incinerator) capable of processing 2,600 tonnes per annum of fish waste, with the developer indicating that the plan is for this to be operational in 2016 (see Section 5.6).

Engagement with a haulage contractor has identified that they also take shipments of fish farm mortalities from the Western Isles, managing both ongoing production tonnages, as well as those associated with mass mortality events – the feedback from this company was that none of these were sent to landfill, and all were sent to Widnes for incineration. Again, for the Western Isles as a whole, another option being considered at the moment (September 2015) includes anaerobic digestion at the Stornoway facility, if this facility can be upgraded to process Category 2 and 3 fish farm waste.

In Shetland, the majority of morts go to landfill at present, with some, a small quantity (see Section 5.6), going to the thermal treatment facility in Lerwick. One respondent intends to replace this with incinerators at all sites while another will request a period of grace before being able to use a proposed new AD plant in Lerwick (possibly opening in October 2017). All understood that it was possible that mass mortality events might have to involve disposal on the mainland, although they expected that this would be very expensive, so a local solution was considered the best way forward. Other logistics companies have expressed their interest in establishing consolidation facilities, to bulk up waste from various locations, including Shetland, storing this for the most cost effective shipments possible, potentially by boat, to their end destinations (see Section 5.7).

In Argyll, only one company presently uses landfill as a major disposal route and is considering either moving to ensiling or installing incineration as future options. All respondents operating in Argyll expressed a keen interest in a local AD solution for their morts disposal.

5.2.3.3 Freshwater Sites

In general, freshwater sites use ensiling for storage of morts. Most dispose of these at the Widnes incinerator and one respondent uses an AD plant. Typically, the volumes are very small requiring only ca. annual pick-up of ensiled material.

5.2.3.4 Costs for Disposal

Landfill costs were expressed as £130-300/t on island sites to £500-550/t in Argyll.

Incineration on site is typically done with incinerators which can process a maximum of 50kg/h. Incinerators of this size, presently in use, include models which have fuel requirements of the order of 10 litres of oil/diesel per hour[10] . Actual costs for on-site incineration are not recorded by any of the respondents. It was commented by one stakeholder that, in practice, some sites may use waste wood locally available, which results in no additional fuel being required.

Costs provided for the management of fish waste to off –site incinerators (the Widnes Incinerator) ranged from around £150/t for mainland fish farm sites to £300/t for island sites (for one respondent).

Indicative costs of disposal through AD were given as between £50 and £60/t. The total cost of disposal of a 26 tonne tanker from Orkney was around £4k (£153/t). A Shetland respondent expected a considerable saving over present landfill costs (£180/t).

The total cost to the industry of mortality disposal is not known. However, if average current costs of disposal are conservatively estimated at greater than £200/tonne then, with an average of around 10,000 tonnes of mortalities, the industry cost is at least £2M per year.

5.2.3.5 Awareness of Disposal Options

All of the respondents that used the Widnes service expressed concern that this was both costly and environmentally sub-optimal. All expressed a desire for disposal options closer to source. Beyond that, awareness of other disposal options was patchy with all respondents seeking information on other options such as AD and potential future options such as bio-refining. One respondent had already taken part in a very small-scale, pilot AD trial using test plant brought to their location. This turned out to be unsuccessful, but did not deter the company from wanting to consider AD as a future management option. They are in discussions with interested parties about moving more of its morts to AD in the future. In Orkney, where most of the morts are exported by tanker for AD, an AD proposal for Stromness was recently put on hold, but AD still remain an option discussed on Orkney as a future island solution for food waste in general. An Orkney respondent said that they would be looking carefully at how the proposed new AD plant in Lerwick operated as a guide to future feasibility for a similar plant on Orkney. Respondents farming in Lewis and Harris were actively discussing options for using the Stornoway AD facility to reduce their costs.

5.3 Anaerobic Digestion (AD) Operators

5.3.1 Regulatory position for both AD and IVC

AD and IVC sites processing ABP material to European standard and approved to do so by AHPA can accept and process cat 2 fish mortalities. It is the duty of the fish farm to produce commercial documents that comply with the ABP legislation ensuring the haulier receives a copy and the original is supplied to the destination premises, the haulier should ensure that the documentation is in place.

[10]http://masterburn.com/mb-350-incinerator/ and http://www.inciner8.com/fuel-consumption.php

However please note, Cat 2 fish mortalities that are produced as a result of notifiable disease will need to be disposed of in compliance with the legislation that applies for that disease in addition to the ABP legislation. During the course of this report, concerns have been raised that current pasteurisation processes used in AD and IVC facilities for Category 2 fish morts, may not meet the requirements of European regulations and from a hazard/risk assessment perspective may not be sufficient for managing the risks associated with fish pathogens. This has been discussed in detail with the Scottish Government which is content with its current position and interpretation. More information on this can be found in Appendix D.

5.3.2 *Methods*

All seven operational ABP registered AD facilities in Scotland were initially contacted by email / telephone. Short interviews were conducted by telephone or face-to-face meeting with follow up emails to confirm information provided. Edinburgh Millerhill joint venture operator Kelda Water Services were also consulted as this facility is planned to be operational in early 2016.

As well as considering specific issues around fish mortalities, discussions were held around wider fish waste reprocessing. Questions were asked on the following:

- ABP categorisation
- Pasteurisation process
- Quantities of fish waste / mortalities taken
- Additional fish waste / mortalities feedstock capacity
- Benefits / limitations of fish wastes as a feedstock for specific facilities
- Gate fees
- Digestate status and markets

5.3.3 *Results*

For illustrative purposes, the locations of the AD facilities engaged with are shown on the map in the following figure 8.

Figure 2. Overview of Scottish Anaerobic Digestion Facilities contacted during Stakeholder Engagement

A summary of key facts about sites can be found below (Table 1) with additional information located in Appendix A, with anonymised information about fish waste processing in the below text. The table shows there are five operational ‘wet’ and two ‘dry’ AD facilities in Scotland. The five wet facilities are all full ABP Category 3 facilities with pasteurisation processes involving a minimum 70°C for 60 minutes. All of these facilities take fish processing waste in varying quantities, with potential capacity for more.

At two of these facilities fish processing waste represents 33% and 40% of feedstock, respectively, on a tonnage basis. In both cases this includes a significant amount of dissolved air flotation (DAF) sludge from fish processing plants. At the other three wet facilities fish processing waste represents a minimal percentage of feedstock.

Three facilities have experience of taking fish mortalities including acid treated materials. Two facilities are currently taking fish mortalities. The third facility has stopped taking Category 2 fish mortalities after specific loads of waste were found to be heavily contaminated with fish farming materials (e.g. netting) and required time intensive decontamination and / or compromised digestate quality.

Perceived benefits and limitations of fish waste (generally speaking) as a feedstock were variable across the five 'wet' facilities and the individuals spoken to. Fish waste was seen as a 'good' feedstock by three. However, at the same time one of these facilities indicated that nitrogen (N) content was a limitation of fish waste (particularly non-ensiled). It was commented that the C:N ratio of ensiled waste would make this more suitable for AD although the nature of this material may make handling more difficult for them – this was a perception, of a liquid waste whose characteristics were not understood i.e. it was not based on actual trials of such waste to date. N content was also mentioned as a limitation of fish waste as a feedstock for AD by the other two facilities. One facility felt fish mortalities specifically were problematic for AD based on comparative analysis with fish processing waste – the latter, from their perspective, having a higher and better suited C:N ratio. Actual problems encountered in practice were put forward by two facilities. As previously mentioned, one facility has experienced problems with the quality of fish mortalities and high physical contamination levels and as a result had stopped taking materials. One facility has had trouble handling fish waste materials which can block pumping equipment.

In comparison to the 'wet' facilities, neither of the two operational 'dry' facilities currently accept fish waste (mortalities or otherwise). The Western Isles facility is currently limited to ABP Category 3 catering waste only, however, the operators are going to tender to add a pasteurisation unit to the plant with the view of taking fish mortalities.

Additional information was obtained on the AD of fish farm waste in Denmark. A summary of the outcomes is provided in the box below.

Box 1. Summary of Discussions with Hashoej Biogas (AD Facility, Denmark)

The Hashoej facility is able to take fish farm waste that can be demonstrated to have died without disease / pathogens being the cause e.g. where oxygen depletion is the cause.

The facility processes 130,000 tonnes per annum, and in terms of the mix and how much fish waste can be accepted, this is dependent on the other types of feedstock being processed at a given time. e.g. if they have a significant amount of slurry (pigs and cattle) then they can take more fish waste. As an extreme example, for indicative purposes, if they were to combine just slurry and fish waste the maximum amount of the latter would be around one third. If this increases to, for example, a 50:50 mix, they would expect to experience what they referred to as "momentarily boiling" (direct translation from Danish), with the production of excessive quantities of sulphates and CO_2.

This facility pasteurises its waste feedstock at 70° Celsius for one hour. The operations manager stated that this means they cannot take Category 2 fish mortalities, because of issues in terms of pathogens – it was commented that their process will not inactivate/kill all of the pathogens of concern in such fish. Category 2 fish farm mortalities, in Denmark, have to be treated using Method 1 (pressure sterilisation).

Two Scottish AD operators were engaged with to discuss what the potential and implications would be of increasing their treatment temperatures from 70 to 85° Celsius, over 25 minutes rather than one hour. The higher temperature (over a shorter time-period) is that used in the Norwegian Method (see Appendix E) along with ensilage, and the objective of asking was to understand whether a variation of this method could be developed, to suit the current Scottish context. The two operators indicated that they believe they would be able to reach the higher temperature using their existing equipment.

Discussions with an AD technology provider[11] have indicated that the capacity of the heat exchanger would need to be increased, with a boiler potentially also required.

[11]Email exchanges with HoSt, based in the Netherlands

Table 1. ABP registered anaerobic digestion (AD) sites in Scotland

Site name	Deerdykes	Energen	Fife Council	John Rennie & Sons	SSE Generation Ltd	Teg	Western Isles	Millerhill
Location	G68 9AZ	G67 3EN	KY12 0RX	AB53 8BP	KA24 4JJ	PH2 9PX	HS2 9JB	Edinburgh
Type	Wet	Wet	Dry	Wet	Wet	Wet	Dry – plug flow	
Listed ABP*	3	3	3	3	3	2+3	3	
Pasteurisation process	70 °C / 60 mins	70 °C / 60 mins	71 °C / 61 mins	70 °C / 60 mins	70 °C / 60 mins	70 °C / 60 mins	57 °C / 320 mins	
Capacity (t/y)	30,000	60,000	43,000	15,000	75,000	16,000	7,000	TBD

*DEFRA registered/approved.

5.4 In Vessel Composting (IVC) Operators

5.4.1 Methods

All twelve operational ABP registered IVC facilities in Scotland were initially contacted by email or telephone. Short interviews were conducted by telephone with follow up emails to confirm information provided. Four facilities are operated as private finance initiative (PFI) contracts for Dumfries & Galloway and Argyll & Bute Councils by Shanks therefore, wider engagement was made with Dumfries & Galloway Council staff and various Shanks staff.

As with the AD facility engagement, discussions were not restricted to fish mortalities and considered fish waste reprocessing generally. Questions were asked on the following:

- ABP categorisation
- Sanitisation process
- Quantities of fish waste / mortalities taken
- Additional fish waste / mortalities feedstock capacity
- Benefits / limitations of fish wastes as a feedstock for specific facilities
- Gate fees
- Compost status and markets

5.4.2 Results

For illustrative purposes, the locations of the IVC facilities engaged with are shown on the map in the following figure 9.

Figure 9. Overview of Scottish In Vessel Composting Facilities contacted during Stakeholder Engagement

A summary of key results can be found below (Table 2). The table shows there are two main types of ABP registered IVC facility in Scotland: covered bay and vertical composting unit (VCU). Two other facilities have unique IVC types and the final facility type is unconfirmed at present (shown as “TBC”).

None of the covered bay type facilities take fish waste (of any type) and appear to represent challenges for developing as potential reprocessing routes for the future. Four of five covered bay IVC sites expressed difficulties with accepting morts, due to a combination of contractual restrictions and / or site-specific issues such as potential odour management. All the covered bay facilities operate a 60°C sanitisation process. Suitable treatment processes for Category 2 fish farm mortalities are discussed elsewhere – this temperature would not be suitable for processing such waste.

Four ABP registered VCU facilities were identified in Scotland. Through the course of the project, one facility reported that they were not currently operational. The remaining three facilities have all taken in the past or currently take fish processing waste. One of these facilities has taken fish mortalities in the past, but no longer does so for a range of operational and regulatory reasons. The benefits of fish waste derived compost, in terms of high N content, were appreciated by facilities with agricultural end markets. Odour was universally reported as a limitation of fish waste as a feedstock and wetness was highlighted by two facilities.

The remaining three facilities all take fish processing waste in greater or lesser quantities. Only one IVC facility is currently taking fish mortalities. In an email response it was stipulated that this was dependant on the cause of death. As with the VCU facilities, the benefit of high N content was appreciated for agricultural land applications. Odour was again highlighted as a limitation of fish waste for reprocessing. For more information on the result in this section please see Appendix A.

Table 2. ABP Registered In Vessel Composting (IVC) Sites in Scotland

Site name	Billy Bowie	Dalinlongart	Evanton Waste Recycling	Galdenoch	GP Plantscape	Gray Composting Services Ltd	Keenan	Levenseat Organics	Lingerton	Moleigh landfill Site	Teg	AH Tucker
Location	KA2 0BA	PA23 8QS	IV16 9XJ	DG9 0RS	G74 2LF	AB45 2XS	AB53 6YH	ML11 8EP	PA31 8RR	PA34 4SD	PH2 9PX	EH55 8LJ
Operator (If different)		Shanks	WM Munro	Shanks					Shanks	Shanks		
Type	VCU	Covered bay	VCU[1]	Covered bay	Covered bay	VCU	VCU	Rotating Drum	Covered bay	Covered bay	Silo	TBC
Listed ABP Category*	2+3	3	3	3	3	3	2+3	2+3	3	3	3	2+3
Capacity	10,000	8,000[3]	n/a	4,000[3]	25,000	12,000	32,000	20,000	8,000[3]	8,000[3]	39,000	10,000

*DEFRA registered / approved. VCU – vertical composting unit

[1]Operation suspended indefinitely

[2]Exempt ABP materials are Category 2 but can be processed at a facility operating to UK rather than EU standards. Exempt materials include; manure, digestive tract and its content, dairy products or breast milk, eggs or egg products

[3]Depending on process and nature of feedstock

Tbc - asked but not confirmed at the time of reporting

5.5 Rendering Companies

5.5.1 Methods

Twelve renderers / processors were identified as operating in Scotland on the “Plantreport” Excel spreadsheet provided by the APHA. An on-line search was carried out to identify renderers / processors potentially able to accept Category 2 fish morts and to identify links between companies, in order to avoid contacting the same company more than once. All contacts were followed-up at least twice, in order to obtain as much information as possible. Scottish companies were contacted initially, in order to identify whether a solution could be offered which retains value within Scotland.

5.5.2 Results Overview

For illustrative purposes, the locations of the rendering facilities engaged with are shown on the map in the following figure 10.

Figure 3. Overview of Processors contacted during Stakeholder Engagement

Eight rendering / processing companies were contacted and one trade body. Partial or full responses were obtained from all eight companies. Of those engaged with, five companies were potentially able to offer a solution, these included Dundas (based in Dumfries), Argent (based in Motherwell), P. Waddingtons (England), Hordafor and Scanbio (Norway).

The remaining companies were unable to take fish morts due to licencing restrictions (Category 3 plants). There was no interest amongst any of the Category 3 renderers to consider upgrading the plant to accept Category 2 material, this was due to a variety of reasons, which included decreased control over the feedstocks accepted into the facility, limited end-product options and company objectives.

At the time of compiling this report Dundas (in association with Argent) are conducting a trial to determine the viability of accepting fish morts. Should the trial prove successful, the companies have commented that they have sufficient capacity to accept and process all fish morts generated in Scotland, details of which can be found in Appendix F.

Table 3. Renderer Responses

Company Name & Location	Their view on ability to accept fish morts	Range of supply	Comments
Dundas Chemical Company / Caledonian Proteins Dumfries	Yes, Category 1 renderer, subject to trial.	All over Scotland	Fishfarm waste is of interest.
Argent Motherwell,	Yes, Cat 1 Facility, interested, but dependent on technical and economic viability	Currently operating in Motherwell, with a new facility being constructed in Standwell, June 2016.	Argent produces 55,000 tonnes per annum (tpa) of biodiesel from the Scottish facility (Motherwell) and will produce 75,000 tpa of biodiesel from the new facility. The current APHA approval would not allow the company to deal with ensiled fish, they are currently limited to accepting oil only, however, this could be amended.
Scanbio Scotland Fort William	Not at current time,	N/A	May be able to offer a potential solution in the future – they closed in Scotland during the first half of 2015 - withdrawing from Scottish market to focus on Norway.
Scanbio Marine Group Norway	Yes	All over Scotland	A biodiesel production project using fish farm mortalities (in Scandinavia) has now stopped.
Omega Proteins / Scott Proteins (Leo Group), Kintore	N/A	N/A	Not yet approved by APHA. Previously, have sought approval as Cat 1 plant. The site is yet to be validated and therefore remains unapproved for rendering.
Hordafor Bekkjarvik, Norway	Category 1, 2 & 3 processor (Norway).	To be determined	Keen to explore options. Would be interested in consider a bulking station near a port.
Rossyew Greenock	No, Category 3 processor	Not applicable	No interest in accepting Cat. 2 materials, - decreases their control and the quality of their product would decrease (current end product – high quality fish oil and proteins). Licence prohibits Cat. 2 materials.
DeMulder & Sons (Part of Saria Group), Lochgelly	No, Category 3 renderer	Not applicable	The facility is a rendering plant and AD facility licenced to accept Category 3 meat waste. There are no plans to accept Category 2 waste because the base is to demonstrate national coverage to customers.
P. Waddington and Co. Buck Street, Bradford, Yorkshire	Yes, Category 1, 2 & 3 renderer	Do not currently service Scottish fish farms.	Waddingtons could offer a rendering service, which could include haulage (if required) - commented that gate fees would vary dependent on the type of fish received e.g. fish generating significant odours would result in higher costs. Cost and capacity data was outstanding at the time of compiling this report.

