# FINAL REPORT

# Identification and prioritisation of risks to food safety and quality associated with the use of recycled waste-derived materials in agriculture and other aspects of food production

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# Executive Summary

Due to the increased importance of resource efficiency and sustainability, there is greater interest in the re-use and recycling of waste and waste-derived materials, and an expanding range of routes via which food could be exposed to these materials. These need to be identified and prioritised so that potential risks to food safety can be appropriately assessed and managed. The aim of this project was to allow the FSA to identify the waste and waste-derived materials and recycling routes of most concern, with the emphasis on consumer safety rather than the wider environmental risks associated with protecting food productivity. A key outcome was to enable t future research to be targeted to investigate the key issues and to fill any data gaps.

A consortium of experts who have previously worked together to undertake risk assessments on the use of certified compost and digestate was assembled for this initial 4-month scoping study. Drawing on previous experience, the project team collated a database of waste and waste-derived materials, potentially hazardous agents and exposure routes that are known to (or could) impact on food safety, including a wide array of recycled waste materials and practices employed in the UK, EU and other countries around the world. A horizon scanning exercise to identify emerging concerns was also undertaken including at a Stakeholder Workshop attended by key food chain stakeholders. This stage of the work concluded with a qualitative priority ranking exercise where the project team used their expertise, together with information gained from the Stakeholder Workshop and a targeted review of the literature, to assess which waste derived materials and recycling routes presented the highest priority for future research. A subset of the waste and waste-derived materials were then selected to disaggregate the information and expert judgements captured in the qualitative prioritisation, using an innovative semi-quantitative risk assessment technique.

The qualitative priority ranking methodology allowed a large number of diverse waste derived materials and recycling modes to be compared (including land spreading, animal bedding, animal feed and packaging), offering a flexible tool which could be used in future as a method for screening and comparing risks from novel recycled materials and recycling routes, and emerging potentially hazardous agents. It was designed to allow comparison of a wide range of disparate waste-derived materials, without focusing on any specific chemicals and was based on expert judgements supported by published scientific evidence. Nevertheless, the outcomes from the priority ranking, supported by the semi-quantitative assessment and the literature review, allowed the project team to identify a number of areas where further information or research is required, in particular:

- The controls and regulations governing use of waste derived materials in food production and packaging in relation to recycling practices in a non-EU context, especially in situations where voluntary controls (such as those adopted by large UK retailers) may not be in place.
- The strength and weaknesses of current policies, regulations and practices in waste management and processing, feed formulation, food production and in the retail supply chain, in the control of food safety risks.

- The factors influencing potential antimicrobial resistance gene transfer from recycled waste materials into the food chain, and the concentrations, environmental behaviour and food chain uptake of nanoparticles.
- The issues associated with mixtures and blends of recycled waste materials, and on the synergistic or antagonistic effects of mixtures of potentially hazardous agents.

We recommend that the tools developed in this project should be used as 'living' documents which are updated periodically as new information emerges and used to support FSA decision-making in the field of waste recycling in the food chain.

## Glossary

| | |
|---|---|
| ABP | Animal By Products |
| AD | Anaerobic digestion |
| AMR | Antimicrobial resistance |
| BSE | Bovine spongiform encephalopathy |
| BSI | British Standards Institute |
| CIP | Clean in place |
| CoGAP | Code of Good Agricultural Practice |
| CoP | Code of Practice |
| EA | Environment Agency |
| EDC | Endocrine disrupting compounds |
| EoW | End of Waste |
| EWC | European Waste Catalogue |
| DEHP | Bis (2-ethylhexyl) phthalate |
| FAB | Fermented alcoholic beverage |
| FYM | Farmyard manure |
| HACCP | Hazard Analysis and Critical Control Point |
| MBMA | Meat and bone meal ash |
| MSW | Municipal solid waste |
| NVZ | Nitrate Vulnerable Zone |
| OCC | Organic compound contaminant |
| PAHs | Polycyclic aromatic hydrocarbons |
| PAS100 | Publicly Available Specification 100 for composted materials |
| PAS110 | Publicly Available Specification 110 for anaerobic digestate |
| PBDD/Fs | Polybrominated dibenzo-*p*-dioxins and dibenzofurans |
| PCBs | Polychlorinated biphenyls |
| PCDD/Fs | Polychlorinated dibenzo-*p*-dioxins and dibenzofurans |
| PEPFAA Code | Prevention of Environmental Pollution from Agricultural Activity (Scotland) |
| PFAS | Perfluorinated alkylated substances |
| POPs | Persistent organic pollutants |
| PLA | Poultry litter ash |

| | |
|---|---|
| PSA | Paper sludge ash |
| PTEs | Potentially toxic elements |
| QP | Quality protocol |
| REA | Rapid evidence assessment |
| RB209 | The Defra Fertiliser Manual (RB209) |
| RMS | Recycled manure solids |
| RTE | Ready to eat (crops) |
| SSGW | Source segregated green waste |
| TSE | Transmissible spongiform encephalopathies |

# 1 Introduction and objectives

Due to the increased importance of resource efficiency and sustainability, there is greater interest in the re-use and recycling of waste and waste-derived materials, and an expanding range of routes via which food could be exposed to these materials. Developments in analytical techniques, together with horizon scanning exercises, mean that new agents that could be a concern for food safety are constantly being identified in materials that are considered to be well-understood (e.g. compost and biosolids), whilst new exposure routes (e.g. use of recycled materials in food packaging and animal bedding) continue to be developed. This results in a vast array of potentially hazardous agents and exposure routes that need to be identified and prioritised so that potential risks to food safety can be appropriately assessed and managed.

The aim of this project was to allow the FSA to identify the key risks (if any) from recycled waste and waste-derived materials and to enable future research projects to be targeted to investigate specific issues of concern to fill any data gaps. The emphasis of the work was on identifying the risks to consumer safety rather than on the wider environmental risks associated with protecting food productivity.

The specific objectives were to:

- Identify the waste and waste-derived materials, potentially hazardous agents and exposure routes that are or could be associated with food production, whether in the UK or from food produced outside the UK.
- Rank the waste and waste-derived materials using qualitative methods and illustratively (for a selected subset) using a semi-quantitative risk assessment technique, all underpinned by data from published literature and outputs from a stakeholder workshop.
- Produce a report that prioritises the waste and waste-derived materials and recycling routes that require further investigation, highlighting significant data/knowledge gaps and detailing how these could be addressed in subsequent studies.

# 2 Approach

A consortium of experts was assembled who have previously worked together to undertake risk assessments on the use of certified compost and digestate using a flexible step-wise methodology (Pollard *et al*., 2008; Villa *et al*., 2012; Hough *et al*., 2012; WRAP, 2016). In this initial 4-month scoping study, a simplified version of the same methodology was adopted to identify the waste and waste-derived materials and recycling routes that comprise the highest priority for future FSA research projects.

Drawing on previous experience, the project team collated a database of waste and waste-derived materials, potentially hazardous agents and exposure routes that are known to (or could) impact on food safety, including recycled waste materials and practices employed in other countries. A horizon scanning exercise to identify emerging concerns was also undertaken at a meeting between the project team and the FSA Steering Group held on 26th January 2016, and at a Stakeholder Workshop held on 24th April 2016 that was attended by key food industry stakeholders. This stage of the work concluded with a qualitative priority ranking exercise where the project team used their expertise in combination with information gained from the stakeholder workshop to make an assessment of the relative severity and likelihood of the risks to food safety. This priority ranking was supplemented and supported by a targeted review of the published literature for each waste-derived product identified on the database. It was intended that the focus of the project would be on new and emerging waste-derived materials, routes and potentially hazardous agents rather than re-evaluate those previously assessed, although some materials that are well understood (e.g. compost and biosolids) were also included as comparators.

A subset of the waste and waste-derived materials that were selected in consultation with the FSA Steering Group, and endorsed at the Stakeholder Workshop, were used to disaggregate the information and expert judgements captured in the qualitative prioritisation exercise using an innovative semi-quantitative risk assessment technique. The aim of the semi-quantitative approach was to validate the qualitative priority ranking and to assess whether such methods could be used in future research projects to estimate the severity and likelihood of risks to food safety from waste-derived recycled materials.

# 3 Qualitative priority ranking

## 3.1 Purpose

The purpose of the qualitative priority ranking exercise was to identify 'source term/recycling mode' combinations (i.e. the waste-derived material of interest and the use to which it is put) and, using expert judgement, to highlight those that require further attention by the FSA. It was intended to provide a rapid screening tool for assessing and comparing a large number of disparate recycled materials and recycling routes, and provided the starting point for more detailed semi-quantitative risk assessments that disaggregate the expert judgement process to make it more transparent (see Section 5).

It is very important to be aware that this methodology only provides a relative priority ranking for use as a rapid screening tool. It does not attempt in any way to quantify the risk of harm; this would require a much more detailed and in depth quantitative risk assessment (QRA).

## 3.2 Methodology development

The qualitative priority ranking methodology was developed in three stages as detailed below.

**Step 1: Definition of the source term/recycling mode combinations**

The first step was to identify 'source term/recycling mode' combinations (i.e. a combination of the waste-derived material of interest and the use to which it is put) that could have implications for food safety. Examples of 'source term/recycling mode' combinations include biosolids that are applied to arable land on which cereals will be grown, recycled manure solids used as bedding for dairy cattle and recycled cardboard used for food packaging.

The source term was considered to be the recycled material at the point at which it is used for its intended purpose. For example, waste water from sewage treatment works was not included as a source term because it undergoes further treatment prior to recycling to agricultural land; however biosolids was a source term because this is the material which is recycled to land. Both paper sludge (crumble) and paper sludge ash (PSA) were included as separate source terms because both these materials can be used in agriculture, although PSA has undergone more 'pre-treatment' prior to use. When identifying the potentially hazardous agents that are present in the different source terms, the material at the point of use was considered and hence any 'pre-treatment' processes were implicitly accounted for (see Section 4.3.2).

The advantage of this approach is that it leads to a manageable number of 'source term/recycling mode' combinations. An obvious disadvantage is that there are multiple potentially hazardous agents in some recycled materials and complex pathways with multiple modifiers to uptake encompassed in the definition of the recycling mode. The expert team were responsible for weighing up the relative importance of these different factors within their qualitative judgements. Whilst the potentially hazardous agents and modifiers to uptake were necessarily aggregated within the qualitative assessment, they were disaggregated to some extent within the semi-quantitative assessment (see Section 4).

**Step 2: Basis for priority ranking**

Each 'source term/recycling mode' combination was assessed on the basis of:

i) The number of different categories of potentially hazardous agents that a source term may contain and whether these are present at concentrations judged to be capable of causing harm in the human food chain;

ii) The number and effectiveness of the modifiers that may be present along an exposure pathway which act to prevent the potentially hazardous agent(s) from entering the human food chain, or conversely lead to accumulation or multiplication of potentially hazardous agents;

iii) The degree of uncertainty regarding the potentially hazardous agents and exposure pathway due to deficiencies in the evidence base.

The highest priority is associated with (i) a source with one or more categories of potentially hazardous agents at concentrations judged capable of causing harm in the human food chain coupled with (ii) a recycling mode pathway with no modifiers which could decrease exposure and (iii) where there is the greatest uncertainty regarding (i) and (ii) due to severe deficiencies in the evidence base. This gives three individual scorable parameters as the basis of an overall relative priority score.

**Step 3: Scoring system**

Each parameter was allocated a score spectrum, with associated qualitative descriptors (shown in Table 1), to generate a combined priority score which allowed the 'source term/recycling mode' combinations to be ranked and separated. The scoring system was intended to be indicative and ranked:

i) The source term content on a 1-5 spectrum. Scoring was facilitated by a simple presence/absence indicator for the broad groups of potentially hazardous agents under consideration (i.e. microbiological, chemical, physical, radiological, nanoparticles, and anti-microbial resistance).

ii) The modifiers to exposure on a 1-5 spectrum.

iii) The uncertainty on a 1-3 spectrum.

A combined score was calculated by multiplying together the 3 scores above to provide an overall priority score in the range 1-75. This score simply represents a means by which the 'source term/recycling mode' combination can be compared relative to each other, to assess the priority which should be afforded to further investigative work. The numbers do not reflect an absolute assessment of the 'risks' to food safety; for example, a 'source term/recycling mode' combination with an overall score of 24 is not four times more risky than one with an overall score of 6, it is simply more likely to merit attention in terms of future research priorities.

**Table 1. Qualitative descriptors of the priority scoring system**

| Score | Qualitative Descriptor | Example |
|---|---|---|
| **Potentially hazardous agents in the source term** | | |
| 5 | Multiple potentially hazardous agents, at high concentrations | Untreated municipal wastewater used for irrigation (non-EU) |
| 4 | Single potentially hazardous agents in high concentrations/several hazards at intermediate concentrations | Canal dredgings applied to agricultural land |
| 3 | Single potentially hazardous agent at intermediate concentrations/several potentially hazardous agents but only at low concentrations | Plant-based food production residues applied to agricultural land |
| 2 | Single potentially hazardous agents at low/very low concentrations | Recycled cardboard/paper used as livestock bedding |
| 1 | No known potentially hazardous agents | Oat feed used as livestock bedding |
| **Exposure pathway** | | |
| 5 | No modifiers to uptake | Not currently used[1] |
| 4 | One partially effective modifier to uptake at a concentration that could plausibly cause harm | Livestock manure applied to ready to eat crops |
| 3 | Multiple partially effective modifiers to uptake at a concentration that could plausibly cause harm | Livestock manure applied to root crops (cooked) or via the meat/milk pathway |
| 2 | One effective modifier and multiple partially effective modifiers to uptake at a concentration that could plausibly cause harm | Biosolids applied to root crops (cooked) or via the meat/milk pathway |
| 1 | Multiple effective modifiers to exposure at a concentration that could plausibly cause harm | Biosolids applied to cereals |
| **Uncertainty** | | |
| 3 | Very little known about potentially hazardous agent concentrations and environmental behaviour | |
| 2 | Some knowledge but not established or recognised through a Quality Protocol or other regulatory controls | |
| 1 | Established, peer-reviewed science underpinning existing risk assessments and/or a Quality Protocol or other regulatory controls.[2] | |

[1]Only used in situations in which there is a plausible/reasonably likely chance of consumption of the source material itself because there is NO modifiers which may limit uptake. Even an unregulated waste applied to ready to eat crops has some possible weak modifiers such as pack house or consumer washing.

[2]This does not indicate zero uncertainty; even established risk assessments require assumptions based on a lack of scientific knowledge.

## 3.3 Populating the priority matrix

### 3.3.1 Source term/recycling mode combinations

The list of source term/recycling mode combinations was identified by the project team, and was refined and supplemented by the FSA Steering Group; suggestions from the Stakeholder Workshop were also included. A complete list of the 'source term/recycling mode' combinations included in the priority ranking exercise is shown in Table 2.

In some instances, the source term covers a range of materials under a common generic term each of which might contain different potentially hazardous agents in varying amounts. For example, there are many different categories of livestock manures including dairy cattle slurry, beef cattle slurry, cattle FYM, pig slurry, pig FYM, poultry manures etc., which may have been managed or stored in different ways prior to land application. To avoid unnecessary duplication in the ranking of priorities, a 'highest plausible hazard' or typical example of the broader source term category was selected. For example, layer manure applied directly to agricultural land from poultry housing was selected as the 'highest plausible hazard' for livestock manures, because it consists largely of undiluted excreta and may also contain eggs, feathers etc. and there will have been little time for pathogen die-off prior to land application. Other types of livestock manure are likely to be diluted with bedding material and/or wash water, and manures which are stored or treated before land application will have undergone some degree of pathogen reduction prior to land application. Similarly, conventionally digested sludge cake was taken as the 'highest plausible hazard' for the range of biosolids products currently applied to agricultural land in the UK as it has not undergone enhanced treatment (to further reduce pathogen numbers) nor is it diluted by water or other materials (e.g. co-compost or liquid digested sludge). This approach enabled the number of source term/recycling mode combinations to be kept at a manageable level and allowed focus on the example source term.

Some source terms could have different recycling modes; for example, waste cardboard used as animal bedding and waste cardboard used to produce new food contact packaging were considered separately. This was because whilst the source materials may have the same combination of potentially hazardous agents present at the point of recycling, the different recycling modes could present different modifiers to uptake into foods.

The majority of the source terms investigated were known to be used for the production of foods in the UK, and it was assumed that any relevant regulations pertaining to their usage were complied with (see Section 3.5). In addition, there were some source term/recycling mode combinations which do not exist in the UK (e.g. olive processing wastes applied to agricultural land) but which may be occur elsewhere in the EU and in non-EU countries; and others (e.g. dried chicken manure used as livestock feed) which are not permitted in the EU but might be practised elsewhere in the world, presenting a potential concern in terms of foods imported from overseas;. these were assigned the descriptors 'non-UK' and 'non-EU', respectively.

Table 2. Source term/recycling mode combinations included in the qualitative risk ranking

| Identifier | Source term/recycling mode combination[1] |
|---|---|
| **Recycling mode - materials applied to agricultural land** | |
| 1 | Biochar |
| 2 | Biosolids |
| 3 | Blood and intestinal contents |
| 4 | Eggshells |
| 5 | Canal dredgings |
| 6 | Clean water sludge |
| 7 | Dairy processing effluents |
| 8 | Distillery wastes |
| 9 | Gypsum from waste plasterboard |
| 10 | Lime from sugar beet processing |
| 11A | Livestock manure |
| 11B | Livestock manure (non EU) |
| 12 | Crop residues |
| 13 | Manure from fish farming (non-EU) |
| 14 | Meat and bone meal ash (MBMA) |
| 15 | Mushroom compost |
| 16 | Plant-based food production residues (non UK) |
| 17 | Paper crumble |
| 18 | Paper sludge ash (PSA) used as a liming agent |
| 19 | Poultry litter ash (PLA) |
| 20 | Source separated human urine (non UK) |
| 21 | Spent mycelium from pharmaceutical production |
| 22 | Tannery waste |
| 23 | Zeolites air filters (non UK) |
| 24 | Feathers/feather meal (non UK) |
| 25 | Whole food-based (source segregated waste) digestate |
| 26 | Fibre food-based (source segregated waste) digestate |
| 27 | Crop-based (source segregated non-waste) digestate |
| 28 | Non-source segregated compost/digestate |
| 29 | Source segregated green compost |
| 30 | Struvite from wastewater used as a fertiliser |
| **Recycling mode - materials used for animal bedding** | |
| 31 | Paper crumble/pulp |
| 32 | Paper sludge ash (PSA) and lime ash |
| 33 | Recycled cardboard/shredded waste paper |
| 34A | Recycled manure solids |

| | |
|---|---|
| 34B | Recycled manure solids (non UK) |
| 35 | Recycled wood-based products |
| 36 | Oat feed |
| 37 | Tyres and tyre crumb |
| 38 | Gypsum from waste plasterboard (non UK) |
| **Recycling mode - materials used in livestock or fish feeds** | |
| 39 | Dried chicken manure (non-EU) |
| 40 | Fish meal |
| 41 | Feather meal (non-EU) |
| 42 | Sugar beet residues |
| 43 | Shellfishery wastes (non UK) |
| 44 | Sawdust used as animal feed bulking agent (non UK) |
| 45A | Former food |
| 45B | Former food (non EU) |
| 46 | Insects/insect protein grown on wastes (non-UK) |
| **Recycling mode - other** | |
| 47 | Alcohol produced in the home from food waste |
| 48 | Artificial soils/compost used in horticulture |
| 49 | Wastewater from fishponds used in aquaponics (non EU) |
| 50 | Untreated municipal wastewater used for irrigation (non EU) |
| 51 | Tertiary treated effluent used for irrigation (non-EU) |
| 52A | Recycled cardboard used as direct contact food packaging |
| 52B | Recycled cardboard used as direct contact food packaging (non EU) |
| 53 | Recycled plastic in food contact packaging (non EU) |
| 54 | Biopolymers in food contact packaging |

[1]All source term/recycling mode combinations are assumed to relate to production and use in the UK food chain unless otherwise indicated

Priority ranking was carried out irrespective of the quantity of recycled material used and the prevalence of a particular recycling mode. This was to better understand the risks associated with specific practices at the functional unit level (e.g. application to an individual field growing crops). Thus a very widespread practice that involves large quantities of recycled materials (e.g. livestock manures applied to agricultural land) was assessed on the same basis as a practice which is much less common or involves much smaller quantities of materials (e.g. struvite from wastewater treatment used as a fertiliser). This was because the aim of the assessment was to understand risks associated with specific practices with the knowledge that prevalence of a practice may change in the future. This generalisation was also made for practical reasons i.e. to avoid having to include another variable in an already complex risk judgement.

The following source term/recycling mode combinations were considered to be outside the project scope and were therefore not included in the priority ranking matrix:

- Novel foods for human consumption are subject to the 'Novel Foods Regulation' (Regulation (EC) No 258/97) and require a pre-market safety assessment before they can be authorised for use. Novel foods fall within the remit of the FSA's Advisory Committee on Novel Foods and Processes (ACNFP).
- Contamination of agricultural land or irrigation water used for growing food crops caused by flooding, accidental spillages or pollution events were excluded as these are not examples of the deliberate recycling of waste materials.

