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Author(s):	David Alonso, Leticia Regueiro, Diego Méndez, Jara Laso, Cheila Almeida, Leonor Nunes, António Marques, Ronan Cooney, Eoghan Clifford.
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GLOSSARY AND ABBREVIATIONS

ABP – Animal by-products

AEL - Associated emission levels

AEPL – Associated Environmental Performance Levels

APA – Agência Portuguesa do Ambiente

BAT – Best available technique

BOD – Biological Oxygen Demand

BREF – Best available techniques reference documents

COD – Chemical Oxygen Demand

DHA – Docosahexaenoic acid

EC – European Commission

ELV – Emission limit value

EMAS – Eco-Management and Audit Scheme

EPA – Eicosapentaenoic acid

EU – European Union

FAO – Food and Agriculture Organisation

FDM – Food, drink and milk industries

FM – Fish meal

FMFO – Fish meal fish oil

FO – Fish oil

GWMR – General Waste Management Regime

IEA - Integrated Environmental Authorisation

IMTA - Integrated multitrophic aquaculture

IPCC – Integrated Pollution Prevention and Control

IPTS – Institute for Prospective Technological Studies

JRC – Joint Research Centre

MITECO – Ministry for Ecological Transition

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PHA – Polyhydroxyalkanoates

PUFA – Polyunsaturated fatty acids

RAS – Recirculating aquaculture systems

SAE – Slaughterhouses, animal by-products industry and edible co-products

TN – Total nitrogen

TOC – Total organic carbon

TP – Total phosphorus

TSS – Total suspended solids

UAE – Ultrasound combined to assisted enzymatic extraction

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EXECUTIVE SUMMARY

This report forms one of the key deliverables of work package 7 – sectoral best available techniques for nutrient recovery, from the Interreg Atlantic Area project NEPTUNUS (EAPA_576/2018). NEPTUNUS aims to promote the sustainable development of the seafood sector in the Atlantic area by supplying a consistent methodology for products eco-labelling and defining eco-innovation strategies for their production and consumption under a circular economy approach. This project will provide key actions for resource efficiency based on life cycle thinking, incorporating producers, policy makers and consumers in the decision-making process.

One of the ways in which the project aims to support the sector is by assessing current and emerging policies and strategies for nutrient recovery from seafood waste streams using best available techniques (BATs).

This document focuses on the BATs that are most applicable for (i) the recovery of nitrogen and phosphorus from emissions to water and (ii) dealing with by-products and discards that are generated by the seafood sector. In many cases the current approach exclusively seeks to minimize emissions, obtaining no benefit apart from compliance with emission limits. This document aims to shift the current paradigm towards a new context with a greater focus on circular economy and the greater use of valuable seafood resources that are currently wasted (and thus also meeting emission limits). In section 1, the BAT concept, it's history and framework are outlined and discussed in the context of aquaculture, seafood and processing activities.

In section 2, the role of animal by-products classification and the legal framework supporting the introduction and implementation of BATs is also presented. The transposition of these European Union regulations into Spanish, Irish and Portuguese national laws are also presented as examples of different approaches in an Atlantic Areas context.

Section 3 of the document, presents and discusses the best available techniques reference documents (BREF) applicable to the seafood sector. This includes general considerations associated with a process or stage of seafood production, including concerns around food safety, economic viability and local conditions. Specific BATs, such as the slaughterhouses, animal by-products industry and edible co-products (SAE) and the food, drink and milk industries (FDM) BAT are discussed at length as relevant examples.

Section 4 outlines the general sectoral BATs that can be employed in seafood activities to reduce emissions to water. Within this context, the role of undervalued waste streams from aquaculture and seafood – sludge and cooking waters – are presented. Section 5, present emerging technologies and strategies which can increase the circularity of seafood systems and help to minimise waste by valorising it.

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An extensive review of the available techniques to reduce the use of raw materials and water was carried out, as well as the techniques to prevent or reduce environmental impacts. In addition, whenever possible, priority was given to techniques which supported use of nutrients from by-products and wastewater, as opposed to the current trend which may focus on trying to minimise the waste generated by industry (i.e., discharge license compliance) but often does not focus on trying to reuse the waste that is necessarily generated.

Potential relationships and connections between different stages of processes and activities are described, in particular if they affect overall environmental performance (by-products or wastes from one activity that may be used as feedstock for another activity).

Many of the current and emerging BATs are still lab scale technologies, as opposed to established technologies. As more pilot scale results and information on products and processes enter into industrial practice, the opportunities for increased seafood circularity and nutrient recovery will increase. Supporting and enabling a sustainable transition to a circular economy.

