Detailed hierarchy of approaches categorised within waste pyramid

Deliverable D6.3

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Glossary

Animal by-product

Products, parts or entire bodies of an animal which are not *intended* for human consumption, (although may or may not be considered as edible for either cultural reasons or otherwise). This includes catering waste, used cooking oil, former foodstuffs, butcher and slaughterhouse waste, blood, feathers, wool, hides and skins, fallen stock, pet animals, zoo and circus animals, hunt trophies, manure, ova, embryos and semen not intended for breeding purposes. These are categorised into one of 3 groups with different requirements based on risk (see appendix).

Bio-waste

Is defined by the EU Waste Framework Directive (WFD 2008/98/EC)[1] to mean biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and *comparable waste from food processing plants* (emphasis added);

BREF Notes

Best Available Technique Reference Notes – compiled for industry sectors following the EU Integrated Pollution Prevention and Control Directive requirements.

By-product

(EU general definition 2008/98)[2]

A *substance or object* is not classified as a waste and instead is a by-product if *(i) further use of the substance or object is certain; (ii) the substance or object can be used directly without any further processing other than normal industrial practice*; (iii) the substance or object is produced as an integral part of a production process; and & (iv) further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.*

normal industrial practice is described in guidance DG Environment (2012) as *all steps which a producer would take for a product, such as the material being filtered, washed, or dried; or adding materials necessary for further use; or carrying out quality control. Some of such processing tasks can be carried out on the production site of the manufacturer, some on the site of the next user, and some by intermediaries, as long as they also meet the criterion of being 'produced as an integral part of a production process'. However, treatments usually considered as a recovery operation cannot, in principle, be considered as normal industrial practice in this sense*

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/218586/l_31220081122en00030030.pdf A proposal to amend the 2008/98 Directive is imminent at the time of writing.
[2] Article 5, EU Waste Framework Directive (2008/98). http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&qid=1491206776227&from=EN

Co-product	Any of two or more products coming from the same unit process or product system.
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.
PAS 100:2011	UK publicly available specification for compost quality in the UK for use as a soil conditioner and growing medium.
PAS 110:2014	UK publicly available specification for the quality of anaerobic digestate for use as a fertiliser.
Process	Set of interrelated or interacting activities that transform inputs into outputs.
Product system	Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.
Production residue	See 'side flow'
Products	Any saleable goods or services.
Recovery process or operation	A waste treatment process where the principal result of is 'waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy (defined in DG 2012 interpreting Article 3(15) of the WFD)
Side flow* **(*REFRESH terminology)**	A material flow of food and inedible parts of food from the food supply chain of the driving product, including wasted driving product, and also final disposal of edible and inedible parts of unconsumed food product after use, e.g. plate leftovers. The stakeholder in the food supply chain producing this flow tries to have as little as possible of it (*per unit of utilised driving product)*. "The less, the better" applies for this flow.
Specified Risk Material (SRM)	Specified Risk Materials are tissues from slaughtered cattle, sheep, goats and related animals over certain ages. Specifically, SRM includes skulls; brain matter; spinal cords; and certain parts of the eviscera, from countries with controlled risk or unknown risk of transmittable spongiform encephalopathy (TSE). It may not necessarily include products containing or derived from those tissues under certain conditions. See table 3 (appended).

Waste Hierarchy	Priority order of waste management strategies, placing prevention at the top, followed by preparing for re-use, recycling, recovery, and as the last option, disposal (EU Waste Framework Directive 2008/98).

List of abbreviations

ABP	Animal by-product
BAT	Best Available Technique
BREF	Best Available Technique Reference (‘*BREF note*’)
CHP	Combined heat & power
FFS	Former foodstuffs
IPPC	Integrated Pollution Prevention and Control (EU Directive 2008/1)
MBM	Meat and bonemeal
PAS	Publicly Available Specification (British Standards)
TRL	Technology readiness level
TSE	Transmittable spongiform encephalopathy
SRM	Specified Risk Material from animal slaughtering
WFD	EU Waste Framework Directive 2008/98
WID	Waste Incineration Directive

1 Executive Summary

1.1 Aims and objectives

The specific aim of this report is to provide a baseline understanding of the current management approaches identified in previous research undertaken by REFRESH[3] with respect to the policy concept of a Waste Hierarchy

The report objective is to categorise management approaches that have been identified for 20 selected food production residues.

The categorisation relates each management approach to preferential tiers of waste management outlined in the EU waste policy's 'Waste Hierarchy'. These tiers are intended to promote measures to encourage waste prevention and resource efficiency over waste recovery and disposal.

1.2 Key results

Seventy-six possible management approaches have been identified from the twenty food production residues selected by previous REFRESH research. However, several of the twenty residues are in fact broader groupings of by-products from different animal sources, so the number of residues considered has been increased to thirty.

Two thirds of the management approaches fall under the Waste Hierarchy category of waste prevention by re-use. This is influenced by many of the food production residues being classed as by-products, and not wastes, when applying EU Directive definitions. This status is defined in EU waste policy typically where further use for food production residues is certain and where additional processing of those residues is considered *normal industry practice*.

However, there is some uncertainty in ascribing this 'non-waste', by-product status to many of the food residues. For example, by-products used as animal feed may be subject to market context which can vary seasonally and yearly. Animal by-products that are rendered into materials could be considered normal industry practice, but this could also be categorised as a waste recovery process.

Few (6 in total) of the approaches identified for management of food chain residues were categorised as the least preferred tier of the Waste Hierarchy: recovery (other). This typically means conversion of food waste residues into energy or fuels.

Partly this is because anaerobic digestion, the most common valorisation approach identified with energy recovery, has been promoted to the preferred tier of recycling, above composting, following lifecycle evidence (DEFRA, 2011b).

[3] http://eu-refresh.org/top-20-food-waste-streams

Due to lack of data sources the extent to which the management approaches identified reflect those most commonly applied, in terms of volumes of food and drink side flows managed across EU Member States, is not known.

The previous REFRESH research has been limited by examples found in literature sources. These sources do not quantify the extent that these management approaches are applied across Europe. National and supranational institutions do not sufficiently capture this detail. For example, Eurostat data only reports the volume of 'bio-waste' that is treated by 'recovery other than energy' which does not distinguish between either waste composted *or* anaerobically digested or indeed whether the bio-waste is green waste or food waste.

Only industry specific surveys would be able to provide this kind of evidence, and these would need to be large enough to anonymise specific companies' commercial sensitivities. To the authors' knowledge the only public survey of this kind is sanctioned through legislation (EU IPPC Directive 2008/1/EC) promoting industry *Best Available Techniques* (BAT). These are compiled in BAT reference notes (also called BREF notes) for both the food, drink and milk and animal livestock slaughtering industry sectors.

Animal feed and anaerobic digestion pathways are currently listed as generic BAT for food, drink and milk industry waste streams with no other specific waste valorisation routes identified. The management approaches taken for livestock and slaughtering are determined heavily by legislative restrictions on meat hygiene and using certain animal by-products in the food and feed chains. The BAT for these are currently in the process of being re-surveyed by technical working groups from the European IPPC Bureau.

1.3 Next steps

With respect to the findings of this report the next steps will be an investigation in more detail of a subset of valorisation opportunities that relate to the approaches identified. This is followed by generic models of valorisation process steps for high level lifecycle assessment and lifecycle cost comparisons.

2 Introduction

2.1 REFRESH

REFRESH is an EU Horizon 2020 funded research project taking action against food waste which runs for 4 years until June 2019. Twenty-six partners from 12 European countries and China are working towards the project's aim to contribute towards Sustainable Development Goal 12.3:

- Halving per capita food waste at the retail and consumer level.
- Reducing food losses along production and supply chains.
- Reducing waste management costs.
- Maximizing the value from un-avoidable food waste and packaging materials.

2.2 Aims and objectives

WP6 – Valorisation of waste streams and co-products

This report forms part of Work Package 6 entitled "Valorisation of waste streams and co-products". The overarching aim of Work Package 6 is to increase sustainable exploitation of food & packaging waste by helping businesses and policy makers by providing knowledge and tools where appropriate.

The specific aim of this report is to provide a baseline understanding of the current management approaches identified by Deliverable 6.9 *Top 20 food waste streams appropriate for valorisation* (Moates et al 2016), with respect to the policy concept of a Waste Hierarchy.

These aims will be met by through the following objectives:

- Reconciling identified management approaches (D6.9) to key food chain side flows (defined in 2.3) with respect to their place in the Waste Hierarchy.
- Identifying, where applicable, any uncertainties and restrictions on valorisation (indirect impacts of diversion from current uses, or safety and quality standards).
- Highlighting, for further investigation, potential for other approaches where key side flows may be valorised appropriately[4].

[4] Appropriateness will be further defined in later work packages regarding technical, economic and legal feasibility, but importantly, whether evidence indicates that a change from current approach to other valorisation approaches is likely to be environmentally beneficial;

2.3 Scope

The scope of Work Package 6 is to focus on valorising food chain co-products, by-products and waste materials which are considered to be side flows. A side flow has been defined by Davis et al (2017) as *a material flow of food and inedible parts of food from the food supply chain of the driving product, including wasted driving product*. However, Davis et al (2017) have further defined valorisation through categorisation in two specific 'REFRESH situations':

RS2 valorisation of side flow that cannot easily be prevented through improvements in efficiency or planning and;

RS3 valorisation of a waste side flow.

Thus, following these, valorisation for the purposes of the REFRESH scope of the work package deliverables excludes treatment of any wasted driving product where it can *readily* be prevented through efficiency (emphasis added). The threshold or objective criteria determining ease of prevention has yet to be defined.

Therefore, the scope of this report concerns only side flows from across the food chain which are non-preventable.

3 Methodology: Categorisation of valorisation approaches

3.1 Introduction

The aim of this report is to identify and collate valorisation approaches used for the current exploitation of 20 key unavoidable food chain co-products, by-products and waste streams and categorise these within a Waste Hierarchy.