### 3.3.2 Potentially hazardous agents

Within the constraints of the project, it was not possible to document detailed information on the concentration/levels of every individual potentially hazardous agent that might be present in each of the source terms (this would be included in a detailed quantitative risk assessment). Therefore, the characterisation of potentially hazardous agents for each source term was *qualitatively* determined in relation to broad groups of different classes of potentially hazardous agents that could cause harm to human health if consumed in food products. The broad potentially hazardous agent classes considered were:

- Microbiological (including bacterial pathogens, viruses, protozoans and prions).
- Chemical (including PTEs, persistent organic pollutants, pharmaceuticals, other toxic chemicals and mycotoxins).
- Physical (including microplastics i.e. small particles of plastic smaller that are manufactured and intentionally included in products e.g. cosmetics [known as primary microplastics] or are produced during the decomposition or mechanical breakdown of larger plastics [known as secondary microplastics]).
- Radiological
- Engineered nanoparticles
- Anti-microbial resistance (i.e. the transfer of AMR genes leading to potential human health impacts)

Animal pathogens (excluding zoonoses), plant pathogens and weed seeds were considered to be outside the project scope because they do not constitute a direct risk to human health via the consumption of affected foodstuffs.

### 3.3.3 Exposure pathways

In the qualitative priority ranking, the exposure pathway defines the overall route that a potentially hazardous agent may follow through the food chain subsequent to the use of the recycled material.

The different exposure pathways encompass different types and numbers of modifiers to the uptake of potentially hazardous agents. These may be environmental (e.g. PTE sorption to soil particles; organic compound degradation by UV light) or regulatory (e.g. no-harvest/grazing intervals following land application of biosolids). The environmental modifiers will be different for different hazards (e.g. pathogens are likely to die-off following land application, whereas PTEs may accumulate in soil over many years). Furthermore, the regulatory modifiers may be different for different recycled materials (e.g. biosolids applications to agricultural land are tightly regulated in terms of PTE concentrations in the receiving soil, whereas livestock manure recycling is not covered by regulations).

The exposure pathway scores provide a very broad indication of what are in reality very complex exposure pathways and are intended to convey a relative indication of the number and strength of the modifiers in place that could limit the uptake of potentially hazardous agents into food. The exposure pathways considered are shown in Table 3. More detailed information on how the exposure pathway scores were assigned is given in the explanatory notes at the start of Appendix.

Ingestion via drinking water and direct inhalation were considered to be outside the scope of the project, as these potential exposure pathways do not pertain to food or food production.

**Table 3. Exposure pathways considered in the qualitative priority ranking**

| Recycling mode | Exposure pathways |
|---|---|
| Recycled materials applied to agricultural land | Cereals for human consumption. |
| | Meat and milk products (including eggs) |
| | Root crops which are in contact with soil but cooked before consumption |
| | Ready to eat (RTE) crops |
| Recycled animal bedding | Meat and milk products (including eggs) |
| Animal feeds: | Meat and milk products (including eggs) |
| | Fish |
| Recycled food packaging material | Direct ingestion of foods which have been in contact with packaging |

### 3.3.4 Uncertainty

The uncertainty scores reflected limitations in the availability of data and/or research information pertaining to a particular source term and recycling mode. A score of '3' might be assigned where very little is known about potentially hazardous agent concentrations and environmental behaviour, whereas a score of '1' could reflect a situation where there is established, peer-reviewed science

## 3.4 Supporting evidence

The literature review and data collation exercise provided the evidence base supporting and underpinning the scores assigned to each source term/recycling mode combination using the expert judgement of the project team and inputs from the FSA Steering Group. This information was presented for each source term in an easily accessible one-page format, as reported in the Appendix, supplemented by a list of references and source materials. This was used by the project team to identify gaps in knowledge or understanding, and to identify any emerging potentially hazardous agents or food safety issues; the one-page reviews were not intended to be comprehensive.

## 3.5 Regulation, compliance and controls

Importantly, the priority ranking assumed compliance with existing regulations in place in the UK and/or the EU, such as the Sludge (Use in Agriculture Regulations) (SI, 1989). However, following the principle of 'highest plausible risk' compliance with voluntary controls such as the Safe Sludge Matrix (ADAS, 2001) and the recommendations in 'The Fertiliser Manual (RB209)' was not assumed. Clearly food safety concerns would be greater in situations where regulations and guidelines are not followed; however, it was outside the scope of this study to assess the degree of compliance.

It was not possible to carry out a comprehensive review of the regulations (or lack of regulations) and enforcement governing the use of recycled materials in all the large number of non-EU countries from which we import food, food ingredients or livestock feeds. These are likely to be different and may or may not be less stringent than those in place in the EU. Practices that are not permitted in the EU may take place in other countries, posing a theoretical concern for food safety. For example, under the EU Animal By-Products (Enforcement) Regulations (EC 1069/2009) it is not permitted to re-use chicken manure in animal feeds; however, there may be non-EU countries from which we import meat or other animal products which continue to use this practise. The priority ranking highlights such situations where there could be an increased level of concern arising from a source material or recycling practice employed outside the EU.

It is important to stress that even though there may be a theoretical risk resulting from the use of a recycled waste material for food production, there is a comprehensive suite of legislation in place at the EU level governing food safety including regulations on labelling and nutrition, biological and chemical safety, use of animal by-products etc. (see http://ec.europa.eu/food/safety/index_en.htm). For foods imported from outside the EU, routine sampling and surveillance is conducted by UK Port Health Authorities and Local Authorities which contributes to improved food safety and standards; a recent FSA study has investigated the effectiveness of this process (Wright *et al*., 2014). In addition, individual retailers, food importers and food producers have comprehensive quality control and assurance schemes in place to provide traceability and ensure food is produced to the standards which they require whilst minimising any risks to food safety; it was not within the scope of this study to assess the effectiveness of such measures.

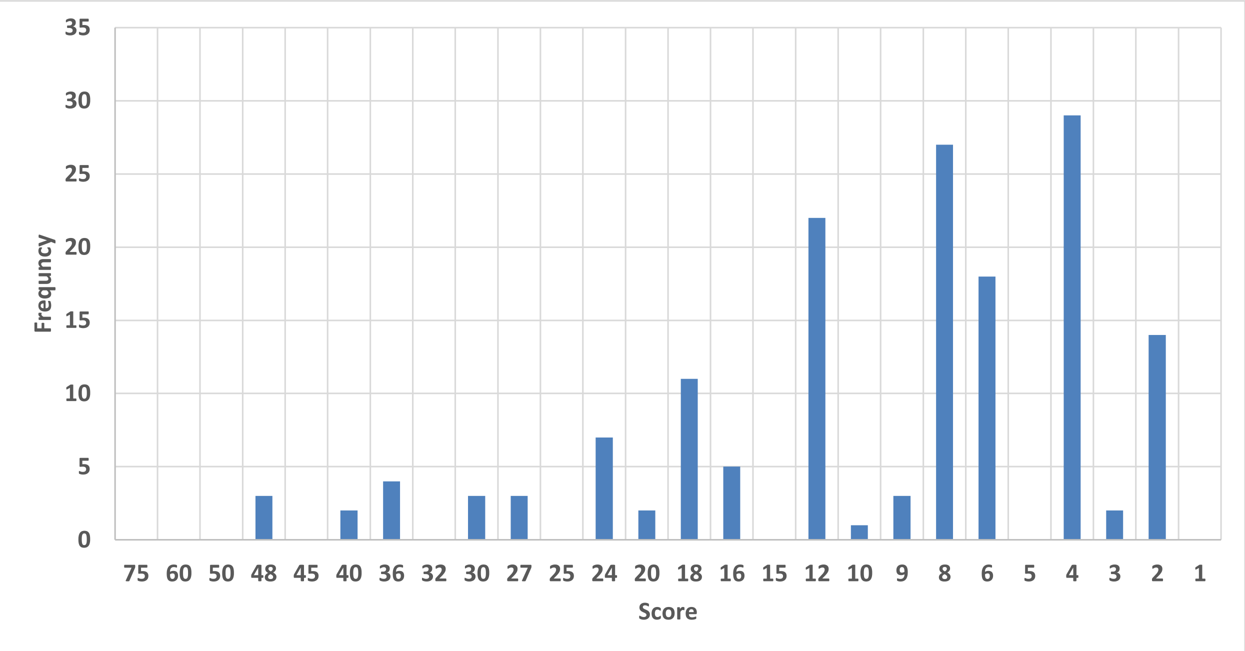
### 3.6 Calibration

Following agreement by the project team on the qualitative priority ranking method and the scenarios to be scored and ranked, the project team met to score several selected scenarios. This helped to establish a common scoring approach and to identify and deal with any uncertainties. The remaining scenarios were then scored by individual experts. A provisional ranking was produced and discussed with the FSA steering group and then presented at the stakeholder workshop attended by representatives with expertise in cardboard and paper packaging, the retail food sector, livestock farming, waste recycling etc. Following the workshop, a second expert panel was held to revisit the scores based on new information and inconsistencies of approach identified by the FSA steering group, the stakeholders and the project team. A final qualitative priority ranking was produced as a result of the second panel meeting.

### 3.7 Priority ranking outcomes

The priority scoring methodology generated a ranked list of the c.150 source term/recycling mode/exposure pathway combinations. The scores assigned ranged from 2 to 48, from a maximum potential range of 1 to 75, with some clustering of scores particularly lower in the range (Figure 1), which is not surprising as most recycled waste and waste-derived products would be expected to present a relatively low risk to food safety.

**Figure 1. Distribution of overall priority scores for each source term/recycling mode/exposure pathway combination**



Three broad priority categories were identified at the top, middle and bottom of the ranking based on the overall score as follows:

- Priority 1 (Score >20) comprising *c.*15% of the source term/recycling mode/exposure pathway combinations.
- Priority 2 (Score 10-20) comprising *c.*20% of the source term/recycling mode/exposure pathway combinations.
- Priority 3 (Score <10) comprising *c.*65% of the source term/recycling mode/exposure pathway combinations.

*Note: the priority class boundaries are methodologically-derived and do not have any specific meaning in terms of the risk of harm.*

The source terms falling into each priority category are shown in Table 4. Each source term appears only once and was categorised according to the highest ranked exposure pathway; source terms are listed in alphabetical order.

Priority 1 comprises the source terms assessed to be those towards which FSA research funding should be directed in the short to medium term. Most of the source terms falling into this category relate to the use of recycled materials in non-EU countries. This assessment is largely driven by the high uncertainty score assigned to the use of many of these materials where little is known about the regulations and controls governing their use; many of these materials may contain relatively high amounts of one or more potentially hazardous agents, although often there are few data on actual concentrations. The Priority 1 ranking for the UK source terms (i.e. non-source segregated compost and tannery wastes applied to agricultural land) was driven by a potentially high concentration of one or more potentially hazardous agents, combined with moderate to high uncertainty as a result of sparse data and limited research. For most of the Priority 1 source terms involving recycling to agricultural land, the exposure pathway of most immediate concern would be ready to eat (RTE) crops where the potentially hazardous agent(s) of concern could be directly ingested by the consumer with few effective modifiers to uptake.

Priority 2 encompasses those source terms which were assessed to be a lower priority for FSA research efforts, but nevertheless could require further consideration in terms of their potential implications for food safety when resources becomes available.

Priority 3 comprises the source terms which were considered to merit the lowest degree of attention, either because they contain few potentially hazardous agents which are present at low concentrations or because there has been a considerable amount of previous research undertaken so that the uncertainty regarding their use is minimal i.e. potential risks to food safety are well documented, understood, controlled and regulated.

**Table 4. Source terms in each priority category (listed in alphabetical order).**

| Identifier | Priority 1 |
|---|---|
| 3 | Blood and Intestinal contents applied to agricultural land |
| 39 | Dried chicken manure as cattle feed and fish feed (non EU) |
| 45B | Former food used as livestock feed (non-EU) |
| 46 | Insect protein used in livestock or fish feed (non-EU) |
| 11B | Livestock manure applied to agricultural land (non-EU) |
| 13 | Manure from fish farming applied to agricultural land (non-EU) |
| 28 | Non-source segregated compost/digestate applied to agricultural land |
| 34B | Recycled manure solids (RMS) used as animal bedding (non-EU) |
| 22 | Tannery waste applied to agricultural land |
| 51 | Tertiary treated effluent used for irrigation (non-EU) |
| 50 | Untreated municipal wastewater used for irrigation (non-EU) |
| 49 | Wastewater from fishponds used in aquaponics (non-EU) |
| **Identifier** | **Priority 2** |
| 1 | Biochars applied to agricultural land |
| 54 | Biopolymers in food contact packaging |
| 5 | Canal dredgings applied to agricultural land |
| 41 | Feather meal used in animal feed (non-EU) |
| 24 | Feathers/feather meal applied to agricultural land - non UK |
| 36 | Fibre food based digestate (source segregated) applied to land |
| 11A | Livestock manure applied to agricultural land |
| 17 | Paper crumble applied to agricultural land |
| 18 | Paper Sludge Ash (PSA) applied to agricultural land |
| 16 | Plant-based food production residues applied to agricultural land - non UK |
| 19 | Poultry litter ash (PLA) applied to agricultural land |
| 52B | Recycled cardboard in direct contact food packaging - non EU |
| 34A | Recycled manure solids (RMS) used as animal bedding UK |
| 53 | Recycled plastic in food contact packaging - non EU |
| 44 | Sawdust used as an animal feed bulking agent - non UK |
| 43 | Shellfishery wastes in animal feed - non UK |
| 21 | Spent mycelium from pharmaceutical production applied to agricultural land |

| | |
|---|---|
| 37 | Tyre crumb used as animal bedding |
| 23 | Zeolites in air filters applied to agricultural land |
| **Identifier** | **Priority 3** |
| 47 | Alcohol produced from food waste |
| 2 | Biosolids applied to agricultural land |
| 6 | Clean water sludge applied to agricultural land |
| 27 | Crop based digestate (source segregated) applied to land |
| 12 | Crop residues incorporated to agricultural land |
| 7 | Dairy processing effluents applied to agricultural land |
| 8 | Distillery wastes applied to agricultural land |
| 4 | Eggshells applied to agricultural land |
| 40 | Fish meal used in livestock feeds |
| 45A | Former food used as livestock feed |
| 29 | Green compost applied to agricultural land |
| 9 | Gypsum (from plasterboard) applied to agricultural land |
| 38 | Gypsum (from plasterboard) used as animal bedding - non UK |
| 48 | Horticultural substrates produced from wastes |
| 10 | Lime from sugar beet applied to agricultural land |
| 14 | Meat and Bone Meal Ash (MBMA) applied to agricultural land |
| 15 | Mushroom compost applied to agricultural land |
| 36 | Oat feed used as animal bedding |
| 31 | Paper crumble used as animal bedding |
| 16 | Plant-based food production residues applied to agricultural land - non UK |
| 52A | Recycled cardboard in direct contact food packaging |
| 33 | Recycled cardboard/paper used as livestock bedding |
| 35 | Recycled wood products used as animal bedding |
| 20 | Source separated human urine applied to agricultural land – non UK |
| 30 | Struvite from wastewater used as a fertiliser |
| 42 | Sugar beet residues used as animal feed |
| 25 | Whole food-based digestate (source segregated) applied to land |

The rankings given in Table 4 should be considered as indicative of the current state of knowledge rather than as an immoveable outcome. In future, the wider usage of some of these materials and recycling modes may generate more information on their composition and a better understanding of how the different potentially hazardous agents behave in the environment and in the food chain. The result is that the scores assigned in the priority matrix will need to be adjusted, so that individual materials could move up or down in the list of priority rankings.

The scores assigned to each source term/recycling mode (or to add new source term/recycling mode combinations) can be amended in a relatively straightforward way, provided the person or persons undertaking the scoring have the appropriate knowledge and expertise, and understand how the scoring system operates and was internally calibrated.

*Note: the current list of source terms and the scores assigned to them were based on expert consensus; any changes or additions would need to be scored by the same team, or the whole list would need re-scoring by a new expert team to maintain internal consistency.*

*The outputs of the risk ranking should not be over-interpreted, as they are relative risk scores based on a methodology which was developed in order to allow risks to be prioritised into broad categories. It is recognised that the scores assigned are to some extent 'subjective', but they are based on the view of experts with experience of and with reference to objective science. Consistency of scoring was addressed by agreeing a standard approach and then using calibration meetings to double check for consistency. It might be expected that the scores would differ to some extent depending on the particular group of experts used to populate the ranking matrix, but at the level of the broad categories of priorities we would expect agreement. The broad prioritisation categories could be validated by more comprehensive use of the semi-quantitative risk assessment methodology (see Section 4), by the selective use of quantitative risk assessments, by having parallel/independent panels or by having more extensive independent peer-review of the expert panel judgements*.

# 4 Semi-quantitative risk assessment

## 4.1 Purpose

The qualitative priority ranking described above produced a relative ranking of the source term/recycling mode combinations. This qualitative approach relied on expert judgements of the attenuation of aggregated hazards through various pathways to the points of exposure.

The semi-quantitative approach was designed to disaggregate the component parts of the qualitative assessment for a selected number of examples, in a higher degree of detail than was practical for the full ranked list in the qualitative assessment. The approach was designed to make the process by which the combined risk score for a source term/recycling mode combination was generated more transparent. It therefore served as a means of validating and providing confidence in the risk ranking, and could be applied to a wider range of waste materials and recycling modes in future work.

Taken together with the qualitative priority ranking, the semi-quantitative assessment enabled the identification of specific potentially hazardous agents and/or scenarios that should be prioritised for further investigation and optionally for fully quantitative risk assessment.

The method developed used the same principles of source and exposure pathway as the qualitative priority ranking. Firstly, the presence and potency of the various categories of potentially hazardous agents in the source were considered; then the modifiers to uptake were identified, and their effectiveness and extent to which they moderate the risks posed by each group of potentially hazardous agents were assessed, using expert judgement, for the selected exposure scenarios.

The method was spreadsheet based and applied a scoring sequence, with supporting information recorded on a separate spreadsheet page, so that the sequence of decisions and evidence supporting each assessment could be traced.

*Note: whilst a variety of factors influencing the uptake of potentially hazardous agents were considered in this assessment it remained a relative measure of concern based on expert judgement. It was* not *an absolute measure of risk, which is best made by a detailed quantitative risk assessment.*

## 4.2 Scenario selection

Three scenarios were selected from the comprehensive qualitative priority ranking list. The selection was designed to include a range of source term/recycling mode/exposure pathway scenarios, where a good evidence base was available for the material under consideration, i.e. without undue uncertainty. The scenarios selected included three different recycling modes (i.e. application to agricultural land, use as livestock bedding, and inclusion in livestock feed) specifically:

- Blood and intestinal contents applied to agricultural land growing RTE crops (UK)
- Former foods used as feed for animals used in meat production(UK)

- Recycled manure solids used as bedding for dairy cattle producing milk (Sub-divided into 'UK' and 'non-EU')

### 4.3 Source term assessment

For each broad category of potentially hazardous agents, the exemplar(s) was selected by applying expert judgement to identify individual potentially hazardous agents of 'plausible highest potency' where enough evidence of sufficient quality was available to support the conclusions drawn; this is recorded in the evidence base section of the spreadsheet and supported by the earlier literature review (see Appendix). Categories of potentially hazardous agents defined within the source term assessment and the exemplars selected are shown in Table 5.

**Table 5. Source term assessments**

| Potentially hazardous agent **category** | **Exemplar** |
|---|---|
| Pathogens | *E. coli* O157 |
| Prions | BSE |
| Mycotoxins | Not specified |
| PTEs | Cd, Pb, Hg, Zn, Cu, |
| POPs | PCDD/Fs |
| Micro-plastics and breakdown products | Not specified |
| Nanoparticles | Zn nanoparticles |
| AMR genes | Colistin |

Scoring for the source term used a 1-10 scale (Table 6) to characterise each material in terms of the potentially hazardous agents present at the point of recycling; the score encompasses the concentration of the potentially hazardous agent, its potency and the seriousness of the consequences of ingestion, and was based on a combination of evidence from the published literature and expert judgement.

For example, in the scenario of 'Blood and intestinal contents applied to agricultural land growing RTE crops (UK)' pathogens, and in particular *E. coli* O157, were given a score of 10 based on the high numbers of this pathogen which could be present in cattle faeces and the seriousness of the consequences if a high population of *E.coli* O157 were to enter the food chain without prior modification/management. Similarly, AMR was assigned a score of 8 because blood and intestinal contents are very likely to be a source of anti-microbial resistance and of nanoparticles from animal feeds.

**Table 6. Descriptors of the source term scores**

| Score | Descriptor |
|---|---|
| 1 | Negligible probability of harm from the specified potentially hazardous agents within the source term |
| ↕ | |
| 10 | High probability of harm from the specified potentially hazardous agents within the source term |

## 4.4 Pathway modifiers

For each scenario, the modifiers to inputs of the potentially hazardous agents present in the source term were identified. The score assigned to the source-term was then moderated along the selected exposure pathway, taking into account the effect of each modifier, i.e. no change, an increase, or a decrease in the probability of harm.

A maximum of five modifiers were considered, with the potential to increase or decrease the source term score within the range of 1-10 at each stage according to the efficacy of the modifier. For example, a source term with a high pathogen load that was initially scored as a '10', might be reduced by assigning a modifier score of '-2' to a score of '8' by dilution in soil and exposure to sunlight following land spreading. This might then be further reduced by '-3' to a final score of '5' during the final processing of the food. This process allows for both reductions (e.g. pathogen reduction during pasteurisation) and increases (e.g. pathogen regrowth during storage; heavy metals accumulation in soil through repeated applications) in risk along an exposure pathway.

## 4.5 Outputs

In contrast to the qualitative priority-ranking, which produced a single relative score for each scenario, the semi-quantitative assessment provided a risk profile of disaggregated potentially hazardous agents for the selected scenarios that was based on expert judgement and underpinned by the evidence from the literature.

The final score for each scenario was reflected as a profile of modified risks originating from the specified source term/recycling mode/exposure pathway combination. This score enabled the 'total risk potential' to be assessed and compared with the qualitative priority ranking (also shown on the spreadsheet). To aid with visualisation of the scores arising from the assessment, a relative-chromatic scale was used for the profile indicator (Figures 2-5).