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1. INTRODUCTION

1.1 General Summary

The waste or by-products generated in the seafood sector are mainly organic and derived from production processes. In the processing plants, fish and seafood parts not intended for human consumption are generated. These parts can be viscera, skins, heads, tails, bones, shells, blood, edible oils, salt, brine, etc. In many instances, these remains are materials with economic value which, being by-products, can be used as raw materials in other industries. These by-products generated by the processing industry have increased considerably in recent years, with most of them mainly intended for the production of fishmeal and fish oil (FMFO).

Several technologies for seafood processing are available in the market, but that require large amounts of water, which in turn generate large amounts of waste and the associated loss of valuable resources. However, they could be recovered within a circular economy and environmental sustainability framework. National and international environmental policies have emphasized the need to angle the production and consumption of economic goods in the direction of less consumption of raw materials and fewer emissions of pollutants and waste. To aid this transition in the seafood sector, it is expected that a number of recovery strategies for energy, carbon and nutrient recovery will be developed in the near future, driven by a growing trend towards a circular economy in the processing industry. The results for these current technologies are not uniform, since different results are obtained depending on the area of activity, type of industry and degree of technological development.

According to the Food and Agriculture Organization of the United Nations (FAO, 2020), 22.2 million tonnes of fishery products from global catch are not used as food. An important part of the raw material not used for human consumption are by-products (trimmings), from the fish processing industry, sourced both from fisheries and aquaculture.

In 2017, Europe produced 16% of the world's fishmeal (FM) and 23% of the world's fish oil (FO), with 29 registered FMFO processing facilities (Figure 1). In 2018, global FM production reached its highest level since 2011 at 5.8 million tonnes, a 20% increase from 2017. FO production was nearly 1.3 million tonnes, the highest level recorded over the past 20 years. Due to the COVID-19 pandemic, the global production in 2019 and 2020 is estimated to be much lower, with 4.9 and 5 million tonnes of FM respectively, and 1.17 and 1.25 million tonnes of FO. Several of the European FMFO plants produce their products exclusively from fish trimmings, as a form of utilization of by-products generated during processing (the majority located in Spain and Portugal), while the rest of the European Union countries do so from both fresh catch landings and trimmings. Spain is the second largest producer in Europe (after Denmark), with 15-18% of total production. An additional driver for the

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utilisation of trimmings in feed has been the growth of the organic finfish aquaculture segment (EUMOFA, 2017; Pelletier and Tyedmers, 2007). For example, the Atlantic salmon sector in Ireland, since 2015 has been 100% organic. This transition required that all FMFO ingredients derived either from sustainably certified aquatic resources (i.e., capture fisheries), by-products from organic aquaculture, discards, by-catch or trimmings, as directed by Commission Regulation (EC) No. 889/2008. There are a number of certification schemes in use to certify FM and FO as organic. Depending on the scheme and the standards, there are only 6 organics certified FMFO suppliers and 10 feed producers in Europe (Naturland, 2020). The conditions and processes for the production of FM and FO differ fundamentally depending on the type of processing industry of origin and destination (EUMOFA, 2021).

Figure 1: An overview of the FMFO plant's location in Europe from the European Fishmeal and Fish Oil Producers. Factories are indicated by the factory symbol and associated members are indicated by gears and fishing symbols.[1]

[1] https://effop.org/about-european-fishmeal/members-of-european-fishmeal/

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However, at a national level there may be other organizations that operate similar management activities to those described above (Figure 2). For example, in Spain the ANFHAPES association (National Association of FM and FO Manufacturers), which is coordinated by ANFACO, represents a total of 8 companies distributed throughout the national territory, and in Cape Verde, which perform appropriate management of the waste generated by the seafood processing industry, producing FM and FO for its commercialization.