5.6 Incineration & Co-Incineration

5.6.1 Methods

In all, 138 incinerators were identified on the "Plantreport" excel spreadsheet forwarded by APHA. Smaller-scale incinerators associated with fish farms or farms were filtered out, and a short-list of 28 was emailed to SEPA for further information on licence requirements. SEPA were able to provide information on 6 facilities to help to identify incinerators that may have the capacity to deal with fish mortalities. Two of these facilities (Penmanshiel Farm and Park Unit) were only able to accept pig waste and were therefore ruled out. The remaining incinerators were contacted. This included incinerators whose main business appeared to be clinical waste, pet crematoriums as well as waste to energy facilities, including Widnes (which several fish farms / hauliers had identified as their current disposal choice).

In addition, one technology provider of small-scale incinerators was contacted. Small-scale incinerators with a threshold capacity of 50kg/hr or less fall below the threshold for regulation by SEPA (in rural areas) and only require APHA approval.

All contacts were followed up at least twice, in order to obtain as much information as possible. Scottish companies were contacted initially, in order to identify whether a solution could be offered which retains value within Scotland.

5.6.2 Results Overview

For illustrative purposes, the locations of the incineration facilities engaged with are shown on the map in the following figure 11.

Figure11. Overview of Incineration Facilities Contacted during Stakeholder Engagement

Eight incineration companies were contacted and partial or full responses were obtained from seven. Of those engaged with, three companies were able to offer a potential solution. This included Widnes (based in Cheshire, England), Vetspeed / Novus Environmental (based in Livingston) who operate several incinerators in North of England including Newcastle, Leeds and Bolton and a small incinerator based on Benbecula, scheduled to be operational by January 2016.

The remaining companies stated that they would be unable to take fish morts for a variety of reasons, both logistical (lacking appropriate equipment to handle the material, unable to process material with the calorific value of fish morts), commercial (unable to compete with AD / IVC gate fees) or regulatory (licenses restricting the types of material that can be accepted).

Table 4. Incinerator Responses

Company Name & Location	Their view on ability to accept fish morts	Range of supply	Comments
Shetland Heat Energy and Power Ltd Shetland	Currently accepting on a small scale.	Area around the Shetland Isles	Capacity likely to decrease in the future. In 2014-15, EfW represented 6% of the disposal option, with the rest going to landfill.
SecAnim Widnes	Yes	Accepting fish farm waste from around Scotland – the mainland and Western Isles.	Currently accepting fish farm waste and have capacity to accept additional tonnages.
Westfield Biomass Plant Lochgelly.	No, Licence permits only Category 3 waste.	Not applicable.	Not interested in fish farm waste.
The Pet Crematorium Larkhall	Yes. Potentially able to accept.	Not applicable i.e. not currently involved with fish farm waste.	Facility predominantly for pets, however can do mass cremations. Would struggle to accept fish morts due to problems with handling (e.g. liquid waste and high volumes). Incinerator burns at 250kg/hr, therefore also issues with capacity.
SRCL Leeds	Yes	From a commercial perspective, not able to cover Scotland.	Handling and logistics costs would be the challenge.
Vetspeed / Novus Environmental Livingston	Yes, licence would allow them to accept.	Do not have current supply chain. Have not accepted fish morts at current time (Nov 2015).	They could offer a haulage service or would accept from an independent haulier –commented that they have capacity across their 3 incinerator sites (one very small-scale facility in Scotland) to process fish morts generated in Scotland.
George MacDonald Isle of Benbecula	Yes, subject to meeting SEPA and APHA conditions. Planning permission secured, with aim of operating in 2016 – to treat Category 1 and 2 licences.	Western Isles	Small-scale incinerator (10 tonnes per day), with the aim of processing both Category 1 & 2 waste - will charge approximately £190 per tonne for fish farms on Benbecula / the Uists (cost includes haulage, disposal and disinfection). Slightly higher charges will be incurred for Harris and Lewis due to increased haulage. Ferry charges (where applicable) would be additional.
Healthcare Shotts	No	No infrastructure in Scotland at the moment.	Have a PPC permit approved for the construction of a pyrolysis facility in the future - fish waste is not currently listed on the permit – no response to question on the potential / interest for adding fish farm waste.
Inciner8 International Southport	No	Incineration equipment provider – not providing a service beyond the supply of equipment.	Company was contacted with the aim of understanding the potential and limitations of technology - for processing fish farm waste on site.

5.7 Hauliers / Logistics Companies

5.7.1 Objectives

The objectives of this engagement were to determine:

- Hauliers able to transport fish mortalities.
- Potential capacity to transport fish mortalities.
- Indicative haulage costs.
- Handling and storage infrastructure required.
- Geographical areas serviced.

5.7.2 Methods

An on-line search was conducted to identify hauliers (across all industries) currently servicing the north-west and islands of Scotland. This focused on both truck and ferry companies. Consultation with fish farm operators and end-disposal facilities highlighted companies that were currently providing the service and these were contacted to find out about additional capacity.

5.7.3 Results Overview

Nine Scottish haulage companies were contacted and at the time of writing responses had been received from eight. Seven were potentially interested in continuing to haul fish morts or would be potentially interested in offering a service. The one company not interested in transporting morts was concerned about potential contamination, spillages, smell, etc since the bulk of their current business is transportation of food.

In addition, several “facilities” are able to offer haulage as part of an integrated service, this included Novus Environmental, SRCL and Dundas (and P. Waddingtons in England). None of these companies currently service fish farms, but have the necessary regulatory licences in place to offer the service.

All haulage companies were able to service all regions in Scotland, and the main limiting factor will be cost. Fish farms with limited handling equipment and access restrictions may need to utilise a specialist haulage contractor (e.g. with a dysab or flexab).

However, it should be emphasised that all hauliers of ABP must be registered with APHA (under ABP regulations).

Additional information can be found in Appendix A.

Table 5. Haulier / Logistic Companies

Company Name & Location	Their view on ability to haul fish morts	Range of supply	Comments
Johnson Marine Shetland	Yes, currently doing this.	Harvest approx. 30% of Scotland's fish from fish farms.	They have 12 workboats washing nets, treating, carrying and harvesting fish. Interested in diversifying the range of their activities, to be involved in more added value processes.
Fergusons Corpach	Yes, currently doing this.	Western Isles, Inner Hebrides (Gigha) and Argyll.	No fish farm waste is taken to landfill – all sent to Widnes (SecAnim).
DFDS Larkhall Larkhall	Yes, although limited interest unless driven by clients.	Not indicated.	Limited interest in transporting morts.
DR Macleod Isle of North Uist	Currently do not offer this service, but potentially able to in the future.	Information outstanding at time of report compilation.	Awaiting information on costs and capacity.
Scanbio Marine Group Norway	They provide a collection and processing service in Norway and were involved in the approval work related to the EU adopting the Norwegian System.	Have stepped back from Scotland at the moment and are focussed on Norway. This could change.	They have some concerns about business in Scotland, related to the regulatory context. If these are addressed this would provide confidence that significant new logistics operations could be developed.
Shetland Transport Shetland	Brief discussion only.		
Calmac Oban	Yes. Not doing it currently, but would be interested in seagoing movements.	West coast of Scotland.	There is a fleet of 33 ships and 2 or 3 are kept ready for short-notice use.
Highland Haulage Glasgow	No, Food is key market sector and there are concerns about cross-contamination and smell.	Not applicable.	
Billie Bowie Kilmarnock	Yes, currently offer this service. Able to transport both whole and ensiled fish.	Fish farms throughout Scotland .	99% of waste transported to Widnes. Vehicle capacities from 10 tonnes to 30 tonnes. Approximately 125 trucks.
Hazco Grangemouth	Yes, currently doing this.	All of mainland Scotland, Western and Northern Isles.	They manage whole and ensiled fish, for both normal operational mortality collections and mass mortalities.

6 Analysis of Processing and Logistics Infrastructure Data

6.1 Anaerobic Digestion and IVC

6.1.1 The Amount of Fish Farm Waste that Scottish AD / IVC Facilities Can Take

Stakeholder engagement with Scottish AD facilities suggests there is capacity to take the annual 10,000 tonnes of fish farm mortalities. This could be achieved either with mortalities going to four out of five wet AD facilities or a single facility. Two facilities claim to each have capacity to take the entire annual tonnage of fish farm mortalities. Given its geographical location, the Western Isles dry AD facility may also be a potentially useful future reprocessing route for fish mortalities with plans to add a pre-treatment process currently in progress.

For IVC facilities, it is not yet clear whether there is capacity to take the annual 10,000 tonnes of fish farm mortalities. Although five facilities indicated they had capacity to take additional waste, two were not able to quantify what tonnage was available. Three facilities collectively could take ~4,500 tonnes using current infrastructure.

6.1.2 What is Known about Processing Finfish Waste at AD / IVC Facilities

Informed by the stakeholder engagement, we can see that both Scottish AD and IVC facilities have experience of processing fish mortalities. Specifically, three AD facilities have processed fish mortalities, although only two are currently doing so. Two IVC facilities have processed fish mortalities, although only one is currently. To maximise input to this project we also drew out information on fish waste other than fish farm mortalities (e.g. fish processing waste, fish market waste) being processed by Scottish AD and IVC facilities.

In terms of the mix / recipes adopted by AD facilities for feedstocks, fish waste was 40% of the feedstock tonnage at one facility. Discussions with the Danish AD facility Hashoej Biogas (130kt per annum) identified that it was difficult for the operator to provide conclusive data in this respect. However, it was commented that if they were supplied on a given day with a feedstock which was mainly cattle slurry and fish waste, they would not want the latter to be more than around one third of the mix).

6.1.3 Inhibiting Factors

Two key limiting factors for AD were drawn out from the literature review; 1) ammonia inhibition of methanogens and, 2) light metals content. The N content of fish waste (leading to generation of ammonia in breakdown) was identified as a limiting factor during the stakeholder engagement. None of the Scottish AD facilities mentioned light metals content.

No inhibiting factors were identified in the composting literature review. The key issues for composting of fish waste are handling of material (wetness) and odour control.

6.1.4 The Mitigation Methods that could be Employed to Alleviate any Inhibiting Factors

Based on the literature review of fish waste processing by AD, three mitigating methods have been considered – co-digestion, feedstock enhancement and ammonia precipitation. Considering wider food waste literature, two further mitigation methods for high N feedstocks included trace element amendment and ammonia stripping. A matrix of these mitigating methods, their advantages / disadvantages and commercial application is shown in the table below.

Co-digestion is seen as a mitigation method as it deals with both ammonia and light metal inhibition. All other identified mitigating methods only deal with ammonia and in the case of one (feedstock enhancement) may worsen light metal inhibition of methanogens.

Table 6. Mitigating methods for AD

Mitigating method	Advantages	Disadvantages	Application
Co-digestion	No or minimal facility upgrade required. Dilutes light metals to minimise light metal inhibition.	Sufficient additional feedstocks not available all year round.	Commercially practiced.
Feedstock enhancement	Potential for higher value product recovery.	May concentrate metals as shown in work on omega-3 extraction (Nges et al., 2012).	Unknown
Trace element amendment	No or minimal facility upgrade required.	Trace element toxicity due to inappropriate dosing.	Nutrient amendment practiced by some operators. Composition unknown but likely to contain trace elements.
Ammonia precipitation		Need partial recirculation of digestate for benefit.	Unknown
Ammonia stripping	Reduces potential toxicity / process inhibition; Can recover ammoniacal fertiliser stream.	Will require significant facility upgrade.	Installed at one AD site in England.

As no limiting factors were found for IVC, mitigating methods have not been considered.

6.2 Rendering and Incineration

6.2.1 *The Amount of Fish Farm Waste that Scottish Incineration / Rendering Facilities Can Take*

Suitable current incineration infrastructure in Scotland is extremely limited, with only one small-scale incinerator in Livingston able to accept morts at the current time. This facility has not historically accepted fish mortalities, however has the necessary licences and capacity required to treat routine mortalities at what is understood to be very low levels. The potential associated with the energy from waste facility on Shetland is increasingly diminishing. Currently, to manage significant tonnages of routine mortalities, or mass mortality episodes, there is incineration capacity available in England e.g. the SecAnim facility at Widnes (already widely utilised by Scottish fish farmers) as well as a number of other possibilities.

In addition, there are a number of smaller scale, local options currently going through planning and recently (2015) planning permission has been granted for an incinerator on Benbecula capable of processing 10 tonnes per day, set up specifically to deal with the problem of processing fish mortalities close to source. Correspondence with one technology provider indicates that another six applications are being considered, utilising their equipment alone. The technology provider believes that this is due to fish farm operators looking to treat fish mortalities in-house rather than pay the costs associated with transporting significant distances to a renderer / incinerator in the central belt of Scotland or for incineration in England.

Subject to successful trials rendering and / or the production of biodiesel will also offer the capacity to treat all fish morts (based on an assumption that 10,000 tonnes are produced annually) within Scotland.

6.2.2 *What is known about Processing Finfish Waste at Incineration / Rendering Facilities*

Incineration is the process where animal carcasses or by-products are burnt at high temperatures (≥ 850 °C) to produce an inorganic ash (Anon, 2002; NABC, 2004). The process is expected to destroy all infective agents (NABC, 2004).

The vast majority of fish mortalities currently being incinerated are those transported to the SecAnim facility in Widnes (part of SARIA group). The facility uses fluidised bed technology to co-incinerate meat and bone meal with various waste liquids. The liquids are needed to make a suitable paste for input. The facility has been designed to accept "wet" animal wastes and therefore fish mortalities do not present an issue, and the company has stated that they would like to increase the amount of fish morts accepted (in any form). Currently fish morts make up 3% of their feedstock.

Despite a long-standing tradition of rendering Category 2 animal by-products, these have tended to focus on terrestrial livestock, and there is limited experience of rendering fish morts, although discussions with Category 1 renderers have not highlighted significant issues.

A review of available literature has also indicated that this an area (incineration of fish morts) which from the perspective of published research, may have received limited attention - with the majority of work carried out for AD or IVC.

Subject to the results from ongoing trials, there may be an alternative processing option through the production of biodiesel. Although a relatively novel approach for Scotland, researchers have evaluated ozone treated fish waste as an alternative for diesel fuel, with positive results, and Kato et al. (2004) concluded that the fish oil obtained had better properties than methyl-esterified vegetable oil waste and was suitable for diesel engines especially in low-temperature areas[12]. Ozone treatment would need to be approved as an ABP disposal method under one of the existing treatments set out in the ABPRs, or as an alternative method recognised by the European Food Safety Authority (EFSA) on presentation of sufficient evidence.

6.2.3 *Inhibiting Factors*

On-going trials will identify potential inhibiting factors associated with rendering fish morts - these are not expected to be technical in nature, but more to do with logistics and associated costs.

In terms of incineration, none of the companies engaged have identified any technical or regulatory issues associated with incinerating fish waste.

There are still many unknowns with regards to the production of biodiesel e.g. the technical ability to obtain fish oils, the percentage and composition and whether it is economically viable to do so. These factors could be determined very quickly by processing samples through demonstrator plant already available in the country.

6.3 Collection Services which Can Undertake the Transfer of Fish Farm Waste to Processing Facilities in Scotland

There are a range of companies currently hauling (or capable of hauling) ABP Category 2 material. Hauliers would typically transport waste from anywhere in Scotland and are currently moving fish farm mortalities predominantly to Widnes. The reasons for this are complex and one haulier indicated that they would never haul to landfill and they know that Widnes can process the material.

Transporting the volumes of fish morts being generated by the aquaculture industry did not appear to pose the industry a problem. Significant mass mortality events clearly put companies under pressure, but there are a range of hauliers that can offer a service, including a number that already have the relevant licences and infrastructure in place.

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[12] http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2621.2006.01513.x/full

Hordafor are able to offer a complete haulage service by boat, using experience gained implementing the Norwegian System (Appendix E). They do not currently operate in Scotland and infrastructure would need to be set up in order to offer a viable solution. Scanbio are in a similar position, but already have appropriately licensed storage infrastructure in Inverness. There could be potential for both Scanbio and / or Hordafor to pick up by boat from individual fish farms, with the boat making multiple stops. Johnson Marine already operating widely and providing a range of service to fish farms in Scotland, are also able and interested in developing services involving bulk haulage of fish farm mortalities by boat, as well as interesting in pursuing added value, associated processes such as AD and biofuel production. Calmac, once they have completed their ongoing procurement programme for the delivery of ferry services, and if successful, would also be interested in diversifying their business model to incorporate the haulage of fish farm mortalities.