This report starts with a section on how the literature review has been conducted, followed by the valorisation approaches identified. Then, the EU Waste Hierarchy is introduced.

The identified valorisation approaches are reconciled with the Waste Hierarchy for analysis and interpretation, and finally conclusions are summarised.

3.2 Literature review

3.2.1 Selecting key co-products, by-products and wastes

Examples of actual uses of selected key food chain co-products, by-products and wastes for were sought from literature sources. These have been further selected as part of a previous Deliverable 6.1 (Sweet et al 2016) using a simple scoring system based on expert judgement of the following:

1. Available volumes;
2. Existing valorisation routes;
3. Whether waste is unavoidable;
4. Policy restrictions;
5. Seasonality;
6. Susceptibility to rapid spoilage and;
7. Geographical dispersion.

3.2.2 Identifying current management approaches

Valorisation can occur at any point in the production chain or product life cycle. This includes the consumer stage which itself does not produce a marketable output but still can theoretically produce material output. Current common management approaches were identified by incidences published in reports, books, research project literature and web sources.

Published commercial literature and web sources were screened to identify where specific waste streams are already being used for valorisation processes. Commercial data sources were used in preference to more academic research literature to ensure that approaches include only those valorisation options that

have moved beyond academic laboratory scale investigations i.e. those with a technology readiness level (TRL) of 9, which is proven at a commercial scale[5].

The details of this process are further described in a previous deliverable report - *D6.1 Valorisation appropriate waste streams* (Sweet et al 2016).

3.3 The Waste Hierarchy

3.3.1 Introduction

The Waste Hierarchy concept has been introduced as part of European waste policy. Within the EU Member States, Article 4 of the revised EU Waste Framework Directive (2008/98/EC) sets out five tiers for dealing with waste in priority order.

Prevention is the most preferred option, followed by re-use, then recycling and other forms of recovery, with disposal such as landfill as the last resort. The Directive lays down a framework of waste management principles and seeks to keep material at the highest possible tier in the hierarchy, redefining waste as a potential resource rather than as an unwanted burden.

Typically, five tiers can be defined from the Waste Hierarchy with regard to food waste:

1. **Waste prevention at source** - Optimising planning to reduce surplus food waste and improving processing/operational efficiencies.

2. **Waste prevention through reuse** – Redistributing or finding alternative uses within the food or feed chain, prevents waste. This includes products not intended for human consumption.

3. **Recycling** - Reprocessing food waste into valued raw materials or new products.

4. **Recovery** – Principally to extract energy from food waste and related residues.

5. **Disposal** - End of life treatment of waste with limited recovery.

3.3.2 Defining waste

The WFD[6] defines waste as 'any substance or object which the holder discards or intends or is required to discard'. In practice, typical evidence for discarding involves depositing material into waste bins or transference to a waste contractor. However, this is not definitive, and for a number of cases and in a very wide range of circumstances, the DG Environment note there remains uncertainty as to what discarding means (European Commission 2012). Therefore, guidance

[5] http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf
[6] Article 3(1) Directive 2008/98/EC

on end-of-waste criteria and by-product definitions have been published by the Commission to further define waste and non-wastes.

With little additional processing and given a certainty of use some food and drink production residues can hold a *non-waste* by-product status (this is defined in greater detail in Section 4.2.1). This can of course change depending on market supply and demand. This may be observed in relation to animal feed commodities for which demand may vary seasonally and annually.

3.3.3 Waste prevention through efficiency

Waste prevention is the highest priority outlined by the Waste Hierarchy. The Waste Framework Directive defines waste prevention as taking measures before a substance, material or product has become waste, which will reduce the quantity of waste[7].

In this case, waste prevention can be met through efficient processing preventing unnecessary side flows or planning to prevent unmanageable surpluses leading to waste.

The scope of work package 6 is to focus on valorising side flows that cannot easily be prevented through improvements in efficiency or planning. This first case, being avoidable therefore, is not relevant to the scope of valorisation approaches.

3.3.4 Waste prevention by re-use

The Waste Hierarchy's criteria for *prevention of a material becoming waste encourages re-use*. This interpretation is reflected in guidance issued by the EU's DG Environment.

The Waste Framework Directive also defines materials as by-products, not waste, if it's certain they replace existing materials or provide value to the market place, where this is lawful to do so and without any direct processing beyond normal industrial practice. Typical examples would be rendered fats, spent brewers or distillers grain used directly as an animal feed. This reflects tier 2 of the Waste Hierarchy (Section 3.3.1).

3.3.5 Recovery - recycling

The Waste Hierarchy indicates that recycling - a form of waste recovery – is reprocessing that upgrades wastes to other useful materials. Food *waste* valorisation processes that do not produce energy or fuels align broadly with the Waste Hierarchy concept of recycling.

The Waste Framework Directive is clear in categorising recovery of a waste specifically for energy and fuel production, as the least preferred valorisation option

[7] Article 4: Directive 2008/98/EC http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&qid=1491206776227&from=EN

of 'other recovery'. This would include heat and electricity from anaerobic digestion (AD) biogas and upgrading to bio-methane as a fuel/energy carrier.

However, the UK guidance on implementing the Waste Hierarchy[8] indicates anaerobic digestion of waste is environmentally better than composting and other recovery options. Therefore, AD plants utilising food waste have been placed into the same Waste Hierarchy level as recycling rather than the less preferred category of other (energy) recovery. This case for categorisation is strengthened where value is obtained from digestate as a fertiliser product. There are indications of a market for this product where quality criteria can be met[9].

For the purposes of this deliverable food waste valorisation approaches shall be categorised as recycling. This is also in line with the food and drink material hierarchy (Section 3.3.9)

3.3.6 Other recovery – energy from waste

Having promoted anaerobic digestion to the level of recycling in the food Waste Hierarchy – 'other recovery' leaves only conversion of wastes to energy or fuels – principally through incineration with energy recovery or liquid biofuel production, though less common recovery techniques of pyrolysis and gasification technologies are also mentioned in Annex 2 of the WFD.

3.3.7 Other recovery – land spreading

Where land spreading can principally be used to benefit agriculture or ecological value this can be classed as a recovery process under the Waste Hierarchy. Whereas treatment on land (biodegradation of liquid or sludgy discards in soils), presumably with little agricultural or ecological benefit, is defined as a disposal operation and of the least preferred option.

3.3.8 Disposal - landfill

Depositing waste into landfill or onto land as the principle reason of treatment or disposal is considered very much a last resort in waste management policy within Europe. Landfill and land treatment (with limited agricultural or ecological benefits) are listed as disposal operations (D1, D2) in Annex 1 of the EU Waste Framework Directive.

Methane emissions from landfill can be managed with energy recovery although unlike other technologies such as anaerobic digestion, landfill sites are not designed principally for energy recovery from wastes.

This is qualified by the WFD where '*disposal means any operation which is not recovery even where the operation has as a secondary consequence* [such as] *the reclamation of substances or energy.* This would exclude energy from landfill gas as a form of recovery.

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[8] DEFRA 2011 Guidance on applying the Waste Hierarchy
[9] This is evidenced in the UK by organisations certificating biofertilisers from AD plant digestate and the publication of quality standards PAS110 for digestate products (BSI, 2014).

3.3.9 The food and drink material hierarchy

Whilst the Waste Hierarchy has been defined by the Waste Framework Directive, there may be exceptions and inconsistencies with direct translation to practices (Van Ewijk et al 2016, Gharfalkar et al 2016). This is recognised by the EU and Article 4 of the Waste Framework Directive allows Member States to take different approaches to implementing policy instruments strictly in adherence to the Hierarchy if there is evidence this may deliver *better environmental outcomes*.

For food waste, as described in Section 3.3.5, evidence has been reported that energy recovery by anaerobic digestion is a better option environmentally than some recycling approaches such as composting and therefore may not necessarily follow the order of the WFD's Waste Hierarchy (DEFRA, 2011b). Due to recognition of cases particular to the treatment of food waste, others have set out the need for a Food Waste Hierarchy (Papargyropoulou et al 2014).

There are many variants of the so-called Food Waste Hierarchy which is also interpreted as a food waste pyramid. An example is given in Figure 1. Again, the notable difference in this example, compared with the Waste Hierarchy, is the recategorisation of *waste sent to anaerobic digestion* in preference to recycling, rather than energy recovery. The approach used in this report is consistent with this recategorisation.