As for the priority ranking, the risk profiling process described above was based on comparative rather than absolute assessment scores. Whilst the expert panel considered the plausible risk of harm to food consumers from using these materials, it is important to note that this is not a quantitative risk assessment. Therefore, a score of '4' cannot be considered to be indicative of half as much risk as a score of '8'. Similarly, whilst a score of '1' for example may be perceived as low risk, it cannot be interpreted as implying there is no risk.

### 4.6 Outcomes of the semi-quantitative risk assessment

Results from the semi-quantitative risk profiles are directly comparable with the outcome of the qualitative assessment (Table 4). For example, the 'former foods' scenario presents the lowest comparative cause for concern across its profile (Figure 3), whereas the 'recycled manure solids used as bedding, non-EU' scenario, presents the greatest relative concern when the full risk profile is viewed (Figure 5). This provides some validation of the qualitative priority ranking methodology, demonstrating that the results from the latter were robust and could therefore be used for prioritisation of research requirements.

The potentially hazardous agents that are judged to be present in the source material directly determine the final risk profile. For example, the 'former foods' scenario has an initial source hazard profile that was considered to be of overall low risk (Figure 3). Given this starting point and the limited opportunity for hazards to increase when incorporated into livestock feed, the final outcome was also one of overall low risk. In contrast, in the 'blood and Intestinal contents to agricultural land' scenario (Figure 2), the source material was considered to have a high potential pathogen and AMR load due to the intestinal contents; in this case, unless there is a modifier that is highly effective, it is inevitable that a notable residual risk remains from the RTE crops growing on land where it was applied.

The risks from materials with significant hazards present at the point of recycling can be reduced via one or more partially effective modifiers. For example, in the 'blood and Intestinal contents to agricultural land' scenario (Figure 2), the high levels of pathogenic bacteria in the source material are modified by application rate controls, die-off in the soil, relatively inefficient transfer from soil to the crop, and consumer washing and trimming; despite these pathway reductions, however, this still represents a relatively high level of concern in comparison with the 'former foods' scenario (Figure 3). In the 'recycled manure solids as bedding (UK)' scenario, the low probability of milk contamination by pathogens and the high effectiveness of the pasteurisation process results in an outcome of negligible concern in the milk consumed in terms of pathogens, although the transfer of antimicrobial resistance remains a concern (Figure 4).

## Figure 2. Semi-quantitative assessment of blood and intestinal contents applied to agricultural land growing RTE crops (UK)

| Blood and intestinal contents applied to agricultural land growing RTE crops (UK) | Potentially hazardous agent | Qualitative priority ranking | Source score (1-10) | 1st modifier (+- <1-10>) | | 2nd modifier (+- <1-10>) | | 3rd modifier (+- <1-10>) | | 4th modifier (+- <1-10>) | | 5th modifier (+- <1-10>) | Semi-quantative relative risk profile |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exemplar | | | | Application rate controls | | Accumulation / attenuation/ die-off pre-harvest in the soil | | Effectiveness of process by which hazard in soil can contaminate the crop pre-harvest or during harvest | | Post-harvest storage / transport / processing | | Consumer washing of RTE crop surfaces / trimming or removal of outer surface | |
| E. coli O157 | Pathogens | Yes | 10 | -2 | 8 | -1 | 7 | -1 | 6 | 0 | 6 | -1 | 5 |
| | Prions | No | 1 | 0 | 1 | 0 | 1 | | 1 | | 1 | | 1 |
| Mycotoxins generally | Mycotoxins | Yes | 2 | -2 | 0 | -3 | -3 | 0 | -3 | 0 | -3 | 0 | -3 |
| Cd / Hg / Pb | PTES | Yes | 4 | -2 | 2 | 1 | 3 | -1 | 2 | 0 | 2 | -1 | 1 |
| Dioxin / furans | POPs | Yes | 3 | -2 | 1 | 0 | 1 | | 1 | | 1 | | 1 |
| | Microplastics | No | 1 | 0 | 1 | 0 | 1 | | 1 | | 1 | | 1 |
| Zn nanoparticles in pig feed | Nanoparticles | Yes | 2 | -2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Colistin resistance gene | AMR genes | Yes | 8 | -2 | 6 | 1 | 7 | -1 | 6 | 0 | 6 | -1 | 5 |
| Qualitative priority ranking scores | Hazard (1-5) | 4 | | | | | | | | | | | |
| | Pathway (1-5) | 3 | | | | | | | | | | | |
| | Uncertainty (1-3) | 1 | | | | | | | | | | | |
| | Relative priority score | 12 | | | | | | | | | | | |

The cells shaded in grey show the original qualitative risk ranking scores for comparison with the semi-quantitative relative risk profile shaded in blue (far right hand column)

## Figure 3. Semi-quantitative assessment of former foods used for animal feeds for animals used in meat production (UK)

| Former foods used as feeds for animals used in meat production (UK) | Potentially hazardous agent | Qualitative priority ranking | Source score (1-10) | 1st modifier (+- <1-10>) | | 2nd modifier (+- <1-10>) | | 3rd modifier (+- <1-10>) | | 4th modifier (+- <1-10>) | | 5th modifier (+- <1-10>) | Semi-quantative relative risk profile |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exemplar | | | | Incorporation into feed | | Breakdown product accumulation | | Post slaughter processing / storage / transport | | Consumer preparation e.g. cooking | | N/A | |
| | Pathogens | No | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| | Prions | No | 1 | 0 | 1 | 0 | 1 | | 1 | | 1 | | 1 |
| | Mycotoxins | No | 1 | 0 | 1 | 0 | 1 | | 1 | | 1 | | 1 |
| | PTEs | No | 1 | 0 | 1 | 0 | 1 | | 1 | | 1 | | 1 |
| | POPs | No | 1 | 0 | 1 | 0 | 1 | | 1 | | 1 | | 1 |
| Packaging associated | Microplastics | Yes | 2 | -1 | 1 | 1 | 2 | 0 | 2 | | 2 | | 2 |
| Packaging associated | Nanoparticles | Yes | 2 | -1 | 1 | 1 | 2 | 0 | 2 | | 2 | | 2 |
| | AMR genes | No | 1 | 0 | 1 | 0 | 1 | | 1 | | 1 | | 1 |
| Qualitative priority ranking scores | Hazard | 2 | | | | | | | | | | | |
| | Pathway | 3 | | | | | | | | | | | |
| | Uncertainty (1-3) | 1 | | | | | | | | | | | |

The cells shaded in grey show the original qualitative risk ranking scores for comparison with the semi-quantitative relative risk profile shaded in blue (far right hand column)

## Figure 4. Semi-quantitative assessment of recycled manure solids used as bedding for dairy cattle producing milk (UK)

| Recycled manure solids used as bedding for dairy cattle producing milk (UK) | Potentially hazardous agent | Qualitative priority ranking | Source score (1-10) | 1st modifier (+- <1-10>) | | 2nd modifier (+- <1-10>) | | 3rd modifier (+- <1-10>) | | 4th modifier (+- <1-10>) | | 5th modifier (+- <1-10>) | Semi-quantative relative risk profile |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exemplar | | | | Attenuation / die-off /accumulation in housing | | Transfer to milk (taking into account amount ingested / effectiveness of skin absorption | | Processing / storage / transport | | Consumer behavior e.g. chilled storage | | N/A | |
| E. coli O157 | Pathogens | Yes | 7 | 1 | 8 | 2 | 10 | -9 | 1 | 0 | 1 | 0 | 1 |
| | Prions | No | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| Mycotoxins generally | Mycotoxins | Yes | 4 | 1 | 5 | -2 | 3 | 0 | 3 | 0 | 3 | 0 | 3 |
| Cd / Hg / Pb | PTEs | Yes | 4 | 0 | 4 | -2 | 2 | 0 | 2 | 0 | 2 | 0 | 2 |
| Dioxin / furans | POPs | Yes | 3 | 0 | 3 | -1 | 2 | 0 | 2 | 0 | 2 | 0 | 2 |
| | Microplastics | No | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| Zn nanoparticles in pig feed | Nanoparticles | Yes | 2 | -2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Colistin resistance gene | AMR genes | Yes | 8 | 1 | 9 | 2 | 11 | 0 | 11 | 0 | 11 | 0 | 11 |
| Qualitative priority ranking scores | Hazard | 3 | | | | | | | | | | | |
| | Pathway | 2 | | | | | | | | | | | |
| | Uncertainty (1-3) | 2 | | | | | | | | | | | |
| | Relative priority score | 12 | | | | | | | | | | | |

The cells shaded in grey show the original qualitative risk ranking scores for comparison with the semi-quantitative relative risk profile shaded in blue (far right hand column)

## Figure 5. Semi-quantitative assessment of recycled manure solids used as bedding for dairy cattle producing milk (non-EU)

| Recycled manure solids used as bedding for dairy cattle producing milk (non-EU) | Potentially hazardous agent | Qualitative priority ranking | Source score (1-10) | 1st modifier (+- <1-10>) | | 2nd modifier (+- <1-10>) | | 3rd modifier (+- <1-10>) | | 4th modifier (+- <1-10>) | | 5th modifier (+- <1-10>) | Semi-quantative relative risk profile |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exemplar | | | | Attenuation / die-off /accumulation in housing | | Transfer to milk (taking into account amount ingested / effectiveness of skin absorption | | Processing / storage / transport | | Consumer behavior e.g. chilled storage | | N/A | |
| E. coli O157 | Pathogens | Yes | 7 | 1 | 8 | 2 | 10 | -7 | 3 | 0 | 3 | 0 | 3 |
| BSE | Prions | Yes | 2 | 0 | 2 | -1 | 1 | 0 | 1 | 0 | 1 | | 1 |
| Mycotoxins generally | Mycotoxins | Yes | 5 | 2 | 7 | -2 | 5 | 0 | 5 | 0 | 5 | | 5 |
| Cd / Hg / Pb | PTEs | Yes | 8 | 0 | 8 | -2 | 6 | 0 | 6 | 0 | 6 | | 6 |
| Dioxin / furans | POPs | Yes | 7 | 0 | 7 | -1 | 6 | 0 | 6 | 0 | 6 | | 6 |
| | Microplastics | Yes | 6 | 0 | 6 | -2 | 4 | 0 | 4 | 0 | 4 | | 4 |
| Zn nanoparticles in pig feed | Nanoparticles | Yes | 3 | -3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| Colistin resistance gene | AMR genes | Yes | 9 | 1 | 10 | 2 | 12 | 0 | 12 | 0 | 12 | | 12 |
| Qualitative priority ranking scores | Hazard | 3 | | | | | | | | | | | |
| | Pathway | 3 | | | | | | | | | | | |
| | Uncertainty (1-3) | 3 | | | | | | | | | | | |
| | Relative priority score | 27 | | | | | | | | | | | |

The cells shaded in grey show the original qualitative risk ranking scores for comparison with the semi-quantitative relative risk profile shaded in blue (far right hand column)

# 5 Summary and recommendations

## 5.1 Summary

A qualitative priority ranking methodology was developed and populated using a combination of expert judgement and information from the published literature; this allowed a large number of diverse waste derived materials and recycling modes to be compared, so that priorities for future research studies could be identified. The methodology offers a flexible tool which could be used in future as a method for screening and comparing risks from novel recycled materials and recycling modes, and emerging potentially hazardous agents.

A further semi-quantitative risk assessment was undertaken to provide a preliminary assessment of risk in which the potentially hazardous agents and their attenuation or accumulation along an exposure pathway were considered at a more disaggregated level for selected waste material/recycling mode scenarios. It also provided validation of the outcomes and documentation of the expert judgements underpinning the qualitative priority ranking methodology.

The source term/recycling mode combinations identified as having the highest priority for research, together with the major concerns associated with each, are shown in Table 7; more information is available in the one-page summaries in the Appendix.

The majority of the priority areas identified in Table 7 relate to practices outside the EU, for which there is little data available and a poor research evidence base; uncertainty was also increased because little is known about any regulations and controls governing food production that may be in place. Of the two UK source term/recycling mode combinations identified as priorities, the use of non-source segregated compost/digestate on agricultural land is not current practice in UK, although it is legally possible via a bespoke permit. However, it is widely practiced in other EU member states and other countries around the world and may become more widespread in the UK in future if certain conditions can be met over its usage. Application of tannery wastes to agricultural land in the UK is governed by the ABP and Environmental Permitting Regulations which will to some extent limit additions of potentially hazardous agents. Also the quantities applied to land are small in comparison with livestock manures, biosolids, digestates and composts hence food or feed crops receiving it will be diluted within the overall food supply chain. Nevertheless, there is a need to better understand the risks associated with the potentially hazardous agents it may contain, in particular arsenic (As) and organic contaminants (see Appendix).

**Table 7. Priorities for further research**

| Identifier | Source term/recycling mode | Major concerns |
|---|---|---|
| 39 | Dried chicken manure as cattle feed and fish feed (non EU) | Unknown but potentially high content of potentially hazardous agents including veterinary medicines, pathogens and AMR. Lack of information on how widespread the practice is outside the EU. Particular concerns related to fish farming in SE Asia. |
| 45B | Former food used as livestock feed (non-EU). | Potential to contain a broader spectrum of potentially hazardous agents than within the EU due to less stringent regulations. High degree of uncertainty relating to controls and regulations. |
| 46 | Insect protein used in livestock or fish feed (non-EU) | General lack of knowledge associated with this novel source of protein. Could become more important in the future. |
| 11B | Livestock manure applied to agricultural land (non-EU) | Could contain high concentrations of a variety of potentially hazardous agents due to poor regulation of livestock feeds and veterinary medicines, and concerns over housing conditions and hygiene. High degree of uncertainty relating to controls and regulations. |
| 13 | Manure from fish farming applied to agricultural land (non-EU) | Unknown but potentially high content of PTEs and veterinary products; potential source of AMR. High degree of uncertainty relating to controls and regulations. |
| 28 | Non-source segregated compost/digestate applied to agricultural land | Known to contain a wide spectrum of potentially hazardous agents including PTEs and POPs. Some ongoing research. |
| 34B | Recycled manure solids (RMS) used as animal bedding (non-EU) | High degree of uncertainty relating to controls and regulations. |
| 22 | Tannery waste applied to agricultural land | Potential to contain a broad spectrum of potentially hazardous agents at high concentrations. |
| 51 | Tertiary treated effluent used for irrigation (non-EU) | Main concern is pharmaceutical compounds. Some research information available, but uncertainty relating to controls and regulations. |
| 50 | Untreated municipal wastewater used for irrigation (non-EU) | Could contain high concentrations of a variety of potentially hazardous agents due to poor regulation and control. |
| 49 | Wastewater from fishponds used in aquaponics (non-EU) | Potential source of PTEs, veterinary medicines and AMR. Very limited evidence base and few regulations |

## 5.2 Evidence gaps and recommendations for further work

This project was an initial 4-month scoping study, therefore the approach adopted was deliberately intended to be 'broad brush' allowing comparison of a wide range of disparate waste-derived materials and potentially hazardous agents. The purpose was not to focus on any particular group of potentially hazardous agents or on specific chemicals, although these might merit further investigation. Nevertheless, the outcomes from the priority ranking, the semi-quantitative assessment and the literature gathered to support both these exercises, allowed the project team to identify a number of areas where further information or research is required.

- The qualitative priority ranking outcomes (supported by the semi-quantitative assessment) indicated that future research should focus on certain recycled materials and practices used in food production outside the EU. Because this assessment was largely driven by the uncertainty involved, research should initially concentrate on gathering evidence and understanding the controls and regulations governing food production and packaging in relation to recycling practices in a non-EU context. *Based on this and on feedback from the Stakeholder Workshop, we recommend that the FSA invest some effort in understanding the approaches taken and practices conducted in a selected number of non-EU nations from which we have significant imports, for foodstuffs that are not supplied to consumers directly via the retail supply chain (where there are comprehensive supply chain checks and controls in place); examples include wholesale fresh produce or meat products intended for use in catering outlets and farmed fish.*
- Food safety risks in the context of waste recycling and food production are moderated by a wide range of policies, regulations and practices in waste management and processing, feed formulation, food production and in the retail supply chain, and involve multiple actors and very often multiple jurisdictions. *A detailed review of this complex system would be invaluable to characterise it, identify its existing strengths as well as its weaknesses, and to establish the role that the FSA could play in advocating the need for change, improving co-ordination between stakeholders and plugging gaps in the control of food safety risks.*
- A number of the wastes and waste derived products that we investigated have been shown to be potential sources of antimicrobial resistance (AMR) including biosolids, livestock manures, digestate, compost, human urine, blood and intestinal contents and fish manure. During the semi-quantitative assessments, it became clear that the risks associated with the transfer of AMR were judged to be high compared with those from some of the other potentially hazardous agents present in waste materials. *We therefore recommend that research is funded to better understand how AMR might be transferred from recycled waste materials into the food chain, and any factors which may impact on the probability of AMR transfer. Issues to be considered include how*

*biocides, such as quaternary ammonium compounds which are present in many organic waste materials, might contribute to the dissemination of AMR.*

- Nanoparticles have been detected in meat (Loeschner *et al*., 2013) and many other foodstuffs, and analytical methods for their detection and characterisation are currently being developed (FSA project FS231071). It was also apparent that nanoparticles have been found in a number of the wastes and waste derived products that we investigated including biosolids, livestock manures, anaerobic digestate and compost. However, there was a lack of information on their concentrations, environmental behaviour and food chain uptake, although there has been some work on biosolids and this is a developing are of research. *It would be timely to undertake a more in depth literature review of nanoparticles in the broad range of different waste derived materials used in food production..*
- For practical reasons, the semi-quantitative assessment was conducted using a small number of scenarios selected from the comprehensive list considered in the qualitative priority ranking. *There are advantages in extending this approach to a greater number of scenarios, as it allows a much more comprehensive understanding of the* potentially hazardous agents *which pose the greatest risk from a particular waste material/recycling mode combination. It would also allow scenarios which require a detailed quantitative risk assessment to be identified. In addition, it would be beneficial to undertake some form of sensitivity analysis to identify the critical parameters that drive the ranking scores produced by the semi-quantitative risk assessments; in particular, where there has been potentially subjective assignment of a value for a 'source term' or 'modifier', testing different values to assess the overall impact would be useful.*
- Future research will need to better understand the risks posed by mixtures and blends of recycled waste materials e.g. ash and digestate blends applied to agricultural land (Semple *et al*., 2015). *There is a need to better understand how such blending could affect issues such as potentially hazardous agent concentrations, bioavailability in soil and crop uptake. Although blending different types of waste could reduce the overall concentration of particular hazardous agents, it could also result in contamination of a much larger total batch or consignment of the final blended product and therefore result in more widespread dissemination of the contaminant. Also for highly toxic chemicals, it could make mitigation of an incident more complex if the contamination was only discovered after the affected material had been deployed to land or used as animal bedding.*
- Whilst there has often been detailed research undertaken into how single potentially hazardous agents present in waste derived materials behave in the environment and the food chain, there is relatively little information on simultaneous exposure to combinations of potentially hazardous agents. *Research is needed to better understand the synergistic or antagonistic effects of mixtures of potentially hazardous agents on, for example, crop uptake or toxicity*.

- Some UK source term/recycling mode combinations that were scored as Priority 2 merit further investigation. *In particular there is a need for more information on the levels of PCDD/Fs (which are currently not routinely analysed) in rural sections of the canal system that are commonly dredged and recycled to agricultural land, and to measure concentrations in receiving soils to better understand the levels of risk this practice might pose to the food, in particular where the land is used to rear animals which can bio-accumulate these chemicals from ingested herbage and soil.*
- The tools developed and deployed in this project should be used as 'living' documents which are updated periodically as new information emerges and used to support FSA decision-making in the field of waste recycling in the food chain. Such updates should be undertaken by the same expert team to ensure internal consistency of scoring (or the whole list of source terms should be re-scored by a different expert team). *This approach could be tested by rescoring the qualitative priority ranking and semi-quantitative assessments once data from recently commissioned studies on recycled manure solids (RMS) and other materials used as livestock bedding are available.*

# 6 Acknowledgements

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# Appendix: Evidence base for priority ranking scores

## 1 Explanatory notes

Details of the scoring system employed for the priority ranking are given in the main report (see Section 3.2). However a further explanation of the scores assigned to the exposure pathways is given below.

**General assumptions for the four exposure scenarios for materials applied to agricultural land**

*Cereal crops:* the hazards of relevance are chemical PTEs and OCCs; pathway via soil application, followed by crop uptake and accumulation in grains that are consumed by humans. Low application rates (of chemical hazards), low potential for transfer via soil and roots into the growing crop and low potential for accumulation in the grain mean that this pathway is normally scored 1. Whilst pathogens may be present in materials applied to land, the pathway to human receptors would typically involve soil splash onto the developing seed head, harvest and processing, prior to consumption. The interval between material application and harvest, combined with normal post-harvest thermal processing, means that this pathway is considered to be negligible for pathogens. The potential for exposure to physical contaminants is normally considered to be negligible in the cereal scenario given the physical separation from the harvested crop and the land-applied waste.

*Meat/dairy:* the hazards of relevance are chemical (PTEs and OCCs; pathway 1 is via soil application, followed by crop uptake and indirect ingestion by grazing livestock; pathway 2 is via soil application and subsequent grazing by livestock, during which they will consume hazards associated with the material directly, in the small proportion of material within reach on the soil surface, ingested with the herbage, as well as on any soil splashed onto the herbage. There is also potential for faecal contamination of meat during slaughter and of dairy products during milking which may provide a route for transfer of AMR genes (Verraes *et al.*, 2013; Toomey *et al.*, 2009) Due to these different routes and the potential for direct exposure, this collective pathway is considered more potent than cereal crops and is usually scored 2. Physical contaminants, are not considered to have a viable exposure pathway in this scenario.