In the future, there may be the potential to implement the Norwegian System in addition to current methods, or variations on this e.g. at a smaller scale to enable bulk pick-ups and possibly storage (ensiled) infrastructure for mass events. A variation on the Norwegian system could involve the continuation of sea haulage and road transport, but with the latter involving the movement of fish farm mortalities to a central treatment facility (rather than using a bulk carrying, sea-going vessel). The use of bulking and ensiling stations located at either Ullapool or Oban may present a more economically feasible means of hauling ensiled fish morts down to facilities in the central belt of Scotland, and dependent upon ensiling capacity, may offer an interim solution for mass events.

7 Costs / Incomes Associated with Options for Managing Fish Farm Waste

7.1 Overview

This section considers the following in terms of the different options for managing fish farm wastes:

- The income stream associated with energy production using fish waste as a feedstock, on the basis of the feed-in tariff for renewable electricity and the renewable heat incentive for heat produced. This is presented, in particular, to highlight the energy and economic value impact associated with diverting fish farm waste from landfill to more sustainable management methods.
- A comparison of the costs to fish farm operators is presented on the basis of existing practices in terms of managing waste (e.g. landfill, incineration, rendering, AD and IVC) versus alternatives. This is particularly important with respect to behaviour which currently involves the landfilling of routine and mass mortality fish farm waste.

7.2 Income Stream for Energy Production Using Fish Waste

Section 7 provides an estimate of the financial impacts on remote landfill operators, associated with losing gate fees for fish farm mortalities. However, the other side of this is the economic benefit to be realised by more sustainable practices, which generate value from the waste streams. Using AD facilities as an example of more sustainable practice, for facilities with the treatment infrastructure for processing morts, the estimates provided in this section give an indication of the economic value which can be recovered from fish farm morts – for energy generation alone. In addition, a gate fee could be charged at suitably licensed AD facilities.

The UK Feed In Tariff (FIT) and Renewable Heat Incentive (RHI) Schemes provide guaranteed incomes for different scales of facility, and different types of technology. For illustrative purposes, this analysis considers the potential income associated with fish waste and energy, using anaerobic digestion and Combined Heat and Power (CHP) as the generating technology.

For an anaerobic digestion facility which processes 1,000 tonnes of fish per annum, this will result in a potential income stream / avoided cost (associated with energy generated by the fish alone) of £139K, using an AD cost benefit calculator developed by Zero Waste Scotland and if both heat and electricity are utilised fully. Details of the calculation can be found in Appendix B.

7.3 Summary of Costs to Fish Farm Operators

The results of stakeholder engagement described previously are summarised in the following Table 7 and Table 8:

- Current practices, end fates for waste.
- Potential, alternative practice and end fates for waste, based on the closest processing facilities.

The data presented in Table 7 and Table 8 indicates that where companies are landfilling fish farm waste at licensed landfill sites, they currently should be able to secure lower cost contracts with more sustainable processes. This applies to both routine mortalities and mass mortality events and includes hauling to the Widnes incinerator, with the exception of fish farm waste currently landfilled on Shetland. In this case, on the basis of currently installed infrastructure, a lower cost option would be dependent on the mainland AD and IVC infrastructure being able to take Shetland's fish farm waste. For the fish farms in all of the regions identified, lower cost options than hauling to Widnes for incineration are available, if the infrastructure is able to accept the waste.

Table 7. Summary of Current Practices, with Indicative, Estimated Costs - Haulage + Gate Fees (Incl. Tax for Landfill) – For Fish Farm Mortalities (Salmon)

Region	£/Tonne - Landfill	£/Tonne for Incineration e.g. Widnes			£/Tonne for AD – Aberdeenshire
		Whole Fish - Mass Morts		Ensiled - Routine	Ensiled - Routine
		10 tonnes/load	25 tonnes/load	25 tonnes/load	25 tonnes/load
W. Isles	£327	£360	£189	£169	n/a
NW Mainland (Highland)	n/a	£285	£159	£139	n/a
Shetland	£174	n/a	n/a	n/a	n/a
Orkney	n/a	£600	£240	n/a	£154
South West (Argyll)	£357	£215	£159	£111	n/a

Table 8. Summary of Alternative Options, With Indicative, Estimated Costs – Haulage + Gate Fees (Incl. Tax for Landfill) – For Fish Farm Mortalities (Salmon)

Region	£/Tonne for Alternative Practices/Options				
	IVC - Mainland	AD - Mainland	AD – Island[1]	Incineration - Mainland[2]	Incineration - Island[3]
	25 tonnes/load	25 tonnes/load	25 tonnes/load	25 tonnes/load	3 tonnes/load
W. Isles	£174		£144		190
NW Mainland (Highland)	£144	£124		£866	
Shetland	£184	£174		£876	
Orkney	£174	£164		£876	
South West (Argyll)	£106	£106		£837	

1. A local AD for Shetland is still very much at the early stages in terms of planning. An application for upgraded processing infrastructure at the Lewis AD facility is being taken forward (Oct 2015)
2. The alternative to Widnes is Novus although the latter is significantly higher cost.
3. This incinerator, on Benbecula, is due to be operational in 2016 (planning consent given), with loads of 3 tonnes being brought to the site

8 Impact on Remote Landfills

8.1 Stakeholder Engagement Results

Scottish waste sites and capacity reports (available on the SEPA website) provide information about the numbers and types of waste management operators holding a Waste Management Licence (WML) or Pollution Prevention Control (PPC) permit, as issued by SEPA.

Ten remote landfill site operators were contacted (using the most recent, SEPA, 2013 database) to quantify the economic impacts that will result from a future change to regulations which prohibits the landfilling of fish farm waste. The results of this consultation are shown in Table 10, with landfill operators being asked if they have ever taken, or currently take fish farm morts, and if so, how much is accepted and the fees associated with this.

8.2 Analysis of Revenue Loss for Remote Landfills

It should be noted that it is known that four landfill sites currently accept fish mortalities, as summarised below:

- Council run landfill at Bennadrove, Western Isles.
- A North Uist site.
- A Shetland Council operated site, at Gremista.
- Shanks operated sites in Argyll and Bute.

Table 9**Error! Reference source not found.** summarises the charging levels and income streams, to show the loss of income associated with the future prohibition of fish farm mortalities from landfill. This is not presented as a conclusive, statistics analysis of tonnages (outwith the scope of work of this project), with confidence levels being provided etc, Instead the information provided, for licensed landfills, indicates the loss of income for those landfill sites which have responded to the consultation and which have indicated that they are taking fish farm waste – the data is presented on a regional basis and, in effect with landfill tax being paid to the government, the loss of income to the landfill site operators is the gate fee indicated.

Table 9. Summary of Income Generated by the Licensed Waste Management Landfilling of Salmon Mortalities

Region	Mortality Tonnes	Landfill Tonnage	% Landfill	£ Landfill Tax/T	£ Landfill Gate Fee / T	£ Total Landfill Cost	Total Tax	Total Gate Fee
W. Isles	2,252	250	11.10%	82.6	189	67,816	20,553	47,263
Highland	2,205	0	0.00%	n/a	n/a	n/a	n/a	n/a
Shetland	3,298	1,700	51.55%	82.6	85	285,090	140,420	144,670
Orkney	581	0	0.00%	n/a	n/a	n/a	n/a	n/a
Argyll	1,662	366	22.02%	82.6	99	66,447	30,232	36,216
TOTAL	**9,998**	**2,316**	**23.16%**			**419,353**	**191,204**	**228,149**

The tonnages identified amount to approximately 23% of the estimated arisings of fish mortalities in the country, with the loss of income for Scotland as a whole, shown to be £228,149.

Table 10. Landfill Operators

Operator Name	Landfill name, Contact & Local Authority Area	Costs	Tonnages	Total	Comments
Shanks Argyll & Bute Limited	Dalinlongart Landfill Site, Sandbank, Dunoon, Argyll & Bute	Landfill gate fee of £104.60. With tax added = £187.20 per tonne.	Fish farm mortalities hauled to landfill range from a minimum of 284 tonnes to a maximum of 489 tonnes over the 5 year period. An average of 366 tonnes.	Gate fee total of £38,323. Total landfill cost, inc tax = £68,587	Confirmation that fish morts are collected for landfill. Tonnage data has been provided annually over the last five years (2010 to 2015).
	Lingerton Landfill Site, Argyll and Bute				
Argyll & Bute Council Kilmory, Lochgilphead,	Gott Bay LFS, Isle of Tiree, Argyll & Bute,	N/A	N/A	N/A	The council has two sites presently licensed for fish waste, located on Mull and Islay, the council advised that they are licensed to be used in emergency situations, however there has been no need for fish farmers to use them, and that fish farms on the islands deal with their own waste.
	Glengorm Landfill Site, Glengorm Rd, Tobermory, Argyll & Bute,	N/A	N/A	N/A	
	Gartbreck LFS, Isle of Islay, Argyll & Bute	N/A	N/A	N/A	
Locheil Logistics Fort William,	Duisky Landfill Site, Kinlocheil, Fort William, Highlands	N/A	N/A	N/A	Email received stating that they have never accepted fish morts at their site.
Shetland Council	Gremista Waste Management Facility, Lerwick, Shetland, William Spence	Landfill charges of £167.70 per tonne.	1,700 tonnes in most recent year.	Uncertain	Follow-up questions asking for more accurate information on the quantity of fish have been asked, but no response at the time of writing.

Operator Name	Landfill name, Contact & Local Authority Area	Costs	Tonnages	Total	Comments
Western Isles Council	Bennadrove Landfill WTS CA ELV, Stornoway, Western Isles		2015: From 01.01.15 to 21.08.15 38.22 tonnes in total. 2014: In 2014 Bennadrove accepted 250.32 tonnes.	2015: Disposal costs were £7,183.64 + Landfill Tax was £3,123.90 + VAT @ 20% 2014: Disposal Costs were £42,911.66 + Landfill Tax @ £19,685.44 + VAT @ 20% in total.	
Highland Council Inverness	Granish Landfill Site Cell 3, By Aviemore	£0	0	0	Highland Council have not accepted fish mortalities at either of their two landfill sites for at least 12 years (which equates to the length of time that the contact had worked at the council). It was commented, that there had not been any enquiries during that time. He felt that the ABP controls had, had some impact and this was possibly why. If a fish farmer were to landfill fish morts, the costs would have been £70.84 + landfill tax for active waste.
	Seater Landfill Site, Bower, by Wick, Highland Council	£0	0	0	

9 The Norwegian System

9.1 Introduction

The Norwegian Food Safety Authority (NFSA) has described how, in terms of disease prevention[13] the Norwegian authorities have required the immediate ensilage of dead fish and animal by-products on aquaculture farms since the 1990s - to prevent the spread of fish diseases. They comment that the approach involves simple and safe storage and maximises the beneficial use of resources, allowing the fish by-products to be used in other sectors.

The NFSA describes how Norwegian Aquaculture produces a large tonnage of fish with resulting large tonnages of fish mortalities and waste. For example, in 2011, about 60 000 tonnes of Category 2 and 200,000 tons of Category 3 waste / by-products were produced. As a result, it was considered that a risk-based, proportionate method for handling fish by-products was needed.

The result is the approval by the European Food Safety Authority (EFSA) of the processing method incorporated and published in the OJ as Regulation (EU) 2015/9, and applying from February 23rd 2015. For simplicity, in this report it is referred to as the "Norwegian System", and it applies to both Category 2 and 3 fish waste. In summary it requires the following:

- Collection of dead fish on a daily basis.
- Ground / chopped and mixed with formic acid pH≤4.
- Storage pH≤4 at least 24 hours.
- Particle size of less than10 mm (after filtration or maceration).
- Heat treatment: at least 85º Celsius for at least 25 minutes.

Before authorisation, an operator's Hazard Analysis and Critical Control Points (HACCP) plan must be assessed and approved,.

The NFSA has produced a simplified diagram of the process, as it is being implemented in Norway, this diagram and further information on the system can be found in Appendix E

9.2 Options for Scotland, in Terms of the Norwegian and Similar Systems

Three potential options are described below (there are likely to be more) in terms of potential synergies with the Norwegian system, or adapting this to suit the Scottish context.

- Option A: The development of a system which copies what happens in Norway from start to finish.
- Option B: The development of a logistics system which safely manages fish waste through grinding / maceration then ensilage - **at sea** (the Norwegian approach). This could then operate on the basis of consolidation centres being established at strategic locations in the country i.e. storage locations where the stabilised, ensiled waste can then be hauled to the most cost effective end-destination e.g. this could be to a Scottish reprocessor, to a processing facility in Norway etc.
- Option C: Where grinding / maceration and ensilage happen on land, with subsequent land haulage to regional, consolidation centres, prior to collection for transportation to an appropriate end destination.

[13] Norwegian Food Safety Authority, 2015, "Heat treatment of fish silage–Method K, Regulation (EU) No 142/2011 as amended by Regulation(EU) 2015/9", Presentation Document.

10 Innovative Business Development Opportunities for Managing Finfish Waste from Fish Farms

A number of innovative technologies have been identified, as having potential for development in the future, as summarised below but more detail can be found in Appendix F:

- Biodiesel production - the maximum amount of oil that could be produced from fish farm mortalities, from Scotland as a whole, would be 1,500 tonnes per annum (based on 10,000 tonnes of waste generated per annum).
- Alkaline hydrolysis – reduces biological material into a sterile aqueous solution,
- Dehydration – not currently used for morts, but a technology is being developed by Tidy Planet targeting this.
- Flymeals – Stirling University lead work in Scotland on incorporating fly larvae into animal feed. They are currently piloting insect based approaches to deal with morts. Their trials utilise flies to break-down whole fish arising from routine mortalities, thereby removing the need to ensile fish and / or transport off-site.
- Small-scale niche markets: fish-skin leather, synthetic hydroxyapatite, vermiculture, mass seaweed culture.

11 Conclusions

1) In the marine aquaculture sector, there has been much consolidation in recent years and there are now fewer, larger farmers, with only 6 companies operating more than 10 marine farm sites. Together these operate 89% of all the active sites – the majority producing Atlantic Salmon. 32 companies operate 106 active salmon smolt sites, in general to produce smolts for transfer to seawater. By comparison, the freshwater rainbow trout sector has 33 operators and 46 active sites, and is therefore an unconsolidated industry compared to Atlantic Salmon.

2) The majority of Scottish fish farm production is in the marine sector which consequently contributes the majority of the mortality biomass. On average, between 2002 and 2014 there has been about 10,000 tonnes of morts annually from an average production of about 150,000 tomes of salmon, i.e. about 6.7%. Marine trout production is ca. 1% of salmon production and has an average mortality rate of 5.6% of production. No data is collated and published on mortalities of freshwater production for any species.

3) The potential of the Scottish waste management industry to process fish farm waste is determined by the regulatory requirements and interpretation of EU regulations. Where AD and IVC sites processing ABP material to European standard and approved to do so by APHA can accept and process Cat 2 fish mortalities giving fish farmers a range of options in Scotland. In addition there are developments in the rendering and biodiesel sector which may provide additional Scottish solutions in the near future.

4) Current practices in terms of managing fish farm mortalities vary by site, the operator and geographical location. However, the ensiling of waste for routine mortalities is commonplace, and less so for mass mortality events, when the capacity for ensiling fish is exceeded and whole fish are stored and removed from site as quickly as possible.

5) In terms of the impact of removing the option of landfilling fish farm mortalities, an estimate has been made on the basis of the information secured from landfill operators – this amounts to a loss of income, for Scottish landfill sites as a whole, of £228k in gate fees. The tonnages associated with this amount to approximately 23% of the estimated fish mortalities in the country, with 2,316 tonnes to be diverted from licensed landfills for alternative processing outcomes.

6) The landfilling of fish farm mortalities was only identified to be taking place on the Western Isles, Shetland and in parts of Argyll. On the Western Isles there are currently plans for the installation of a number of small-scale incinerators, while, on Benbecula, planning permission has been given (2014)

for what is classified as a small-scale thermal treatment facility (incinerator) capable of processing 2,600 tonnes per annum of fish waste - the plan is for this to be operational in 2016. In Argyll, only one company presently uses landfill as a major disposal route and is considering either moving to ensiling or installing incineration as future options. All respondents operating in Argyll expressed a keen interest in a local AD solution for their morts disposal. On Shetland, the incinerator has been the alternative to landfill to date, however, this is a diminishing opportunity, for a number of technical and regulatory reasons, and the potential for a local AD facility and / or biodiesel processing capability has been under consideration.

7) Stakeholder engagement with Scottish AD facilities suggests there is capacity to take the annual 10,000 tonnes of fish farm mortalities. It is not yet clear what the capacity would be for IVC facilities although a number of facilities have indicated that they can take additional fish waste without quantifying this.

8) Engagement with stakeholders such as fish farmers, logistics companies (hauliers) and AD operators has identified that a significant quantity of fish farm mortalities are being sent to Widnes for incineration, even where there are potentially lower cost options in Scotland. In the case of one haulier, the inability of two AD facilities in Scotland to confirm that they could accept Cat 2 fish (from a regulatory perspective) led to Widnes being identified as the compliant option for processing this waste. However, this has been addressed by APHA and Scottish Government who have clarified their position, with AD and IVC in Scotland.