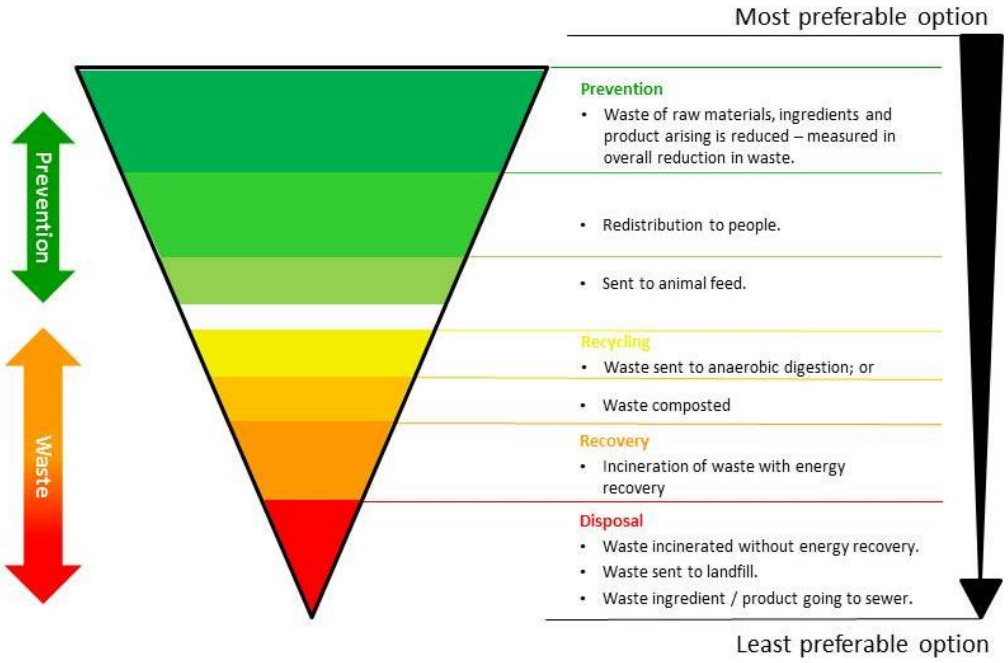


Figure 1*. Food & drink material hierarchy (WRAP, 2016)*

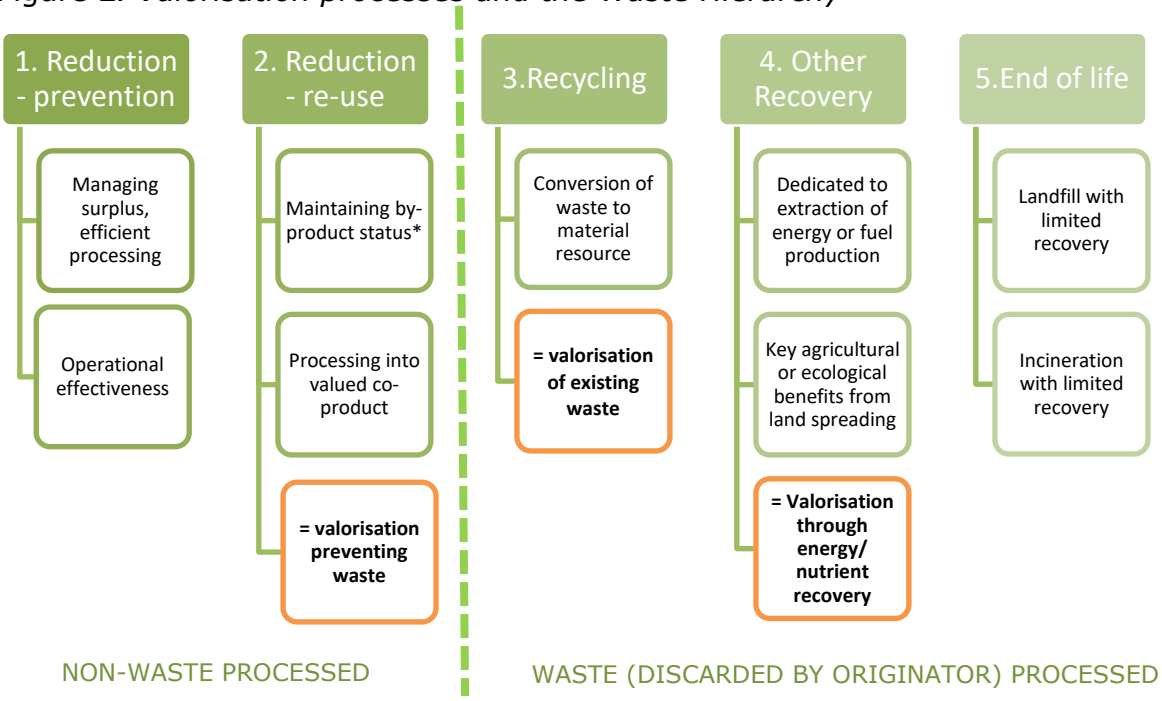
3.3.10 Valorisation and the Waste Hierarchy

A previous EU project FUSIONS[10], defined 'valorisation and conversion' as processing of non-waste material flows leaving the food chain. This definition included re-use and recycling food and inedible parts of the food supply chain including examples of animal feed, bio-based materials and biochemical processing. Notably, composting, anaerobic digestion and bioenergy production were not considered to be valorisation, but rather management of waste flows. Except for *recycling,* which is included as a *waste* recovery and should encompass composting, this broadly aligns with the Waste Hierarchy distinction between waste prevention and recovery approaches.

A definition for valorisation given by REFRESH[11] includes *processing of material to increase overall value, typically through the conversion to more useful products such as fuels, chemicals and biomaterials*. In this case, valorisation includes exploitation of both by-products and food wastes for greater *overall value[12].*

These cover the Waste Hierarchy cases numbered 2-4 in Section 3.3.1. Figure 2 indicates how definitions in the Waste Hierarchy (green boxes) can relate to valorisation (orange boxes).

Figure 2*. Valorisation processes and the Waste Hierarchy*



** By-product (non-waste) status is subject to material being an integral part of production, but not being the purpose of production, with certain reuse (see Figure 4 and Section 4.2.1 for further details of the WFD definition of non-waste by-products).*

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[10] Östergren et al (2014) Definitional Framework for Food Waste Full Report.
[11] REFRESH Information Management Protocol D8.1 – updated version January 2017.
[12] The definition of value is not substantiated, it is presumed this is overall economic value to producers only, rather than any wider environmental and societal benefits A more inclusive definition of valorisation could be *Processing food chain side flows to increase overall value to producer, environment and society, typically through re-use as food or feeds, but also by conversion to other products, fuels or energy.*

3.3.11 The Waste Hierarchy in relation to REFRESH situations

The Waste Hierarchy can be related to a set of wider and slightly differing definitions in the REFRESH project (Davis et al 2017)[13]. These REFRESH situations were developed to be more intuitive and simpler by encompassing co-products, by-products and wastes within the definition of side flows. Table 1 shows how the Waste Hierarchy broadly relates to REFRESH situations for food chain side flows[14].

Table 1 How the Waste Hierarchy relates to REFRESH situations

Waste Hierarchy level		Description	REFRESH Situation (RS)
1.	Waste Prevention	Waste reduction at source through improving processing efficiencies.	RS 1 Prevention of side flow
		Waste reduction at source through further reuse	RS 2 side flow valorisation benefitting generator
		Material is used directly/with certain use/lawfully and becomes a by-product	
2.	Waste recovery by recycling	Recycling: Waste is principally recovered by reprocessing waste into new materials replacing other materials.	RS 3 Valorisation as part of waste management *(no value to generator)*
3.	Waste recovery by other means	Waste is *principally* recovered for energy or fuels.	
4.	Disposal	End of life treatment with limited recovery.	RS 4 End of life

REFRESH situation 3's definition - where '*the driving motivation of these processes is the disposal…generating some value for someone other than the generator'* (Davis et al 2017) – on initial consideration, departs from the Waste Framework Directive article 3(15)'s definition of waste recovery where: '*The **principal** result is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy',* but aligns more with the WFD definition of disposal (WFD level 4. in Table 1).

[13] Davis et al (2017) *Generic Strategy LCA and LCC. Guidance for LCA and LCC focused on prevention, valorisation and treatment of side flows from the food supply chain. Refresh Work Package 5.*
[14] A **side flow** has been defined by Davis et al (2017) as a material flow of food and inedible parts of food from the food supply chain of the driving product, *including wasted driving product*.

The determining criteria given in guidance from the DG Environment (European Commission 2012) is that the waste is *principally used* - meaning the greater part of it - for substituting materials or energy.

However, the REFRESH situation appears to be from the perspective (and '*motivation'*) of the side flow producer, not the operators of waste recovery '*processes*' or a wider societal benefit/policy perspective. Therefore, this REFRESH situation 3 is considered to related to the principal waste recovery process as defined by the WFD.

4 Results

4.1 Valorisation approaches identified

4.1.1 Overview of results

The following are a summary of approaches that have been identified in the literature review from Deliverable 6.9 with respect to their position in the Food Waste Hierarchy outlined in Section 3 .

Of the seventy-six management approaches identified for the list of twenty side flows, two thirds fall under the Waste Hierarchy category of waste prevention by re-use. This is partly due to the number of animal by-products. Notably, these do not fall within the EU WFD remit unless these are subject to waste disposal operations. Supporting this categorisation is an acceptance that rendering valued animal *by-products* into commodities with existing markets is *normal industrial practice* rather than a waste recovery process.

In addition, production residues from beverages or vegetable or fruit products are utilised as animal feeds either directly as moist feeds, or with normal industrial process steps such as drying or storage ('clamping'). Almost a half of recycling approaches identified concern anaerobic digestion, with composting identified from literature as management approaches for only four side flows.

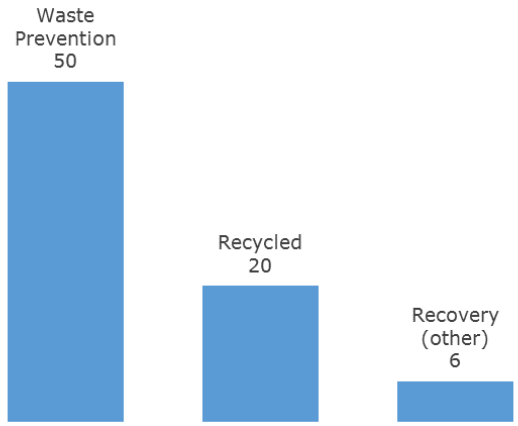

Figure 3 Identified management approaches categorised into the Waste Hierarchy.

The results (shown in Figure 3) are only categorised incidences of management approaches found in literature. Therefore, due to lack of data, it cannot be substantiated that these reflect the actual modal management approaches by volumes of materials processed in Europe, and must not be observed as such.

In part, these numbers are predicated on the groupings of the 20 key side flows made in D6.9 (see Table 2). For example, bones are counted as one side flow from meat processing even though this may cover side flows of bones from beef, lamb, pork and poultry from separate processing plants.

In view of this, where specific side flows are exclusive, e.g. feathers for poultry or products from non-ruminant materials this group has been split – therefore the number of side flows have been increased from twenty to thirty.