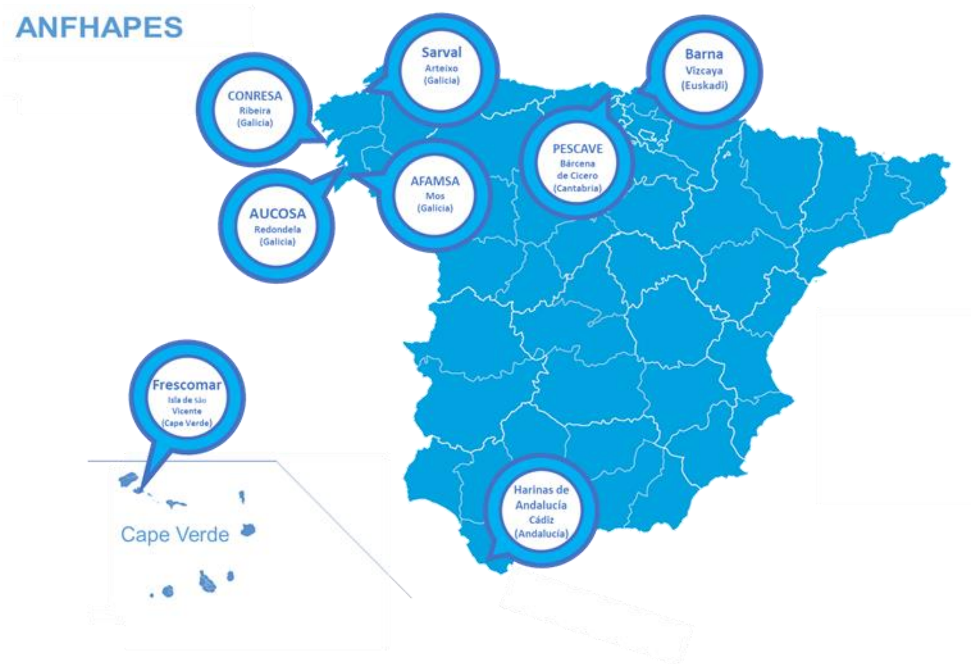

Figure 2: An overview of the FMFO plants from Spain in ANFHAPES association. Image courtesy of ANFACO-CECOPESCA.

The production of FMFO requires that the raw material, during its processing, is subdivided into three fractions: solid material (dry fat free material), oil and water, which are separated mechanically during the processing process itself (Figure 3). The production of meals is mainly intended for high protein feed, while FO are used as ingredients in aquaculture feed or for human consumption (they provide a balanced amount of essential amino acids, minerals, phospholipids and omega-3 fatty acids (i.e., docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA)). The quality of these meals as a final product may vary in terms of protein and mineral (ash) content, as well as the concentrations of small amino acids (i.e., glycine, proline, hydroxyproline) compared to products obtained from fresh fish (ANFACO, 2012).

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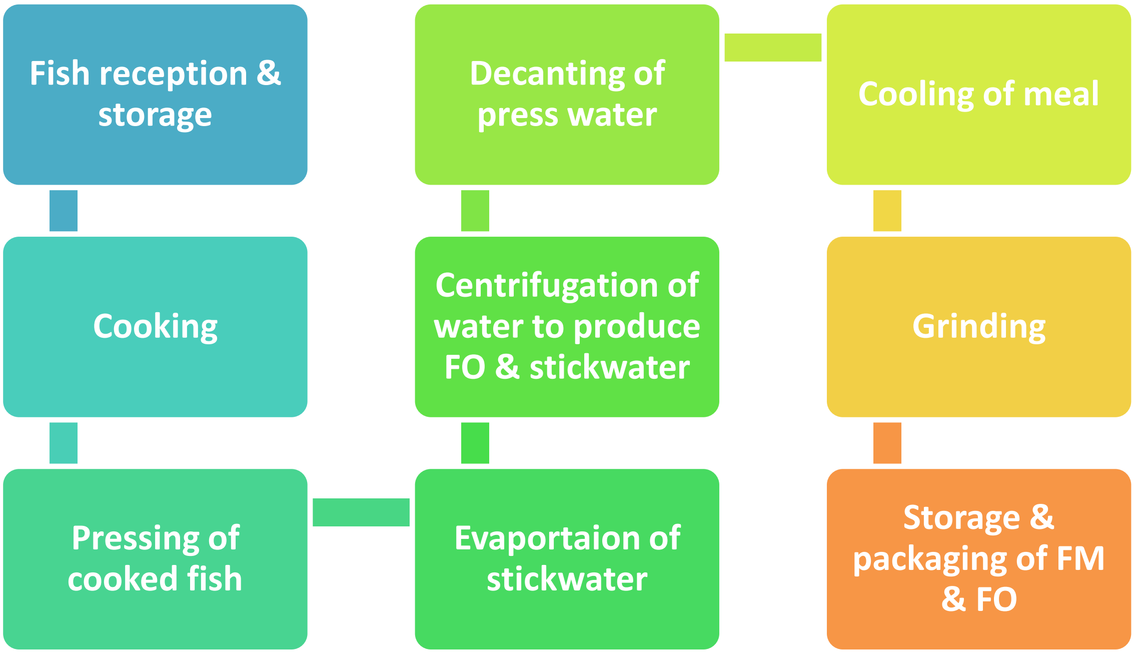

Figure 3: The primary steps in the production of FM and FO from the Irish Environmental Protection Agency's 2008 guidance note for BATs and FM and FO.