9) Where companies are landfilling fish farm waste at licensed landfill sites, the data indicates that they are currently able to secure alternative, lower cost contracts with more sustainable processes for both routine mortalities and mass mortality events. This includes hauling to the Widnes incinerator, with the exception of fish farm waste currently landfilled on Shetland. In this case, on the basis of currently installed infrastructure, a lower cost option would be dependent on the mainland AD and IVC infrastructure being able to take Shetland's fish farm waste. For the fish farms in all of the regions identified, lower cost options than hauling to Widnes for incineration are available, if the facilities are able to accept the waste (from a regulatory perspective).

10) With regards to future infrastructure developments, there is the potential for the rendering and biodiesel production industries in Scotland to take at least the routine mortalities which are generated by fish farming. The results of trials, to confirm the extent of this potential were still underway at the time of writing this report.

11) Other European countries regulators / companies engaged with during the course of this project have taken a different perspective to the regulatory approach currently in place in Scotland for treating Category 2 fish farm mortalities. There is a concern that current UK practice for processing Category 2 fish morts through AD and IVC this may not comply with the European regulations and, from a hazard / risk assessment perspective, may not be sufficient for managing the risks associated with fish pathogens. This has been discussed in detail with the Scottish Government which is happy with its current stance.

12 Recommendations

1) A number of potential opportunities for the movement of fish farm waste more cost effectively (than is currently the case) have been identified. These involve establishing consolidation centres at different locations across the country. Cost benefit analyses, business planning and pilot / demonstration projects could all be carried out to describe in detail the extent of the opportunities, issues and risks associated with such developments. There may be value in considering whether financial support to assist in taking forward such projects is a possibility.

2) There may be value in work being carried out to collate data currently being collected on smolt mortalities. Although the tonnages are considered to be significantly lower than the fish farm mortalities given in this report, they may also represent significant tonnages at a very local level, which could make a contribution to otherwise small-scale, resource efficiency projects.

3) Confirmation from the European Commission regarding the current treatment of fish farm mortalities in Scotland.

Appendix A

13 Review of the Potential Processing and Logistics Infrastructure in Scotland for Managing Fish Farm Waste

13.1 Processing Fish Farm Waste through Existing AD and IVC Facilities

13.1.1 Objectives

The objective is to review the potential capacity we have within Scotland to process fish farm waste through existing AD & IVC, considering the following:

- What percentage of the overall input at Scottish AD & IVC plants, could this fish waste represent (on an individual as well as collective basis, listed as a percentage and tonnage)?
- How much is known about processing this material through AD & IVC in a UK context i.e. with a mix of input materials including general food waste and not just co-digested with manures / slurries or crop residues?
- What is the likely inhibiting factor(s) if any?
- What mitigation methods could be employed to alleviate any inhibiting factors (include costs / process modifications and which industry this would impact: fish or organics' recycling)?
- Are there collection services which could undertake the transfer of this material to Scottish AD & IVC plants (volume, geographical location, ABP category etc.) – if not, why not?

The above has been examined through a combination of literature/desk-based review and stakeholder engagement as noted below.

13.1.2 Literature and Desk-based Review

13.1.2.1 Anaerobic Digestion

A search of primary literature articles on anaerobic digestion of fish waste was carried out using the Web of Science™ database. Search terms and result numbers for general 'topic' and more specific 'title' restrictors are illustrated in the table below. The resulting article abstracts were subsequently screened for relevance.

Table 11. Web of Science searches – article returns

Search term	Topic	Title
Anaerobic digestion + fish* + ammon*	67	0
Anaerobic digestion + fish*	533	14 (10 relevant)
Anaerobic digestion + fish* + waste	303	5

*allow different endings

Literature on anaerobic digestion of fish waste was found to be more diverse than that on composting with articles covering aspects including co-digestion, feedstock enhancement / pre-treatment, reactor design and processing, and microbial strain enrichment[14].

Fish waste is often seen as an attractive AD feedstock, being rich in lipids and protein it has a high methane yield (Nges et al., 2012). However, at the same time it may present problems for anaerobic digestion as protein degradation can lead to high ammonia generation which can inhibit methanogenic microorganisms (Schnurer and Nordberg, 2008[15]). Thermophilic AD processes in particular are at risk as free ammonia (NH_3) is more readily available at higher temperatures. Another potential detrimental property of fish waste as an AD feedstock is light metal content (particularly calcium, sodium, potassium and magnesium) which can a inhibit methanogens.

Although methanogenic communities may adapt to higher ammonia concentrations (Schnurer and Nordberg, 1988), the most straightforward way to deal with high N fish waste would appear to be co-digestion. Co-digestion with various C rich substrates has been studied including farm manures / slurries and sewage sludge, crop biomass, strawberry waste and sisal pulp (Callaghan et al., 1998[16];Nges et al., 2012; Serrano et al., 2013). In fact ammonia generation by high N feedstocks such as fish waste can be useful in buffering C rich feedstock which can generate high volatile fatty acid levels. In addition, where feedstocks contain inhibitory compounds such as light metals, these can be diluted to acceptable concentrations by co-digestion.

Of particular relevance to this project is a Norwegian led study using ABP Category 2 fish waste treated by the 'fish silage processing method (FSPM) (Estevez et al., 2014[17]). The article reports characteristics of FSPM alongside other fish wastes (from other literature sources) including biochemical methane potential (BMP) as illustrated below (Table 12).

Table 12. Characteristics of fish waste including FSPM treated ABP Category 2 material (taken from Estevez et al., 2014)

Type of waste	TS (% w/w)	Fat (%)	Protein (%)	Maximum methane yield
(ml gVS-1)				
Tuna solid waste	37	3.74	22.6	280
Mackerel solid waste	32	11.8	17.82	350
Fish offal	29.6	8.2	20.3	-

[14] Gumisiriza, R. MShandete, A.M., Rubindamayugi, M.S.T., Kansiime, F. & Kivaisi (2009) Enhancement of anaerobic digestion of Nile perch fish processing wastewater. African Journal of Biotechnology, 8, 328-333.
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[15] Schnurer, A., Nordberg A., (2008) Ammonia, a selective agent for methane production by syntorophic oxidation at mesophilic temperature. Water Science Technology, 57(5), 735-740.
[16] Callaghan FJ, Wase DAJ, Thayanithy K, Forster CF (1998) An examination of the continuous anaerobic co-digestion of cattle slurry and fish offal. Process Safety and Environmental Protection, 76: 224-228.
[17] Estevez, M.M., Sapci, Z., Linjordet, R., Morken, J. (2014) Incorporation of fish by-product into the semi-continuous anaerobic co-digestion of pre-treated lignocellulose and cow manure, with recovery of digestate's nutrients. Renewable Energy Journal, 66, 550-558.

Type of waste	TS (% w/w)	Fat (%)	Protein (%)	Maximum methane yield
FSPM	50.2	30	-	450-500

Estevez et al. (2014) tested the FSPM treated material by co-digestion with pre-treated (steam-exploded) lignocellulose material and cow manure (two C rich feedstocks). Lignocellulose material and cow manure were also tested without fish waste. Digestion was carried out in a semi-continuous reactor involving liquid digestate recirculation to demonstrate the negative impacts of ammonium-N (NH_4^+-N) on the process. The presence of fish waste increased NH_4^+-N and propionic acid in the reactor compared to the non–fish waste fed reactor. To control NH_4^+-N, a fraction of liquid digestate (~50 %) was not recirculated into the reactor. To treat the liquid fraction, NH_4^+-N was precipitated as struvite and found to achieve 87 % removal rate. The authors suggest that the NH_4^+-N could be recovered and added to the solid digestate to improve its N nutritional value for land application. The accumulation of propionic acid in digesters treating food waste at high NH_4^+-N concentration has been elsewhere previously reported (Banks et al., 2012[18]). Banks et al. (2012) conducted batch and semi-continuous studies using source segregated domestic food waste feedstock to assess trace element amendment on AD. The experiments showed that addition of trace elements selenium and cobalt supported stable digestion of food waste at higher organic loading rates.

Finally, Nges et al. (2012) acknowledged that fish waste contains potential higher value added products including omega-3 fatty acids. The work assessed the anaerobic digestion of the residual waste (fish sludge) following extraction of omega-3 fatty acids and soluble protein. The fish sludge was compared against untreated material and also co-digested with Jerusalem artichoke residues in batch digestion experiments. The authors conclude that treated fish sludge still required co-digestion. Otherwise, this work would benefit from further evaluation with continuous or semi-continuous reactor studies.

In conclusion, the peer review literature provides clear support for co-digestion of fish waste which mitigates the need for costly facility upgrades such as ammonia stripping which have been studied in the context of food waste digestion. (Interestingly the continuous reactor studies on co-digestion involving fish waste were limited to stirred tank reactors and therefore mimic most closely the ‘wet’ commercial systems found in Scotland. No literature relating specifically to dry-based AD for fish waste was identified – the Western Isles facility (a dry plug flow system) is currently engaged in research with the University of West of Scotland to help bridge information gaps. Regarding trace element addition for stable digestion, we are aware of several UK AD facilities feeding reactors with nutrient supplements – it is currently unknown whether this practice is universal. The composition of such supplements is also unknown (bespoke, proprietary information).

13.1.2.2 Composting

As with AD, a search of primary literature articles was carried out using the Web of Science™ database. Search terms and result numbers for general ‘topic’ and more specific ‘title’ restrictors are presented in the following table. ‘Mortalities’ was deemed too specific a search term to be used.

Table 13. Web of Science searches – article returns

Search terms	Topic	Title
Compost* + fish* + ammonia	28	0

[18] Banks, C.J., Zhang, Y., Jiang, Y.,Heaven. S (2012) Trace element requirements for stable food waste digestion at elevated ammonia concentrations. Bioresource Technology Journal, 104, Page 127-35.

Search terms	Topic	Title
Compost* + fish* + waste	205	12 (10 relevant)
[In-]vessel compost* + fish* + waste	4 (3 relevant)	2

*allow different endings, [ ] – not used in search

Resulting article abstracts were subsequently screened as necessary for relevance. For example, 'fish' is an acronym used for the molecular biology technique 'fluorescent in situ hybridisation' and therefore may lead indicate articles of non-relevance. Further screening of results identified 10 articles of relevance on composting of fish waste and the end use suitability of compost derived (in part) from fish waste feedstock.

Seven of the articles were available through subscription of which five were full length primary research articles. In the five articles, fish waste was composted with carbon rich bulking agents of various types (Illera-Vives et al., 2013; Illera-Vives et al., 2015; Laos et al., 1998; Liao et al., 1995; Liao et al., 1997[19]). In essence, the studies addressed three relevant areas; 1) optimisation of feedstock ratios, 2) effects of different carbon rich bulking agents on the composting process and, 3) assessment of compost quality for agricultural and horticultural application. A summary of the co-composting strategies and key relevant conclusions found in the five primary research articles is presented in Table 14. As expected, co-composting of fish waste was with carbon rich feedstocks and bulking agents. Liao et al., (1997) operated at C:N ratios of 25:1 and 26:1 with fir sawdust and alder chips respectively and therefore within the range normally considered suitable for composting (i.e. 25-35:1). Illera-Vives et al., (2013) used pine bark to improve aeration and raise carbon content.

Table 14. Comparison of composting fish waste primary literature

	Illera-Vives et al., 2013	Illera-Vives et al., 2015	Laos et al., 1998	Liao et al., 1995	Liao et al., 1997
Scale	Pilot		Pilot	Full	Full
In-vessel*	No		Yes	Yes	Yes
Fish waste	Fish processing waste		Fish offal	Fish guts	Fish viscera
Other feedstocks	Seaweed and pine bark		Sawdust /		
Wood shaving	sawdust		Sawdust / wood chips		

[19] Illera-Vives M, Seoane Labandeira S, López-Mosquera ME. (2013) Production of compost from marine waste: evaluation of the product for use in ecological agriculture. Journal of Applied Phycology, 25: 1395-1403.
Illera-Vives M, Labandeira SS, Brito LM, Lopez-Fabal A, Lopez-Mosquera ME. (2015) Evaluation of compost from seaweed and fish waste as a fertilizer for horticultural use. Scientia Horticulturae, 186: 101-107.
Laos F, Mazzarino MJ, Walter I, Roselli L (1998) Composting of fish waste with wood by-products and testing compost quality as a soil amendment: Experiences in the Patagonia Region of Argentina. Compost Science & Utilisation, 6 (1): 59-66.
Liao PH, May AC, Chieng ST (1995) Monitoring process efficiency of a full-scale in-vessel system for composting fisheries wastes. Bioresource Technology, 54 (2): 159-163.
Liao PH, Jones L, Lau AK, Walkemeyer S, Egan B, Holbek N (1997) Composting of fish wastes in a full-scale in-vessel system. Bioresource Technology, 59 (2-3): 163-168

	Illera-Vives et al., 2013	Illera-Vives et al., 2015	Laos et al., 1998	Liao et al., 1995	Liao et al., 1997
Feedstock ratio (fish waste:other)	1:1 seaweed:3 pine bark (v:v:v)		3:1 (w:w)	1:1.3 and 1:1 (w:w)	1:1.3 fir sawdust (w:w) or 1:2 alder chips (w:w)
Relevant conclusion(s)	High salinity		More available N in mature compost compared to 'organic commercial product'	1:1.3 deemed a better composting mix	Alder chips were a good bulking agent

*EU animal by-product standards requirement for treating fish waste

The two non-primary literature articles, taken from one issue of the industry journal Biocycle, supported the above. Brinton (1994)[20] discussed the use of straw (particularly waste straw) as a carbon rich feedstock and bulking agent for co-composting with fish waste. The article upheld the need for appropriate feedstock mixes and composting conditions when using fish waste as a compost feedstock and the need for 'quick' handling of material to minimise odour generation. In the same Biocycle issue, Goldstein (1994)[21] quoted a trial by researchers at Washington State University (WSU) on composting fish waste with sawdust at a C:N ratio of 30:1, corroborating previously mentioned articles. The high N content of fish waste derived compost was highlighted, and benefit for growth on potted geranium plants illustrated.

In conclusion, the articles support the results of the stakeholder engagement in terms of benefits and limitations of fish waste as a composting feedstock. Specifically, the key benefit being the potential to produce higher N content compost which is appreciated by agricultural markets. The limitations are the odour generation which requires appropriate and well maintained odour / ammonia emission control systems. When composting fish waste it is therefore imperative that biofilters are maintained appropriately to ensure they are in full working order.

13.2 Processing Fish Farm Waste through Rendering and Incineration Infrastructure

13.2.1 Objectives

The objective is to review the capacity within Scotland to process fish farm waste through incineration / rendering in terms of the following considerations:

- What percentage of fish farm waste could the Scottish incineration / rendering plants take?
- How much do we know about putting this material through incineration / rendering?
- What is the likely inhibiting factor(s) if any?
- What mitigation methods could be employed to alleviate any inhibiting factors (include costs and to which industry this would impact fish or reprocessors)?
- Are there collection services which could undertake the transfer of fish farm waste to incineration / rendering plants in Scotland (volume, geographical location, ABP category etc.) – if not, why not?

[20] Brinton R (1994) Composting research – Low-cost options for fish waste. Biocycle, 35 (3): 68-70.
[21] Goldstein J (1994) Economics of fish waste composting. Biocycle, 35 (3): 70-70.

The above has been examined through a combination of literature / desk-based review and stakeholder engagement, with the section on the latter, described later below providing the industry view in terms of the above considerations.

13.2.2 Literature and Desk-Based Review

The rendering process is one whereby water is removed from tissues using heat, producing fish oil (in this context) and protein residue[22]. An indicative example of potential steps and outputs are shown in the figure below.

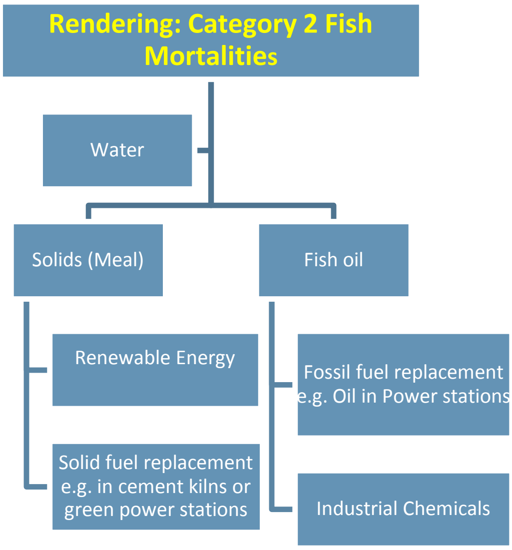

Figure 4. Overview of Potential Rendering Products (for Category 2 materials)

The 2005 SEPA report evaluating fish waste management techniques, concluded that a small number of commercial facilities had permission from the then State Veterinary Services (SVS) to treat Category 2 wastes, however, these were principally renderers and incinerators of animal remains. In 2005, the two operating Category 1 rendering facilities in Scotland were not willing to take fish waste for what were described as technical reasons. The report concluded that the animal remains incinerators would not be able to take significant quantities of fish wastes, due to the wet nature of the waste, stating

> "*At present (report written 2005), the only cost effective option available to the Aquaculture industry, for the disposal of Category 2 fish material, is ensiling and export to Scandinavia*."