4.1.2 Summary table

The following table represents the categorisation of the key valorisation approaches identified from the literature review with respect to their possible position in the food Waste Hierarchy.

Table 2 *Summary of identified management approaches and interpretation of their position in the Waste Hierarchy.*

Driving products	Side flow material description	Current management	Nearest likely categorisation within the food Waste Hierarchy
Ales, lagers & spirits	Spent grains, distillers dark grain & draff	Moist animal feed (direct)	Waste Prevention
		Animal feed processed offsite	Waste prevention
		Anaerobic digestion	Recycled
Apple juice & cider	Raw pomace	Moist animal feed (direct to livestock)	Waste Prevention
		Animal feed dried onsite as normal industrial operation	Waste Prevention
		Minority approaches < 15% in the UK cider industry have been reported for non-feed use either anaerobically digested or one larger UK producer has been reported to be extracting antioxidant and phytochemicals though this reference [6] may be outdated.	Recycled
Cheese	Whey, whey concentrate and whey permeate	Production of foodstuffs: whey powder, demineralised whey, whey protein concentrates, isolates, texturisers & hydrolysed peptides, lactose, transformation to glucose, ricotta cheese production.	Waste Prevention
		Direct to animal feed as a by-product (raw liquid for pigs or dried whey powder)	Waste Prevention
		Feed supplements/additives such as Lactose recovered / reprocessed offsite as for concentrates	Waste Prevention
Eggs	Egg shell waste (shell)	Source of calcium (processed) for use in animal feed and pet food	Waste Prevention
		Filler for use in plastics	Recycled
Lamb, beef, pork & poultry	Blood	Production of foodstuffs (raw, plasma, albumin) from blood intended for human consumption and taken from healthy animals deemed fit for human consumption by ante and post mortem inspection.	Waste Prevention
		Production of pharmaceutical serum, plasma, albumin, cells, defibrinated blood & citrated blood typically assume to be from ABP Cat 3 [8]	Waste Prevention

	Blood (continued)	Production of processed pet food from ABP Cat 3 and subject to ABP regulations compliance [1] and prohibiting ruminant blood derived products being fed to pet horses, pigs and poultry. This is prohibited by EU TSE regulations [2]	Waste Prevention
		Blood meal fertiliser rendered from ABP Cat 3 and subject to ABP regulations process requirements	Waste Prevention
		Anaerobic digestion of blood from category ABP Cat 2 or 3, where any pre-treatment and process complies with ABP regulations.	Recycled
Lamb, beef, pork	Bones	Production of food grade gelatine.	Waste Prevention
		Production of pharmaceutical products from gelatine.	Waste Prevention
		Production of pet food. Excepting, the feeding of any classed as ruminant derived processed animal proteins to pet horses, pigs and poultry. This is prohibited by EU TSE regulations [2].	Waste Prevention
		Bone meal fertiliser rendered from category 2 ABP (compliant to ABP regulations)	Waste Prevention
		Production of tricalcium and dicalcium phosphate for animal feed supplements (rendered). The feeding of other ruminant derived processed animal proteins to any farmed animals is prohibited by EU TSE regulations [2].	Waste Prevention
		Production of glues	Waste Prevention
		Composting (where process is compliant with ABP regulations)	Recycled
		Anaerobic digestion (where process is compliant with ABP regulations) [3]	Recycled
	Skin	Production of foodstuffs (sausage casing, catalase, additives) where side flows are intended as edible co-products. [6]	Waste Prevention
		Production of pharmaceuticals gelatine and collagen	Waste Prevention
	Hooves & horn	Production of glues	Waste Prevention
	Heads and Feet	Pet food manufacture from meat meal. *Excepting the feeding of any classed as ruminant derived processed animal proteins to pet horses, pigs and poultry is prohibited by EU TSE regulations [2].*	Waste Prevention
	Hides and skin (excluding leather products)	Production of animal feed from hydrolysed proteins only, otherwise feeding of ruminant derived processed animal proteins to any farmed animals is prohibited by EU TSE regulations [2].	Waste Prevention

	Hair, hooves, feet and residues (scraps)	Anaerobic digestion (where process is compliant with ABP regulations)	Recycled
		Composting (where process is compliant with ABP regulations)	Recycled
	White and red offal including guts & giblets	Production of foodstuffs (sausage casing, catalase, additives) where side flows are Intended as edible co-products.	Waste prevention
		Production of pharmaceuticals (gelatine, collagen, fat, insulin, heparin, pepsin, steroids, cholesterol) from ABP 3 [8].	Waste prevention
		Production of animal feed (hydrolysed proteins only). The feeding of ruminant derived processed animal proteins to any farmed animals is prohibited by EU TSE regulations [2].	Waste prevention
		Production of pet food (meat meal, fat) ABP not intended for human consumption. Excluding beef/lamb derived animal proteins to pet horses, pigs and poultry which is prohibited by EU TSE regulations [2].	Waste Prevention
		Production of dye.	Recycled
		Anaerobic digestion (where process is compliant with ABP regulations) [3]	Recycled
		In vessel composting (where process is compliant with ABP regulations)	Recycled
	Carcass fat and fatty residues from slaughter for food products	Production of foodstuffs such as lard for bakery products, and derivatives used in food manufacture such as emulsifiers (e.g. lecithin from glycerine)	Waste prevention
		Cat 2 & 3 from ABP approved processes for rendered tallow or platform chemicals such as stearic acid, for detergents and other industrial uses with specific FA profiles.	Waste Prevention
		Production of oleochemicals from pharmaceutical grade tallow for cosmetics and soap from ABP approved processes	Waste Prevention
		Production of processed pet food. Excluding ruminant derived processed animal proteins to pet horses, pigs and poultry. This is prohibited by EU TSE regulations [2].	Waste Prevention
		Anaerobic Digestion (where process is compliant with ABP regulations)	Recycled
		Biofuels – esterified to fatty acid methyl esters for transport fuels or burnt for energy in industrial processes [7] subject to compliance with EU Waste Incineration Directive.	Recovery (other)

Pork & Poultry only	Carcass fat and fatty residues from slaughter not intended for human consumption	Farmed animal feed - only from gelatine and collagen and hydrolysed proteins (polypeptides, peptides and amino acids) and used only for non-ruminant farmed livestock and aquaculture feed (article 7 and Annex 4 of the EU TSE regulations) [2]	Waste Prevention
	Blood (Cat 3 ABP not intended for human consumption)	Processed into farmed animal feed (as non-ruminant proteins and restricted by article 7 and Annex 4 of the EU TSE regulations [2] to feed products only for non-ruminant farmed animals including those reared under aquaculture.	Waste Prevention
Poultry	Skin	Production of low gel, low viscosity products	Waste Prevention
	Feathers	Production of feather meal animal feed via hydrolysation.	Waste Prevention
		Production of feather meal fertiliser	Waste Prevention
		Production of pillow and furniture fillers	Waste Prevention
	Edible offal	Liver and other organs consumed in food products (paté etc.)	Waste Prevention
	Heads, neck, feet, offal & bones (Cat 3 ABP)	Production of poultry rendered fat/processed hydrolysed poultry proteins for pet food and animal feed restricted by article 7 and Annex 4 of the EU TSE regulations [2] to feed for non-ruminant farmed animals including aquaculture	Waste Prevention
	Heads, neck, feet, offal & bones (Cat 1-2 ABP)	Combustion for energy production in fluidised bed power plant generating electricity [7]	Recovery (other)
Light wines	Grape pomace or marc (skin and seeds)	Production of ethanol (obligated/supported by EC 1493/1999 to send lees and marc for distillation for energy production in preference to prevent over pressing [4]).	Recovery (other)
		Extraction of antioxidants (resveratrol), pigments & oils for nutraceutical and cosmetics industry.	Recycled
		Production of grapeseed oil & grapeseed flour for cooking oil & food ingredient).	Recycled
		Production of bio-based packaging.	Recycled
		Anaerobic digestion [5]	Recycled
Oranges	Citrus zest, peel, seed, membrane residue after juice extraction	Dried for pectin production	Waste Prevention
		Dried de-pectinised cattle feed (direct to animal feed)	Waste Prevention
		Production of animal feed - Moist feed supplied directly	Waste Prevention
Potatoes	Fibre, concentrated potato juice from	Protein extraction for animal feed -dried at source	Waste Prevention

	potato starch production	Land spread - with beneficial contribution as fertiliser	Recovery (other)
	Peelings	Animal feed - may be used directly as potato feed or combined with potato puree to give potato puree feed	Waste Prevention
Spirits	Organic wastes, mash from grain, fruit or potato	Animal feed	Waste Prevention
		Composting	Recycled
Sugar	Sugar beet pulp	Animal feed – pressed pulp transferred as by-product fed fresh or ensiled	Waste Prevention
		Re-processed (blended) with molasses to give molassed sugar beet feed (MSBF)	Recycled
Tomatoes	Pomace (skin, pulp & seeds)	Animal feed direct to farm	Waste Prevention
		Anaerobic digestion [5]	Recycled
Vegetable oil & margarine	Crude & extracted press cake or spent meal	Animal feed as co-product direct from source	Waste Prevention
		Production of fuels.	Recovery (other)
		Industrial uses (kernel oil, wood treatment, activated carbon) waste reprocessed offsite	Recycled
Olive oil	Olive stones	Production of fuels.	Recovery (other)
		Industrial uses (kernel oil, wood, activated carbon)	Recycled
Wheat milling	Wheat middlings	Feed for use by cattle, sheep and pigs	Waste Prevention

[1] https://www.gov.uk/guidance/using-animal-by-products-to-make-pet-food

[2] EU TSE Regulations (EC) No 999/2001 (as amended)

[3] Composting and anaerobic digestion plants can only treat category 3 animal by-products, category 2 animal by-products if they have been pressure rendered, and certain specified category 2 materials such as manure, digestive contract, milk and milk products.

[4] EC 1493/1999, as amended.