*Root crops (cooked):* Two pathways are considered in this scenario: 1) the uptake of chemical hazards into the crop during growth (and subsequent consumption), and 2) direct ingestion of hazards in any soil adhering to the crop surface after cooking. Although considered remote, the potential for ingestion of PTEs or OCCs in adhering soil, combined with the potential for ingestion of these hazards in the crop itself mean that this scenario is normally scored 2. The act of cooking is expected to attenuate any residual pathogens to a satisfactory level.

*RTE crops:* Two pathways are considered in this scenario: 1) the uptake of hazards into the crop during growth (and subsequent consumption), and 2) direct ingestion of hazards, including AMR genes, in any soil adhering to the crop after harvest and before consumption. Given the close proximity of RTE crops to the treated soil surface (e.g leafy salads), the potential for soil splash, and the lack of cooking prior to consumption, this is considered the most potent scenario and is usually scored 3.

Specific legislation governs the use of biosolids on agricultural land in the UK (the Sludge (Use in Agriculture) Regulations, 1989. SI 1263). These require that specified PTEs in soils receiving biosolids do not exceed specific concentrations, and that the average annual addition of these PTEs does not exceed a specified loading rate (over any given ten year period). These regulations also state: No fruit or vegetable crops, other than fruit trees, shall be growing or being harvested in the soil at the time of the use; a ten month harvest interval applies for fruit and vegetable crops which are grown in direct contact with the soil and normally eaten raw; a three week grazing (and forage harvest) interval applied for land that is grazed or cropped for forage. Our exposure pathway scorings reflect these controls, which act as the benchmark against which pathways for other materials have been compared.

## 1. Biochar applied to agricultural land

**Comments**.

This scenario only considers biochars from food waste as a 'worst case' scenario due to levels of dioxins potentially present in these materials. Biochars from other sources (e.g. virgin timber and crop residues) tend to contain significantly lower concentrations (Anon., 2014).

**Potentially hazardous agent score: 3**

While concentrations of PTEs tend to be low in biochars derived from food waste, concentrations of PCBs and PCDD/Fs have been shown to become elevated (in the parts per million range) during biochar production. It would also be expected that PBDD/F) would occur. There is evidence, for example, that the polybrominated diphenyl ether, BDE-209, which is a common contaminant of fish, can be converted to polybrominated dioxins at normal cooking temperatures (e.g. Vetter *et al*., 2015). It is also likely that various brominated flame-retardants, including BDE-209, could at least be partially converted to PBDD/Fs during the formation of biochars made from food waste. Given the toxicity of these substances is high even at very low concentrations, this represents a non-trivial hazard (Anon, 2014). Provided that the feedstock contains very low levels of chlorine (i.e. no higher than the concentration of chlorine found in plants growing in non-saline environments) the risk of dioxin formation at toxic levels is low. At present, however, we do not have sufficient understanding of the relationship between chlorine in the feedstock, pyrolysis production variables and conditions and formation of PCBs, furans and dioxins (Anon., 2014).

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
| | **Meat/dairy: 3** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 2** |

Pathway scores reflect limited knowledge of variation in PCDD/F transfer, transformation, and decay. The meat/dairy pathways is thought to be a more susceptible or efficient pathway for the transfer and uptake of PCDD/Fs or related POPs (which are the main potentially hazardous agents of concern) than the crop pathways, hence the higher score assigned. PTE uptake by plants can be reduced by biochar additions (e.g. Mendez *et al*., 2012)

**Uncertainty score: 2**

PCDD/Fs are costly to measure and require specialist facilities hence they are rarely included in quality protocols. While the Biochar Quality Mandate (Anon., 2014) does include both PCBs and PCDD/Fs, this is a draft protocol and has not been adopted by the regulator or the industry.

**Knowledge gaps/emerging risks**

Biochar can contain a mixture of potentially harmful substances. The focus here has been on the most toxic of these; little is understood about the combined risks of being exposed to the mixture of contaminants present. There could also be more concern associated with biochars produced from MSW (a known practice in some EU states).

## 2. Biosolids applied to agricultural land

**Comments**

Digested sludge cake was taken as a 'highest plausible hazard' example of biosolids applied to agricultural land, which will have undergone conventional treatment requiring a 99% reduction in pathogens. Other biosolids products (advanced digestion, lime stabilised, thermally dried,) will have undergone enhanced treatment which are likely to further reduce pathogen concentrations or are more dilute (e.g. digested liquid, co-compost) and therefore apply lower concentrations of hazards.

**Potentially hazardous agent score: 3**

Known to contain PTEs (including Cd and Pb), pathogens, OCCs and nanoparticles (Brar *et al*., 2009; Yang *et al*., 2014). A recognised source of AMR (e.g. Reinthaler *et al*., 2003; Martins da Costa *et al*., 2006; Rahube *et a*l., 2014). Most physical hazards are removed by screening/treatment, although micro-plastic contamination is likely. Radiological hazards unknown but thought unlikely. Rigby *et al*. (2015) recently reported biosolids PCDD/F concentrations in the range 10.5 – 12.4 ng $WHO_{2005}$ TEQ/kg, compared with 2.42 ng $WHO_{2005}$ TEQ/kg for rural soils; concentrations of PBDD/Fs were considerably higher at 40-78 $WHO_{2005}$ TEQ/kg, based on the TEF values for PCDD/F congeners and may be a greater concern. High levels of PFAS compounds have been reported in the USA (Sepulvado *et al.,* 2011)

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
| | **Meat/dairy: 2** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 3** |

Standard pathway scores have been applied (see explanatory notes).

Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PEPFAA code) may also control hazard addition rates, *although compliance has not been assumed here*.

**Uncertainty score: 1**

There is good evidence from a substantial body of research over many years, both from the UK and overseas. This examines both chemical (e.g. Chambers *et al*., 2010; Chambers *et al*., 2011; Sutherland & Taylor, 2012; UKWIR, 2014; Rigby *et al*, 2015) and biological (e.g. Gale 2005) hazards. There are a number of emerging hazards for which evidence is less robust, and these are highlighted below.

**Knowledge gaps/emerging risks**

Silver nanoparticles in sludge may be harmful to soil microorganisms (Schlich *et al,* 2013) and may increase metal (Zn) uptake by plants (Judy *et al*., 2015) and hence into the food chain. Silver nanoparticles from biosolids appear to be associated with soil particles rather than available for crop uptake (Pradas de Real *et al*., 2016). Brar *et al*. (2010) cite potential risks to human health from some types of nanoparticles. Micro-plastics are not thought to present a significant risk to human health via terrestrial exposure pathways, although they can via aquatic pathways in the marine environment (Cole *et al.*, 2011) and could be considered an emerging contaminant for biosolids in the terrestrial context. Emerging concern over effects of sludge POPs on ovarian function in sheep and possibly humans (Lea *et al*., 2016), The effects of EDCs in sheep have also been investigated (e.g. Rhind *et al*., 2010; Evans *et al*., 2014) Radiological hazards are unlikely to be a risk, but no evidence currently

| |
|---|
| available. Transfer of AMR is a possibility, but no/very limited data available. |

## 3. Blood and Intestinal contents applied to agricultural land

**Comments**.

Under the National measures enabled in the Animal By Products Regulation (EC) 1069/2009, intestinal content from healthy animals that are slaughtered (category 2) can be recycled to land (Defra & APHA, 2014).

Intestinal content applied direct to land is 'highest plausible risk' example of livestock fluids applied to agricultural land as it consists largely of undiluted material. Livestock manures (cattle and pig slurry arise from the lairage at the abattoir) are recycled under the same regime. These materials contain intestinal fauna that includes pathogens and subclinical infection. The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated. Sub-surface application or immediate incorporation is usually proposed to meet odour and emission requirements of the Environment Regulator.

**Potentially hazardous agent score: 4**

Similar hazard profile to livestock manures; the material may contain PTEs and veterinary medicines, POPs and pathogens. A likely source of anti-microbial resistance; indeed the gut has been described as 'the epicentre of antibiotic resistance' (Carlet, 2012). For example, tetracycline resistant strains of *Megasphaera elsdenii* (a bacterium commonly present in the pig and human gut) have been detected in pig intestines (Stanton & Humphrey,. 2011). Intestinal contents are a potential source of nanoparticles in animal feeds(Swain *et al*., 2015; USDHHS, 2015)

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|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 1**<br>**Meat/dairy: 2**<br>**Root crops (cooked): 2**<br>**RTE crops: 3** |

Standard pathway scores have been applied (see explanatory notes).

Blood is injected to agricultural land which may protect pathogens from UV light and temperature extremes, hence prolonging survival times (Nicholson *et al*., 2005). The ABP regulations require a 3 week withdrawal of grazing livestock and 4 weeks for pigs from land which receives the application. Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PePFA code) may also control hazard addition rates, *although compliance has not been assumed here*.

**Uncertainty score: 2**

This practice is regulated and has been undertaken for many years in the UK.

**Knowledge gaps/emerging risks**

Sub-clinical infection levels in livestock and risk from antimicrobial resistance arising from blood and intestinal contents applications to land are poorly understood.

## 4. Eggshells applied to agricultural land

**Comments**.

Normally eggshells must be processed in accordance with animal by product regulations before application to land, but eggshell from flocks that have not tested positive for Salmonella can be applied to land. They must have been crushed and processed to ensure that liquid content (yoke and albumen) make up less than 4% of the weight of the shells (Defra & APHA, 2014).

The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated. Immediate incorporation is usually proposed to meet odour and emission requirements of the Environment Regulator.

**Potentially hazardous agent score: 2**

Mainly pathogens.

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 1**<br>**Meat/dairy: 2**<br>**Root crops (cooked): 2**<br>**RTE crops: 3** |

Standard pathway scores have been applied (see explanatory notes).

The ABP regulation requires a 3 week withdrawal of grazing livestock and 4 weeks for pigs from land which receives the application. Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PEPFAA code) may also control hazard addition rates, *although compliance has not been assumed here*.

**Uncertainty score: 1**

This practice is regulated and has been undertaken for many years in the UK.

**Knowledge gaps/emerging risks**

The risk of transfer of AMR is poorly understood.

| 5. Canal dredgings applied to agricultural land |
|---|
| Comments |
| The Canal and River Trust place contracts for dredging waterways and land spreading of the dredgings is an economic option for recycling. The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated. The silts are analysed before removal and only low contaminated silts are selected for recycling to land. Unlike most other materials the relatively low nutrient and contaminant concentration of selected silts enables in high mass application rates, typically 1,200 to 1,500 tonne/ha of soil like material. If high mass application rates of canal dredgings are applied to farm land, even quite moderate rates of chemical or other contaminants in the dredgings could substantially raise contaminant levels in the affected land and therefore also in crops or livestock produced on the treated land. |
| Potentially hazardous agent score: 4 |
| Known to contain PTEs, POPs (petroleum hydrocarbons and PAHs) that have a high affinity for organic rich fines in sediments, so where there is potential contamination of the water from which the dredgings are taken, these may accumulate in the sediments. Could also contain elevated levels of other POPs, physical contaminants, microbiological contaminants. Many canals are located in areas with industrial heritage and, historically, could have been affected by polluted waste water from mining and industrial activities (*e.g.* Zheng *et al*, 2007; Galvez-Cloutier & Dubé, 1998; Bromhead *et al*, 1994). |
| Exposure pathway scores: Cereals for human consumption: 1<br>Meat/dairy: 2<br>Root crops (cooked): 2<br>RTE crops: 3 |
| Standard pathway scores have been applied (see explanatory notes).<br>The silt is ploughed into soils preventing access by livestock and providing dilution of contaminant levels in the resultant mixed topsoil. Deployments must show that the resultant soil PTE concentrations would not be raised beyond the CoP for Sewage Sludge maxima. Canada Country guidelines (CCME, 2008) are used to assess suitable applications to limit hydrocarbons in the aggregate mixed soil. Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PEPFAA code) may also control hazard addition rates, *although compliance has not been assumed here*. |
| Uncertainty score: 1 |
| This practice is regulated and has been undertaken for many years in the UK. The risk from canal dredgings has been appraised as relatively low (Defra 2010). |
| Knowledge gaps/emerging risks |

The level of pathogens in silt and the water from untreated and historic discharge is not known. Many canals and water courses in Eastern European countries have historic pollution containing POPs and PTEs, although this is localised and may contain high levels of pathogens (Berge & Medbow 2007). Several non UK use reports are cited in Defra (2010).

Flooding of rivers with industrial catchments can result in the deposition of highly contaminated sediment onto flood-prone pasture, which results in substantially increased levels of contaminants( e.g. dioxins, PCBs, PBDEs) in dairy cattle reared on the contaminated pasture (*e.g.* Hendriks *et al*, 1996; Lake *et al*, 2006; Lake *et al*, 2011) and in beef (Lake *et al*, 2014). The adverse effects of spreading contaminated dredgings onto land, or the deposition of contaminated sediment as a result of flooding, can be far reaching and serious (*e.g.* Cullen *et al*, 1996; Kannan *et al*, 2008). Research has not yet evaluated levels of theses contaminants in soils receiving silts from canals or other dredged water bodies.

Analysis of canal silts is currently limited to PTEs (As, Cd, Cr, Cu, Pb, Ni, Zn, B, Hg, Mg, Se, F, Ba), PAH (16), TPH and phenolic compounds index (not disaggregated). Most research has focussed on silts dredged from canals in urban areas. Research is required to determine levels of a full suite of POPs (including PCDD/Fs), their transport to rural stretches of canals and their accumulation in agricultural soils, forages and livestock products.

| **6.** Clean water sludge applied to agricultural land | |
|---|---|
| Comments | |
| Clean water sludge (or filter cake) is produced from the treatment of abstracted surface water for drinking water. The process includes flocculation and precipitation methods to remove dissolved and suspended material including agrochemicals. The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated. Unlike most other waste materials, the low nutrient concentrations enable high mass application rates. | |
| Potentially hazardous agent score: 2 | |
| Known to contain high levels of aluminium from flocculants, although research on benefits and effects on PTEs in soil has shown that aluminium does not come into solution at the pH of well managed agricultural soils (Royle, 2001); low pH soils are to be avoided. Could contain cryptosporidium and other pathogens, including AMR genes. | |
| Exposure pathway scores: | Cereals for human consumption: 1<br>Meat/dairy: 2<br>Root crops (cooked): 2<br>RTE crops: 3 |
| Standard pathway scores have been applied (see explanatory notes).<br>The applied filter cake is ploughed into the field soils to give aggregate levels of PTEs and POPs in the resultant mixed topsoil. Deployments have to show that the resultant soil concentration of PTE would not be raised beyond the CoP for sewage sludge maxima. Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PEPFAA code) may also control hazard addition rates, *although compliance has not been assumed here*. | |
| Uncertainty score: 1 | |
| This practice is regulated and has been undertaken for many years in the UK. | |
| Knowledge gaps/emerging risks | |
| The level of pathogens and agrochemicals in the filter cake are not known. It would be desirable to confirm the level of contribution to residual agro chemicals in the soil in comparison to that applied directly to crops in crop protection products More information is required on AMR genes in clean water sludge. | |

| 7. Dairy processing effluents applied to agricultural land | |
|---|---|
| **Comments**. | |
| Under the animal by products regulation milk (category 2) can be recycled to land. The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated. Sub surface application or immediate incorporation is usually proposed to meet odour and emission requirements of the Environment Regulator | |
| **Potentially hazardous agent score: 2** | |
| Potential source of anti-microbial resistance. CIP washdown contains biocides and disinfectants that contain heavy metals. | |
| **Exposure pathway scores:** | **Cereals for human consumption: 1**<br>**Meat/dairy: 2**<br>**Root crops (cooked): 2**<br>**RTE crops: 3** |
| Standard pathway scores have been applied (see explanatory notes).<br>Hygiene control of animal by product material is by HACCP type systems. The regulation requires a 3 week withdrawal of grazing livestock that receives the application. Injected/incorporation to agricultural land may protect pathogens from UV light and temperature extremes, hence prolonging survival times (Nicholson *et al*., 2005). Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PEPFAA code) may also control hazard addition rates, *although compliance has not been assumed here*. | |
| **Uncertainty score: 1** | |
| This practice is regulated and has been undertaken for many years in the UK. | |
| **Knowledge gaps/emerging risks** | |
| Little information is available on threats to meat/dairy from the potential for the spread of AMR from the waste back to cows where it could propagate latently in harmless commensals before transferring to pathogens. | |

## 8. Distillery wastes applied to agricultural land

**Comments**.

It was assumed that application rates would reflect crop requirements for major nutrients (NPK), rather than when trying to rectify copper deficiency. As distillery effluents tend to be low in nutrients, an application rate in excess of 110 $m^3$ $ha^{-1}$ was assumed when assessing this scenario, which is in line with 'plausible highest hazard'.

**Potentially hazardous agent score: 2**

Known to contain some heavy metals, in particular copper and zinc, although these are more an environmental than a food safety issue. Medium-term trials in Scotland have indicated that accumulation of these metals rarely exceeds limits set out in the Sludge (Use in Agriculture) Regulations (Cundill & Dobbie, 2008) and could be of particular benefit on copper-deficient soils (Sinclair & Withers, 1995). The low pH of the effluents combined with the high application rates needed to meet crop nutrient requirements can increase plant availability of other heavy metals in the receiving soil (EA, 2013).

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
| | **Meat/dairy: 1** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 2** |

Pathway scores reflect copper and zinc contents being generally lower than biosolids, and receiving environment tending to be copper-deficient soils. As the material is unlikely to contain pathogens, the risk to RTE crops was assessed to be lower than for biosolids.

Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PEPFAA code) may also control hazard addition rates, *although compliance has not been assumed here*.

**Uncertainty score: 1**

This practice is regulated and has been undertaken for many years in the UK.

**Knowledge gaps/emerging risks**

Current focus has been on metal contents (specifically copper in the UK, and a wider suite elsewhere with a number of studies undertaken in Africa, e.g. Bezuneh & Kebede 2015). Far less is known about organic contaminants, such as pesticide residues, that may be present in these effluents especially in developing country settings. Work undertaken on distillery effluents derived from sugar cane have identified that carry over of organochlorine pesticide residues may be an issue (e.g. Begum *et al.*, 2009).

## 9. Gypsum (from plasterboard) applied to agricultural land

**Comments**

Gypsum (calcium sulphate) from plasterboard can be applied to agricultural land as a sulphur fertiliser or to improve soil structure on damaged (sodic) soils.

The Publicly Available Specification PAS109:2013 (BSI, 2013) and Quality Protocol (EA, 2015c) no longer allows application as a soil treatment agent. The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated.

**Potentially hazardous agent score: 2**

The main hazards of concern are PTEs and impurities from paper and plastics. Possible risk from asbestos; may also contain physical hazards.

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
| | **Meat/dairy: 2** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 2** |

The main barrier to PTE exposure is soil chemistry; high pH will limit metal availability and uptake by crops. As the material is unlikely to contain pathogens, the risk to RTE crops was assessed to be lower than for biosolids.

There is a requirement to demonstrate that the resultant level of PTEs in the soil are below those in the Sludge Code of Practice. Applications must be in accordance with CoGAP, NVZ regulations and RB209 guidance.

**Uncertainty score: 1**

There is a robust evidence base which was gathered for the QP (WRAP/EA, 2011) that shows low levels of PTEs and other contaminants can be expected in plasterboard.

**Knowledge gaps/emerging risks**

| 10. Lime from sugar beet applied to agricultural land | |
|---|---|
| **Comments** | |
| Milk of lime is used as part of the sugar purification process (along with carbon dioxide) to precipitate calcium carbonate. This is filtered, washed and pressed to produce a co-product that is primarily recycled to land as well as being used in mushroom production amongst other (non-food production) uses. | |
| **Potentially hazardous agent score: 2** | |
| Due to the source (sugar beet), addition of lime and the processing methodology, pathogens will likely be absent or highly reduced in number (compared to background populations in agricultural soils), low concentrations of PTEs and POPs may well also be present, but only at background (soil) concentrations. | |
| **Exposure pathway scores:** | **Cereals for human consumption: 1**<br>**Meat/dairy: 2**<br>**Root crops (cooked): 2**<br>**RTE crops: 2** |
| Since there are no legislative controls over applications to land, the main barrier to PTE exposure is soil chemistry; high pH will limit metal availability and uptake by crops. As the material is unlikely to contain pathogens, the risk to RTE crops was assessed to be lower than for biosolids. | |
| **Uncertainty score: 1** | |
| Sugar beet lime producers have undertaken detailed assessments of the co-product for a range of possible hazards (including PTEs, POPs and pathogens).<br>Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PEPFAA code) may also control hazard addition rates, *although compliance has not been assumed here*. | |
| **Knowledge gaps/emerging risks** | |
| Given the source of the material (sugar beet grown in agricultural soil), it is possible, but unlikely, that nanoparticles and/or microplastics could be present. | |

## 11A. Livestock manure applied to agricultural land

**Comments**

Layer manure applied direct to land from housing was used as a 'highest plausible risk' example of livestock manure applied to agricultural land as it consists largely of undiluted excreta and may contain physical contaminants such as eggs, feathers etc. Other livestock manures e.g. cattle and pig slurry/FYM, broiler/turkey litter are likely to be diluted with bedding material and/or washdown water. Manures stored or treated before application will have undergone some degree of pathogen reduction.