Since that time there have been significant developments, as described in the stakeholder engagement section later in this report, with no exports of waste to Scandinavia.

The use of incineration as an option has changed little within the ten year time period, with both Shetland and Widnes still the only two open access incinerators used to process fish mortalities. Shetland limit intake due to issues with calorific value and their throughput appears to have remained reasonably stable over time.

Incineration of fish mortalities can take place in plants approved under the ABP(E)(S) regulations or the Waste Incineration Directive. It is also possible to site small-scale (i.e. <50kg/hr) incinerators at the fish farm, subject to APHA approval. On-site incinerators must ensure that the exhaust gas is held at 850°C for 2 seconds, or 1,100°C for 0.2 seconds[23]. Mobile incinerators can be used subject to the same regulations.

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[22] https://www.gov.uk/government/uploads/.../scho0195bjjv-e-e.pdf

[23] https://www.gov.uk/guidance/animal-by-products-how-to-burn-them-at-an-incinerator-site

SEPA commented in discussions that it was developing guidance for the use of small-scale incinerators in rural areas only, which had a capacity of less than 50 kg/hour. Unless they caused a nuisance, the aim was that the operators of such incinerators would follow the guidance and not have any requirements from SEPA in terms of permitting / licensing; compliance requirements will be limited to approval by APHA. At the time of writing it is understood that drafts of this guidance and the approach have not yet been issued.

The SecAnim Widnes fluidised bed combustor appears to take fewer fish mortalities per week now than in recent years. The intake of fish silage was estimated in the SEPA Report (2005) to be on average 50 - 70 tonnes/week[24] in 2005, as compared to 26 - 28 tonnes per week in 2015. Part of the reason for this decline may be explained by differences in reporting (the 2015 figures represent routine morts only). The gate fees at both the Widnes and Shetland facilities have almost doubled in the past ten years:

- Shetland Energy Recovery plant: Gate fee increased from £23.07 (2005) to £44.47 (2015) per tonne.
- Widnes fluidised bed combustor: Gate fee increased from £32.50 (2005) to £55 (2015) per tonne.

In the 2005 SEPA Report the total cost of disposal by incineration (including ensiling and transport) was approximately £105 per tonne. In 2015 the cost of haulage and incineration at Widnes range between £139 and £600 per tonne - from the north-west mainland and Orkney respectively. The incineration capacity potentially available within Scotland itself is very small-scale and significantly more expensive than at Widnes. This is outlined further, later in this report. Although not currently utilised by the aquaculture industry, there are possibilities to utilise additional incinerators (predominantly those burning clinical waste), this option was not considered by the 2005 report.

The two Norwegian processors (Scanbio and Hordafor) identified in the Poseidon report are no longer active in the Scottish market, however correspondence / discussions with both have indicated an interest in providing solutions in the future. In direct contrast however, one Scottish renderer is currently trialling processing fish mortalities.

Using Google scholar the following search terms were inputted – “fish mortalities incineration”, “fish mortalities incinerate,” “incineration fish waste”, “Render fish mortalities”, “render fish waste” and “processing fish waste” . No detailed academic articles relating to incinerating or rendering fish waste were found. Although there were some articles / patents relating to a general overview of the fish and / or animal by-product industry, these articles did not discuss inhibitory or mitigating factors.

It should be noted that another legal use of Category 2 fish meal would be in feed for fur animals. Fur farming is illegal in the UK, but is allowed in other EU Member States.

13.2.3 Rendering Results in Detail

13.2.3.1 Introduction

The previous table provides information on a range of rendering opportunities. This section provides more detailed feedback from four rendering / processing companies: (i) Dundas Chemical Company / Caledonian Proteins, (ii) Argent Energy, (iii) Scanbio Marine and (iv) Hordafor. The result of engagement with the former director of the UK Rendering Association (no longer operational) is also provided. The organisations provided significant inputs in terms of market development opportunities and issues.

[24] http://www.gov.scot/Publications/2005/03/20717/52863

13.2.3.2 Dundas Chemical Company / Caledonian Proteins

Dundas Chemical Company are Category 1 renderers based in Dumfries and Galloway. The rendering process involves heating Category 1 ABPs to remove moisture and to separate oils and proteins to produce two products; MBM (Meat and Bone Meal)[25] and Tallow[26].

Dundas are actively pursuing the fish mort market at the moment – their facility has historically rendered fish morts, (both ensiled and whole) on an ad-hoc basis, however a trial during 2015 focussed on the whole process – collection, handling and processing. In terms of potential inhibitory factors, Dundas are not aware of any issues that should influence the outcomes of the trial.

The facility has a spare capacity of 1,000 tonnes per week (total capacity 3,000 tonnes per week) and the company anticipate that this spare capacity could be used to process fish mortalities, enabling the value from processing fish waste to be retained in Scotland.

With regards to potential gate fees, the trials will help to inform these, however Dundas anticipate that they will be cost competitive due to their Scottish location and ability to offer both haulage and processing (thereby enabling them to offer haulage at cost price).

13.2.3.3 Argent Energy

Argent Energy was established in 2001 and has an operational facility near Motherwell, Scotland that started production of biodiesel in 2005. The plant has been the focus of an EU project to develop and demonstrate biodiesel production using a mixture of animal tallow and used cooking oil rather than virgin oils and in 2009 received funding from the Scottish Government to build a pre-processing facility. The company's main output from the facility is biodiesel, however there are also several by-products, these include glycerine (for AD), a small amount of fertiliser and a heavier 'biofuel oil' which is used as fuel in the facility's boiler.

The facility in Motherwell produces approximately 55,000 tonnes of biodiesel annually (typically viable feedstocks contain between 20 – 99% oil). An additional facility is being constructed in Stanlow, (scheduled to be complete June / July 2016), and when the Stanlow plant is operational it will produce an additional 75,000 tonnes of biodiesel annually. The company therefore has a very large feedstock requirement and internal discussions had considered fish morts and the potential viability of processing through the facility. Argent provide diesel to all of Stagecoach's buses across the UK. This is described as a high quality, blended fuel with between 20 & 30% being biodiesel and the remainder a mineral diesel.

In order to determine the potential viability of fish morts, the company carried out trials in late 2015, as summarised below:

- Preliminary testing to determine oil recovery – involving the sampling of ensiled fish waste.
- Additional testing to determine the processes that would be required to extract the oil.

Indicative views on the potential associated with fish farm waste following the trials above are given below:

- Whole fish, typically from mass mortality events and ensiled fish, more typically from routine operations, are the two ways in which fish farm waste could be delivered to them. Their preference would be to take ensiled waste for the following reasons:
    - It will be easier to manage, in terms of odours, the condition of the fish, and by being more sludge-like in nature.
    - The acid will have, in effect, begun the oil separation process, making subsequent processing easier. The type of acid would be an influence in terms of process management, but this is an operational detail, rather than an issue.

[25] Meat and Bone Meal is the protein product after the fat and moisture have been extracted.
[26] Tallow is the fat extracted from animal/fish tissue.

- Their process is Method 1 (pressure sterilisation) which means that they are able to process Cat 1, 2 and 3 wastes – fish farm waste can therefore be managed without any issues.

It was mentioned that a biodiesel producer elsewhere in Europe had decided to stop the processing of fish farm waste to produce biodiesel (see the Scanbio consultation response). Argent commented that the limitations are process and output based, with the key being the production of a biodiesel that meets the appropriate EN standards. They already produce biodiesel from sewage grease, and therefore believe that they have a robust process, with 90% of their feedstock is also provided to them by renderers.

In terms of the fish farm waste at this point in time it is estimated that oil may represent around 15% of the fish mort tonnage input, but ongoing work on this would establish the actual percentage with more confidence. The differences between ensiled and whole fish will be understood with greater clarity as more work is done in this area. The other two outputs (in addition to fish oil) would be solids and water (the former could be up to 50% TS w/w). They would anticipate that the solids would be sent for rendering, with the potential for more oil to be extracted. Water would be disposed of under a discharge consent.

Their testing has indicated that they would be able to incorporate up to 5% of fish oil in a biodiesel fuel – after this there is the potential for complications to start arising (between 7 and 9% could cause some concerns).

As stated in this report, it is estimated that the annual tonnage of fish farm mortalities is 10,000 tonnes, with more than 2,300 tonnes disposed of at licensed landfill sites. 5% of the current production at Motherwell would equate to 2,750 tonnes per annum of fish oil. This may require between 13,750 tonnes and 27,500 tonnes of fish waste (for 20% & 10% fish oil content respectively). This therefore exceeds the total quantity of fish morts currently estimated to be produced in Scotland.

Argent are very much at the early days of considering whether the processing of fishfarm morts is something which has a strong business case. This is directly related to potential quality issues versus the commercial benefits. There is the potential for such waste to be accepted without any cost to the supplier other than transport costs – this would depend on the cost of separation versus benefits realised.

13.2.3.4 Scanbio Marine Group Norway

Scanbio Marine Group decided to stop their biodiesel production project, as referenced in the Enerfish Feasibility Study (for the Shetlands) (Appendix F). They commented that they could not produce a biodiesel that the car manufacturers in Europe would provide a warranty for, in terms of their engine performance – that the existing standard was established based on biodiesel production from rapeseed and that they could not achieve the required quality using fish waste. An important aspect of this is the condition of the fish waste as received from the fish farms.

Scanbio commented that their system was approved by the EC in 2015, as an alternative for processing Category 2 fish mortalities (the Norwegian System). They also commented that the outputs from this have been supplied to an AD facility in Denmark, and also as a feed for mink, again in Denmark, with the latter now stopped. In terms of the outputs from their system that go for AD it was commented that in Denmark Category 2 fish farm mortalities have to, by law, be processed using Method 1 (pressure sterilisation). In Finland, it was commented that the Norwegian system sufficed (pH4 for 24 hours, 85^{o} Celsius for 25 minutes etc as noted in Appendix E).

13.2.3.5 Hordafor

Hordafor is a Norwegian company specialising in the handling and processing of by-products from fisheries and aquaculture. They were engaged with for the purpose of establishing what they could potentially offer the Scottish aquaculture market and to gain additional information on the Norwegian ensiling method, which Hordafor have helped to pioneer.

It was stated that Hordafor do not currently provide a service in Scotland, although they are one of the market leaders in Norway and also operate in the Faroe Islands. They are interested in entering the Scottish market. Hordafor outlined a number of potential options that may be viable for Scotland:

Option 1: Fish farms could arrange to have ensiled morts transported to a central port storage facility e.g. Aberdeen, where it would be stored and bulked prior to pick-up by a Hordafor vessel. The minimum pick-up would be 600 tonnes of ensiled fish. Hordafor have commented that ensiled fish could be stored for a significant period of time, to assist meeting the minimum collection tonnage (e.g. up to 1 year), provided the waste was monitored to ensure that pH levels were kept below 4. Hordafor have indicated that they would expect costs to be in the region of £160 per tonne (with this price decreasing with larger volumes). Collection of silage at the west coast would be more expensive because of the distance. The ideal scenario after collection is that the waste is then hauled in the most cost effective way possible to a processing facility in Scotland, to produce biogas, with the resulting energy sold into Scottish markets. It should be noted that only ensiled fish could be managed in this way (long storage periods) which means that for mass mortality events, fish would need to be hauled and managed differently.

Option 2: Hordafor have vessels equipped to slaughter up to 200-300 tonnes of fish per day (depending on size and "freshness" of fish). This offers a solution for extreme, mass mortality events, and it is believed has been used by one fish farm operator in Scotland. The result would be that rather than the current process, where fish are stored and transported to an incinerator or AD plant, they would be electrically stunned / slaughtered on board, before being processed in Norway. This option would typically only be used for very extreme events where alternative options were not available. For comparison purposes, Norway typically has 10-20 extreme events per year, compared to one in Scotland, so this alternative approach is unlikely to represent a viable option on a regular basis. This is further compounded by the average size and number of Scottish fish farms (smaller). Hordafor typically charge approximately £320 an hour for such services. There could be additional costs for sailing, if it is not in combination with a collection.

Option 3: Hordafor are buyers of Category 3 waste, so fish farms which also have processing facilities (to produce fish for the market) may be able to negotiate an improved deal for managing Category 2 waste if Category 3 waste is part of the deal. Category 3 waste has a range of potential markets, undergoing a range of processes to produce protein concentrate and fish oil, which commands a high price. Indicative costs associated with this option could not be provided.

Option 4: Provision of a service picking up Category 2 fish mortalities from multiple farms in Scotland e.g. Shetland / Orkney islands. An exact cost for this could not be provided. However, Hordafor believe that it would be cheaper than £160 per tonne due to the sharing of the logistics costs. Hordafor believe that this would be the best solution. There may be an option to also collect Category 3 but this would require an investment in vessels and tanks and is not feasible at the moment. This option would need careful consideration due to the limited number of deep ports and smaller scale of farms in Scotland compared to Norway.

Hordafor have indicated that if there was interest they would need to obtain approval from Norwegian Authorities to import Cat 2 from Scotland for processing. They do not anticipate any issues in obtaining permission. They have indicated that at the moment their only outlet for Category 2 fish mortality waste in Norway (after heat treatment of the ensiled material) is anaerobic digestion, with approximately 20,000 tonnes going to the Danish market. The morts are sterilised at >85 degrees Celsius for more than 25mins (now an approved method, and forming part of the Animal By-Product Implementing Regulations). Hordafor are aware of potential issues associated with morts as a feedstock for anaerobic digestion predominantly due to acid build-up (from ensiling the waste) and the nitrogen content – they have commented that the significance of each, individually, has still to be fully established. However, the company that they supply overcomes the issues by limiting morts accepted to no more than 5% of feedstock and, potentially are buffering the waste (details not provided).

Historically, fish morts were also used within feed for fur animals until this was restricted approximately two years ago. Hordafor hope to get back into this market, because the company feels that morts were a good product and continue to have potential as a feed for fur animals.

13.2.4 UK Rendering Association

The UK Rendering Association is now dormant, and the former director provided contact details for potentially suitable renderers and recommended contact with FABRA (Foodchain and Biomass Renewables Association). Based on their work with renderers in the past, the former director was not aware of renderers generally accepting or using fish morts, however he could see no technical reason why this should be the case (for Category 1 & 2 facilities) – it was felt that the current situation was due to traditional feedstocks generally being terrestrial based.

13.2.5 Incineration Results in Detail

13.2.5.1 Introduction

At the time of writing (November 2015), the two main locations for the commercial incineration of fish farm mortalities generated in Scotland are the SecAnim plant in Widnes and the energy recovery plant on Shetland. The following sections provide information on these sites, as well as on the technology provider Inciner8, to get a view on the opportunities and limitations associated with small-scale, on site incinerators. A number of other players have indicated their potential, or otherwise, for being able to take fish farm mortalities, as indicated in the previous table.

13.2.5.2 Shetland Heat Energy and Power

The Energy Recovery Plant in Lerwick generates hot water by burning waste (from Shetland, Orkney and offshore) for the Lerwick District Heating Scheme which is operated by Shetland Heat Energy and Power Ltd (SHEAP). The Plant burns 22,000 tonnes of waste per year and generates 7MW of energy[27].

The incinerator on Shetland does currently accept fish morts (Whole fish only, ensiled / liquid waste is not permitted). However, this is small-scale compared to the quantity landfilled i.e. in 2014-15, this amounted to 6% (108 tonnes) of the overall quantity of fish farm mortalities managed through landfilling or EfW on Shetland (1,795 tonnes)[28].

During large scale mass kills, there is insufficient capacity and fish morts are landfilled. Volumes of fish morts accepted at the waste to energy plant in the future are likely to decrease due to changes in local authority recycling collection scheme, which is anticipated to decrease the calorific value of the waste received by the facility. Fish morts currently pose a problem to the facility due to their low calorific value and the liquid nature of the waste.

13.2.5.3 SecAnim, Widnes

The Bubbling Fluidised Bed (BFB) combined heat and power (CHP) combustion plant in Widnes, Cheshire appears to accept the majority of fish morts within Scotland. The plant is operated by SecAnim, part of SARIA and PDM group. When opened in 2000, the facility was the world's first commercial meat and bonemeal (MBM) combustion plant. The plant generates renewable electricity from biomass and produces bio-fuels for industry. SecAnim also provides Fallen Stock collection services to livestock farmers and operates a Category 1 rendering plant.

The facility generally receives one load (approximately 26/28 tonnes) per week of macerated fish (typically arising from routine morts), which represents approximately 3% of their total feedstock throughput. However, the facility will also receive whole fish from mass mortality events as and when required, which can amount to 50 tonnes per day (350 tonnes per week i.e. ten times the amount of routine mortalities in a week). The overall tonnage in terms of routine plus mass mortality events was

[27] http://www.shetland.gov.uk/waste/energyrecovery.asp
[28] Shetland Council, email correspondence, October 2015.

not provided, but it was commented that capacity is not an issue and it would not present them with any technical / commercial difficulties managing all of the fish farm mortalities generated in Scotland– this would still represent a relatively small percentage of their feedstock.

Routine morts generally arrive macerated and are incinerated to produce electricity. Mass events generally arrive as whole fish which are rendered to produce i) tallow and ii) meat and bone meal. The meat and bone meal is then put through the incinerator.