[5] Example co-digestion in 1MW plant, Northern Italy, Source: BTS Biogas GmbH.

[6] Confidential reviews with industry stakeholders, UK Waste resources action programme (WRAP): Resource efficiency in the UK cider sector.

[7] The first UK Waste Incineration Directive (WID) compliant commercial meat and bonemeal (MBM) residue fluidised bed combustion & combined heat & power (CHP) plant has been constructed in Widnes, Cheshire. Since 2008 WID requirements many UK renderers were unable to continue using ABP as combustible fuel source in their pre-existing plants.

[8] EU notice: note for guidance on minimising the risk of transmitting animal spongiform encephalopathy agents via human and veterinary medicinal products (EMA/410/01 rev.3) (2011/C 73/01), and by proxy, associated pharmaceutical products, states: *As a general rule, and unless properly justified, all animal by-products used as starting materials in the manufacture of medicinal products should be 'Category 3 (i.e. safe) materials or equivalent', as defined in Regulation (EC) No 1774/2002.*

4.1.3 Human consumption

In addition to primary products, dairy, meat, vegetable and fruit processing sites may reduce waste by preventing by-products becoming wastes by reprocessing and introducing components of these directly back into the food chain as additional secondary co-products for human consumption.

Key examples found are whey, a by-product from cheese production utilised as a food ingredient. Animal fats fit for human consumption can be rendered for re-introduction into bakery products. Collagen and gelatine extracted from skins, hides and bones meat processing industry is used for production of gelling agents and casings in food products. Pectin, also a gelling agent and emulsifier used in foods processing, is extracted from citrus and apple pomace, the by-products of fruit juice production.

The advantage of valorisation of a side stream directly from the point of production over valorisation as part of waste management is that the materials may carry a lower risk of contamination, its provenance is traceable, and it may be of a higher quality. These factors increase its chance of meeting the Waste Hierarchy criteria for waste prevention through re-use within the food supply chain.

4.1.4 Animal feed

Using food chain by-products directly for animal feed (i.e. with limited processing steps) has been an established practice on an industrial scale for many decades. Although more tightly regulated in the wake of the foot and mouth disease / bovine spongiform encephalopathy, the use of by-products as animal feed represents a major valorisation route for industries, such as brewing, where spent grains are usually diverted directly to cattle as moist feed. Similar practices exist for other bulk side streams from the food processing industry such as apple / cider pomace, oil press cake and potato peel. Former foodstuffs such as bread, biscuits, confectionery, crisps and breakfast cereals are also routinely processed into high quality, high performance feedstuffs for livestock, such that National and European associations representing these processers have been established[15].

In many of these cases side flows removed to farms directly as feed or if dried as typical industry practice, these may not be defined as a waste, but rather as a by-product under the WFD, (European Commission 2012). In this case it may be prevented from being a waste:

Although not all production residues destined for animal feed are automatically non-wastes, where feed materials are produced deliberately in adapted production processes, or may not be produced deliberately but meet the cumulative by-product criteria of the court as their further use in animal feed is certain, without further processing outside of the production process of that material. In addition, the feed material is governed by legislation such as Regulation 178/2002 on food law and Directive 96/25/EC on the circulation and use of feed material. In both cases, this material can therefore be considered to fall outside of the definition of waste[16]*.*

4.1.5 Animal by-products

The Waste Framework Directive does not fully apply to the processing of animal by-products (not intended for human consumption). These are covered separately

[15]European Former Foodstuffs Products Association http://www.effpa.eu/members
[16] 2007 COM (2007) 59, Annex 1 (p11): Communication from the commission to the council and the European parliament on the Interpretative Communication on waste and by-products.

through 1069/2009 (EC) Regulations unless they *are destined for incineration, landfilling or use in a biogas or composting plant, since these are typical waste-treatment operations.*

In addition, the EU transmissible spongiform encephalopathies (TSE) Regulations[17] also prevent certain animal tissues entering the feed or food chain. These are detailed in Annex A. This has shifted valorisation pathways considerably for countries designated as having a controlled or uncertain risk of TSE. Therefore, where the overriding condition for its management, first and foremost, is the reduction of disease risk, categorising the treatment of ABP side streams in the Waste Hierarchy may not be suitable for the purposes of highlighting valorisation approaches.

However, rendered materials from animal by-products such as hydrolysed proteins, fats, blood and bone meal derivatives have maintained established markets (oleochemicals, cosmetics, pharmaceuticals, certain animal feeds and pet foods, biofuels and organic fertilisers) by aligning processes with changes in regulatory requirements.

4.1.6 Anaerobic digestion

Anaerobic digestion capacity has increased in part from subsidies by Member States for meeting renewable energy targets. The number of biogas plants has tripled since 2009, reaching over 17,300 biogas plants and 459 biomethane plants in operation in Europe (in late 2015)[18]. Examples can be observed where animal slaughtering, food manufacturing[19] and vegetable processing sites[20], winery and fruit processers[21] utilise by-products to generate power with on-site anaerobic digestion plants.

The extent to which food waste is used throughout Europe as a feedstock directly from side streams is not freely available, however a significant proportion of plants will utilise food waste in combination with other feedstocks, such as maize grown specifically as a dedicated feedstock[22]. In the UK, a register of AD plants[23] indicates the importance of both municipal and agri-food chain materials used as feedstocks for AD plants generating energy.

4.1.7 Composting

Commercial composting forms an important route for the disposal of large tonnages of bio-waste. In addition, the reduced availability of suitable landfill sites and the taxation of disposal by landfill acts as a serious deterrent to the continuing disposal of biodegradable waste to landfill.

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[17] Regulations (EC) No 999/2001 (as amended)
[18] European Biogas Association website accessed 06/04/2017
[19] Bernard Matthews Foods Ltd, Holton, Suffolk, UK
[20] Staples Vegetables Ltd, Boston, Lincolnshire, UK
[21] e.g. AD plant in Chiesea Italy utilises grape marc, tomato and olive pomace as feed stocks
[22] The European Biogas Association conducts surveys on current capacity and feedstock but access is restricted to industry members.
[23] WRAP website accessed 06/04/2017.

However, it is difficult to draw any conclusions on the relative importance of food chain waste composting as a management approach from EU bio-waste statistics alone.

Though composting is reported to dominate approaches to management of bio-waste, according to a non-governmental organisation representing composting stakeholders across Europe, this may in part reflect the management of green waste from municipal estates management which accounts for 'more than 50% of this bio-waste'[24]. In some cases, digestate from anaerobic digestion is further composted adding complexity to this situation. Six national reports produced by this organisation also do not allow a consistent break down of food waste volumes that are composted[25].

Carbon dioxide emissions directly from composting biogenic material being of short duration carbon cycle is commonly considered to have a negligible net global warming impact. Composting is technology dependent but can also result in some contribution to global warming impacts from methane emissions subject to process temperature (Ermolaev et al, 2015).

One benefit of waste derived compost has been its substitution of non-renewable horticultural peat which, when extracted may have a net global warming impact through the relatively rapid release of the carbon that it has accrued over a longer duration which would otherwise remain stored. In 2011 the then UK government implemented a formal consultation process for a policy of voluntary phase out of peat for amateur use by 2030 (the dominant market in the UK)[26]

The operation of food waste composting sites that include animal by-products including municipal or catering waste is subject to the Animal By-products Regulations which cover all aspects relating to the collection, treatment, storage and use of animal by-products (ABPs). The legislation was initially brought into force in 2002 and was subsequently revised in 2009 (EC No 1069/2009, European Commission, 2009).

[24] European Composting Network (2017) Bio-waste Recycling in Europe Against the Backdrop of the Circular Economy Package
[25] European Composting Network (2017) Country reports for Finland, Hungary Italy, Ireland, Netherlands and Sweden. Accessed April 2017.
[26] 2013 DEFRA, UK. Government Response to the Sustainable Growing Media Task Force