**Potentially hazardous agent score: 4**

Known to contain PTEs, in particular pig manures contain Zn and Cu from feed supplements and veterinary medicines, although these are subject to regulation in the EU which will limit manure concentrations (Nicholson *et al*., 1999). Rollett *et al*. (2011) reported mainly European data which were below the upper limit values (for DEHP, PAHs, PCBs and PCDD/Fs) proposed in the 3rd Draft EU Sludge Directive (EU, 2000) and the Draft Biowaste Directive (EU, 2001); no references to PBDE, PFOS, triclosan or tributyl tin concentrations in livestock manures were found. Potential source of veterinary medicine residues, anti-microbial resistance (e.g. Faldynova *et al.*, 2013; Wichmann *et al*., 2014; Xu *et al*., 2015), nanoparticles (Swain *et al*., 2015; USDHHS, 2015; Alvarodo *et al*., 2015) and mycotoxins. Pig and poultry manures may contain physical contaminants from materials used as 'toys' to enrich cages/pens.

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 2** |
| | **Meat/dairy: 3** |
| | **Root crops (cooked): 3** |
| | **RTE crops: 4** |

There are no specific controls on hazard inputs from livestock manure application rates to land (and hence the amounts of hazards applied). Exposure pathway scores are higher than for biosolids due to the lack of regulatory controls. Applications may be controlled by the Code of Practice, RB209 recommendations and NVZ regulations. The Managing Manures for Farm Safety booklet (2009) gives guidance for reducing the risks of microbiological contamination of food crops.

**Uncertainty score: 1**

There is good evidence from a substantial body of research from the UK and overseas over many years on livestock manures applied to land covering nutrients, PTEs and pathogens, although there is less information on AMR transfer following landspreading of manures.

**Knowledge gaps/emerging risks**

Little data available on POPs in UK livestock manures but the review by Rollett *et al.* (2010) suggests that all reported concentrations are below suggested limit values in the 3rd Draft EU Sludge Directive. Additional data on POPs in selected UK manures can be found in Taylor *et al*. (2011). Reports of uptake of animal health products into root crops can be found in Boxall *et al*. (2006). More information is needed on organoarsenic (As) use in the EU and to what extent this accumulates in poultry manures (see Nachman *et al*, 2012). Some uncertainly associated with the use of veterinary pharmaceuticals because usage guidance may not always be followed. More information on AMR and nanoparticles in manures is needed.

## 11B. Livestock manure applied to agricultural land – non EU

**Comments**

In general it would be expected that manure use in some non-EU countries is less well regulated and controlled, with less information on their hazard contents. There may be different types of manures produced in some other countries which are not found in the UK (e.g. mink slurry).

**Potentially hazardous agent score: 4**

Hazard content likely to be higher than in the EU with less control over application rates.

Livestock feeds may contain more/different supplements and veterinary medicines use may be greater and less tightly regulated, increasing likely PTE and other contaminant concentrations in the manures. There may also be concerns over animal housing conditions and hygiene related issues which could increase manure pathogen contents.

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 2** |
| | **Meat/dairy: 3** |
| | **Root crops (cooked): 3** |
| | **RTE crops: 4** |

Exposure pathway scores are the same as those for manures in the UK/EU as it is assumed that there is also no regulatory control on manure use outside the EU.

**Uncertainty score: 3**

It is not known what regulations, if any, are in place governing manure applications in some non-EU countries from which we import food.

**Knowledge gaps/emerging risks**

More information is required on types of manures, hazard contents and regulations in non-EU countries from which we import food.

Note that the US FDA is conducting a risk assessment of foodborne illness associated with pathogens from produce grown in fields amended with untreated biological soil amendments of animal origin. (http://www.fda.gov/Food/FoodScienceResearch/RiskSafetyAssessment/ucm496835.htm )

## 12. Crop residues incorporated to agricultural land

**Comments**

Crop residues such as cereal/oilseed rape straw, maize stover etc. are often incorporated back into the soil as a means of maintaining soil nutrients, organic matter and physical condition. Maize is highest hazard.

**Potentially hazardous agent score: 2**

Concentrations of most hazards are likely to be very low. May contain pesticide/fungicide/herbicide residues. There is a possible risk that crop residues could harbour fungal spores which could increase the incidence or prevalence of fungal infection and therefore mycotoxin contamination in subsequent cereal crops.

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 2** |
| | **Meat/dairy: 1** |
| | **Root crops (cooked): 1** |
| | **RTE crops: 1** |

No regulatory controls on the incorporation of crop residues apart from those relating to the use of crop protection products. The score of 2 has been allocated to the 'cereals for human consumption' exposure pathway to reflect the risk of mycotoxin exposure.

**Uncertainty score: 1**

Use of crop protection products is well researched and regulated in the EU.

**Knowledge gaps/emerging risks**

Recent AHDB funded research on straw incorporation and removal (Nicholson *et al.*, 2014) discusses the implications of herbicide residues on the potential end uses of straw. For example, certain herbicides (e.g. HRAC group O Pyridine carboxylic acid family) specifically preclude some end uses for straw, for example as horticultural mulches, and/or prescribe the incorporation of straw in the following crop.

More information is required on mycotoxin contamination of following crops if straw and other crop residues are not removed.

| 13. Manures from fish farming applied to agricultural land – non EU |
|---|
| **Comments** |
| Livestock and poultry manure are good organic fertilizers for fish farming: 40–50 kg of organic manure will produce 1 kg of fresh fish and wastewater from ponds along with the silt may be used as pond fertilizers. Pond silt can be used as fertilizer for fodder crops, which in turn, can be used to raise live-stock and poultry or as fish feed. Large quantities of feed and manure are added to the fish ponds every year. This results in a considerable amount of residue settling on the bottom of the pond. Moreover, fish and aquatic animal excrement and bodies, and alluvial soil also settle on the bottom of the pond. The organic material decomposed by bacteria forms a great deal of humus, which combines with the sludge on the bottom of the pond to form silt. An appropriate amount of silt is beneficial to the pond as a fertilizer; however, an excessive amount of silt is detrimental to water quality. Surplus nitrites will induce haemorrhagic septicemia in fish. Silt contains a lot of ichthyopathogenic parasites and other harmful organisms. The thicker the silt, the more the pond water will deteriorate. Thus, excess silt is removed after the pond is drained and is often applied to agricultural land in countries outside of the EU; or indeed such material is then used to seed new ponds. |
| **Potentially hazardous agent score: 4** |
| The silt is likely to contain PTEs, and potentially POPs, veterinary medicines, dye products and other chemicals. The material is likely to also contain AMR bacteria (e.g. Guardabassi *et al.,* 1999), pathogens and possibly parasites. Sludges from salt water farms can contain sodium which may impact soil structure and crop health. |
| **Exposure pathway scores:** **Cereals for human consumption: 2**<br>**Meat/dairy: 3**<br>**Root crops (cooked): 3**<br>**RTE crops: 4** |
| Pathway scores are higher than the standard scores, due to the lack of regulatory controls relating to land application. |
| **Uncertainty score: 3** |
| This score reflects the level of uncertainty and the large number of unknowns associated with this practice. Some previous research on nutrient value e.g. the EU AQUATRAET (Improvement and Innovation of Aquaculture Effluent Treatment Technology) project, see Chadwick *et al*. (2006). |
| **Knowledge gaps/emerging risks** |
| There are many uncertainties in the nature of the silt from aquaculture ponds. There are extensive benefits of using such materials but also significant needs to understand more about the nature of the waste silts and it particular the potential for transfer of AMR. |

## 14. Meat and bone meal ash (MBMA) applied to agricultural land

Comments

There are 3 sites in the UK that burn meat and bone meal (MBM). It is produced by rendering category 1 and category 2 animal by products. Large quantities were produced at the height of the BSE crisis. Incineration is the effective way of destruction of TSE prions in Category 1 Animal By-products. The incineration process is regulated and to market the MBM ash as a high phosphate fertiliser each producer must gain individual end of waste (EoW) status by submission of evidence. Non EoW status MBM could be spread on land under an exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated.

Potentially hazardous agent score: 2

Known to contain POPs; Rigby *et al*. (2015) recently reported MBMA PCDD/F concentrations in the range 7.43 – 83.1 ng $WHO_{2005}$ TEQ/kg, compared with 2.42 ng $WHO_{2005}$ TEQ/kg for rural soils. EoW submissions demonstrate loadings to land in normal use as a fertiliser are at similar or lower levels to those in comparator conventional phosphate fertilisers. Once qualified as an EoW product there are no specific controls on use. Prions are destroyed by incineration. Combustion is always complete (it is not permitted to produce MBMA with insufficient incineration).

| | |
|---|---|
| Exposure pathway scores: | Cereals for human consumption: 1 |
| | Meat/dairy: 3 |
| | Root crops (cooked): 2 |
| | RTE crops: 2 |

As the material is unlikely to contain pathogens, the risk to RTE crops was assessed to be lower than for biosolids. Because PSA can contain relatively high levels of PCDD/Fs and other POPs formed by pyrolysis or combustion, which are efficiently bio-accumulated in milk, meat and eggs from soil ingested by grazing livestock or free-range hens, the meat/dairy exposure pathway has been scored higher than biosolids.

Application rates to land are limited by the Code of Practice, RB209 recommendations. Standard Rules deployments would have to show that there resultant soil concentration of PTEs and POPs would not be raised beyond regulated and recommended maxima (Defra Project SP1605: Studies to support soil policy).

Uncertainty score: 1

There is good evidence of control POPs and PTEs as required by the ABP Regulations.

Knowledge gaps/emerging risks

Little data available as there are only 3 producers in the UK. Each EoW approval will be different. Unknown incidence of non-EoW compliant material and its fate.

Outside the EU incineration may not meet the temperature time requirement; such material can be used as a fertiliser and would pose increased risk from both prions and PCDD/Fs.

## 15. Spent mushroom compost to agricultural land

**Comments**

Produced by mixing livestock manures and straw, followed by in vessel composting process with peak heating to destroy pathogens. Following production, spent mushroom compost is pasteurised "cook–out" to destroy pathogens and fungal disease organisms. The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated.). Immediate incorporation is usually proposed to meet emission requirements of the Environment Regulator.

**Potentially hazardous agent score: 2**

Mushroom compost is likely to contain similar levels of PTEs to composted manure, as this is the bulk input to the mushroom compost (Defra, 2010) typically waste (broiler chicken litter). The organic matter loss from composting concentrates the PTE in the remaining dry matter. Mushroom compost may contain traces of fungicides used to treat fungal competitors, although it is generally low in other organics. Pasteurisation at two stages in the process kills pathogens.

| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
|---|---|
| | **Meat/dairy: 2** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 3** |

Standard pathway scores have been applied (see explanatory notes).

Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PEPFAA code) may also control hazard addition rates, *although compliance has not been assumed here*.

**Uncertainty score: 1**

There have been numerous studies of the use of spent mushroom compost as an alternative to peat in horticulture.

**Knowledge gaps/emerging risks**

The level of direct application to land without pre-treatment in non EU countries is not known.

## 16. Plant-based food production residues applied to agricultural land – non UK

**Comments**

Many different plant-based food production residues may be applied to agricultural land, but are not commonly used in the UK. Some examples include olive oil processing wastes, bagasse (sugar cane stalk residues), vinasse (from sugar processing), winery wastes, tea/coffee/cocoa production wastes, fruit/fruit juice/vegetable processing wastes, tobacco dust. Many of these materials will undergo further processing (e.g. digestion, composting) prior to land application, although some are applied without pre-treatment in solid or liquid form. They generally contain nitrogen and other nutrients as well as organic matter which make them suitable for recycling to agricultural land.

A review of treatment methods, material properties, potential waste uses and the regulatory environment (in the EU and USA) for some of these materials can be found in Arvanitoyannis (2008).

**Potentially hazardous agent score: 3**

The hazard content of many of these materials is not known, but they are likely to contain herbicide, pesticide and fungicide residues, chemical residues from production processes and could also contain pathogens and physical contaminants such as plastics.

Olive oil wastes contain high concentrations of phenols (Arvanitoyannis, 2008) but PTE concentrations tend to be low (e.g. Roig *et al*., 2006; Chowdhury *et al*., 2013). Vinasse also has low PTE concentrations (Christofoletti *et al*., 2013). Any crop residues that are ashed or incompletely burnt, or are heated and dried using hot air contaminated with smoke, would be expected to contain PAHs and possibly also other combustion products such as PCDD/Fs and could lead to contamination of crops if used as mulch.

| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
|---|---|
| | **Meat/dairy: 2** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 3** |

Exposure pathways scores were assessed to be similar to biosolids, despite the potential lack of regulation outside the EU.

**Uncertainty score: 2**

More information is needed on hazard contents and the regulatory environment around use of these materials.

**Knowledge gaps/emerging risks**

Olive mill wastes are an important issue in Mediterranean countries so there has been extensive research published in the literature on their treatment, nutrient content and impacts on soils (e.g. Hansen, 2014). Some research has also been undertaken on the nutrient and soil conditioning properties of tobacco dust (Shakeel, 2014) but there is very little information on its potential hazard contents.

## 17. Paper crumble applied to agricultural land

**Comments**

Paper crumble is applied to agricultural land primarily for its liming properties and organic matter content. The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated.

**Potentially hazardous agent score: 2**

The PTE content depends on the treatment process with higher concentrations in secondary biologically treated materials; however, concentrations are lower than biosolids and similar to livestock manures (EA, 2005). Pathogens are unlikely to be present in primary and secondary physical/chemical treated material. EA (2005) suggests that POP concentrations are likely to be low; however unpublished data from a recent FSA funded study indicate that PCDD/F concentrations can be relatively high in the range 4.85 - 7.15 ng $WHO_{2005}$ TEQ/kg, compared with 2.42 ng $WHO_{2005}$ TEQ/kg for rural soils (Rigby *et al*., 2015) .

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
| | **Meat/dairy: 2** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 3** |

The Code of Practice for Landspreading of Paper Sludge applies (CPI, 2014). Applications must also comply with NVZ regulations.

Uptake of metals by crops will be limited by the high pH of the paper crumble.

**Uncertainty score: 2**

Reasonable level of information pertaining to this practice in the UK

**Knowledge gaps/emerging risks**

More up to date information needed on contaminant concentrations in different types of paper crumble as the current information is pre-2005 (EA, 2005); summary information from a recent project is given in EA (2015) but no analysis data is presented.

| 18. Paper sludge ash (PSA) applied to agricultural land |
|---|
| **Comments** |
| PSA is the residue from the incineration of paper sludge. The chemical composition of the sludge can vary, being influenced by the operations and processes at the particular paper mill. In most cases, paper sludge is co-combusted with other material such as wood, rejects and other sludges.<br>PSA is normally spread to land as a liming or soil treatment agent. It is typically spread at an application rate of 10 t/ha for arable land and 7.5 t/ha for grassland. An unpublished risk assessment by WRc for the Environment Agency estimated that no more than one application of PSA per year or 10 applications in 10 years should be made. |
| **Potentially hazardous agent score: 2** |
| Concentrations of cadmium, copper, chromium, titanium and zinc in PSA can be higher than background concentrations in soil in urban and rural areas. The presence of organic contaminants in PSA is generally regarded in the literature as negligible, but there is limited quantitative evidence to support this assumption. Rigby *et al*. (2015) recently reported a low PCDD/F concentration of 0.12 ng $WHO_{2005}$ TEQ/kg for a single PSA sample, compared with 2.42 ng $WHO_{2005}$ TEQ/kg for rural soils, although not all PSA batches from different sources would always contain low levels of these contaminants.<br>In terms of physical contaminants, residual metal may be present in PSA if paper sludge is co-burnt with other material, although plastic residues are unlikely to be present if the incineration conditions are correct. It is unlikely that PSA is a risk to receptors through plant and animal pathogens and/or invasive weeds (EA, 2015). |
| **Exposure pathway scores:** **Cereals for human consumption: 1**<br>**Meat/dairy: 3**<br>**Root crops (cooked): 2**<br>**RTE crops: 2** |
| PSA is unlikely to contain pathogens therefore the RTE exposure pathway scores are lower than for biosolids. Because PSA can contain relatively high levels of PCDD/Fs and other POPs formed by pyrolysis or combustion, which are efficiently bio-accumulated in milk, meat and eggs from soil ingested by grazing livestock or free-range hens, the meat/dairy exposure pathway has been scored higher than biosolids. |
| **Uncertainty score: 2** |
| Knowledge recently collated as part of the EA Rapid Evidence Assessment (EA, 2015) |
| **Knowledge gaps/emerging risks** |
| The REA has a number of limitations; primarily the lack of time to obtain information from UK producers of PSA, the reliance on the unpublished draft WRc report and the lack of further UK based quantitative data (EA, 2015) |

## 19. Poultry litter ash (PLA) applied to agricultural land

Comments

Poultry litter ash (PLA) is produced by power stations that burn broiler chicken litter. Lesser proportions of dry organic materials can be co-combusted. The ash can achieve end of waste (EoW) status by compliance with a quality protocol. It is them marketed as a phosphate and potash fertiliser product. Following changes to the EU Regulation 1069 (2000) litter can also be combusted in smaller incinerators for heat recovery. The incineration process is regulated.

Potentially hazardous agent score: 2

Known to contain PTEs (EA, 2015b) and POPs, but there are limit levels for PTEs specified in the QP (WRAP/EA, 2012). Rigby *et al*. (2015) recently reported PLA PCDD/F concentrations in the range 0.91 – 12.3 ng $WHO_{2005}$ TEQ/kg, compared with 0.12 $WHO_{2005}$ TEQ/kg for PSA and 2.42 ng $WHO_{2005}$ TEQ/kg for rural soils. However, the highest PCDD/F concentration in one of the two MBNA samples analysed by Rigby *et al.* (2015) was considerably higher than that for PLA although PLA still had higher concentration of PBDD/Fs than either of the MBNA samples.

Exposure pathway scores:

- Cereals for human consumption: 1
- Meat/dairy: 3
- Root crops (cooked): 2
- RTE crops: 2

PLA is unlikely to contain pathogens therefore the RTE exposure pathway scores are lower than for biosolids. Because PLA can contain relatively high levels of PCDD/Fs and other POPs formed by pyrolysis or combustion, which are efficiently bio-accumulated in milk, meat and eggs from soil ingested by grazing livestock or free-range hens, the meat/dairy exposure pathway has been scored higher than biosolids.

Limit levels in the EoW protocol result in loadings to land in normal use as a fertiliser at similar or lower levels to those where conventional fertilisers are used (WRAP, 2010). Once qualified as an EoW product there are no specific controls on the use, however application rates to land could be limited by NVZ regulations, the Code of Practice and RB209 recommendations.

Uncertainty score: 2

There is a reasonable amount of evidence through the EoW quality protocol of control POP and PTE.

Knowledge gaps/emerging risks

Farm based combustors may not apply for EoW and recycle on their own land; the extent of this practice is not known.

EA(2015b) concluded that “the two applications of PLA to agricultural soils presented no significant environmental or human health risks” but that “It would be beneficial to undertake a longer term study to assess whether potential substances of concern build up through long-term use”

## 20. Source separated human urine applied to agricultural land – non UK

**Comments**

Large scale application of separated human urine is not currently undertaken in the UK, however it is practiced in other EU countries e.g. Sweden, where guidelines for usage in crop production have been produced (Joensson *et al*., 2004) and in less developed countries where nutrients are scarce and applications are likely to be less strictly controlled.

As concentrations of nutrients in urine tend to be in excess of plant requirements, it is assumed urine is diluted roughly 10:1 with water or a solid bulking agent such as woodchip. To be representative of a worst-case scenario. It was assumed that no other pre-treatment of urine had been undertaken.

**Potentially hazardous agent score: 2**

Known to contain PhACs (Pharmaceutically Active Compounds) and recent research has indicated that 14 PhACs commonly found in urine may pose a risk with respect to either eco-toxicological or human-health endpoints. Potential source of AMR (Schaberg *et al.*, 1977) although there is very little data available.

**Exposure pathway scores:**

**Cereals for human consumption: 1**

**Meat/dairy: 2**

**Root crops (cooked): 2**

**RTE crops: 2**

Unlikely to contain pathogens therefore the RTE exposure pathway scores are lower than for biosolids.

Risks are very low if application rate of urine is in accordance with crop requirements. If application rate of urine are in excess of plant requirements then the risk would be increased.

**Uncertainty score: 2**

There is good recent evidence from a substantial body of research from Scandinavia and Africa on urine applied to land in terms of fertilizer potential. There is some work undertaken on PhACs (e.g. Khan & Nicell, 2010 ). There are no controls on PhAC inputs, but risks can be minimised through matching application rates to crop requirements.

**Knowledge gaps/emerging risks**

Hormones and pharmaceutical residues occur in urine (see Winker (2009) for concentrations). There is the possibility that if urine is reused in agriculture, these micro-pollutants would be taken up by plants and thereby enter the human food chain. This is a risk; however a full evaluation of the potential toxic effects of pharmaceuticals ingested by humans with crops is very difficult and has not yet been done. The risks need to be put in perspective compared to pharmaceutical residues contained in e.g. animal manure, or the risks resulting from pesticide use. In sewer-based sanitation systems, these micropollutants are discharged from sewage treatment plants into surface water bodies and can reach the groundwater in the long run. For example, detected concentrations of pharmaceutical residues in groundwater lay in the range of 50 ng/l in Germany (Heberer *et al*., 2000). Some research has been undertaken on the recovery of struvite from human urine (e.g. Gantenbein *et al*., 2009).

## 21. Composted pharmaceutical mycelium to agricultural land

**Comments**

Mycelium is an output of the pharmaceutical and animal health products industries. The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated. Immediate incorporation is usually proposed to meet odour and emission requirements of the Environment Regulator. It is not in the list of permitted substances for standard permits for composting, although initial proposals have been for demonstration trials under EA position statement

**Potentially hazardous agent score: 3**

Potential source of anti-microbial resistance and pharmaceutical residues..

**Exposure pathway scores:**

**Cereals for human consumption: 1**

**Meat/dairy: 2**

**Root crops (cooked): 2**

**RTE crops: 2**

Unlikely to contain pathogens therefore the RTE exposure pathway scores are lower than for biosolids.