However, due to technological developments in recent years and increased social awareness, it's considered that the use of marine by-products for FM and FO is an inefficient and unsustainable practice. Particularly, when it can be exploited in other high potential value products such as enzymes, collagen, pigments, etc. Therefore, more responsible management and valuation of the nutrients and products derived from seafood waste streams is required.

1.2 BAT concept

The concept of Best Available Techniques (BAT) originated in the 1970s and was first used in the 1980s in the EU in the directives for air and water protection (Silvo et al., 2005). According to the Integrated Pollution Prevention and Control (IPPC) Directive (2008/1/EC), in Europe, BAT is the most effective and advanced methodology for the sustainable development of industrial processes. It is in line with the best technical and operational suitability of all possible techniques that comply with the emission limit values (ELVs). These ELVs are designed to prevent and reduce the impacts on the environment. "Techniques" means both the technology used and the way in which the installation is designed, constructed, maintained, developed and dismantled; "available techniques" means those developed on a scale which allows their application in the relevant sector, under economically and technically feasible conditions, considering costs and benefits that are reasonably accessible.

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“Best” means most effective in achieving a high general level of protection of the whole environment.

BATs are particularly efficient techniques from an environmental point of view, due to their low resource consumption or low environmental impact and are technically and economically feasible for any industry concerned. These techniques are one of the issues that must be considered when determining emission limits values (ELVs), although without specifying the use of a particular technique or technology (Figure 4).

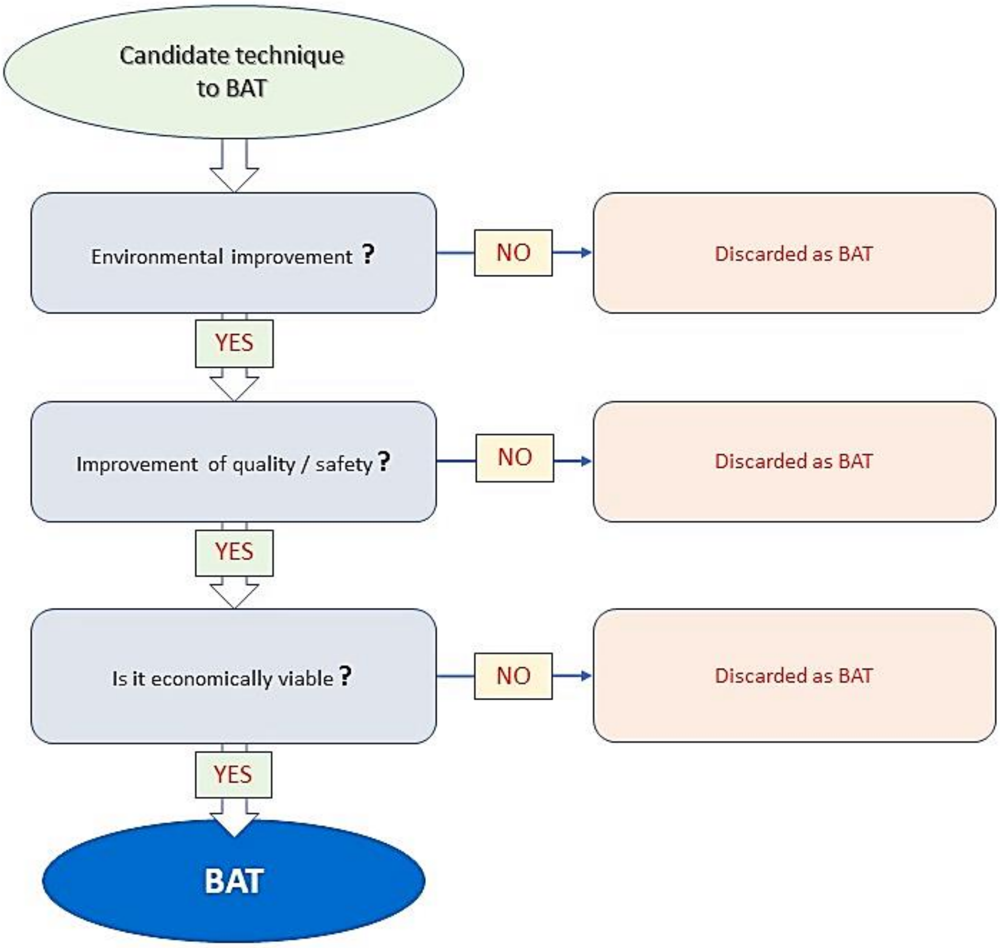

Figure 4: BATs decision tree. ANFACO_CECOPESCA pers. comm.