4.2 Analysis and interpretation

4.2.1 Non-waste by-products

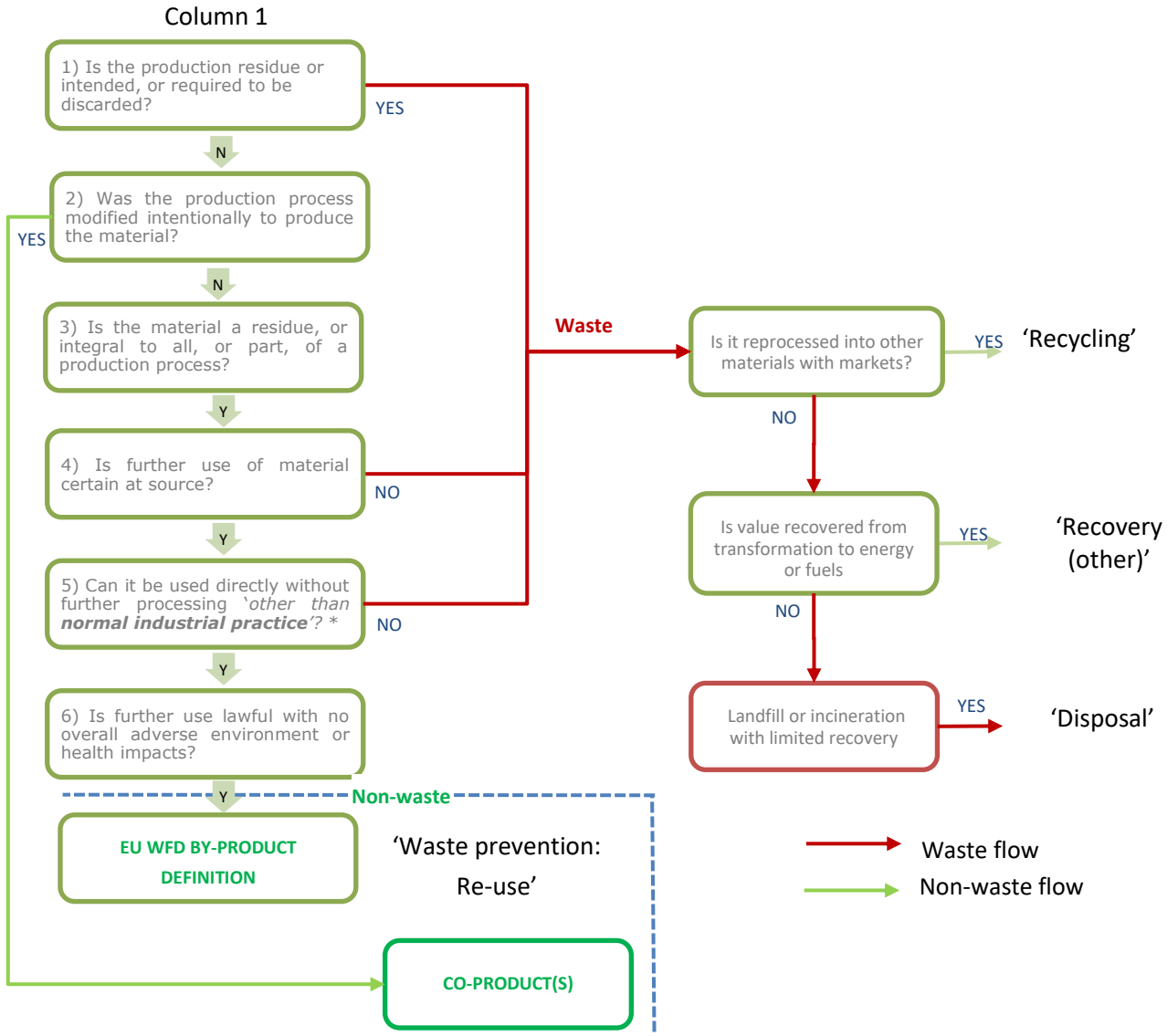
As outlined in Section 3.3.1 and 3.3.10, the WFD, which introduces the Waste Hierarchy as a policy tool, also distinguishes between what constitutes a by-product and a waste. It is notable that many of the selected 'wastes' listed from Deliverable 6.1 (Sweet et al 2016) may also be defined not as wastes but by-products under the EU Waste Framework Directive. This may be particularly relevant for animal feeds which may be considered as by-products.

By-product status is dependent on consistent markets and limited additional processing. Where access to those markets can be supported by producers by ensuring normal industrial practices such as e.g. preventing spoilage through drying or maintaining quality through adequate local storage and access for suitable for customers, then production residues' waste status may be removed under EU legislation.

The relationship between the Waste Hierarchy, co-product and by-product definition is shown in Figure 4. These are taken from WFD guidance issued in 2012 by the DG Environment [27]

[27] Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste (DG Environment 2012)

Figure 4 By-products and the Waste Hierarchy



*Normal industrial practice has been further qualified as:

i) All steps which a producer would take for a product, such as the material being filtered, washed, or dried; or adding materials necessary for further use; or carrying out quality control.

ii) Some of such processing tasks can be carried out on the production site of the manufacturer, some on the site of the next user, and some by intermediaries, as long as they also meet the criterion of being 'produced as an integral part of a production process'.

However, treatments usually considered as a recovery operation cannot, in principle, be considered as normal industrial practice in this sense.

European Commission (2012)

4.2.2 Co-products

There is no formal legislative definition of 'co-product' in the EU Waste Framework Directive. The DG Environment guidance[27] suggests a 'production residue' may become a co-product where processes are specially modified to produce the material.

The term is also acquired in Lifecycle Assessment (LCA) where environmental burdens are associated with processes resulting in more than one product. EU JRC guidance defines a co-product where the market value is above zero at the point of separation (JRC, 2010)[28]. In LCA environmental burdens of processes shared by more than one co-product may be attributed to each co-product using methods of physical or economic allocation at the point of separation or by product substitution approaches. This will depend on market contexts. However, market values, or the selection of the average or marginal substituted products, may vary with market context and an enterprise's commercial circumstances. These methods of allocation or substitution, if not chosen with care, could potentially lead to perverse swings in environmental burdens attributed to products.

Where side flows can be legitimately considered to be upgraded to co-products of the driving product, this may alter how environmental burdens of upstream production processes are shared. For modelling later deliverables in work package 6 this has potential for additional effort and further challenges in communicating environmental benefits of valorisation approaches using LCA.

End of waste criteria also covers conversion of wastes into materials with a market, typically resulting from regulatory or quality approved recovery processes such as recycling or reprocessing, (European Commission 2012). With anaerobic digestion for example energy and digestate may be considered valorisation co-products.

4.2.3 Extent of food waste compared to food chain by-products

WRAP have conducted surveys and reviewed environmental permitting data in the UK to extrapolate national estimates of the use or treatment of food surplus and production residues from the food chain, (Figure 5). The majority, 3.5 Million tonnes, of food and drink manufacturing residues and animal by products (blue text) are re-used for animal feeds and non-waste by-products rendered for other uses.

Of the actual 1.7 Million tonnes of manufacturing food **waste** reported, 70% of the are shown to be recovered through thermal processes or landspreading, 29% are recycled as compost or anaerobically digested to energy and fertilisers, with a minor amount being landfilled. WRAP suggest more than half of this **food chain waste** (red figures) could be preventable in line with REFRESH situation 1.

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[28] JRC (2010) ILCD Manual states in 14.4.1.2: Market value of waste / end-of-life product is above zero, i.e. it is a co-product (Refers to aspect of ISO 14044:2006 chapter 4.3.4.3); *If the market value of the waste / end-of-life product at its point of origin is above zero, in LCA perspective it is a co-product and the multifunctionality is to be solved by allocation.*

There are limited sources to make this kind of analysis across the EU Member States. A national study in France (ADEME, 2016), only concerns preventable food waste intended for human consumption (REFRESH situation 1) which does not cover the scope of this report.

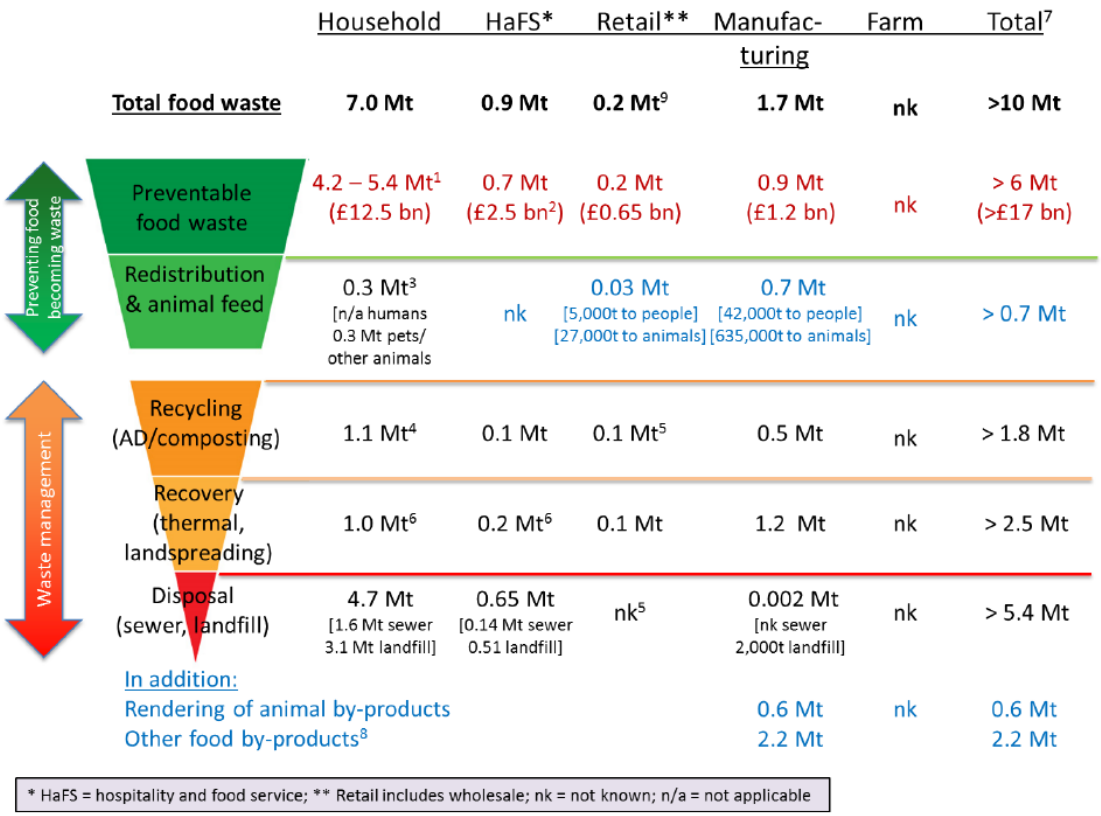

Figure 5 Food waste arisings in the UK, and the treatment and disposal routes (WRAP 2017)

([8]Other food by products are for example spent brewers grain and sugar beet pulp.)

The extent of the use of domestic food production residues as animal feed is not reported for individual materials, however. For example, statistics such as those published by the UK Government indicates the widespread commercial utilisation of spent grain, meal cake and fruit residues for modern animal husbandry, but the origin of these materials (whether imported or from domestic food chain sources) is not given alongside this data to enable this analysis.

4.2.4 Waste prevention and reduction at source

Waste prevention at source can be observed where side flows can attain some market value at the point of production, and as such reduce the burden of (what is defined as) waste. Examples found, such as spent grains and fruit pomace, may be routinely taken from the processor and either utilised directly, in these examples as a moist animal feed or with some measures at source (drying) to prevent spoilage and nuisance before also being used as an animal feed. These are supplementing some demand for virgin animal feeds and therefore loosely fulfil the Waste Directive's definition for by-products and waste reduction at source by replacing other materials. This interpretation of a direct form of re-use, within the original tenet of the Directive, is uncertain and could be challenged however.