Voluntary guidelines (e.g. Farm assurance schemes, RB209 recommendations, CoGAP and the PEPFAA code) may also control hazard addition rates, *although compliance has not been assumed here*.

**Uncertainty score: 3**

Little evidence in the public sector as confidentiality agreements are in place.

**Knowledge gaps/emerging risks**

There is potential for direct application to land without treatment in no EU countries

## 22. Tannery wastes applied to agricultural land

**Comments**

Conventional leather tanning activities are highly polluting and produce large amounts of organic and chemical pollutants. Wastes generated by the leather processing industries pose a major challenge to the environment. More than 600,000 tons per year of solid waste are generated worldwide by leather industry and approximately 40–50% of the hides are lost to shavings and trimmings. Wastes originate from all stages of leather making, such as fine leather particles, residues from various chemical discharges and reagents from different waste liquors comprising of large pieces of leather cuttings, trimmings and gross shavings, fleshing residues, solid hair debris and remnants of paper bags. Tanning refers to the process by which collagen fibres in a hide react with a chemical agent (tannin, alum or other chemicals). However, the term leather tanning also commonly refers to the entire leather-making process. Out of 1000 kg of raw hide, nearly 850 kg is generated as solid wastes in leather processing. Only 150 Kg of the raw material is converted in to leather. A typical tannery generates a large amount of waste in the form of fleshing (56-60%), chrome shaving, chrome splits and buffing dust (35-40%), skin trimming (5-7%) and hair (2-5%). During the tanning process at least 300 kg of chemicals (lime, salt etc.) are added per ton of hides. The material is applied to agricultural land by exemption from the Environmental Permitting Regulations (SI, 2010), and agricultural or ecological benefit must be demonstrated.

**Potentially hazardous agent score: 5**

The key material remaining after processing include waste hair and effluent treatment sludge, of which the total solids content is variable. High concentration of salts, Cr, As, ammonia, dye, solvent chemicals and traces of organic contaminants from tanning processes are often present. The treatments undertaken in the tannery will effectively disinfect the material with the main exception of anthrax, although this risk is quite small as anthrax in farm animals is very rare in the UK.

| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
|---|---|
| | **Meat/dairy: 2** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 3** |

Standard pathway scores have been applied (see explanatory notes) as applications are governed by ABP and Environmental Permitting Regulations.

Voluntary controls will also limit application rates e.g. CoGAP, RB209 recommendations, although *compliance has not been assumed here*.

**Uncertainty score: 2**

Little published information and data available.

**Knowledge gaps/emerging risks**

There is a need to better understand the risks associated with the potentially hazardous agents it may contain, in particular arsenic (As) and organic contaminants

## 23. Zeolite air filters applied to agricultural land – non UK

**Comments**

Zeolite is a natural mineral that has widespread application as an absorbent. It can be used a filter material in the removal of odours from industrial processes including intensive animal and poultry production. The ability of zeolite to retain ammonia from air ventilated from livestock buildings raises the possibility of its reuse in agriculture either by spreading the biofilter media directly to land, or by recovering an ammonium-rich solution by regenerating the media (Dumas, 2015).

Other materials (e.g. bark) also have the potential to be used a biofilters which could be recycled back to agricultural land.

**Potentially hazardous agent score: 2**

Filtration has the potential to concentrate the particle-borne and gaseous contaminants in the animal house atmosphere such as feather-debris, faecal pathogens, and ammoniacal nitrogen. If the spent zeolite were recycled to land then the faecal pathogens would be the relevant hazard of concern.

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
| | **Meat/dairy: 2** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 3** |

Exposure pathway scores assessed to be similar to biosolids.

To cause harm, faecal pathogens would have to survive for the period between application and harvest and any post-harvest processing / cooking. There are multiple barriers in place and exposure risk is assessed as low.

**Uncertainty score: 3**

This is not an established recycling route and as such there has been no research on the accumulation of pathogens in biofilter material or any other hazards for that matter. Whilst there is knowledge about pathogen survival in agricultural soils the lack of specific knowledge about this recycling route suggests an uncertainty score of 3.

**Knowledge gaps/emerging risks**

The concept of zeolite filtration has received some attention see for example Koelliker et al. (1980; Luo & Linset, 2006). The idea of reuse of this material has recently been proposed in the United States (Dumas, 2015). There is also evidence of a plant growth trial using this material (Kusa et al., 2002).

## 24. Feathers/feather meal applied to agricultural land

**Comments**

Feather meal is made by partially hydrolysing feathers under conditions of high temperature and pressure followed by drying and grinding. It can be used as a slow release fertiliser in organic farming because of its high nitrogen content (see Hadas & Kautsky, 1994). One such production facility is operated by the Leo Group in Penrith and the product is marketed as fertiliser or as animal protein pet food ingredient. Feather deployments to land occur in the UK (Paul Newell-Price, ADAS, pers. comm.).

**Potentially hazardous agent score: 3**

Any pathogens present will be removed by processing but PTEs and some POPs many remain. Potential source of antimicrobial resistance. Potential source of arsenic exposure in humans as a result of organoarsenic drugs used in the production of broilers in USA (Nachman *et al*, 2012); could also be a source of pharmaceutical residues and personal care products in the food chain(Love *et al*., 2012).

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 1** |
| | **Meat/dairy: 2** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 3** |

Standard pathway scores have been applied (see explanatory notes) as applications are governed by ABP and Environmental Permitting Regulations.

**Uncertainty score: 2**

Very little information available specific to this product but there is guidance on similar ABP derived fertilisers (AHPA & Defra, 2014) https://www.gov.uk/guidance/making-fertiliser-from-processed-animal-by-products-abps

**Knowledge gaps/emerging risks**

Whereas processing feathers to meal is regulated and established, a process to convert chicken feathers and carcasses to liquid organic fertiliser has been reported in SE Asia (http://www.philstar.com/agriculture/225537/chicken-feather-waste-fertilizer)

End of waste status and CE marking is likely to in future be determined under forthcoming revised EU Fertilisers Regulation (EU, 2016)

More information is required on how widespread usage is. May be more relevant for home-grown garden produce than commercial agriculture.

| 25. Food-based digestate (whole) applied to agricultural land | |
|---|---|
| **Comments** | |
| Food-based digestate is assumed to have been derived from source-segregated category 3 animal by-products and/or catering waste. Anaerobic digestion processes accepting these materials must include a pasteurisation stage. Whole digestate is the most common form which is applied to agricultural land with a very low dry matter (*c*.95% moisture). See scenario 26 for the higher dry matter fibre digestate. | |
| **Potentially hazardous agent score: 3** | |
| Known to contain PTEs (including Zn and Cd) and very low concentrations of POPs (WRAP, 2016b). May contain thermally tolerant pathogens that are able to survive pasteurisation, but most are controlled by pasteurisation. Most physical hazards should be removed by screening/treatment, but incidental levels are likely to be present. Potential source of AMR (Wolters *et al*., 2014) and nanoparticles (Edouk, 2015). | |
| **Exposure pathway scores:** | **Cereals for human consumption: 1**<br>**Meat/dairy: 2**<br>**Root crops (cooked): 2**<br>**RTE crops: 3** |
| Standard pathway scores have been applied (see explanatory notes)<br>Crop Assurance Schemes are highly likely to prevent the use of food-based digestate ahead of RTE crops. Voluntary controls will also limit application rates e.g. Good Practice Guidance (WRAP, 2016), CoGAP, RB209 recommendations, although *compliance has not been assumed here*. | |
| **Uncertainty score: 1** | |
| Good evidence from a substantial body of research from the UK (e.g. WRAP, 2016a – *in press*) covering PTEs, POPs and pathogens. There is some uncertainty around pathways for physical contaminants (specifically, their physical inclusion within specific root crops, and subsequent potential for harm). | |
| **Knowledge gaps/emerging risks** | |
| Research has been undertaken on *Clostridium botulinum* (ZWS, 2015), which found no increased risk, however, the results (particularly for botulinum toxin) are limited by the current analytical methodologies. Potential source of antimicrobial resistance and microplastics/nanoparticles, but thought unlikely; however, there is no data relating to food-based digestate.<br>The data on PCDD/Fs and PCBs concentrations is limited and no data for brominated analogues of PCDD/Fs and PCBs in anaerobic digestate produced from food waste was found. Vetter *et al* (2014), have demonstrated PBDD/Fs formation in salmon spiked with BDE-209 at normal cooking temperature, and cooking of salmon naturally contaminated with BDE 209 would therefore also be | |

expected to result in elevated PBDD/F contamination which could subsequently be present in food-based digestate.

## 26. Food-based digestate (fibre) applied to agricultural land

**Comments**

Fibre digestate (the solid fraction post separation) was taken as a 'worst case' example of food-based digestate applied to agricultural land. Food-based digestate is assumed to have been derived from source-segregated category 3 animal by-products and/or catering waste. Anaerobic digestion processes accepting these materials must include a pasteurisation stage.

**Potentially hazardous agent score: 3**

Known to contain PTEs (including Zn and Cd) and potentially POPs. Could contain thermally tolerant pathogens that are able to survive pasteurisation, but most are controlled by pasteurisation. Most physical hazards should be removed by screening/treatment. Due to the lower moisture content, most hazards (except those which are soluble) will be present at increased concentrations (when compared to whole digestate). Potential source of AMR (Wolters *et a*l., 2014) and nanoparticles (Edouk, 2015).

Adherence to BSI PAS110 is regarded as conferring a degree of confidence in the quality of digestates that differentiates them from those produced outwith the framework of an accredited system; *compliance with PAS110 has not been assumed here*.

**Exposure pathway scores:**

**Cereals for human consumption: 1**

**Meat/dairy: 2**

**Root crops (cooked): 2**

**RTE crops: 3**

Standard pathway scores have been applied (see explanatory notes)

Crop Assurance Schemes are likely to prevent the use of digestate ahead of RTE crops. Voluntary controls will also limit application rates e.g. Good Practice Guidance (WRAP, 2016), CoGAP, RB209 recommendations, although *compliance has not been assumed here*.

**Uncertainty score: 2**

There is limited data specifically on fibre digestate, however, given the only difference between whole and fibre digestate is dry solids content and the addition of polymer, it is highly likely that the work undertaken on whole digestate is applicable to fibre digestate (e.g. WRAP, 2016a *in press*). There is some uncertainty around pathways for physical contaminants (specifically, potential for their physical inclusion within specific root crops, and subsequent potential for harm)

**Knowledge gaps/emerging risks**

There is limited data on the fate of hazards post separation, although it is thought likely that all non-soluble hazards will be present in the fibre fraction and therefore at greater concentrations than in the whole digestate. Research has been undertaken on *Clostridium botulinum* (ZWS, 2015), which found no increased risk, however, the results (particularly for botulinum toxins) are limited by the current analytical methodologies. Potential source of AMR and microplastics/nanoparticles, but thought unlikely, however, there is no data relating to food-based digestate.

## 27. Crop-based digestate applied to agricultural land

**Comments**

The anaerobic digestion of 'purpose grown crops', crop residues and crop wastes typically produces a fibre and liquor fraction which are spread to land for their nutrient and organic matter benefit. Anaerobic digestion processes accepting these materials do not need to include a pasteurisation stage. Assuming only purpose grown crops and crop residues are used, the environmental regulators have decided that the waste regulations will not be applied. If crop processing wastes are used, the waste regulations will normally apply.

Livestock manures are sometimes also included in digestion systems processing crops/crop residues, however, these are not covered in this scenario as undigested manures are considered elsewhere (see Scenario 10). The digestion process would be expected to reduce pathogen hazards associated with manures, although such reductions are unpredictable, due to differences in digester design and feeding regime, which can mean that exposure to digestion conditions can vary from a few minutes to many days.

**Potentially hazardous agent score: 2**

Known to contain PTEs (including Cu and Cd), soil-borne pathogens and POPs will be present, but only at background (soil) levels.

| | |
|---|---|
| **Exposure pathway scores:** | **Cereals for human consumption: 2** |
| | **Meat/dairy: 1** |
| | **Root crops (cooked): 1** |
| | **RTE crops: 1** |

Standard pathway scores have been applied (see explanatory notes)

Voluntary controls will also limit application rates e.g. Good Practice Guidance (WRAP, 2016), CoGAP, RB209 recommendations, although *compliance has not been assumed here*.

**Uncertainty score: 2**

Limited data on crop-based digestate, however, given the source (crops which were destined for food production) the potential hazards are inherently limited to those present in soils/crops already.

**Knowledge gaps/emerging risks**

It is widely known that *Clostridium botulinum* is present in soils. There is no data demonstrating that *Clostridium botulinum* will multiply during anaerobic digestion, however the limited analytical methodologies may be a factor (particularly for botulinum toxins). Growing maize as a previous crop is highlighted as an increased risk for mycotoxins in following cereal crops. While there is no data on the fate of mycotoxins during digestion, they are known to bind strongly to clay minerals.

## 28. Non-source segregated compost/digestate applied to agricultural land

**Comments**

There are no data illustrating potential differences between the hazards present in non-source segregated compost (EWC code 19.05.99) or digestate (EWC code 19.06.04), as such they have been considered as a single material – i.e. the sanitised organic fraction from a mechanical-biological treatment process. These processes are covered by the Animal By-Products Regulations, and must include a pasteurisation stage (for AD) or sanitisation stage (for composting), to reduce pathogens.

*Note: the use of non-source segregated compost/digestate on agricultural land is not current practice in UK (although it is legally possible via a bespoke permit). It is widely practiced in other EU member states and other countries around the world.*

**Potentially hazardous agent score: 4**

Known to contain PTEs (including Cd and Pb), POPs and potentially nanoparticles (Stamou *et al*., 2015), microplastics and anti-microbial resistance. Rigby *et al*. (2015) recently reported PCDD/F concentrations in the range 11.2 – 18.2 ng $WHO_{2005}$ TEQ/kg, compared with 2.42 ng $WHO_{2005}$ TEQ/kg for rural soils; higher concentrations of PBDD/Fs (18 & 32 ng $WHO_{2005}$ TEQ/kg) were found in the two samples of MBT-CLO investigated. Some physical hazards are removed by screening/treatment, although microplastic contamination is likely. Radiological hazards are possible but unknown. Pathogens are controlled by the animal by-products regulations on sanitisation requirements. Potential source of AMR (Wolters *et al*., 2014; Riber *et al*., 2014) and nanoparticles (Edouk, 2015).

**Exposure pathway scores:**

**Cereals for human consumption: 1**

**Meat/dairy: 2**

**Root crops (cooked): 2**

**RTE crops: 3**

Standard pathway scores have been applied (see explanatory notes). Voluntary controls will also limit application rates e.g. Good Practice Guidance (WRAP, 2016), CoGAP, RB209 recommendations, although *compliance has not been assumed here*.

**Uncertainty score: 2**

There is good evidence from specific producers of non-source segregated compost/digestate, but only generic data for this category of materials (EA, 2009). Due to the non-source segregated nature, there is no limit on the type of hazards that maybe present. There is ongoing research (e.g. Rigby *et al*, 2015) into potential risks.

**Knowledge gaps/emerging risks**

Since this category of materials is derived from non-source-segregated inputs (i.e. mixed wastes that are mechanically separated prior to treatment of the recovered organic fraction), they can include a very wide range of hazards. These have been characterised in detail for a small number of MBT facilities, but variations between processes mean that these data are not readily transferable. The characterisation also relies upon hazards being known and detectable using available analytical techniques. Stamou (2015) undertook a life cycle assessment which indicated that nanoparticle additions to compost posed some increased risks to ecosystem and human health that were mainly attributed to the accumulation of silver in soils.

## 29. Source segregated green waste compost applied to agricultural land

**Comments**

Green compost is assumed to have been derived from source-segregated biodegradable waste. Green compost is the most common form which is applied to agricultural land and has fewest statutory controls over its production and use (when compared with other types of source-segregated compost, particularly green/food compost)..

**Potentially hazardous agent score: 2**

Hough *et al* (2012) identified a range of potentially hazardous agents present in green compost which included PTEs, PAHs, PCBs, PCCD/Fs, pathogens and physical contaminants. However, levels of these substances in green compost are generally low (Taylor *et al.*, 2011). Could contain thermally tolerant pathogens that are able to survive composting, but the majority of pathogens would be controlled. Most physical hazards should be removed by screening/treatment.

BSI PAS100 outlines requirements for input material selection, the composting process, the minimum quality of composted materials, and the storage, labelling and traceability of compost products. Adherence to PAS100 is regarded as conferring a degree of confidence in the quality of composts that differentiates them from composts produced outwith the framework of an accredited system; *compliance with PAS100 has not been assumed here*.

**Exposure pathway score:**

**Cereals for human consumption: 1**

**Meat/dairy: 2**

**Root crops (cooked): 2**

**RTE crops: 3**

Standard pathway scores have been applied (see explanatory notes)

Voluntary controls will also limit application rates e.g. Good Practice Guidance (WRAP, 2016), CoGAP, RB209 recommendations, although *compliance has not been assumed here*.

**Uncertainty score: 1**

There is good evidence from a substantial body of research from the UK (e.g. WRAP, 2016b – *in press*) covering PTEs, POPs and pathogens. A quantitative risk assessment has already been undertaken for source segregated green compost which meets the PAS100 specification and its use in livestock production; see Hough *et al.* (2012). Within the limitations of available information, SSGW compost was found to pose less risk to grazing livestock, or the environment, than other commonly-used soil amendments such as biosolids and farmyard manure.

**Knowledge gaps/emerging risks**

Research has been undertaken on pesticide residues (WRAP, 2010), but there are unknowns around the potential human health effects of certain products. Source of small plastic particles, however, there are no data on quantities or effects on human health.

## 30. Struvite from wastewater used as a fertiliser

**Comments**

Struvite was selected as an exemplar of a novel fertiliser derived from waste material

Struvite (magnesium ammonium phosphate) is a phosphate mineral that can form naturally in high P concentration wastes such as sludge liquors. Struvite precipitation can cause troublesome deposits which can foul pipes, pumps and screens requiring expensive remedial works. There has been interest in managing this natural precipitation process to recover P from sludge liquor by controlling pH and by the addition of magnesium salts to improve precipitation rates. Several processes have been developed to generate high quality P fertilisers from P-rich waste streams. During the precipitation process there is the potential for harmful chemicals in the sludge liquor to adsorb to the struvite minerals and even pathogens to become incorporated which could theoretically pose a health risk to consumers of foods fertilised with struvite products.

**Potentially hazardous agent score: 2**

There is evidence that antibiotics, metals, POPs and pathogens can be incorporated into struvite crystals at low concentrations. (Basakcilardan-Kabakci *et al*., 2007; Decrey *et a*l., 2011; Pratt *et al*., 2012; Le Corre *et al*, 2009; Ronteltap *et al*., 2007).

| | |
|---|---|
| **Exposure pathway score:** | **Cereals for human consumption: 1** |
| | **Meat/dairy: 2** |
| | **Root crops (cooked): 2** |
| | **RTE crops: 2** |

Struvite demonstrates quite low levels of solubility in the field and this is a reason why it may not be suitable in many agronomic applications. This low solubility also means, however, that any hazards incorporated at the crystal formation stage will also be released quite slowly thus reducing the concentrations of hazardous substance available to growing plants.

**Uncertainty score: 2**

There is a small database on hazards associated with struvite but those studies that have been conducted suggest a "watching brief" rather than the need for a high level of concern.

**Knowledge gaps/emerging risks**

Some research has been undertaken on the recovery of struvite from human urine (e.g. Gantenbein et al., 2009).

| 31. Paper crumble/pulp used as animal bedding |
|---|
| **Comments** |
| Paper crumble/pulp can be used as an alternative bedding material in the beef/dairy sector because of its high absorbency. There is no readily available information on how widespread this practice is but there are several UK suppliers. Proprietary granulated products are also available.<br>Not used to any extent in the pig and poultry sectors (J. Gittins & D. Moorhouse, ADAS, *pers. comm*.) |
| **Potentially hazardous agent score: 2** |
| The PTE content depends on the treatment process with higher concentrations in secondary biologically treated materials; however, concentrations are lower than biosolids and similar to livestock manures (EA, 2005). Rigby *et al* (2015) also reported low PTE concentrations in dried paper sludge used as animal bedding. Pathogens are unlikely to be present in primary and secondary physical/chemical treated material; however when wet, it can provide good conditions for pathogens to flourish. EA (2005) suggests that POP concentrations are likely to be low; however unpublished data from a recent FSA funded study indicate that PCDD/F concentrations are in the range 4.85 - 7.15 ng $WHO_{2005}$ TEQ/kg, compared with 0.12 ng $WHO_{2005}$ TEQ/kg for PSA and 2.42 ng $WHO_{2005}$ TEQ/kg for rural soils (Rigby *et al*., 2015). |
| **Exposure pathway scores: Meat/dairy: 2** |
| To enter the food chain, any hazards in paper crumble would need to be directly ingested (incidentally) or absorbed through the skin and then be transferred to milk or meat, which may be further pasteurised, cooked or processed presenting multiple barriers to intake for pathogens (pasteurisation and cooking will not be barriers to non-labile chemicals). |
| **Uncertainty score: 2** |
| No previous UK research on risks from paper crumble used as bedding material. |
| **Knowledge gaps/emerging risks** |
| Ongoing FSA research on transfer of POPs from bedding materials into milk. (FSA102009a;b)<br>More up to date information needed on contaminant concentrations in different types of paper crumble; current information is pre 2005 (EA, 2005). |

| 32. Paper sludge ash (PSA) and lime ash used as a dessicant in animal bedding |
|---|
| **Comments** |
| Paper sludge ash (PSA) and lime ash may be added to cattle bedding material for their dessicant properties.<br>Not used to any extent in the pig and poultry sectors (J. Gittins & D. Moorhouse, ADAS, *pers. comm*.) |
| **Potentially hazardous agent score: 2** |
| PSA contains PTEs; ashes may contain some POPs as a result of combustion processes. Unlikely to contain pathogens. Rigby *et al*. (2015) found low levels of PTEs |
| **Exposure pathway scores: Meat/dairy: 2** |
| To enter the food chain, any hazards would need to be directly ingested (incidentally) or absorbed through the skin and then be transferred to milk or meat, which may be further pasteurised, cooked or processed presenting multiple barriers to intake for pathogens (pasteurisation and cooking will not be barriers to non-labile chemicals)..<br>Diluted by other bedding therefore won't eat as much as paper crumble. |
| **Uncertainty score: 2** |
| No known previous research on risks from use of ashes in bedding material. |
| **Knowledge gaps/emerging risks** |
| Ongoing FSA research on transfer of POPs from bedding materials into milk and poultry. (FSA102009a;b) |

## 33. Recycled cardboard/shredded paper used as animal bedding

**Comments**

Recycled cardboard or shredded paper may be used as an alternative bedding material for various types of livestock. Shredded paper is not widely used on farms as it is not particularly absorbent.