Compared to other available techniques used to perform a particular operation or practice in an industrial food production plant, a BAT technique candidate must provide a significant environmental benefit in terms of resource savings and/or reduction of the environmental impact produced, though it does not mean that nutrient recovery as such is required. In the case of the food industry, it is important to highlight that food safety can be a major

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barrier to certain recovery, reuse or recycling techniques due to contaminants and detergents. Although wastewater treatment processes, such as the removal of waste and sludge from physical-chemical and/or biological systems, are also considered.

After this first requirement has been fulfilled, the BAT candidate technique should be available on the market and, in addition, be compatible with the production of quality, safe foodstuffs whose manufacture does not involve an industrial or professional risk.

Therefore, a technique could not be considered a BAT if it is economically unviable for the industry. The adoption of BATs by a facility should not involve a cost that would put the continuity of the activity at serious risk. In this sense, it should be remembered that, in old facilities, a change of technology is a costly investment that is not always affordable, while in new facilities it is more viable to include, in addition to other criteria, the environmental variable and therefore BATs. This would be one of the main ideas in the emerging or prospective legislation, which would encourage the adoption of environmentally friendly production techniques.

BATs are published in BREFs, which are reference documents presenting objective technical and economic data resulting from the exchange of information provided according to Article 13 of Directive 2010/75/EU between Member States, industries concerned and non-governmental organizations promoting environmental protection. The BREFs contain the necessary information to formulate BAT conclusions for the activities considered. These documents describe the techniques applied, current emissions and consumption levels, in order to determine the best available techniques, as well as conclusions on these on emerging techniques.

For the establishment of BAT reference documents, this exchange of information should relate to:

(a) the performance of installations and techniques in terms of emissions of short and long period averages and associated reference conditions, consumption and type of raw materials, water consumption, energy use and waste generation.

(b) techniques employed, associated controls, cross-media effects, technical and economic feasibility and developments.

(c) best available techniques and emerging techniques identified after consideration of the issues referred in points (a) and (b).

These descriptive documents do not prescribe the use of any particular technique or technology, and do not constitute an interpretation of Directive 2010/75/EU. Therefore, the aim of a BREF is to determine a BAT (in a transparent and objective way, based on technically and economically solid

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information), to limit imbalances in the EU in terms of the level of emissions from industrial activities and to promote better environmental performance across EU members.

BREF documents should not be considered as a manual of techniques for pollution prevention and control. They should include references to other relevant "vertical" (specific techniques) or "horizontal" (generic scope information) BREFs, in order to facilitate complementary use and to ensure consistency between the different documents.

Due to the dynamic nature of BATs, the revision of BREFs is a continuous process. BREFs are revised periodically to update and complete previous baseline information using the most recent data; to remove obsolete or outdated data and rectify inconsistencies with other BREFs or correct any mistakes.

When developing a BREF the description of the techniques should be concise and sufficient to be useful for authorities and plant operators. Technical terminology and acronyms that have not been defined shall be avoided. BAT conclusions should be structured by common characteristics as appropriate, i.e., ecological problems, stages of the production process or final products.

The European Commission includes guidance, throughout the BREF documents, to promote best waste management and resource efficiency practices.

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2. LEGAL FRAMEWORK AND CURRENT LEGISLATION

IPPC is an important piece of EU legislation that introduces the obligation to apply a regime of environmental multimedia (water, air and soil) licensing for defined industrial activities. However, IPPC only applies to large industrial installations and cannot be used by smaller ones. Moreover, even when IPPC is applied, it is not applied in exclusivity terms. The coordination and drafting of this work are carried out by the IPPC Bureau, a department designated by the European Commission within the Institute for Prospective Technological Studies (IPTS) of the Joint Research Centre (JRC), whose headquarters are in Seville, Spain. The result of the so called "Seville process" is the BREF or European Reference Documents on Best Available Techniques. BREF documents started to be developed with the implementation of Council Directive 96/61/EC on IPCC. With the Industrial Emissions Directive coming into legal effect, these documents need to be revised and adapted to the new legal framework. The IPCC Bureau is currently in the process of revising and updating the BREFs previously developed. The IPPC Directive is concerned with the control of major industrial installations, with defined activities such as ELVs and other conditions to prevent or reduce emissions to air, water and soil. These conditions usually reflect an assessment of "best available techniques" (BAT), although more stringent requirements may be imposed when necessary to meet environmental quality standards.