4.2.5 Challenges in quantifying valorisation approaches

Though many publications can be observed regarding publicly and privately funded laboratory and pilot scale research characterising and extracting functional ingredients from food wastes (e.g. see Mirabella et al 2013 for a review), there is limited evidence available to determine the extent to which these have translated into commercial valorisation opportunities.

Currently, it is considered that most valorisation approaches identified that fall into the Waste Hierarchy categories of waste prevention and recycling are likely to be conducted by specialist processers typically requiring bulk material handling and processing of low value by-products and wastes at different sites to the producers in the food chain.

Limited evidence has been found from this literature review to quantify the extent to which the different management approaches identified are actually being implemented. Although legislation requires licencing and registration of *waste* contractors there are no easily accessible registers, excepting animal by-products, detailing food residue processers in EU Member States and the type of residues and nature of processing. In addition, as outlined in Section 4.1, many of the side flows listed in Table 1 may fall outside the EU legal definition of controlled wastes.

To properly qualify the extent to which companies are exploiting specific side streams through valorisation approaches requires representative surveys of industrial producers and intermediaries to find out the fate of by-products or process materials. Commercial sensitivity will be a key challenge in carrying this out.

There is little evidence for the application of approaches focussing on extracting higher value components from food residues that can be seen published in scientific literature. This is probably due to a higher level of risk for the diversification of an enterprise, but also because the bulk residues remaining extraction of single high value materials are of low value and may cost more to dispose of (Waldron 2007). One way of overcoming such barriers to valorisation could be to encourage research communities to investigate 'whole waste' processing; by applying a systems level

perspective to the management of food production residues the optimum approach to commercially viable exploitation may be identified.

4.2.6 Best Available Technique (BAT) reference notes

The largest publicly available review of regulated food drink and milk processing industries best available techniques (BATs) was carried out following Article 16.2 of the Integrated Pollution Prevention and Control (IPPC) Directive which aims to prevent emissions and waste production[29]. The original BAT review took four years, indicating the challenges of documenting practices in a diverse and commercially sensitive environment. A recent draft update published in January 2017 documents only anaerobic digestion and animal feed as BATs[30].

Beyond these and mainstream processes such as milk whey derivatives, there is little that indicates evidence for any other mainstreamed valorisation processes for secondary co-products, by-products and wastes installed at the same site of primary production.

The BAT for Livestock slaughtering and animal by-product processing sector is currently collecting data to update the original (and likely to be outdated) document[31] published in 2005 and a draft has not yet been completed at the time of this report.

[29] Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (IPPC) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31996L0061:en:HTML
[30] First Draft (January 2017). Best Available Techniques (BAT) Reference Document in the Food, Drink and Milk Industries Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control) Joint Research Centre European IPPC Bureau.
[31] Pers Comm. Adrian Kesterson 23/03/17 Technical Advisor, Foodchain Biomass and Renewables Association (FABRA) UK.

5 Conclusions

Excluding those restricted legally from re-use in the feed and food chains due to animal disease risk, many food chain residues identified are already subject to further use as raw materials or products within the context of normal industrial practice.

The application of the current interpretation of a food waste hierarchy shows that many of the food chain materials identified can therefore conceivably fall into the highest category - waste prevention.

There are few useful sources of data, however, to determine the extent (quantities and proportion utilised) for which management approach is applied across the EU, since typically such activities are conducted commercially by numerous operators. Trade bodies representing operators in some sectors can provide some information, but this is limited.

The merit of using the current interpretation of a food waste hierarchy is questionable. However, it leads to the key questions of whether there are better economic and environmental outcomes achievable by diverting food production residues from the current exploitation pathways within the hierarchy's waste prevention category to alternative waste prevention valorisation routes.

This can only be determined through sensible application of consequential lifecycle assessment (LCA) methods to specific selected cases. Care must be taken where a review of existing available LCA evidence is attempted, which often may be case specific, and use different goals, assumptions and boundaries. This is beyond the scope of this deliverable but will be addressed for selected cases in future deliverables (D5.5 and D6.10.).

As a desk based literature review there are two key limitations to categorising the management approaches of commercial enterprises throughout Europe regarding food chain side streams, and their place in the Waste Hierarchy.

Firstly, no formal sources were found that capture suitable information relating to commercial scale of waste valorisation examples deployed throughout the EU. Commercial sensitivity is likely to be a key barrier for accessing such data directly from companies.

Industry wide documents such as the EU Best Available Technique (BAT) references documents for food, drink and milk industries do not appear to document valorisation of food waste beyond anaerobic digestion and animal feed routes. Therefore, the information presented in this report is simply based on finding individual references indicating a management approach has been identified, and may not comprehensively represent the actual extent or variation of management approaches.

One approach to capture this information for policy making would be to embed primary research questions regarding on and off site food waste valorisation within

the process for updating BAT reference surveys undertaken by the European IPPC Bureau (EIPPCB).

The survey typically covers larger operations that are considered more likely able to make viable investments due to larger processing capacity, consolidation of waste streams and increased economies of scale.

Secondly, in some cases careful assessment is required to interpret the relative environmental merits of management approaches to determine which tier they reside within the Waste Hierarchy or even within the same tier. Examples of this can be observed where animal slaughtering, food manufacturing[32] and vegetable processing sites[33] utilise by-products to generate energy with on-site anaerobic digestion plants. This is classed as recovery other in the Waste Hierarchy, but through lifecycle evidence quoted by one Member State this is classified at the same level of environmental merit as recycling in a Waste Hierarchy.

Therefore, the Waste Hierarchy categorisation given in this report should be taken as a first step and not used as a robust metric to establish current sustainability status of the management approaches of the key side streams that have been identified. This will require a more nuanced application of lifecycle assessment approaches.

5.1.1 Next steps

The value of the REFRESH project will be to investigate in future deliverables the relative environmental and economic merits of the different alternative valorisation options (D5.5 and D6.10). This will support evidence to better define these within a food Waste Hierarchy.

Key to this next step is interaction with industry, particularly through the route of the National Piloting Working Platforms in the REFRESH piloting countries (NL, DE, HU, ES), which will provide WP6 with guidance on business and consumer acceptance for different management approaches for these waste streams.

A number of valorisation options in use are then to be evaluated, and further literature reviews will be undertaken to identify, where applicable, new technologies and approaches that are not currently in use.

[32] Bernard Matthews Foods Ltd, Holton, Suffolk,UK.
[33] Staples Vegetables Ltd, Boston, Lincolnshire, UK.

6 References

ADEME. 2016. Pertes et gaspillages alimentaires: l'état des lieux et leur gestion par étapes de la chaîne alimentaire. INCOME Consulting - AK2C. Angers, France: ADEME.

Arcadis 2009. Final report: Assessment of the options to improve the management of Bio-waste in the European Union. Annex d: Industrial Biowaste. Brussels: European Commission DG Environment.

BIOIS. 2010. Preparatory study on food waste across EU 27. Bio Intelligence Service. Brussels: European Commission (DG_ENV). http://ec.europa.eu/environment/eussd/pdf/bio_foodwaste_report.pdf

BSI. 2011. PAS 100 - Specification for composted materials. London: BSI Standards Limited. http://www.wrap.org.uk/sites/files/wrap/PAS%20100_2011.pdf

BSI. 2014. PAS 110 - Specification for whole digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials. London: BSI Standards Limited. http://www.wrap.org.uk/content/bsi-pas-110-specification-digestate

Crawshaw, Robin. 2001. Co-product feeds. Nottingham, UK: Nottingham University Press.

Crawshaw, R. 2009. "Food industry co-products as animal feeds." In K.W. Waldron, ed. Handbook of waste management and co-product recovery in food processing (Volume 2). Cambridge, UK: Woodhead Publishing.

DEFRA. 2011a. Guidance on applying the Waste Hierarchy. London: DEFRA. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69403/pb13530-waste-hierarchy-guidance.pdf

DEFRA. 2011b. Applying the Waste Hierarchy: evidence summary. London, DEFRA. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69404/pb13529-waste-hierarchy-summary.pdf

Ermolaev, E., A. Jarvis, C. Sundberg, S. Smårs, M. Pell, and H. Jönsson. 2015. "Nitrous oxide and methane emissions from food waste composting at different temperatures." Waste Management 46: 113-119.

European Commission. 1996. Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control, Official Journal of the European Union. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31996L0061:en:HTML, accessed on 7 June 2017.

European Commission. 2009. (Animal By-product) Regulations (EC) 1069/2009, Official Journal of the European Union. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:300:0001:0033:EN:PDF

European Commission. 2011. (Animal By-product) Regulations (EC) 142/2011, Official Journal of the European Union.

http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:054:0001:0254:EN:PDF

European Commission. 2012. Guidelines on the interpretation of key provisions of Directive 2008/98/EC on waste. Brussels: European Commission Directorate-General Environment. http://ec.europa.eu/environment/waste/framework/pdf/guidance_doc.pdf, accessed on 7 June 2017.

van Ewijk, S., and J.A. Stegemann. 2016. "Limitations of the Waste Hierarchy for achieving absolute reductions in material throughput." Journal of Cleaner Production 132: 122-128.

Food Standards Agency. 2011. Industry guide on edible co-products and animal by products. London: Food Standards Agency for England, Wales and Northern Ireland. https://www.food.gov.uk/sites/default/files/multimedia/pdfs/ediblecoprod.pdf

Garcia-Garcia, G, E. Woolley, and S. Rahimifard. 2015. A framework for a more efficient approach to food waste management, International Journal of Food Engineering 1(1): 65-72.

Gharfalkar, M., R. Court, C. Campbell, Z. Zulfiqur Ali, and G. Hillier. 2015. "Analysis of Waste Hierarchy in the European waste directive 2008/98/EC." Waste Management 39: 305-313.