The facility would be keen to process additional fish mortalities and, as indicated above, SecAnim have commented that they have spare capacity. Fish morts are generally booked in under the name of the haulage contractor, with a number of haulage contractors providing regular deliveries to Widnes from Scotland.

13.2.5.4 Inciner8 (Technology Provider for Small-Scale Incinerators)

Inciner8 provide small-scale site-based and mobile incinerators that could provide a solution for fish farm operators wanting to treat fish mortalities on-site, rather than pay additional logistics costs. The company offers a range of grated incinerators (burn comes from underneath as well as above) that could process fish mortalities, with no technical issues. During the consultation, Inciner8 indicated that approximately six fish farm operators had purchased small-scale incinerators and were going through the planning process. They believe that this is due to fish farmers not wanting to send fish mortalities to off-site treatment facilities with the associated costs involved. Technical specifications for specific incinerators suitable for the aquaculture industry are shown on the company’s website. The largest of the company’s systems is 1,250kg/hour, compared to the more typical maximum at fish farms of 50kg/hour.

13.3 Logistics Capacity for Managing Fish Farm Waste

13.3.1 Objectives

The logistics infrastructure in the country has been considered through stakeholder engagement with a number of hauliers. The objectives of this work have been to:

- Gather information on current suitable collection services.
- Identify a number of current logistics companies to determine the feasibility of transporting fish waste to alternative ABP compliant end disposal points, and the costs of doing so.
- Identify potential synergies with alternative logistics companies that could potentially transport fish, these may include logistics companies within the following areas; fish feed, off-shore renewables, passenger transport, tourist & food processing.
- In Norway, there is a designated ferry collecting fish waste - a similar system will be explored for Scotland.

The above has been examined mainly through stakeholder engagement, as described later in the report, to provide the industry view. This has been supported by a brief review of the haulage / logistics infrastructure, as indicated below.

13.3.2 Desk-based Review

Ensilage offers fish farms a relatively simple, low technology process for storing mortalities. Ensiling units can be small in size and can be utilised to deal with mortalities as and when required, offering greater flexibility for logistics options and an option to bulk up relatively small volumes. Ensilage (on-site) and in larger sites to service multiple fish farms will be considered.

There are currently a range of logistics companies offering services to fish farms. These include passenger ferry operators, large Norwegian fish processors e.g. Scanbio and Hordafor and smaller logistics companies.

Through a combination of web searches, industry knowledge and stakeholder engagement, a number of logistics / haulage companies have been identified which provide services involving ferry and road haulage. The three major players hauling fish morts, as identified by the fish farming companies themselves, are Billie Bowie, Ferguson Transport and Hazco. Shanks also offer a haulage service to their sites.

However, there are a range of logistics companies offering services to fish farms, including food hauliers, fish feed suppliers and providers of harvesting, fish management and maintenance, some of which have highlighted their interest in transporting fish morts in the future i.e. there is the potential for the development of a broader logistics base, more competitive market and possibly more innovation involving new entrants – see the outcomes of stakeholder engagement in this area, in the next section of this report. This includes an interest in the bulk movement of fish using dedicated seagoing vessels, where practicable. There are also a range of facilities that offer an integrated haulage service, including a Scottish renderer (Dundas). In Norway, there is a designated seagoing vessel collecting fish waste, and the companies Hordafor and Scanbio have indicated a potential interest in exploring whether a similar system could be introduced for Scotland. Because of the special interest in the Norwegian system this is described in some detail, in Appendix E.

13.3.3 Haulier Results in Detail

13.3.3.1 Introduction

More information is provided on the responses provided by the hauliers mentioned in Table 7. All of those responding in detail are described here since there was significant variation in ideas and opportunities for further supporting the movement of fish farm waste from landfill to alternative treatment facilities.

13.3.3.2 Johnson Marine

Based on Shetland, they work for a number of multi-nationals. They have 12 workboats that wash nets, treat fish, carry and harvest fish - motorised power washers on 4 – 5 boats. They harvest around 30% of Scotland’s fish farms. Their activities include moving juvenile fish around, grading and harvesting fish. The movement of fish farm mortalities is currently undertaken by the fish farm companies’ own work-boats.

Salmon and pelagic fish processing factories are close to the harbour, producing significant quantities of fish waste. Johnson Marine are considering moving fish gut waste from the factories to an AD facility, since this offers back-hauling efficiencies. They typically would not move mortalities, but there may be a one-off circumstance that would require this. At the moment they are working with a number of partners on options surrounding Anaerobic Digestion plants utilising fish waste, mortalities etc and are still at the stage of gathering information and identifying if there are commercial opportunities. They are in early discussions for an AD facility on Shetland. They have estimated that there could be as much as 15,000 tonnes per annum of fish waste generated on the Shetlands in the future, with 6,000 to 7,000 tonnes per annum of this being fish gut waste and, on average, 1,500 tonnes per annum of salmon mortalities from fish farms around Shetland. The ban on dumping fish at sea has been identified as something which could also result in significant feedstocks for AD (see Section 5.3). Their interest and considerations at the moment include Lerwick as a central processing repository for fish, with fish gut tonnages being the forecastable, baseload.

They have identified the tonnages of fish farm mortalities for the Shetland area being managed through landfill and the Shetland EfW facility. In 2014 – 15 this amounted to 1,795 tonnes. This equates to approximately 30 tonnes per week, compared to 135 tonnes/week of fish guts, with the potential (uncertain) for new fish landings in the future added to this.

Moving fish for processing on the mainland (eg Peterhead) would be on the limit of viability for a small, bulk carrier (capacity 300 to 500 tonnes). This would be assisted if Orkney waste plus regular trips to Norway could be factored into the haulage movements (since on the west coast of Norway approximately 200,000 tonnes per annum of fish guts are processed, giving economies of scale). They are interested in the Norwegian Method and commented that this would require dedicated boats – they would not use the same boats to haul fish for market and fish mortalities.

13.3.3.3 Ferguson Transport

Fergusons collect from the Western Isles, Inner Hebrides (Gigha, small scale) and Argyll. None of the waste they collect is sent to landfill – all is sent for incineration at Widnes. The cost of accepting solid fish waste at Widnes was described as being double that of macerated / ensiled waste. Fish farm waste is collected in a number of different ways:

- Mass mortalities – whole fish, not ensiled, in bins, collected off boats – special landing craft used. For some recent events, this has involved 5 landing craft being rented out.
- On some occasions they have been working flat-out over periods of a fortnight, to collect and haul fish waste from mass mortality events, using two tankers to take the waste to Widnes.
- For more standard levels of fish morts storage tanks are now more common than before, being stored in containers with capacities of 10,000 and 20,000 litres.
- For whole fish, gulley suckers are usually used. However, such vehicles can take twice as much ensiled fish as whole fish.

13.3.3.4 DFDS

DFDS commented that they are the largest provider of transportation services to the Scottish salmon and seafood industries, however they only collect fish for human consumption. The company currently services Aberdeen, Fraserburgh and Peterhead on the east and Ayr / Prestwick on the west. Collections are made by DR Macleod and Shetland Transport further north. Generally, they only deal with mortalities in unusual circumstances. It is not a service that they currently offer, or a market opportunity that they are currently exploring, however they would consider offering the service if there was demand from fish farms. i.e. this would need to be client driven.

13.3.3.5 DR Macleod

DR Macleod are located on Stornoway and operate 55 large commercial vehicles, plus approximately 90 trailers, supplemented with approximately a dozen smaller vans for local deliveries. DR Macleod currently hauls fish for human consumption from fish farms on the Western Isles and transport this down to DFDS. Although not currently transporting fish morts, the company would consider this, if there was a demand. DR Macleod frequently service fish farms and therefore providing a regular service would not present them with an issue. The main issues of concern were the types of container that the fish would be stored in and whether they would need to be refrigerated, but they do have a range of vehicles that could be utilised and were very positive and confident that they could deal with the demand.

13.3.3.6 Scanbio Marine Group Norway

The focus of Scanbio’s activities is Norway, and they have stepped back recently from Scotland. They have commented that in terms of developing infrastructure in Scotland the focus should be on (i) biosafety, then (ii) logistics and then (ii) how to do this in the most cost effective way possible. They commented that the regulatory position in Scotland is something which needs some attention.

The Norwegian System involves the servicing of around 700 to 800 sites, by Scanbio and Hordafor, with 10 vessels involved, ranging in size from 350 tonnes to 800 tonnes payload capacity. The system in place was described as follows:

- Fish farm cages must have a mortality management system in place, at sea.
- Every day, fish mortalities generated are required to be ground / macerated, ensiled and kept in small tanks. The vessels mentioned above then come alongside to collect these, at sea.
- There is a so-called “ambulance service” for mass mortality events when the fish farms processing equipment cannot manage the tonnage involved. By law, a vessel must be at the fish farm within a defined timescale (38 hours was mentioned, but this needs to be confirmed).

This vessel can slaughter the fish using approved systems, and can then grind / macerate and ensile it. The vast majority of fish waste managed is Category 2, but some Category 3 waste is also managed – this is determined on a site by site and case by case basis.

- The collection vessels take the ensiled fish waste to the treatment facility, where it is exposed to a temperature of 85º Celsius for 25 minutes. This facility has a capacity for treating 40,000 to 50,000 tonnes per annum. It has spare capacity and could take fish morts from Scotland, if the same preliminary treatment process were in place.

13.3.3.7 Calmac

Calmac do not currently own their own boat and have not considered fish farm waste and its haulage. However, they are always interested in new opportunities and have looked at a range of alternative business opportunities in the past. Their interest would be in seagoing haulage, with land-based opportunities less so. After October 2016 they would be able to look at this closely, after the current procurement period for new ferry services has finished - there is then a mobilisation period between May and October 2016. They currently operate 26 harbours/ports on behalf of Caledonian Maritime Assets Ltd (CMAL), the latter having a fleet of 33 ships, which Calmac operates on their behalf. There are always 2 or 3 ships ready for use (redundancy is deliberately built in to the operations) and there would therefore be the potential for one of three to be considered for hauling fish mortalities. These would be roll-on roll-off vessels which may be well suited for the movement of large quantities of fish.

13.3.3.8 Hazco

They manage the collections of a range of salmon and trout fish farms across the country, covering all of the mainland, the Western and Northern Isles, for both whole and macerated / ensiled fish - normal and mass mortalities. Mass mortality events before have required them to move 400 to 500 tonnes of both ensiled and whole fish, tankered from specific locations over a six-month period. They generally move Category 2 fish farm mortalities, since it is difficult to identify what fish waste is Cat 2 or 3. Sites have a range of collection infrastructure, including remote tanks, with 20,000 litre capacity for ensiled / macerated fish. Sometimes collections are from special bins or IBCs, with the waste ideally pumped from these to the tanker. Ensiled and macerated fish are preferred in terms of ease of handling and haulage. They have investigated the potential for hauling mortalities to AD operators in Scotland, which have initially indicated that they can take such waste. However, when Hazco have asked for the licence / permit information to confirm that they can take Cat 2 fish farm waste the facilities have been unable to provide this. Category 2 mortalities are therefore taken for incineration at Widnes and the Category 3 to IVC for composting.

13.3.3.9 Billie Bowie

Billie Bowie is one of three companies regularly mentioned by fish farms as the haulier used to transport fish mortalities. The company has a range of vehicles to transport both liquid ensiled fish waste and whole raw fish. Liquid waste is generally transported by dysab or vacuum tanker. Whole fish can be transported by flevac (which sucks whole fish directly into the vehicle, and is typically used where access is limited) or within sealed skips on back of lorry. They can typically transport up to 30 tonnes of fish at a time, but this will depend upon the vehicle. The company routinely operates throughout mainland Scotland and the Western Isles, and typically transport fish morts to Widnes because it is their view that Scottish AD plants are not set up to deal with such waste. They are able to transport fish mortalities to and from any location in Scotland.

Appendix B

14 Income Stream for Energy Production Using Fish Waste

Section 8 provides an estimate of the financial impacts on remote landfill operators, associated with losing gate fees for fish farm mortalities. However, the other side of this is the economic benefit to be realised by more sustainable practices, which generate value from the waste streams (Section 7). Using AD facilities as an example of more sustainable practice, for facilities with the treatment infrastructure for processing such mortalities, the estimates provided in this section give an indication of the economic value which can be recovered from fish farm waste streams – for energy generation alone. (In addition, a gate fee could be charged at suitably licensed AD facilities, as indicated in the following section).

The UK Feed In Tariff (FIT) and Renewable Heat Incentive (RHI) Schemes provide guaranteed incomes for different scales of facility, and different types of technology. For illustrative purposes, this analysis considers the potential income associated with fish waste and energy, using anaerobic digestion and Combined Heat and Power (CHP) as the generating technology.

One tonne of whole fish may produce approximately 156m^3 of methane[29]. With a calorific value of 36MJ/m^3, this translates to 5,616 MJ of energy available which can be generated as a mix of electrical and heat outputs (equivalent to 1,560kWhours). If the electrical conversion efficiency is 35% this equates to 546 kWhours of electricity per tonne. If 50% of the heat produced is recoverable, a third may be required to heat the digester itself, leaving 522 kWhours with export potential.

For an anaerobic digestion facility which processes 1,000 tonnes of fish per annum, this will result in a potential income stream / avoided cost (associated with energy generated by the fish alone) of £139K, as broken down below (using an AD cost benefit calculator developed by Zero Waste Scotland).

- Electricity: £73K (£50K FIT tariff and £23K export price)
- Heat: £66K (£40K renewable heat incentive and £26K avoided heating costs).

The above is based on the following assumptions:

- Electricity generated is fed into the grid and not used on site.
- There is a suitable receptor for using the heat generated.
- The electricity and heat generated are for facilities operating at the smaller of the facility scales shown on the tables below (showing the Ofgem tariff rates for different sizes of facility).

Once landfill is removed as an option for managing fish mortalities, the loss in income generated (landfill gate fees) can be offset to some extent by any future investment in processing plant, such as AD. This report has indicated that 2,316 tonnes of waste has been identified by stakeholders as being landfilled per annum, generating £228K in gate fees alone for rural landfill operators. By comparison, a pro rata scaling up of the income stated above, as a result of energy production (from the anaerobic digestion of fish) could give £321K per annum (gate fees would also be charged in addition to this).

The income calculated above used the October 2015 Ofgem tariff structure for the Feed-In Tariff and Renewable Heat Incentive, as summarised in the tables below.

[29] Aqua Enviro Report, 2012, "Orkney AD Feedstock Testing", Zero Waste Scotland

Table 15. Feed In Tariff & Export Payment Rate for Non-Photovoltaic Installations, 1st April 2015 to 31st March 2016 (Source: Ofgem)

Description	£/kWhour
less than or equal to 250kWe	0.0912
More than 250kWe but not exceeding 500kWe	0.0842
Greater than 500kWe	0.0868
Export tariff - All	0.0485

Table 16. Non-Domestic Renewable Heat Incentive Tariffs on or After the 1st of October 2015 (Source: Ofgem)

Description	£/kWhour
<200kWth	0.0762
200kWth and above, less than 600kWth	0.0599
600kWth and above.	0.0224
Estimate for avoided heating cost*	0.05

*Not part of the Ofgem tariff structure –an estimate for pricing purposes.

Appendix C

15 Research in Scotland on the Management of Fish and Fish Farm Waste and Forthcoming, Related Developments

15.1 Strategic Research Carried Out

In 2004 Poseidon produced a report for the Scottish Government on fish waste management techniques[30] describing a range of available and emerging technologies for managing fish waste. In a Scottish context, with the exception of composting, the emerging technologies listed would appear to have made little impact in the period since 2004 (with respect to fish farm waste). A number of these techniques have been considered (Appendix F) , in terms of the potential they may represent in 2015.

The SEPA, 2005 report for the Scottish fish waste management group[31], provides an overview of fish farming practices, in terms of waste arisings, infrastructure (and need), disposal routes and technical options. This Zero Waste Scotland report considers many of these aspects of the industry and through up to date research and stakeholder engagement provides more detailed information on what is happening in a range of geographical locations across the country, with respect to AD, IVC, rendering and incineration.

Zero Waste Scotland's 2015 report[32], *Sector Study on Beer, Whisky and Fish,* explores potential options for various by-products arising from these industries. The report looks at the fishing industry as a whole (fish farms, processing and capture) and therefore presents a wider scope and range of end markets / disposal options than might be available for fish farm morts alone. It indicates that approximately 4-11% of salmon are lost as mortalities, resulting in approximately 4,999 tonnes of fish mortalities across Scotland. Based on work carried out in Section 3, the authors believe this estimate to be on the low side (10,000 tonnes is reported in this section).

The Zero Waste Scotland report provides a general overview for a range of options for fish mortalities, which include anaerobic digestion, composting, etc. The report also refers to the following, in the context of fish waste as a whole:

- Agricultural benefit, notably because of their high nitrogen content.
- Composting: they can be co-composted with a suitable high carbon content material such as shredded garden or wood wastes.
- Anaerobic digestion: carried out commercially, notably for fish mortalities that cannot be entered into the human or animal food chains. Protein is difficult to process in AD, with the nitrogen component producing ammonia contamination.
- Kalundborg Symbiosis, Denmark: described as the world's first working industrial symbiosis, developed since 1961 with multiple flows of resources established between chemical industries, agriculture and fish farms.

The latter case study, Kalundborg, has been considered in this report, and is described later, among a number of other future opportunities.