The European Commission has developed the 2012/119/EU[2] decision which establishes guidelines on data collection, as well as guidance on the drafting of BAT reference documents and on their quality assurance. These BREF documents describe, for each of the industrial sectors, the techniques used, the current emissions to all relevant environments and consumption levels, the techniques considered in determining BAT, as well as conclusions on BAT and emerging techniques.

The action principles of recent European Directives and national and regional laws (the IPPC Law as the clearest example), are prevention, valorisation and elimination, in this decreasing order of importance, where the alternative chosen by the company must first observe practical measures that promote prevention, or at least the reduction of waste generation.

However, waste management in the seafood sector aimed at prevention or minimization may encounter major obstacles. The reason is that the raw materials have a variable composition or proportion of edible/non-edible parts that does not depend on the activity of the industries in the sector, (i.e., there is a proportion of parts that will inevitably end up as by-products/waste). In the context of seafood, this proportion can be quite high, depending on the species (Table 1). Each species has a percentage of inedible parts that must be

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012D0119

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disposed on land if they have not been removed previously during operations in the fishing vessels (i.e., viscera and heads).

Table 1: *An overview of the edible yield and composition of seafood products and their waste.* Adapted from FAO (1989) and Venugopal (2021).

	Yield (as % of whole weight)		Wastes
Species	**Skinless Fillet**	**Edible Flesh**	
Atlantic cod	34	47	Skins, heads, frames, viscera
Blue whiting	28	49	Skins, heads, frames, viscera
Chub mackerel	46	57	Skins, heads, frames, viscera
European hake	41	53	Skins, heads, frames, viscera
Blue mussel	*	24	Shell, byssal threads
Pacific cupped oyster	*	10	Shell, fouling
Penaeid shrimps	*	57	Shell, organic material

*No data

Regulation (EC) 1774/2002 established the sanitary standards applicable to animal by-products (ABPs) not intended for human consumption (currently repealed by regulation (EC) 1069/2009[3]). For these purposes, by-products are classified into 3 categories based on their risk to human and animal health and specifies the conditions under which they can be managed (Figure 5).

[3] http://data.europa.eu/eli/reg/2009/1069/oj

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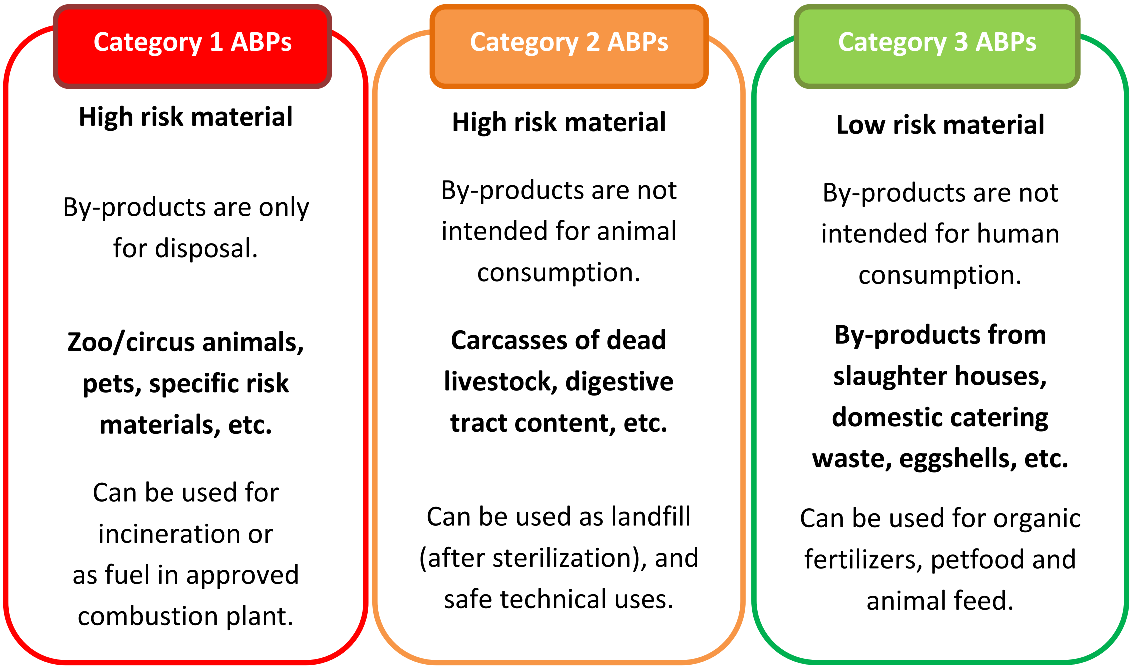

Figure 5: ABPs categories as established by Regulation EC No. 1069/2009.