These materials not widely used in the poultry industry (J. Gittins, ADAS, *pers. comm*.). Cardboard/ shredded paper is occasionally used in fully slatted raised farrowing pens to provide nesting material for farrowing sows and a drying medium for newly born piglets. Must follow good practice and a recommendations in Assurance Schemes, of which 92% of all pigs producers are members (D. Moorhouse, ADAS, *pers. Comm*.)

**Potentially hazardous agent score: 2**

No published information but likely to contain Zn from ink residues; may be POPs present and may contain microplastic residues from packaging. Unlikely to contain pathogens at the start, but bacterial counts can increase as the material becomes wet (QMS/SAC guidance). In practice, the hazard content will depend on how effective source segregation is and on the cleanliness of the cardboard with respect to chemical contamination.

**Exposure pathway scores:** **Meat/dairy: 2**

To enter the food chain, any hazards would need to be directly ingested (incidentally) or absorbed through the skin and then be transferred to milk or meat, which may be further pasteurised, cooked or processed presenting multiple barriers to intake for pathogens (pasteurisation and cooking will not be barriers to non-labile chemicals).

**Uncertainty score: 2**

No previous research on risks from recycled cardboard and shredded paper used as bedding material.

**Knowledge gaps/emerging risks**

Ongoing FSA research on transfer of POPs from bedding materials into milk and poultry. (FSA102009a;b)

More information is needed on microplastic content. If plastic, or microplastics, are present, it is possible, these could get broken down into much smaller plastic fragments in the gizzard. If the resulting nanoscale plastic fragments have adverse effects on the gut biology or function, including the gut microflora, I suppose it’s possible that this could affect the susceptibility of birds to microbiological contamination as well as uptake of chemical contaminants.

May be more widely used and with less regulatory control outside the UK especially in countries where bedding costs are high.

## 34A. Recycled manure solids (RMS) used as animal bedding

**Comments**

Recycled manure solids (RMS) obtained by mechanical separation of manure removed from dairy cow housing may be used as bedding. RMS has been used for many years in the EU and parts of the USA where it may be composted or digested prior to use, but in the UK usually no further processing occurs.

RMS is currently permitted for use as bedding in the UK for dairy cattle providing certain conditions are met and best practice is used. It is a legal requirement to complete the self-assessment form provided by Red Tractor. Not used in the pig and poultry sectors (J. Gittins & D. Moorhouse, ADAS, *pers. comm*.)

**Potentially hazardous agent score: 3**

Known to contain PTEs (in particular Zn and Cu from feed supplements) and pathogens; bacterial counts will increase once material gets wet (QMS/SAC). Potential source of anti-microbial resistance ((e.g. Faldynova *et al.*, 2013; Wichmann *et al*., 2014; Xu *et al*., 2015). POP and PTEs contents are not known but can be assumed to be similar to cattle FYM. Likely to contain vet meds and breakdown products. A potential source of nanoparticles from animal feeds(Swain *et al*., 2015; USDHHS, 2015).

**Exposure pathway scores:** **Meat/dairy: 2**

Possibility of pathogen transfer in dairy cows via direct contact with teats. Other potentially hazardous agents would need to be directly ingested (incidentally) or absorbed through the skin and then be transferred to milk or meat, which may be further pasteurised, cooked or processed presenting multiple barriers to intake for pathogens (pasteurisation and cooking will not be barriers to non-labile chemicals)..

**Uncertainty score: 2**

Little previous UK research available on risks from RMS; summary of peer reviewed literature given in Green *et al*. (2014). Position statement and advice published in 2015 (ACMSF, 2015; AHDB, 2015).

US research suggests RMS can be used without affecting herd health (Garcia &Diaz-Royon, 2015) or somatic cell counts in milk (Endres, 2013) but udder health may be compromised (Endres, 2013)

**Knowledge gaps/emerging risks**

Ongoing research by Dairy Co on levels of pathogens and AMR patterns in RMS

Ongoing FSA research on transfer of POPs from bedding materials into milk and poultry. (FSA102009a;b)

| 34B Recycled manure solids (RMS) used as animal bedding – non-EU |
|---|
| **Comments** |
| Recycled manure solids (RMS) obtained by mechanical separation of manure removed from dairy cow housing may be used as bedding. RMS has been used for many years in the EU and parts of the USA where it may be composted or digested prior to use. |
| **Potentially hazardous agent score: 3** |
| Known to contain PTEs (in particular Zn and Cu from feed supplements) and pathogens; bacterial counts will increase once material gets wet (QMS/SAC). Potential source of anti-microbial resistance (AMR). POP and PTEs contents are not known but can be assumed to be similar to cattle FYM. Likely to contain vet meds and breakdown products. |
| **Exposure pathway scores: Meat/dairy: 3** |
| Exposure assessed to be higher outside the EU due to lack of regulatory control |
| **Uncertainty score: 3** |
| High degree of uncertainty over usage and regulation outside the EU |
| **Knowledge gaps/emerging risks** |
| May be more widely used and with less regulatory control outside the UK especially where bedding costs are high. |

## 35. Recycled wood products used as animal bedding

**Comments**

Waste wood products (i.e. sawdust, wood shavings, woodchips, woodfines, wood bark) may be used as bedding providing they have been produced from untreated wood and are free from contaminants (see SAC/QMS guidance).

Sometimes used for pigs under straw to improve drainage (D. Moorhouse, ADAS, *pers. comm*.)

**Potentially hazardous agent score: 2**

It may be difficult to guarantee that wood fines (i.e. finely chopped clean timber, MDF, offcuts, pallets which have undergone cleaning using magnets) are 100% contaminant free. Indeed, research reported by Rigby *et al.* (2015) indicates that recycled wood can contain comparatively high levels of POPs including PCDD/Fs, PCBs, PBDD/Fs, PBDEs; this study reported PCDD/F concentrations in the range 1.33 – 26.3 ng WHO2005 TEQ/kg, compared with 2.42 ng WHO2005 TEQ/kg for rural soils.

Unscreened products may contain wire staples, nails, shards of wood and plastic fragments. Damp sawdust may increase pathogen counts compared with some other bedding materials due to its high moisture content.

**Exposure pathway scores:** **Meat/dairy: 2**

To enter the food chain, any hazards in recycled wood products would need to be directly ingested (incidentally consumed bedding) or absorbed through the skin and then be transferred to milk or meat, (pasteurisation and cooking will not be barriers to non-labile chemicals)..

**Uncertainty score: 2**

Little information available on the contaminant content of some of these products

**Knowledge gaps/emerging risks**

Ongoing FSA research on transfer of POPs from bedding materials into milk and poultry. (FSA102009a;b).

May be more widely used and with less regulatory control outside the UK especially where bedding costs are high.

| 36. Oat feed used as animal bedding |
|---|
| **Comments** |
| Likely to be sold under a brand name/s, oat feed is a co-product from the human porridge and oat milling industry and consists of finely milled oat husks; it has a good level of absorbency. |
| **Potentially hazardous agent score: 1** |
| Hazard content likely to be minimal since this is a waste from human food production; similar or lower hazard content to straw. Anecdotal evidence of reduced cell counts in dairy herds (FaneValley, 2014). |
| **Exposure pathway scores: Meat/dairy: 2** |
| To enter the food chain, any hazards in oat feed would need to be directly ingested (incidentally consumed bedding) or absorbed through the skin and then be transferred to milk or meat, which may be further pasteurised, cooked or processed presenting multiple barriers to intake for pathogens (pasteurisation and cooking will not be barriers to non-labile chemicals).. Animals could eat more of this than their usual bedding. |
| **Uncertainty score: 1** |
| Very little information available but no reasons to believe there might be any additional risks compared with using straw. |
| **Knowledge gaps/emerging risks** |
| Ongoing FSA research on transfer of POPs from bedding materials into milk and poultry. (FSA102009a;b), although this does not include the use of oat feed as a bedding material. |

## 37. Shredded tyres/crumb rubber used for animal bedding

**Comments**

Shredded recycled tyres may be used as an animal bedding material. Crumb rubber can also be used to manufacture mats for animals housed indoors. Tends to be more common for equestrian use, but can also be used for cattle.

**Potentially hazardous agent score: 3**

Natural and synthetic rubber used in tyres may contain additives such as Zn, S, black carbon nanoparticles and aromatic rubber process oils containing PAHs. To date, studies on the release of chemicals from crumb rubber have reported very low concentrations of chemicals. http://www.dec.ny.gov/chemical/46862.html The crumb may also contain Pb picked up from usage on roads (i.e. lead weights from balancing tyres, road paint etc.)

The global supply chain for virgin tyres makes understanding the environmental and health aspects of crumb rubber complicated. Tyres made in China, for example, may contain chemicals that are not allowed in North America or Europe, such as lead oxide or certain process oils. Another factor is age: older tires are more likely to contain phased-out chemicals than newer ones (Vallette, 2013).

**Exposure pathway scores:** **Meat/dairy: 2**

Animals are unlikely to deliberate eat the material but may accidentally ingest small particles. Absorption of PAHs through the skin is possible.

**Uncertainty score: 3**

There appears to be some debate as to the levels of contaminants present in crumb rubber and its safety for various end uses (see for example Vallette, 2013). No information found on the safety implications of usage as animal bedding.

**Knowledge gaps/emerging risks**

There has been recent media coverage of health risks associated with rubber crumb used on artificial sports pitches. There have been a number of studies in the US .assessing the risks from artificial turf usage (e.g. Sullivan, 2006; Lim & Walker, 2009).

There is a need to know how used bedding is disposed of

| 38. Gypsum (from plasterboard) used as animal bedding – non UK |
|---|
| **Comments** |
| Gypsum (calcium sulphate) from plasterboard could be added to animal bedding as dessicant. This practice is no longer permitted in the UK (EA/SEPA, 2012) but may be still be permitted elsewhere in the EU and overseas. |
| **Potentially hazardous agent score: 2** |
| The main concern would be PTEs (See Source item 9) |
| **Exposure pathway scores:** **Meat/dairy: 2** |
| To enter the food chain, any hazards it would need to be directly ingested (incidentally consumed bedding) or absorbed through the skin and then be transferred to milk or meat. |
| **Uncertainty score: 2** |
| Little information available |
| **Knowledge gaps/emerging risks** |
| More information is needed on how widespread this practice is outside the UK. |

## 39. Dried chicken manure used in livestock feed (non-EU only)

**Comments**

Recycled animal waste, such as processed chicken manure and litter, has been used as a feed ingredient for almost 40 years. This animal waste contains large amounts of protein, fibre, and minerals, and has been deliberately mixed into animal feed for these nutrients. Generally, animal waste is used within the States where it is produced because the bulk and weight of the product makes interstate shipment uneconomical. Normally, this animal waste is used by small farmers and owners of beef and dairy herds as a winter supplement for mother cows and weaned calves. Poultry manure has potential use as a livestock feed due to its high protein, fibre and mineral content, combined with the low cost.

EU Animal By-product Regulations prevent its use in the UK and EU but may be used in other countries where livestock feed is scarce and/or expensive e.g. south-east Asia

**Potentially hazardous agent score: 4**

Could potentially contain drugs suspected or known to be used in the feed or as a therapeutic treatment of source animals; pesticides used on the source animal, facility, and wastes for pest control; pathogenic organisms including *C. botulinum*; PTEs (including arsenic, cadmium, copper, lead, mercury, and selenium; parasitic larva or ova; mycotoxins, such as aflatoxin. The pathogen content will be reduced by processing but may still be present. May potentially contain physical contaminants e.g. microplastics (see Source Item 10 Livestock manures). Potential source of AMR although it has been suggested that laying hens are a less important reservoir of antibiotic resistant bacteria than cattle and pigs (Faldynova *et al.*, 2013) A potential source of nanoparticles in animal feeds(Swain *et al.*, 2015; USDHHS, 2015)

**Exposure pathway scores: Meat/dairy/fish: 3**

Risk of transfer of one or more potentially hazardous agents from feed to milk, meat or fish, which may be further pasteurised, cooked or processed presenting some barriers to intake.

**Uncertainty score: 2**

Some older research information has been published which was summarised by Muller (1980)

**Knowledge gaps/emerging risks**

More information needed on how widespread this practice is outside the EU where regulations may be less stringent.

Banned in Australia under the Ruminant Feed Ban and Poultry Litter Ban (Beltz, 2008). Permitted in (at least parts of) the USA for beef cattle since 2005 (Daniel & Olson, 2005) although some guidelines apply (e.g. not to be fed within 21 days of slaughter). Could be more widely used for fish farming in Malayasia/Thailand (see Mukherjee *et al.*, 1992 for information on various forms of integrated livestock-fish production systems)

## 40. Fish meal/oil used in livestock feed

**Comments**

The use of fish byproducts for feeding animals is not a new. In the UK the term fish meal means a product obtained by drying and grinding or otherwise treating fish or fish waste to which no other matter has been added. The term white fish meal is reserved for a product containing not more than 6% oil and not more than 4% salt, obtained from white fish or white fish waste such as filleting offal. Virtually any fish or shellfish in the sea can be used to make fish meal. The nutritional value of proteins from vertebrate fish differs little from one species to another; whole shellfish would however give a nutritionally poorer meal because of the low protein content of the shell. Most of the world's fish meal is made from whole fish; the pelagic species are used most for this purpose. Countries with major industrial fisheries are Peru, Norway and South Africa. Some countries like the UK make fish meal from unsold fish and from offal i.e. the heads, skeletons and trimmings left over when the edible portions are cut off. Other countries like Denmark and Iceland use both industrial fish and processing waste. Fish meal made mainly from filleting offal usually has a slightly lower protein content and a higher mineral content than meal made from whole fish, but a high proportion of small whole fish in the raw material can have the same effect.

Fish meal can be defined as a solid product obtained by removing most of the water and some or all of the oil from fish or fish waste. Fish meal is generally sold as a powder, and is used mostly in compound foods for poultry, pigs and farmed fish; it is far too valuable to be used as a fertilizer.

The only animal proteins permitted in feed as per EU regulations are: fishmeal/ fish oils/ non-ruminant gelatine/ di-calcium phosphate and hydrolysed protein/ milk and milk products/ egg and egg products

**Potentially hazardous agent score: 2**

May contain microbiological hazards but these will be reduced by processing. Possible source of antimicrobial resistance. EU regulations set limits on hazard concentrations in livestock feeds including heavy metals such as As, Pb, Hg and Cd, dioxin, aflatoxin, certain pesticides etc.

**Exposure pathway scores: Meat/dairy: 3**

Contaminants may be transferred from feed to milk or meat, which may be further pasteurised, cooked or processed presenting some barriers to intake.

**Uncertainty score: 1**

Regulations governing permitted concentrations of contaminants in livestock feeds reduce the uncertainty. Covered in the UK under a comprehensive legal framework including EC Directive 2002/32 on undesirable substances in animal feeds; feed assurance schemes such as FEMAS, UFAS and TASCC also place conditions on use.

**Knowledge gaps/emerging risks**

## 41. Feather meal/feathers used in livestock feed – non EU

**Comments**

Feather meal is made by partially hydrolysing feathers under conditions of high temperature and pressure followed by drying and grinding. Utilised in feeds for its relatively high protein content.

EU Animal By-product Regulations prevent its use in the UK and EU but may be used in other countries where livestock feed is scarce and/or expensive e.g. south-east Asia and the USA.

Also crushed/ground feathers – not treated, Banned in Eu

**Potentially hazardous agent score: 3**

Antimicrobials used in poultry production have the potential to bioaccumulate in poultry feathers but available data are scarce. Following poultry slaughter, feathers are converted by rendering into feather meal and sold as fertilizer and animal feed, thereby providing a potential pathway for re-entry of drugs into the human food supply chain. Any pathogens present will be removed by processing but PTEs and some POPs may remain. Potential source of antimicrobial resistance. Potential source of arsenic exposure in humans as a result of organoarsenic drugs used in the production of broilers in USA (Nachman *et al*, 2012); could also be a source of pharmaceutical residues and personal care products in the food chain (Love *et al*., 2012).

**Exposure pathway scores: Meat/dairy/fish: 3**

Contaminants may be transferred from feed to milk or meat, which may be further pasteurised, cooked or processed presenting some barriers to intake.

**Uncertainty score: 2**

Some information on the energy content and nutrient analysis of feather meal from the US (see Chandler, undated; Sulabo *et al*, 2013). Few data located on the hazard content or transfer into food products.

**Knowledge gaps/emerging risks**

More information needed on how widespread this practice is outside the EU where regulations may be less stringent. Feathers have in the past been an ingredient in fish feeds (FAO, 1980). Love et al (2012) found antimicrobial residues in feather meal. More studies are needed to better understand potential risks posed to consumers by drug residues in feather meal.

| 42. Sugar beet residues used as animal feed |
| --- |
| **Comments** |
| After extraction of sugar from sugar beet, the pulp is pressed and dried to produce an animal feed high in energy and fibre. |
| **Potentially hazardous agent score: 2** |
| No known hazards of concern. Culture medium for bacteria?? Agrochemical residue ? Mycotoxin ?<br>EU regulations set limits on hazard concentrations in livestock feeds including heavy metals such as As, Pb, Hg and Cd, dioxin, aflatoxin, certain pesticides etc. |
| **Exposure pathway scores: Meat/dairy: 3** |
| Contaminants may be transferred from feed to milk or meat, which may be further pasteurised, cooked or processed presenting some barriers to intake. |
| **Uncertainty score: 1** |
| Produced in the UK and EU in accordance with feed quality assurance standards |
| **Knowledge gaps/emerging risks** |
| |

## 43. Shellfishery wastes as fish feed

**Comments**

Shellfish shells must be processed before application to land, by removal of the soft tissue and flesh from the shell. The shell should be crushed and washed and ideally any biological material degraded (Seafish, 2010). It is not possible to completely remove soft tissue and flesh from crustaceans, such as crabs, but shells from crustaceans can be spread on land without processing, if they have been cooked in a government approved fishery products processing plant, soft tissue and flesh have been removed to leave no more than 40% volatile solids, the shells have been crushed (but not reduced to powder), if the shells are stored before application to land, and farmed animals do not have access to them. No farmed animal can access the land where the shells are applied for 21 days after application (pigs can't access the land for 60 days); and the land where the shells are applied is ploughed immediately after application or some other method is used to mix the shells into the soil immediately after application. There is little consideration, however, of the use of shellfish wastes especially emanating from crustaceans in entering feed stocks for animals.

**Potentially hazardous agent score: 2**

There is the opportunity for pathogens and PTEs to enter the feed or food. Typically seafood pathogens are not transmitted directly to humans, may be opportunity for parasites and chemicals resulting from toxic algae.

**Exposure pathway scores: Fish: 3**

Potential pathways to humans to occur if food is contaminated through ingestion of such wastes in feed.

**Uncertainty score: 2**

There is uncertainty around the likelihood of this pathway and the significance of scale of any processing/ production. It is inevitable that crustacean waste shells find their way into the production of fish feeds.

**Knowledge gaps/emerging risks**

Significant gaps in knowledge exist.

## 44. Sawdust as bulking agents in animal feeds

**Comments**

As ruminants are able to utilise cellulose through enzymatic solubilisation, studies have been carried out to establish whether wood products could be used in addition to grass and other feeds. In India, for example, a suitable solid state fermentation process has been developed to enhance the biological composition and nutrition value of sawdust using *Pleurotus sajor-caju* (Lal & Panda, 1995). Cellulose made from sawdust can possibly be used as feed if it is carefully derived and finely ground. Wood flour is a fine wood meal obtained from so called fat trees (softwoods and "smooth" hardwoods which contain a fatty oil; this can be added to normal feed, as it is partially digestible. (http://www.wood-report.de/seiten/sawdust.html). There is guidance from the US on emergency feeding of sawdust to dairy cattle (Adams, 1997). Similar guidance from Australia (Blackwood, 2006) provides rules for use and specifies that sawdust from treated timbers must not be used as it could contain Cu, Cd or As. A recent paper from the EU SAFEWASTES project reported that feeding larch sawdust to dairy cattle could improve liver health (Tedesco *et al*., 2015)

**Potentially hazardous agent score: 2**

Hazard profile similar to waste wood animal bedding? If used in the EU, the materials would have to comply with EU feeding stuff regulations which set limits on hazard concentrations in livestock feeds including heavy metals such as As, Pb, Hg and Cd, dioxin, aflatoxin, certain pesticides etc.

**Exposure pathway scores:** **Meat/dairy: 3**

**Uncertainty score: 2**

Very little information available and uncertainty over how widespread is the use.