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[30] Poseidon, 2004, "Evaluation of Fish Waste Management Techniques", Scottish Government
[31] SEPA, 2005, "Developing a Framework for a Sustainable Fish Waste Management Infrastructure", Scottish Fish Waste Management Group.
[32] Zero Waste Scotland, 2015, "Sector Study on Beer, Whisky and Fish".

15.2 The Impacts and Opportunities Associated with the Landing Obligation ("Discard Ban")

As part of the reformed Common Fisheries Policy (CFP) it has been agreed that catches of quota fish may no longer be discarded. Instead, all of the catch must be landed and counted against quota. The discard ban, or Landing Obligation, only applies to species subject to catch limits[33]. The Scottish Government has consulted on the way the new system of quota allocation will work in the North Sea and the North Western area but is yet to publish the results and its response, which will in any case need to be approved by the European Commission. Quotas are computed from a variety of indicators of which fishing mortality is key. Mortality which occurs from discarded fish is currently estimated and included in the quota calculation (the government estimates that the ban will tackle 25,000 tonnes of dead fish currently thrown back into the sea[34]). Once the landing obligation comes into force (2016-2019 depending on species) quotas will include fish previously discarded. It is the government's intention that the landing obligation will not result in an overall increase in mortality and that it will not result in fish being landed that cannot be sold as they are above quota, but it seems highly likely that some over quota fish will be landed. Fish that are not subject to quotas will continue to be discarded at sea if they have no market value.

Fish that are landed which are above quota cannot directly enter the human food chain but will be regarded as Category 3 wastes and so may have higher value than Category 2 morts. A study commissioned by Seafish on issues around utilising such material[35] concluded:

> *"This feasibility study reveals that there is enough interest in UK registered commercial bulk outlets dealing with Category 3 animal by-products to utilise fish discards not destined for human consumption. Most see this as an opportunity to expand their current business while others see it as an opportunity to develop further solutions. As a result, commercial outlets could utilise all of the non-human consumption discards that would be landed with the implementation of a discard ban. However, the financial returns to the catching sector would be low (less than £150 per tonne) compared to the human food chain."*

Although it is impossible to predict the outcome of the Landing Obligation policy, which will be implemented in stages from 2016-19, any additional waste produced may increase the viability of decentralised morts processing facilities.

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33 http://www.gov.scot/Topics/marine/Sea-Fisheries/discards
34 http://news.scotland.gov.uk/News/Future-of-fishing-195e.aspx
35 Mangi, S.C. and Catchpole, T.L. (2012) Utilising discards not destined for human consumption in bulk outlets, Commissioned by Sea Fish Industry Authority, ISBN 978-1-906634-67-4, 51 pages.

Appendix D

16 The Legislative Position

16.1 The Key EC and Scottish Regulations

The key European and Scottish animal by-products regulations (ABPRs) related to waste/mortalities from fish farms are as summarised below:

- EC No 1069/2009 – laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation).
- EU No. 142/2011 - The EU ABP Implementing Regulation (implementing EC No. 1069/2009).
- EU Reg No 2015/9 –amending Regulation (EU) No 142/2011 implementing Regulation (EC) No 1069/2009.
- Animal By-Products (Enforcement) (Scotland) Regulations 2013 – referred to below as the ABP(E)(S).

EU Reg No 2015/9 refers to an alternative ensilage method that has been added to the ABP Implementing Regulations – this is the Norwegian System, as described in detail later in this report. In Scotland the ABP(E)(S) regulations allow new alternative processing methods approved by the EU to be used as they become available, without the need for new regulations (i.e. the Norwegian System can now be used in Scotland).

The above regulations define the treatment required for processing Category 2 and 3 fish farm mortalities, as well as the end products arising from this treatment.

16.2 The Animal By-product Regulations and the Processing Implications for Fish Farm Waste

The Scottish Government's interpretation of European Regulations, in terms of what are acceptable processing requirements for Category 2 fish farm mortalities, is based on interpretation of articles 13e)(i) and 13g) in EC No. 1069/2009 (Section 1 of Chapter I, General Provisions). These are summarised below:

- Article 13e)(i): "Category 2 material shall be composted or transformed into biogas following processing by pressure sterilisation and permanent marking of the resulting material."
- Article 13g): "Category 2 material shall be in the case of material originating from aquatic materials, ensiled, composted or transformed into biogas."

The Regulation, EU No. 142/2011, (referred to as the "Implementing Regulations" from this point on) sets out the different types of treatment for various categories and types of ABPs and the Scottish Government's view is that the treatment required for Category 2 fish farm waste is pasteurisation at 70^{o} Celsius for one hour (maximum particle size of 12mm), as set out in Box 2. It is the Government's view that if there was a requirement to render Category 2 aquatic ABP prior to transforming it into compost or biogas then Article 13(g) would be unnecessary, as this requirement is already covered in Article 13(e).

Box 2. EU NO. 142/2011 Annex V Chapter 1 (Requirements Applicable to Plants) Section 1 (Biogas Plants)

A biogas plant must be equipped with a pasteurisation / hygienisation unit, which cannot be by-passed for the animal by-products or derived products introduced with a maximum particle size of 12 mm before entering the unit, with:

(a) installations for monitoring that the temperature of 70 Celsius is reached during the time of one hour.
(b) recording device to record continuously the results of the monitoring measurements referred to in point (a); and
(c) an adequate system to prevent insufficient heating.

2. By way of derogation from point 1, a pasteurisation / hygienisation unit shall not be mandatory for biogas plants that transform only:

(a) Category 2 material that has been processed in accordance with processing method 1 as set out in Chapter III of Annex IV.
(b) Category 3 material that has been processed in accordance with any of the processing methods 1 to 5 or processing method 7, or in the case of material originating from aquatic animals, any of the processing methods 1 to 7, as set out in Chapter III of Annex IV.

It should be noted that in Annex V of the Implementing Regulations (as referred to in Box 2), there is no specific mention of Category 2 aquatic ABP.

From a review of the Implementing Regulations it has been identified that there is the potential for the intention of the regulations to differ from the Scottish Government's interpretation – in effect, that 70ºCelsius for one hour may not be a method which can be prescribed for treating Category 2 fish farm waste. This view may be supported by the EU's risk assessment work indicating that treatment at this temperature and duration is insufficient for managing the risks associated with fish pathogens.

Having reviewed the wording of the EU regulations, these could have been written more clearly than is currently the case, to define what treatment is required for processing Category 2 waste / mortalities from fish farms (aquatic animals). A number of aspects of the Implementing Regulations are considered with respect to this. In Annex IV, Chapter II, Section 3, (Processing Methods for Category 1 and Category 2 material) it states:

> *"Unless the competent authority requires the application of pressure sterilisation (Method 1), Category 1 and Category 2 material shall be processed in accordance with processing methods 2, 3, 4 or 5, as referred to in Chapter III."*

In Section 4 of the above chapter (Processing of Category 3 material), paragraph 4 states:

> *"Category 3 material shall be processed in accordance with any of the processing methods 1 to 5 or processing method 7, or, in the case of material originating from aquatic animals, with any of the processing methods 1 to 7, as referred to in Chapter III."*

Chapter III referred to above is therefore key with respect to the standard processing methods that should apply to fish farm waste. A summarised version of this is shown below, with the key points commented on and some additional context provided:

- Method 1: Pressure sterilisation, 133 Celsius at 3 bar pressure, for at least 20 minutes, with particle size less than 50mm. (This is method applied to Category 2 fish farm mortalities in Denmark. Norway also tried to introduce this but there was resistance from the fish farmers, and the Norwegian System was evaluated and proven to be satisfactory instead – following the principles of Method 7).
- Method 2, 3, 4 and 5: A range of different temperature criteria, particle sizes, processes etc are required, all above 100 Celsius,

- Method 6: For Category 3 animal by-products originating from aquatic animal or aquatic invertebrate only: reduction involving defined particle sizes, treatment with formic acid to maintain pH at 4.0 or lower for at least 24 hours, then temperature treatment at either 70 Celsius or 90 Celsius, for at least one hour.
- Method 7: Any method authorised by the competent authority where the relevant hazards have been identified in the starting material, the risks in view of the animal health status of the Member State, the capacity of the processing method to reduce the hazards etc.

Method 6, specifically stated to be for Category 3 aquatic animals involves a more rigorous treatment regime than that stated in Box 1, for pasteurisation.

To complement the above analysis, the hazard (biosafety) aspect of processing requirements is considered, as referred to in Method 7 of the Implementing Regulations, in terms of EU research carried out in this area, along with other published, peer reviewed research. To summarise this appendix, the scenario of no acidification, 12mm size and 70^{o} Celsius treatment for one hour (pasteurisation) is an area of concern. None of the risk assessment work referred to in the appendix, in the context of fish pathogens / disease, indicate that this level of treatment is sufficient for managing the risks associated with fish pathogens (higher temperatures are indicated as being required, or potentially 70 Celsius for a longer period). It should be noted, again, that this is the interpretation of the regulators in Denmark, with the Norwegian sector using the 2015 EU-approved method described later in this report – referred to as “The Norwegian Method” i.e. pasteurisation at 70^{o}Celsius is not a method that has been considered there for the treatment of Category 2 fish farm mortalities.

The significance of the above is also emphasised since at the moment unless fish farmers can clearly demonstrate that fish farm mortalities have not occurred as the result of disease/pathogens, the Animal and Plant Health Agency (APHA)[36] has confirmed that it will need to be classified as Category 2 waste.

The concerns, summarised above, have been discussed in depth with the Scottish Government, which has confirmed that it is confident with its interpretation of the EU regulations.

Appendix E

17 The Norwegian System

17.1 Hazard Analysis and Critical Control Points (HACCP) planning

The EFSA provided a scientific opinion on the evaluation of the Norwegian method[37], on the basis of the HACCP plan proposed by the applicant prior to approval. This are shown in the following table, with the view expressed that:

> *"The HACCP scheme proposed can be considered satisfactory provided that the whole scheme is verified under full scale conditions"*

Table 17. Table Extract from EFSA, 2011 Scientific Opinion: "Processing Steps and HACCP Plan Proposed by Applicant

Step	Description	Point of Action	Monitoring
Reception of material	Fish silage has been stored at pH ≤4.0 for at least 24 hours before it is collected.	pH 4 has to be ensured.	A sample is collected for each consignment collected by the vessel/truck and pH is measured.
Storage	Fish silage are pumped into designated storage tanks.	Traceability has to be ensured	Records are kept of volumes pumped into and out of all storage tanks.
Control prior to processing	Smaller changes in pH are normal the following days after fish silage production.	To ensure pH ≤4.0, a sample of the total volume in the reception storage tank is measured.	pH measurements in the storage tank prior to processing.
Pre-heating	The silage is heated up to a temperature above 85°C through a heat exchanger (high temperature steam).	Temperature >85°C has to be ensured.	Temperature records are kept
Ensure particle size< 10 mm	Both filter and a fine grinding macerator are used.	Particle size less than 10 mm has to be ensured.	Filter and macerator are controlled daily for damage.
Heat treatment	The pre-heated silage with correct particle size is piped into a heat treatment tank.	Temperature of ≥85 °C in ≥25 minutes.	Continuous temperature measurements are performed by sensors.
End product tank	The heat treated fish silage is pumped into the end product tank.	Volumes of batches are recorded.	Records of batches pumped into the tank and records of further use are kept.
Waste	Filter residues is empirically less than 0.5‰, handled as	Disposal of filter by incineration or processed	

[37] EFSA, 2011, Scientific Opinion on the evaluation of a new processing method for ABP Category 2 materials of fish origin, EFSA Journal 2011; 9(9):2389

Step	Description	Point of Action	Monitoring
	non-processed Category 2 material.	in a processing plant approved in accordance with Article13 using any of the processing methods 1 to 5.	
Step	Description	Point of Action	Monitoring
Reception of material	Fish silage has been stored at pH ≤4.0 for at least 24 hours before it is collected.	pH 4 has to be ensured.	A sample is collected for each consignment collected by the vessel/truck and pH is measured.

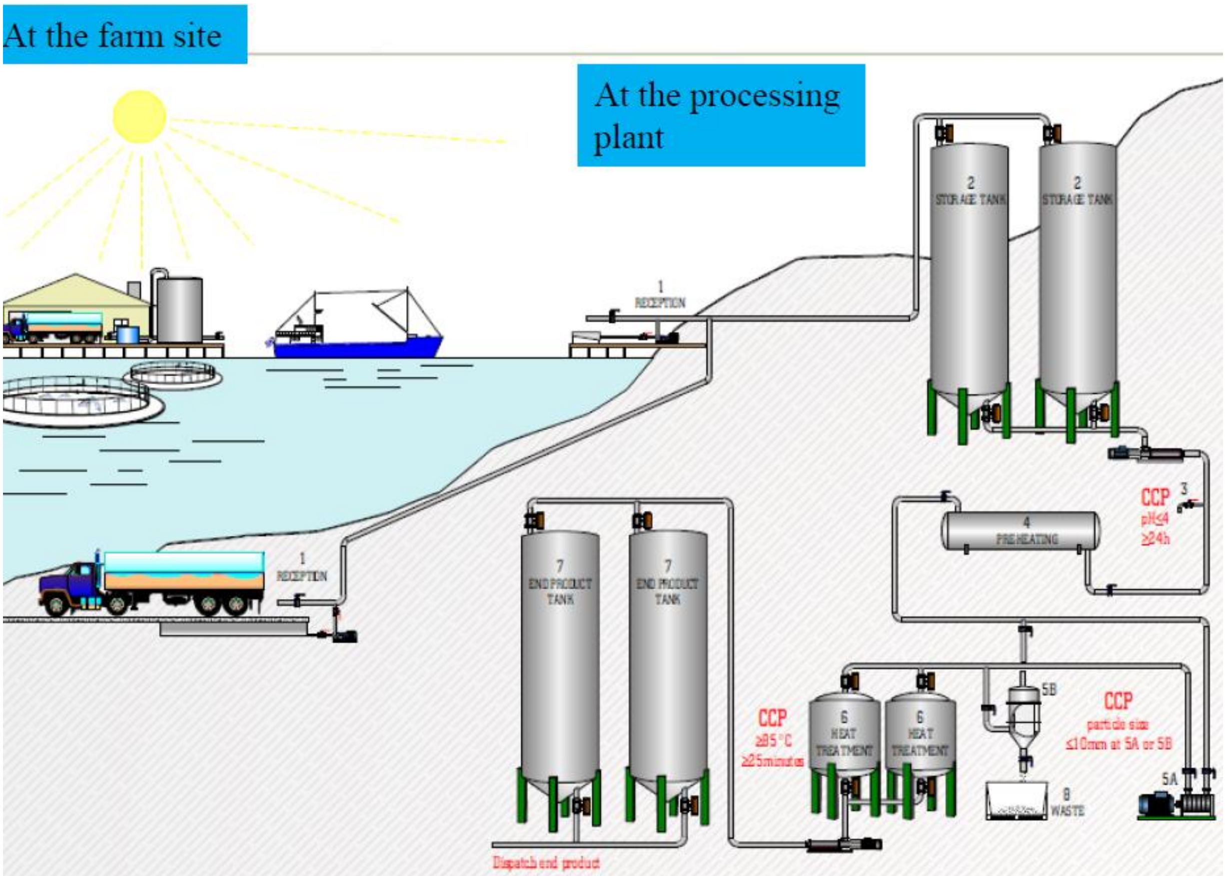

Figure 5. Extract from the NFSA Presentation on the Heat Treatment of Silage, 2015.

The final product derived from the ensilaging of fish material may:

1. For Category 2 materials, be used for purposes referred to in Article 13(a) to (d) and (g) to (i) of Regulation (EC) No 1069/2009 without further processing or as feed for animals referred to in Article 18 or Article 36(a)(ii) of that Regulation; or
2. For Category 3 materials, be used for purposes referred to in Article 14 of Regulation (EC) No 1069/2009.

For indicative purposes, Box 3 shows extracts related to the potential uses of Category 2 waste that has been treated according to the Norwegian Method.

Box 3. Extracts from EC Reg 1069/2009 Relevant to the Norwegian Method Outputs
Article 13
Disposal and use of Category 2 material

Category 2 material shall be:
(a) disposed of as waste by incineration:
(i) directly without prior processing; or
(ii) following processing, by pressure sterilisation if the competent authority so requires, and permanent marking of the resulting material;
(b) recovered or disposed of by co-incineration, if the Category 2 material is waste:
(i) directly without prior processing; or
(ii) following processing, by pressure sterilisation if the competent authority so requires, and permanent marking of the resulting material;
(c) disposed of in an authorised landfill, following processing by pressure sterilisation and permanent marking of the resulting material;
(d) used for the manufacturing of organic fertilisers or soil improvers to be placed on the market in accordance with Article 32 following processing by pressure sterilisation, when applicable, and permanent marking of the resulting material;
(g) in the case of material originating from aquatic animals, ensiled, composted or transformed into biogas;
(h) used as a fuel for combustion with or without prior processing; or
(i) used for the manufacture of derived products referred to in Articles 33, 34 and 36 and placed on the market in accordance with those Articles.