The ABPs industry processes all raw materials not directly destined for human consumption and some of those destined for human consumption. The permissible ways of use and disposition are governed by Regulation (EC) No. 1069/2009 of the European Parliament and of the Council of 21st October 2009, laying down health rules on animal by-products not intended for human consumption. According to Regulation EC No. 1069/2009, shells from shellfish and fish residues at slaughtering are considered Category 3 ABPs. These products can be transformed to be used as feed ingredients. Regulation EU No. 142/2011[4] provides 7 standard processing methods for these ABPs. Industries must store these by-products in appropriate hygienic-sanitary conditions (sealed and refrigerated containers), as well as having to regulate the management of the collected by-products by an authorized manager (i.e., FM and FO manufacturers).

In most cases, the valorisation of the by-products or, as the case may be, the elimination of this material as waste, is carried out by companies other than the production facility itself. In such a case, the production facility has the obligation to manage them adequately until they are transferred to other companies.

[4] http://data.europa.eu/eli/reg/2011/142/2021-12-05

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2.1 Spanish legislation

In Spain, the national management of BREF documents is administrated by the Ministry for Ecological Transition (MITECO), which regulates basic state legislation to transpose European Directives and provides guidance on BAT. The MITECO is the designated authority to provide the available information on BATs for the granting of the Integrated Environmental Authorization (IEA), both to the environmental authorities and to the industry, in accordance with the provisions of Law 16/2002. However, Autonomous Communities are responsible for granting the IEA monitoring and control. The industrial sectors involved can take part in the development of the BREFs and in some cases promote sectoral guides for their application.

The definition of organic by-products includes the parts or organs of the animal that are not directly marketable and which, in terms of the quantity generated during processing, are an important resource. Although from an environmental point of view they can be classified as waste, according to basic legislation (Law 22/2011, of July 28, on waste and contaminated soils[5]), they are considered by-products according to Regulation (EC) No. 1069/2009 of the European Parliament and of the Council, of 21st October 2009, laying down health rules concerning animal by-products and derived products not intended for human consumption[6]). Industrial wastewater, as well as all wastewater discharged and used for any commercial or industrial activity, is defined by Directive 91/271/CEE[7] on Urban Wastewater Treatment.

European Directives 2006/12/EC[8] and 2008/98/EC[9], designed to protect the environment and human health, promote the prevention and reduction of the environmental impact from the waste generation and management. It is based on prevention and recovery of the waste generated, as the seafood canning, and other processing industries are aligned with the obligations established by these Directives. Through the implementation of the environmental management plan (called SGMA in Spain), the prevention of environmental impact is integrated and compliance with environmental regulations can be measured in accordance with regulations such as EMAS (Eco-Management and Audit Scheme) or the ISO 14001 standard.

In Spain, ABPs generated that need specific treatment are defined as "animal by-products not intended for human consumption (SANDACH)" and are subject to specific legislation at European level: Regulation 1069/2009/EC derogating Regulation 1774/2002/EC. The Royal Decree 1528/2012[10] established

[5] https://www.boe.es/eli/es/l/2011/07/28/22/con
[6] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32009R1069&qid=1644400116818
[7] https://eur-lex.europa.eu/eli/dir/1991/271/oj
[8] http://data.europa.eu/eli/dec/2006/12(1)/oj
[9] https://eur-lex.europa.eu/eli/dir/1991/271/oj
[10] https://www.boe.es/eli/es/rd/2012/11/08/1528

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the conditions for the application of EU regulations on SANDACH. Among other measures, it established the National Commission for ABPs not intended for human consumption, responsible for monitoring and coordinating the implementation of regulations on SANDACH. All establishments that operate with SANDACH must be registered and controlled by the Competent Authority. Their management, from the moment that they are generated until their final use, recovery or destruction is regulated to ensure that they do not generate risks to human health, animal health or the environment, guaranteeing the safety of the human and animal food chain.