JRC. 2010. European Commission - Joint Research Centre - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition March 2010. Luxembourg: Publications Office of the European Union.

Mirabella, N., V. Castellani and S. Sala. 2014. "Current options for the Valorisation of food manufacturing waste: a review." Journal of Cleaner Production 65: 28-41.

Moates, G., N. Sweet, K. Bygrave and K. Waldron. 2016. Top 20 Food waste streams. REFRESH Project Deliverable 6.9. WRAP/IFR.

Morley, N, and C. Bartlett. 2008. Mapping Waste in the Food Industry. Oakdene Hollins. Aylesbury, UK: Department for Environment Food and Rural Affairs / Food and Drink Federation.

NNFCC. 2016. "Anaerobic Digestion – The official information portal on anaerobic digestion". http://www.biogas-info.co.uk, accessed on 7 June 2016.

Östergren, K., J. Gustavsson, H. Bos-Brouwers, T. Timmermans, O.-J. Hansen, H. Møller, G. Anderson, C. O'Connor, H. Soethoudt, T. Quested, S. Easteal, A. Politano, C. Bellettato, M. Canali, L. Falasconi, S. Gaiani, M. Vittuari, F. Schneider, G. Moates, K. Waldron, and B. Redlingshöfer. 2014. FUSIONS Definitional Framework for Food Waste. Full report, Sweden, ISBN 978-91-7290-331-9.

Papargyropoulou E., R. Lozano, J.K. Steinberger, N. Wright and Z. bin Ujang. 2014. "The Food Waste Hierarchy as a framework for the management of food surplus and food waste." Journal of Cleaner Production 76: 106-115.

Parfitt, J., S. Woodham, E. Swan, T. Castella and A. Parry. 2016. Quantification of food surplus, waste and related materials in the grocery supply chain. Final report – v2 May 2016. Banbury, UK: Waste Resources Action Programme. http://www.wrap.org.uk

Sweet, N., K. Bygrave, G. Moates and K. Waldron. 2016. Valorisation appropriate waste streams. REFRESH Project Deliverable 6.1. WRAP/IFR. European Commission. http://eu-refresh.org/medium-list-waste-streams-appropriate-valorisation

US EPA. 2017. "Food Recovery Hierarchy". https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy, accessed on 6 June 2017.

Vision 2020. "The Food Waste Hierarchy". http://www.vision2020.info/ban-food-waste/the-food-waste-hierarchy/, accessed on 6 June 2017.

Waldron K. 2007. "Waste minimization, management and co-product recovery in food processing: an introduction." In K.W. Waldron, ed. Handbook of waste management and co-product recovery in food processing (Volume 1). Cambridge, UK: Woodhead Publishing.

Waldron, K, and E. Nichols. 2009. "Composting of food-chain waste for agricultural and horticultural use." In K.W. Waldron, ed. Handbook of waste management and co-product recovery in food processing (Volume 2). Cambridge, UK: Woodhead Publishing.

WRAP. 2012. "Resource efficiency in the UK cider sector". http://www.wrap.org.uk/sites/files/wrap/Cider%20guidance%20FINAL%20010512%20AG.pdf, accessed on 6 June 2017.

WRAP. 2016. "Guidance for food and drink manufacturers and retailers on the use of food surplus as animal feed". http://www.wrap.org.uk/content/animal-feed-guidance-document, accessed on 7 June 2016.

WRAP. 2017. "Estimates of Food Surplus and Waste Arisings in the UK. Updated summary". http://www.wrap.org.uk/sites/files/wrap/Estimates_%20in_the_UK_Jan17.pdf, accessed on 5 June 2017.

7 Annex A

7.1 EU Animal by-product (ABP) regulations

According to UK guidance on ABPs[34] the following are prohibited as feed for farmed animals including horses and donkeys includes:

- All meat and fish, including shellfish, raw, partially or fully cooked
- Scraps and catering waste from any commercial or (non-vegan) household kitchen
- Ruminant derived gelatine and collagen
- Unprocessed permissible PAP raw materials such as raw eggs or raw milk.

Below is a description published by the UK Government[35] of the 3 categories of animal by-products which pertains to the EU Animal By-product Regulations 1069/2009 (as amended):

7.1.1 Category 1 ABPs

Category 1 ABPs are classed as high risk. They include:

- carcasses and all body parts of animals suspected of being infected with TSE (transmissible spongiform encephalopathy)
- carcasses of wild animals suspected of being infected with a disease that humans or animals could contract carcasses of animals used in experiments
- parts of animals that are contaminated due to illegal treatments
- international catering waste
- carcasses and body parts from zoo and circus animals or pets
- specified risk material (body parts that pose a particular disease risk, e.g. cows' spinal cords)

7.1.2 Category 2 ABPs

Category 2 ABPs are classed as high risk. They include:

- animals rejected from abattoirs due to having infectious diseases
- carcasses containing residues from authorised treatments
- unhatched poultry that has died in its shell
- carcasses of animals killed for disease control purposes

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[34] DEFRA guidance published 2014: https://www.gov.uk/guidance/supplying-and-using-animal-by-products-as-farm-animal-feed

[35] Guidance: Animal by-product categories, site approval, hygiene and disposal Source UK Department for Environment, Food & Rural Affairs and Animal and Plant Health Agency Part of: Guidance for the animal by-product industry, Published:4 September 2014 Last updated: 6 November 2014, Accessed April 2017.

- carcasses of dead livestock
- manure
- digestive tract content

7.1.3 Category 3 ABPs

Category 3 ABPs are classed as low risk. They include:

- carcasses or body parts passed fit for humans to eat, at a slaughterhouse
- products or foods of animal origin originally meant for human consumption but withdrawn for commercial reasons, not because it's unfit to eat
- domestic catering waste
- shells from shellfish with soft tissue
- eggs, egg by-products, hatchery by-products and eggshells
- aquatic animals, aquatic and terrestrial invertebrates
- hides and skins from slaughterhouses
- animal hides, skins, hooves, feathers, wool, horns, and hair that had no signs of infectious disease at death
- processed animal proteins (PAP)

PAP are animal proteins processed (in accordance with ABP regulations) from any category 3 ABP above, except:

- milk, colostrum or products derived from them
- eggs and egg products, including eggshells
- gelatine
- collagen
- hydrolysed proteins
- dicalcium phosphate and tricalcium phosphate of animal origin
- blood products

7.2 EU TSE regulations

7.2.1 Animal feed bans

Due to Transmissible Spongiform Encephalopathy (TSE) disease amongst farmed animal populations, feed bans preventing certain animal derived proteins and specified risk materials (SRM) entering the food and feed chain has been legislated across Europe since 2001[36] . This bans the feeding of protein derived from animals to ruminants[37]. In addition, specified risk materials and certain animal proteins are banned as feed for all farm animals, including horses, and also for pigs, poultry or

[36] EU TSE Regulation (EC) No 999/2001 (as amended) Laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies, (as amended).
[37] Ruminants being any mammals which can survive by grazing on grasses and pasture, such as cattle, goats, sheep, camels, llamas, giraffes, bison, buffalos, deer, wildebeest and antelope.

horses kept as pets. Specific exemptions to this are listed in the second column in table 3.

7.2.2 Specified risk materials

Specified Risk Material (SRM) are animal tissues identified as carrying a greater TSE infectivity risk. The materials are listed in column one of table 3. The list of SRM to be removed and destroyed depends on the risk status of the country of origin.

Currently (as of May 2017[38]) the following Member States are considered to have a controlled BSE risk:

- France
- Greece
- Ireland
- UK (England & Wales only)

The remaining Member States are therefore considered to have a negligible BSE risk status.

[38] World organisation for animal health http://www.oie.int/animal-health-in-the-world/official-disease-status/bse/list-of-bse-risk-status/

Table 3 Summarised list of animal protein sources and their feed ban status.

Feed ban includes following specified risk material (SRM) (for disposal)	Exempted by-products and processed animal proteins*:
BOVINE SRM • Spinal cord, skull, brain and eyes (>12 months) • **Tonsils & last 4m small intestine (all ages) • **Vertebral column, (excl. tail vertebrae), • **Cervical, thoracic & lumbar vertebrae, & sacrum, incl. ganglia (> 30 months). • **Caecum & Mesentery-incl. fat, ganglion complex & nerves, (all ages) OVINES AND CAPRINE SRM • Skull, brain, eyes, tonsils, spinal cord (>12 month) • Spleen and ileum (all ages)	Category 3 animal by-products that include: • Non-ruminant blood products for use **in *non-ruminant feeds only*** • Milk, milk-based products, milk-derived products • Colostrum, colostrum products • Centrifuge or separator sludge • Non-ruminant gelatine & collagen • Hydrolysed proteins (including collagen and gelatine only from ruminant hides) • Derived dicalcium & tricalcium phosphate supplements for ***non-ruminant feeds only*** • Eggs & egg-products, including eggshells • Products containing the above, e.g. bakery products with cooked egg, but no meat, fish or shellfish

*This is subject to processing/sterilisation required by the Animal By-Product Regulations and subject to authorisation to make feed with these products (implementing EC 1069/2009, & 142/2011).

** Can be processed as food and feed if Negligible BSE risk country of origin but is considered a specified risk material (SRM) if from a country with a Controlled or undetermined risk

Sources: FABRA UK[39], DEFRA[40], EU[41]

[39] Material from presentation: An overview of the UK Animal By-Products Industry Steve Durrant, UK Food & Biomass Renewables Association (FABRA) received from personal correspondence (23/03/2017) with Adrian Kesterson, Technical Advisor, (FABRA).
[40] The Animal and Plant Health Agency, Department for Environment, Food and Rural Affairs, UK. Guidance note on feed controls in the transmissible spongiform encephalopathies regulations.
[41] EU TSE Regulation (EC) No 999/2001 Laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies, (as amended).