Article 18
Special feeding purposes

1. The competent authority may, by way of derogation from Articles 13 and 14, authorise, under conditions which ensure the control of risks to public and animal health, the collection and use of Category 2 material, provided that it comes from animals which were not killed or did not die as a result of the presence or suspected presence of a disease communicable to humans or animals, and of Category 3 material for feeding to:
(a) zoo animals;
(b) circus animals;
(c) reptiles and birds of prey other than zoo or circus animals;
(d) fur animals;
Etc (see the regulations for the full listing)

Article 36
Placing on the market of other derived products

Operators may place on the market derived products, other than the products referred to in Articles 31, 32, 33 and 35, provided:
(a) those products are:
(ii) intended for feeding to fur animals; and
Etc (see the regulations for the full listing)

17.2 Options for Scotland, in Terms of the Norwegian and Similar Systems

According to the Norwegian Scientific Committee for Food Safety, the Norwegian method will[38]:

> *"inactivate non-spore-forming bacteria, Clostridium perfringens, moulds, Saprolegnia, parasites and viruses in Category 2 and 3 material of fish origin. For Category 2 and 3 material from fish cultivated in marine waters in net cages, where dead fish are removed on a daily basis the levels of C. botulinum will be low, and the method will inactivate C. botulinum present."*

Three potential options are described below (there are likely to be more) in terms of potential synergies with the Norwegian system, or adapting this to suit the Scottish context:

- Option A: The development of a system which copies what happens in Norway from start to finish.
- Option B: The development of a logistics system which safely manages fish waste through grinding / maceration then ensilage - at sea (the Norwegian approach). This could then operate on the basis of consolidation centres being established at strategic locations in the country i.e. storage locations where the stabilised, ensiled waste can then be hauled to the most cost effective end-destination e.g. this could be to a Scottish reprocessor, to a processing facility in Norway etc.
- Option C: Where grinding / maceration and ensilage happen on land, with subsequent land haulage to regional, consolidation centres, prior to collection for transportation to an appropriate end destination.

For Option A to operate in Scotland, three technical issues would require to be addressed:

1. A suitable vessel would have to be acquired that would be able to access fish farm sites on a sufficiently regular basis to be able to remove ensiled morts and the necessary infrastructure would have to be developed to allow safe transfer of the morts from storage tanks / IBCs to the vessel.
2. The movement between farms could increase the risk of disease spread within and between disease management areas More detailed stakeholder engagement with fish farming and logistics companies would be required, along with consultations with Marine Scotland, the APHA and SEPA.
3. A processing plant would have to be developed, at a location convenient to both the industry and onward hauliers, in order to provide the maceration and heat treatment as well as to store the product prior to transport to ultimate use.

In addition to these issues, it may be necessary to have an additional vessel available to deal with mass mortality events. With respect to issue 2 above, the Code of Good Practice for Scottish Finfish Aquaculture states:

> *"3.36 As far as is reasonably practicable in marine FMAs, personnel, equipment and personal protective equipment should be site specific.*
> *3.37 Where movement between marine FMAs is unavoidable, cleaning and disinfection should, as far as is reasonably practicable, be in accordance with the Standard Disinfection Protocols (Annex 4)."*

Annex 4 provides guidance on the effective disinfection of vessels. It also specifically mentions that "bus-stop" type vessel movements may be vectors of disease transmission.

As mentioned in discussions with Scanbio (see earlier section), in Norway ensiling equipment is located at sea (not on land) on fish farm flotillas, able to macerate / grind, and ensile routine mortalities

[38]Norwegian Scientific Committee for Food Safety, 2010, "Assessment of the Fish Silage Processing Method (FSPM) for treatment of category 2 and 3 material of fish origin. Opinion of the Panel on Animal Feed of the Norwegian Scientific Committee for Food Safety (24.03.2010).

prior to collection by a specialist boat. When mass mortality events occur, which overwhelm the processing capacity of the sea-borne equipment, an ambulatory system is in place (a legal requirement) that means a boat with greater processing capacity, and the ability to slaughter fish appropriately must be at the fish farm within a legally specified timescale. At the moment, in Norway, Scanbio and Hordafor operate 10 vessels, ranging between 350 tonnes and 800 tonnes payload capacity for fish. Scanbio have estimated that one 350 tonne vessel is likely to be large enough to implement the Norwegian system in Scotland.

The biosecurity aspect of a bus-stop vessel mort-collecting service would need much more detailed work, to understand the methodologies required, and it is likely that such a vessel or vessels would have to visit many farms across companies and regions to collect a full load. It would therefore have to have a “bomb proof” material handling system together with pristine external surfaces which could be thoroughly disinfected between farms (the Code of Good Practice referred to above, and accepted disinfection protocols should be referred to) It should be noted that in 1999 a mass mortality event took place which was the result of a transfer of disease between different fish farms. Any system employed would need to demonstrate that the risk of events such as this would not be increased by the introduction of the Norwegian System.

The Norwegian System could also be considered in conjunction with existing farm practices, as indicated for Option C. At present a substantial proportion of Scottish morts are transported by road to the Widnes incinerator. There is no reason why this ensiled material could not be transported by road to a processing plant which would provide maceration and heat treatment. Indeed, to reduce road miles, it might be useful if there were several such plants throughout the fish farming area which had sufficient storage capacity to warrant a regular marine vessel pick up and could then be transferred to be further processed in Scotland or elsewhere. This would totally avoid the need for vessels to visit farms, but also reduce the transportation costs presently experienced by the industry.

Appendix F

18 Innovative Business Development Opportunities for Managing Finfish Waste from Fish Farms

18.1 Biodiesel Production

The Enerfish feasibility study for Shetland concluded that 100,000 litres (approximately 22,000 gallons, or 83 tonnes) of biodiesel could be produced from ensiled salmon mortalities arising on Shetland.[39] A weblink describing the work of the forum and its partners at the Gremista Waste Recycling Facility[40] indicates that the consortium are now exploring the possibility of making diesel fuel from Category 2 wastes using Preseco equipment. The organisation has been contacted, but a response was outstanding at the time of compiling the report.

The report identifies that there may be potential opportunities for certain smaller islands, which lack alternative biodiesel processing plants and where there is an existing fishing industry. Shetland, possibly Orkney and the Western Isles are identified. The report prepares a cost benefit analysis for a range of scenarios including the processing of Category 2 and 3 waste. However, the report indicates that the value obtained from alternative uses of Category 3 waste (through fish feed, pharmaceutical uses, etc) means that, by comparison, the use of Category 3 material as potential feedstock for biodiesel is not the most financially attractive way forward.

However, diverting salmon mortalities from landfill does represent a potentially useful economic opportunity. The report identifies Scanbio Oil, as the largest company in this sector and reports on the production of a new Category 2 salmon plant at Lysoysund which supplies significant quantities of what is described to be bio-fuel oil. Scanbio were contacted to discuss the process and the viability of implementing a similar process in Scotland. However, they commented that they had stopped the biodiesel project referenced in the Shetland study – the reasons are set out in the consultation response provided earlier. Their process, using fish waste, did not provide the desired outputs.

For the UK, the feasibility study indicates that there is a micro scale biodiesel production facility taking fish waste from an inland fishery company operating in England, and a large supermarket in the east of England, part of a major UK supermarket chain. No additional company details are provided within the report.

Although a relatively novel approach for Scotland, researchers have evaluated ozone treated fish waste as an alternative for diesel fuel, with positive results and Kato et al. (2004) concluded that the fish oil obtained had better properties than methyl-esterified vegetable oil waste and was suitable for diesel engines especially in low-temperature areas - indicating potential viability for both small-scale and large scale biodiesel production as a potential solution for Scotland. However, this would be subject to approval under the ABP regulations.

A key opportunity in a Scottish context appears to be related to the work currently being carried out by a renderer in the country (results not available at the time of writing) where there is some confidence that a fish oil can be produced for subsequent processing into biodiesel. Another Scottish-based company, which already produces 55,000 tonnes of biodiesel from a range of waste streams in the country (supplying Stagecoach with 100% of its Scottish bus fleet fuel demand) is interested in carrying out its own trials, directly, using fish waste. With around 15% of the fish potentially being converted into oil, the maximum amount of oil that could be produced from fish farm mortalities, from

[39] http://www.shetlandrenewables.com/assets/files/WP6%20Enerfish%20Report%20D13%20Final%20Report.pdf
[40] http://www.shetlandrenewables.com/forum-investingating-biodiesel-from-fish-oil

Scotland as a whole, would be 1,500 tonnes per annum (based on 10,000 tonnes of waste generated per annum – see earlier section).

18.2 Alkaline Hydrolysis

There were several innovative business development opportunities identified for managing finfish waste for fish farms such as:

- Alkaline hydrolysis
- Dehydration
- Eco-Industrial Sympiosis
- Biodiesel production

Alkaline hydrolysis (AH) was developed in the 1990s and is hence a relatively new technology. It uses sodium hydroxide or potassium hydroxide at temperatures of up to 180°C for up to six hours and at high pressure to reduce biological material (e.g. morts) into ashes in a sterile aqueous solution consisting of peptides, amino acids, sugars, and soaps (Kaye et al., 1998; NABC, 2004; Shafer et al.,18 2000, 2001).

There appears to be one company based in Glasgow (Resomation) who are at the forefront of the technology, however the current focus is the application of the process as an alternative to cremation and possibly disposal of animal carcasses. As an indicative cost, the price for an AH chamber for treating human bodies is in the region of £130,000 to £260,000, depending on its size and capacity[41]. Whilst one fish farm in Scotland has used an alkaline solution as an alternative to ensiling, it is unknown whether this process is still on-going. It is generally accepted that alkaline hydrolysis is an acceptable disposal solution for fish mortalities; "although possible on a small scale, this is a costly process." [42]

18.3 Dehydration

Dehydration is not presently used for morts, but the process description presented below, provided by the company Tidy Planet Ltd, is being developed with morts as one of the target waste streams for processing. To avoid repetition, where system performance and cost data is described in this section, this is provided by Tidy Planet and is not the view of the report authors. It is understood that Tidy Planet have not yet developed a technology of this type that has been validated and approved by the APHA.

The process involves thermal evaporation of a continuously mixed slurry of macerated fish material heated at up to 150°C and kept above 100°C for ~ 6h. With an oily fish like salmon, this results in a dehydrated (<5% water) oily paste, which can subsequently be processed to separate the meal from the oil. Tidy Planet is developing this process with the Whiteshore Cockle landfill site in Uist. SEPA have accepted that this process completely sterilises the products. The process reduces the weight of the material by around 60%, offering significant transport savings.

Fish mortalities have to be dehydrated soon after death so as to ensure product quality. The systems could therefore be operated at site level or could service multiple sites (as is planned for the Whiteshore Cockle site, North Uist). If the mortality rate peaked at greater than local dehydration capacity, morts could be kept "fresh" in refrigeration containers evening out supply and demand. Tidy Planet expressed an interest in the logistics of transportation of the resulting products for which they are confident that markets are available.

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[41] http://www.calebwilde.com/2014/07/alkaline-hydrolysis-water-cremation-and-the-ick-factor/#sthash.cn43a91O.dpufThe

[42] Sangster, M. (2005) Developing a framework for a sustainable fish waste management infrastructure, on behalf of The Scottish Fish Waste Management Group. 19 pages.

18.4 Flymeals

There is a large body of work on producing animal feed meals from insects[43] and their use as fish feeds has been assessed[44]. Fly meals are typically deficient in omega-3 fatty acids essential for fish growth but this can be improved by growing the fly larvae on fish offal as substrate[45].

Stirling University lead work in Scotland on incorporating fly larvae into animal feeds[46,47]. They are currently piloting insect based approaches to deal with Scottish Salmon morts. Their trials utilise flies to break-down whole fish arising from routine mortalities, thereby removing the need to ensile fish and / or transport off-site.

It is seen by researchers as a potential on-site solution for rural fish farms to deal with routine mortalities that combats costs of transport and recognises that there are limited high value end disposal options for fish mortalities. The team are developing a demonstrator system to treat up to 100kg of fish morts per week (which would be representative of an average sized fish farm). Discussions indicated that there were still a number of hurdles that will need to jumped prior to commercialisation, most notably these include temperature (the system requires temperatures above 20°C to sustain itself) the difficulties associated with breaking down proteins and lipids and finally establishing end markets for larvae.

A key inhibiting factor for the team is a lack of clarity on how the regulations should be interpreted/ enforced for aquatic life and the relevance of ABPR for aquatic life. The European Food Standards agency has said, in this respect[48]:

> *"Further research for better assessment of microbiological and chemical risks from insects as food and feed including studies on the occurrence of hazards when using particular substrates, like food waste and manure is recommended."*

18.5 Small Scale Niche Markets

Consultation was undertaken with The Industrial Biotechnology Innovation Centre (IBioIC), Napier University and Highlands and Islands Enterprise to determine potential laboratory and / or pilot stage research that may present a solution to the aqua-culture industry in the future, in addition to a literature review.

There are a number of small scale niche markets that have been considered but that are unlikely to present a large-scale commercial solution to the aqua-culture industry at the current time. These are summarised below.

18.5.1 Fish Skin Leather

There are a small number of niche tanners utilising discarded fish skins (Category 3 material). In Scotland a project involves the collection of local salmon skins from Arbroath Smokies, tans them and sells them either as fish skins for crafters or as finished products e.g. wallets.

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[43] Sanchez-Muros, M.-J., Barroso, F.G. and Manzano-Agugliaro, F. 2014. Insect meal as renewable source of food for animal feeding: a review. Journal of Cleaner Production. 65. 16-27.
[44] Barroso, F.G., de Haro, C., Sanchez-Muros, M.-J., Venegas, E., Martinez-Sanchez, A. and Perez-Banon, C. 2014. The potential of various insect species for use as food for fish. Aquaculture. 422. 193-201.
[45] St-Hilaire, S., Cranfill, K., McGuire, M.A., Mosley, E.E., Tomberlin, J.K., Newton, L., Sealey, W., Sheppard, C. and Irving, S. 2007. Fish offal recycling by the black soldier fly produces a foodstuff high in omega-3 fatty acids. Journal of the World Aquaculture Society. 38. 309-313.
[46] http://www.proteinsect.eu/
[47] Telephone conversation with Professor David Little, University of Stirling (8th October 2015)
[48] EFSA, "Risk Profile Related to Production and Consumption of Insects as Food andmFeed", EFSA Journal. Online source: http://www.efsa.europa.eu/en/efsajournal/pub/4257

The organisation would be willing to take skins from any fish (assuming death could be accounted for), however this type of set-up is more suited to fish processing facilities and is small-scale, unable to provide a long-term solution to dealing with large quantities of fish mortalities across Scotland.

18.5.2 *Synthetic Hydroxyapatite*

Synthetic hydroxyapatite is currently used in surgery and dentistry and there are medical advantages in extracting biological hydroxyapatite from animal bones including from fish bones[49]. However, there are large sources of raw material from Category 1 fish wastes for what is a niche product and no prospect of fish morts being an attractive source.

18.5.3 *Vermiculture*

Feeding earthworms on food scraps or animal manures (vermiculture or vermicomposting) produces an earth like compost[50]. Vermicomposting is carried out at a large scale for waste processing in several countries[51] Although typical vermicomposting systems do not allow a large proportion of animal by-products to be added, there has been some work on processing fish wastes in this way[52] and it is possible that further development work would allow small scale fish wastes to be utilised in this way in niche circumstances. It is, however, difficult to envisage this as a large scale solution to morts disposal on the basis of current understanding and legislative restrictions (as referred to previously).

18.5.4 *Mass Seaweed Culture*

Mass seaweed (macroalgae) cultivation is widely practiced in Asia with a total annual production of 23.8 million tonnes of aquatic algae (US$6.4 billion)[53] mostly for food. Several studies have dealt with the possibility of using cultured macroalgae for bio-methane production via anaerobic digestion[54] but this is not economic at present. None the less seaweed production is likely to rise over time for non-energy uses (e.g. food) and a future seaweed industry may be able to provide waste material to co-digest with morts which might be useful in areas where there is a lack of agriculture co-digestible material.

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[49] Akram, M., Ahmed, R., Shakir, I., Ibrahim, W.A.W. and Hussain, R. 2014. Extracting hydroxyapatite and its precursors from natural resources. Journal of Materials Science. 49. 1461-1475.
[50]https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=7&ved=0CFMQFjAGahUKEwjc18774bLIAhWHSBQKHVnoBhc&url=http%3A%2F%2Faqua.wisc.edu%2Fpublications%2FPDFs%2FVermicomposting.pdf&usg=AFQjCNFCDJnZn28rpkvxCMBPR_3IQG626g&sig2=R9TkOrnmtWNv3WH72cTrqw&cad=rja
[51] Aalok et al. (2008) Vermicomposting: A Better Option for Organic Solid Waste Management. J. Hum. Ecol., 24(1): 59-64
[52] http://www.ummera.com/vermicomposting.php
[53] FAO. 2014. The State of World Fisheries and Aquaculture 2014. Rome. 223 pp.
[54] Hughes, A.D., Kelly, M.S., Black, K.D. and Stanley, M.S. 2012. Biogas from Macroalgae: is it time to revisit the idea? Biotechnology for biofuels. 5. 86.
Hughes, A.D., Black, K.D., Campbell, I., Davidson, K., Kelly, M.S. and Stanley, M.S. 2012. Does seaweed offer a solution for bioenergy with biological carbon capture and storage? Greenhouse Gas Sci. Technol. 2. 402-407.

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