**Knowledge gaps/emerging risks**

More information required on the quality of sawdust feed ingredients that could be used outside the EU

| 45A. Former foods used in animal feeds |
| --- |
| **Comments** |
| Only former foodstuffs which are not catering waste (as defined by Defra under EU regulations*) and fall into one of the following categories may be fed: bakery products, pasta, chocolate, sweets and similar products such as breakfast cereals; dairy products; pasteurised, cooked or processed eggs.<br>*Catering waste is defined as 'all waste food including used cooking oil originating in restaurants, catering facilities and kitchens, including central kitchens and household kitchens' |
| **Potentially hazardous agent score: 2** |
| As these materials are former foods the hazard content will necessarily be very low. There is a small chance that there will be some traces of former packaging material. UK have introduced a de facto tolerance of 0.15% but the EU are developing legislation on tolerance levels. Former foods are covered in the UK under a comprehensive legal framework including EC Directive 2002/32 on undesirable substances in animal feeds; feed assurance schemes such as FEMAS, UFAS and TASCC also place conditions on the use of former foodstuffs.<br>It was assumed for the purposes of this assessment that these materials are stored in a dry environment so that fungal spores and mycotoxins are not produced, and that they are protected from infestations of vermin which could contaminate the materials with pathogens. |
| **Exposure pathway scores: Meat/dairy: 3** |
| Packaging residues *per se* unlikely to be transferred to food products, although there is some risk that chemicals leaching from former packaging materials could be consumed by livestock. |
| **Uncertainty score: 1** |
| Well controlled and regulated within the EU. UKFFPA founded in 2013. |
| **Knowledge gaps/emerging risks** |
| |

| 45B. Former foods used in animal feeds (non-EU) |
| --- |
| **Comments** |
| Outside the EU, there is potentially much less stringent regulation in place for the use of former foodstuffs as livestock feeds. |
| **Potentially hazardous agent score: 3** |
| Lack of regulation could mean that the spectrum of potentially hazardous agents present in former feeds is greater than in the EU. Hazards could include pathogens, and higher proportions of former packaging materials and the chemicals associated with them.<br>For the purposes of this assessment, it was assumed that outside the EU these materials may not be stored in a dry environment so that fungal spores and mycotoxins could be produced, and that they may not be protected from infestations of vermin which could contaminate the materials with pathogens. |
| **Exposure pathway scores: Meat/dairy: 3** |
| Packaging residues *per se* unlikely to be transferred to food products, although there is some risk that chemicals leaching from former packaging materials could be consumed by livestock. |
| **Uncertainty score: 3** |
| High level of uncertainty over the controls and regulations in place outside the EU |
| **Knowledge gaps/emerging risks** |
| |

## 46. Insect protein in animal feeds – non EU

**Comments**

There is huge potential for using insect protein as a source of animal feed for pigs, poultry and fish in the EU. The deliberate feeding of insect protein to farmed animals intended for food is not currently permitted under EU law, however there is a growing desire to reduce reliance on imports of protein feeds from non-EU countries. Insects are an innovative source of feed and a potential viable option for farmers to consider for inclusion in livestock diets. They are also a natural component of the diet of poultry, pigs and fish. It is likely that the EU may use the novel food regulations for the market authorization of such products. This particular scenario considers the growing of insects on waste products for their use in animal feeds, specifically considering the use of insects as being fed directly to farmed fish.

**Potentially hazardous agent score: 3**

There is a potential hazard from the transference of PTEs, POPs and pathogens; AMR may also be an issue.

**Exposure pathway scores:** **Fish: 3**

The insects are likely to be fed directly to the fish from the waste on which they are feeding; insects are unlikely to be treated or purged prior to feeding. Possibility of PTE and POP bioconcentration in the fish

**Uncertainty score: 3**

The pathway scores reflect the lack of knowledge associated with this potential food stuff. There is a need to evaluate insects as a novel source of protein for animal feed and to ensure that methodologies are safe at all scales and for all producers both in developed and developing countries. It is required to determine the safety and quality criteria for insect protein products and their analysis for contaminants, taints and changes in nutritional profile.

**Knowledge gaps/emerging risks**

There is little published data about the risks of using insects as a direct feed or a feed ingredient and how these can be managed, so there is a need for caution. Different feedstocks and insect combinations may result in different risks. A recent overview on the use of insects as a potential new ingredient for poultry feed has been published by ADAS (Ramsden, 2016).

## 47. Alcohol produced from food waste

**Comments**

Brewing from bread is not new and beer may originally been a by-product of bread-making 10,000 years ago. About 500 kg of bread gives 4,000 litres of 7% beer. Food waste may contain spores from both fungi and bacteria. Furthermore breads may go mouldy and the chemicals in those moulds could then be present in the product. There are well-documented cases of botulism poisoning in prisons from drinking “pruno” made for fermenting unpeeled potatoes from the kitchen.

**Potentially hazardous agent score: 2**

The potential hazards are culturing of anaerobic microbiological agents, e.g. Clostridrial spores and also retention of soluble toxins from the moulds. Bread *per se* is unlikely to have many clostridial spores, but moulds could be present. Any waste food with soil (e.g. RTE crops, potato peelings) or poultry carcases could contain *Clostridrium botulinum* spores which could be cultured in the wort. Rice and other foods could contain *Bacillus cereus* spores.

**Exposure pathway scores: Alcoholic beverages for human consumption: 2**

Boiling of the wort is the major microbial barrier, killing all vegetative bacteria, most viruses and fungi. However, spores of *B. cereus* and *C. botulinum* will survive. Kim *et al*. (2014) have challenged the common belief that pathogens cannot survive in fermented alcoholic beverages (FABs) with only a 1.5 log reduction in *E. coli* O157 in 28 days in beer (5C) and *B. cereus* spore counts remaining constant. The key barrier to *C. botulinum* is not to store the wort for long periods. Thus post-boil wort has a pH of 5.0-5.2 in which *C. botulinum* can grow, but pH drops to 4.0-4.4 during fermentation, inhibiting growth.

**Uncertainty score: 2**

Although only limited information is available on microbiological safety of FABs, information on wort processing/storage is well understood.

**Knowledge gaps/emerging risks**

Commercially available microbrewed beer contains high numbers of micro-organisms including coliforms, spores and fungi, and unexpectedly the count is not affected by alcohol content. *B. cereus* was detected in 55% of microbrewed beer samples and 2% of pasteurised beer (Jeon *et al*., 2015). It is not clear what risks these present to consumers.

| 48 Horticultural substrates produced from wastes |
|---|
| **Comments** |
| The impetus to transform waste from food, agricultural, construction, water and indeed horticultural industries into viable commercial products has increased markedly in the last three decades. Pressures to reduce peat as a growing medium in some European countries has led to uptake of renewable resources such as bark, coir and green compost: all formerly regarded as wastes. Indeed some materials, notably coir are now recognised as highly valued substrate constituents and production contributes significantly to the local economy in parts of India and Sri Lanka. .<br>The ISHS recently held a Symposium on Transformation of Organic Waste to Horticultural Resource (http://www.ishs.org/ishs-book/1112). Various waste products have been explored as potential feedstocks for composting processes including waste wood, kitchen wastes, market place waste and biochar. |
| **Potentially hazardous agent score: 2** |
| Could expect a similar hazard profile to green compost, but will depend on the feedstock and mixture/blend. Because horticulture demands quality and consistency of product (at least in developed nations) growing media are likely to be subject to strict quality control and testing. |
| **Exposure pathway scores: RTE crops: 2** |
| Potential for the substrate to contaminate the crop; the extent will depend on the type of crop, the proximity to the substrate and crop cultivation/management methods. |
| **Uncertainty score: 2** |
| Little information available. |
| **Knowledge gaps/emerging risks** |
| |

| 49. Wastewater from fishponds used in aquaponics – non-EU |
|---|
| **Comments** |
| Aquaponics is the combined culture of fish and plants in essentially closed recirculating systems. Nutrients generated by the fish, either by direct excretion or microbial breakdown of organic wastes, are absorbed by plants cultured hydroponically. Fish provide most of the nutrients required for plant nutrition. As the aquaculture effluent flows through the hydroponic component of the recirculating system, fish waste metabolites are removed by nitrification and direct uptake by plants, thereby treating the water, which flows back to the fish rearing component for reuse. Aquaponics, which began in ancient China and Mexico, is gaining popularity around the world as a means of local food production ranging in scale from small-scale backyard aquaponics operations to commercial-scale aquaponics farms. It is possible for hobbyists to start out with aquaponics kits available online and at hydroponics supply stores. |
| **Potentially hazardous agent score: 4** |
| Likely to contain PTEs and veterinary medicines used to treat fish. Significant possibility of pathogens being present. There is also the opportunity for the potential development of AMR in such closed systems. Levels of odorous compounds (GEOSIM) can also cause an off-flavour earthy taint in the food produced which is unpleasant for consumers. |
| **Exposure pathway scores: RTE crops: 4** |
| Few barriers to prevent transfer of potentially hazardous agents to RTE crops. PTEs and veterinary medicines residues could bioconcentrate within the cropping system. |
| **Uncertainty score: 3** |
| There are few regulations and very limited documented evidence so the uncertainty remains high. |
| **Knowledge gaps/emerging risks** |
| Aquaponics is a growing industry and is yet to be regulated – *Tilapia* is often cultured under recirculated conditions or in ponds and waste waters ae often applied to agricultural areas or used for crop irrigation which although not strictly aquaponics raises the same concerns. The use of aquaponics outside of the EU also raises uncertainties. |

## 50. Untreated municipal wastewater used for irrigation - non EU

**Comments**

Municipal wastewater and industrial effluents represent a potentially valuable source of water and nutrients for agricultural reuse. If reuse occurs with inadequate controls on wastewater treatment and irrigation water quality standards there is a risk of exposure to hazards through the food chain. Whilst regulation is strict in the EU, in countries where environmental regulation and enforcement is lax there is a more significant risk of exposure, especially in the RTE sector.

**Potentially hazardous agent score: 5**

Untreated municipal wastewater is a non-source segregated waste stream with no effective control over what goes down the drain. It may contain faecal pathogens, parasites, oestrogenic compounds, antibiotics, heavy metals and POPs. However, many agricultural areas are rural and underdeveloped so crop protection produce residues and chemical pollutant content m ay be low.

| | | |
|---|---|---|
| **Exposure pathway scores:** | **Cereals:** | **3** |
| | **Meat/dairy:** | **3** |
| | **Root crops:** | **4** |
| | **RTE crops:** | **4** |

The greatest risks are associated with the direct reuse of untreated wastewater or situations in which untreated wastewater contaminated surface is used in urban/peri-urban agriculture with little dilution from rain-fed run-off. Where such sources are used for the irrigation of fresh produce there are very substantive risks of exposure due to potentially short durations between application and harvest, direct contact between the irrigation water and the edible parts of the crop, and the potential for ineffective processing barriers to prevent exposure (in the case of RTE). This is a particular concern for microbiological risks. However, for chemical contamination, root crops might be vulnerable to uptake through their prolonged exposure to the soil (more so than cereals) especially in situations where repeated application / no control over application rates has led to hazardous chemical accumulation in the soil. Wu *et a*l (2015) conclude that “Studies to date have provided clear evidence to suggest that PPCPs can transfer from soil to plants when treated wastewater or biosolids are used in agriculture”. For example Malchi *et al* (2014) demonstrated how non-ionic pharmaceutical compounds accumulated to concentrations of toxicological concern in carrots irrigated with treated wastewater and grown in lysimeters. Recently Azanu *et al.* (2016) have shown that the antibiotics tetracycline and amoxicillin can be taken up into lettuce (an RTE crop) from irrigated water, leading to concerns over AMR.

Untreated irrigation water can be used to irrigate pasture and fodder crops used to produce meat or dairy products that are exported to the UK. It is not clear how common this practice is, however Zia *et al*. (2016) reported PTE concentration in fodder crops (and vegetables) grown in Pakistan that had been irrigated with untreated wastewater.

**Uncertainty score: 2**

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|---|
| Some knowledge in the literature on the hazards present, but weak regulatory controls. |
| **Knowledge gaps/emerging risks** |
| There is a substantive database available on urban irrigation practices in developing countries and on the quality of irrigation water used for urban vegetable production (Drechsel & Keraita, 2014). This tends to focus on small-holder agriculture in the peri-urban zone producing food for local markets. Irrigated plantation agriculture is a traditional form of tropical agriculture that has supplied the developed world with crops such as tea, coffee and cocoa which due to their processing requirements pose a low risk due to the combination of the plantations often being remote from urban areas and the complex processing steps which help to mitigate some risks. The growth in the irrigated fresh produce export market in developing countries does however pose a plausibly heightened risk due to high levels of urban wastewater polluting surface waters used for irrigation, low water quality regulation and enforcement, short durations between application, harvest, and transit to market, and the consumption of foods uncooked in some cases. Standing in-between high risk sources and exposure of consumers are the in-company QA and contaminant verification processes which can be thorough. Whilst regular water quality monitoring of surface water sources used for irrigation is relatively rare in the developing world, there are detailed surveys that have been done as part of specific catchment studies e.g. Berge & Medba (2005). |

## 51. Tertiary treated effluent for irrigation – non-EU

**Comments**

Fresh water scarcity worldwide has led to increased use of reclaimed wastewater as an alternative source for crop irrigation. But the presence of pharmaceutical compounds (PCs) in treated effluents has raised concerns over the potential exposure for consumers.

**Potentially hazardous agent score: 3**

Pharmaceuticals and metabolites (e.g. carbamazepine, caffeine, and lamotrigine, metoprolol, bezafibrate, clofibric acid, diclofenac, gemfibrozil, ibuprofen, ketoprofen, naproxen, sulfamethoxazole, and sildenafil). Although the materials is tertiary treated, it may not be completely pathogen free

| | | |
|---|---|---|
| **Exposure pathway scores:** | **Cereals:** | **3** |
| | **Root crops:** | **4** |
| | **RTE crops:** | **4** |

Meat/milk pathway not scored as grass for grazing and animal fodder crops are not likely to be irrigated. Exposure pathways scores are higher than standard scores due to lack of regulation.

**Uncertainty score: 2**

Some ongoing research on pharmaceutical compound uptake into various food crops. Lack of information on regulatory controls and guidelines

**Knowledge gaps/emerging risks**

Recent studies have evaluated uptake of pharmaceutical compounds by vegetables irrigated with treated wastewater (Goldstein *et al*., 2014; Malachi *et al*., 2014) and have shown that individuals consuming reclaimed waste water irrigated produce excreted carbamazepine and its metabolites in their urine (Paltiel *et al*., 2016).

## 52A. Recycled cardboard in direct contact food packaging -

**Comments**

Regulation (EC) 1935/2004 sets the benchmark for all packaging materials in food contact applications. It is commonly known by the supply chain as the "Framework" Regulation. Article 3 of the Regulation requires that: "Materials and articles… shall be manufactured in compliance with good manufacturing practice so that, under normal or foreseeable conditions of use, they do not transfer their constituents to food in quantities which could:

- endanger human health, or•
- bring about an unacceptable change in the composition of the food, or•
- bring about a deterioration in its organoleptic characteristics".•

There is pan-European legislation specific to certain materials (e.g. plastics) but – while some national provisions exist – there is currently no specific legislation at EU level for paper and board in food contact applications. The European Paper and Board Industry has therefore decided to publish its own Industry Guideline for the Compliance of Paper & Board Materials and Articles for Food Contact and have developed Good Manufacturing Practice guidance (www.paper.org.uk/current_issues/food_contact.html). Guidance from FoodDrinkEurope on safe use of recycled paper and board for food contact use has recently been updated (FDE, 2016).

**Potentially hazardous agent score: 2**

Only cardboard from specified sources can be used to manufacture food contact packaging hence the hazard score will be low. Industry Guidelines specify maximum permitted concentrations for Cd, Pb, Mg, antimicrobial substances, Michler's ketone, DEAB, Azo colourants, dyes and colourants, fluorescent whitening agents, PAHs, DBP and DEHP (CEPI, 2012). A potential source of mineral oil hydrocarbons (EFSA, 2013).

Direct ingestion of harmful contaminants is unlikely due to the comprehensive set of legislation and controls for the manufacture of food packaging products outlined above..

**Exposure pathway scores:** **Food contact with RTE crops: 2**

The barrier to exposure will be the rate of migration into foods which will depend on storage time and conditions.

Migration of mineral oils into foods from packaging has been demonstrated (Biedermann *et al*., 2011)

**Uncertainty score: 1**

Within the UK, recycled card/paper has been used for many years to make food contact materials. The risks are well understood and controlled.

**Knowledge gaps/emerging risks**

| 52B. Recycled cardboard in direct contact food packaging – non EU |
|---|
| **Comments** |
| Outside the EU, the manufacture of food contact packaging is likely to be differently, and possibly less strictly, regulated than in the UK/EU. |
| **Potentially hazardous agent score: 2** |
| Due to less stringent regulation of the materials used to manufacture the card, the hazard content is likely to be higher than within the EU. Potential contaminants include Cd, Pb, Mg, antimicrobial substances, Michler's ketone, DEAB, Azo colourants, dyes and colourants, fluorescent whitening agents, PAHs, DBP and DEHP (CEPI, 2012). A potential source of mineral oil hydrocarbons (EFSA, 2013). |
| **Exposure pathway scores:** **Food contact with RTE crops: 2** |
| Migration of mineral oils into foods from packaging has been demonstrated (Biedermann *et al*., 2011).<br>Risk likely to be higher than for UK/EU due to lack of regulation. However supermarkets will assess all their food supply chains and will require information on where and how all packaging materials are produced. |
| **Uncertainty score: 3** |
| Very little information available on regulation and controls outside the EU. However supermarkets will assess all their food supply chains and will require information on where and how all packaging materials are produced. |
| **Knowledge gaps/emerging risks** |
| |

| 53. Recycled plastic in food contact packaging – non EU |
|---|
| **Comments** |
| Within the EU, Regulation (EC) No. 1935/2004 sets out the law on chemical migration from all materials and articles in contact with food. It includes provisions for materials and articles expected to come into contact with foods or to transfer their constituents to food (such as printing inks and adhesive labels).. These general laws are supplemented by specific laws governing particular materials, such recycled plastic materials (Regulation EC 282/2008). EFSA have assessed the safety of a range of plastic recycling processes and continue to issue and update their guidance documents (http://www.efsa.europa.eu/en/topics/topic/plasticrecycling ).<br><br>The US and Canada also have strict food contact material legislation as described in the Code of Federal Legislation (CFR): 21 CFR 174 - 21 CFR 190 (USA) and Division 23 of the Food and Drugs Act and Regulations, Section B.23.0001 (Canada). In other countries, the manufacture of food contact packaging is likely to be differently, and possibly less strictly, regulated and may permit plastic recycling processes that are not approved in the EU. |
| **Potentially hazardous agent score: 2** |
| Due to the permeable nature of plastics, the possibility that chemical contaminants resulting from post-consumer misuse or abuse remain in the recycled materials and migrate into food is one of the major concerns regarding the safety of recycled plastics used in food packaging applications. Because the processing of recycled plastic materials involves high temperatures and the use of sanitizers and cleaning agents which would effectively eliminate any level of microbial organisms in the material, exposure to microbial contaminants should not be of concern.<br><br>Substances of potential concern include formaldehyde, endocrine disrupting chemicals (e.g. bisphenol A, tributyltin, triclosan and phthalates - DEHP); several hundred other chemicals have also been measured in plastic food packaging although it is not clear whether these are at concentrations sufficient to cause concern (see Muncke *et al*., 2013). |
| **Exposure pathway scores:** **Food contact with RTE crops: 2** |
| Exposure will depend on the rate of migration from the packaging material into the food which will be controlled by various factors including the nature of the chemical, the type of food, the length of time in the packaging, temperature and environmental conditions etc. |
| **Uncertainty score: 3** |
| More information required on plastic recycling processes and regulations in non-EU countries. Whilst larger supermarkets will assess all their food supply chains and will require information on where and how all packaging materials are produced, smaller organisations are unlikely to have the same level of oversight. |
| **Knowledge gaps/emerging risks** |
| Research on chemicals in food packaging continues to be published and 'scare stories' are often reported in the press. |

| 54. Biopolymers in food contact packaging - | FN |
|---|---|

**Comments**

Biopolymers (also called renewable polymers) are produced from biomass for use in the packaging industry. Biomass comes from crops such as sugar beet, potatoes or wheat: when used to produce biopolymers, these are classified as non-food crops. Waste biomass residues from forestry or agriculture can also be used to make biopolymers (e.g. Ballina-Casarrubia *et al*., 2016; Valdes *et al*., 2014); tannery/leather wastes have also been suggested (Zainescu *et al*., 2013).

Many types of packaging can be made from biopolymers e.g. food trays, blown starch pellets for shipping fragile goods, thin films for wrapping.

**Potentially hazardous agent score: 2**

Hazard content likely to be low in the crop-based source materials but potentially could contain pesticide/herbicide residues and mycotoxins; tannery wastes could contain Cr. Processing will eliminate pathogens, although it is possible that some chemicals (or their breakdown products) used during manufacture may be present in the resulting biopolymer and could subsequently leach into food, particularly from drink packaging

Biopolymers used for food packaging will have to comply with Regulation (EC) No. 1935/2004

**Exposure pathway scores:** **Food contact with RTE crops: 2**

Exposure will depend on the rate of migration from the biopolymer into the food which will be controlled by various factors including the nature of the hazard, the type of food, the length of time in the packaging, temperature and environmental conditions etc.

**Uncertainty score: 3**

As this is a relatively new technology there is little information on biopolymers produced from waste used in food packaging.

**Knowledge gaps/emerging risks**

This is a developing area of concern. There is a need to keep a watching brief on which wastes are being used to produce biopolymers and to assess any risks as and when appropriate.

## 5 Supporting literature


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