According to this, most of the by-products of animal products originating in Spain produced in the seafood sector are identified as category 3 material (e.g., blood/cooking waters/remains of raw material/remains of cooked material/shells). The organic waste is based on Regulation 767/2009/EC[11], which includes a prohibition on the use of animal waste to feed any other animal (Article 6, Annex III). This invalidates all integrated multitrophic aquaculture (IMTA) systems in which filter feeders and detritivores (bivalves, anemones, etc.) are farmed together with fish or feed on their waste. Currently, only the treatment of this waste as landfill, for incineration or biogas production is allowed. Another approach will be possible from 2022, with the new Regulation (EU) 2019/1009[12] laying down rules for the marketing of fertilizers in Europe, replacing the current Regulation (EC) 2003/2003 (European Community, 2003) which only allows free trade of conventional nonorganic fertilizers. For sludge waste, the legislation is based on EU water protection legislation, which is based on four main pillars:

1) Urban Wastewater Treatment Directive (Council Directive 91/271/EEC of European Community[13])
2) Directive on Nitrate Pollution from Agricultural Sources (Council Directive 91/767/EEC, Nitrates Directive; European Community, 1991[14]),
3) Water Framework Directive (Directive 2000/60/EC[15])
4) EU water legislation.

For the control of the water discharges from the companies in the sector, there are limits in the physical-chemical values of these effluents, since they must ensure that there are no significant increases over time, by means of water controls in the receiving medium, which are also established in the discharge authorizations of each autonomous community. For example, in Galicia the microbiological levels are established by the limits of the law 9/2010

[11] http://data.europa.eu/eli/reg/2009/767/oj
[12] http://data.europa.eu/eli/reg/2019/1009/oj
[13] http://data.europa.eu/eli/dir/1991/271/2014-01-01
[14] http://data.europa.eu/eli/dir/1991/676/oj
[15] https://www.boe.es/buscar/doc.php?id=DOUE-L-2000-82524

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of Waters of Galicia[16]. In addition, the characteristics of the wastewater depend directly on the specific activity of the company and the area where it is discharged, to which more restrictive limits can be established.

In Spain, Law 1/2016 of December 16th 2016[17], on integrated pollution prevention and control, defines best available techniques as "the most effective and advanced stage of development of activities and their modes of operation, which demonstrate the practical ability of certain techniques to constitute, in principle, the bases for emission limit values aimed at avoiding or, where this is not possible, generally reducing emissions and the impact on the environment and human health".

2.2 Irish Legislation

Within an Irish context, all facilities that require an Industrial emissions license must apply BAT. This licensing is carried out by the Environmental Protection Agency (EPA)[18]. The implementation of the BATs is expected to lead to reductions in the emissions to air, water and soil, while reducing energy and water consumption.

As outlined in the EPA BAT Guidance Note for the Manufacturing of Fish Meal and Oils[19], BAT was introduced in the IPPC Directive, 96/61/EC. The Directive was incorporated into Irish law by the Protection of the Environment Act 2003. In order to meet the requirements of the Directive, relevant Sections of the Environmental Protection Agency Act 1992 and the Waste Management Act 1996 were amended to replace BATNEEC (Best Available Technology Not Entailing Excessive Costs) with BAT. BAT is defined in Section 5 of the Environmental Protection Agency Acts 1992[20] to 2007 and Section 5(2) of the Waste Management Acts 1996[21] to 2008 as the "most effective and advanced stage in the development of an activity and its methods of operation, which indicate the practical suitability of particular techniques for providing, in principle, the basis for emission values designed to prevent or eliminate or where that is not practicable, generally to reduce an emission and its impacts on the environment as a whole".

Similar to Spain and the other EU countries, once a BREF is reviewed and adopted, a Commission Implementing Decision (CID) (listing the BAT

[16] https://www.boe.es/eli/es-ga/l/2010/11/04/9
[17] https://www.boe.es/eli/es/rdlg/2016/12/16/1
[18] *An Ghníomhaireacht um Chaomhnú Comhshaoil* in the Irish language.
[19] https://www.epa.ie/publications/licensing--permitting/industrial/ied/bat-guidance-note-for-the-fish-meal--fish-oil-sector.php
[20] https://www.irishstatutebook.ie/eli/1992/act/7/section/5/enacted/en/html
[21] https://www.irishstatutebook.ie/eli/1996/act/10/enacted/en/html
[19] *http://data.europa.eu/eli/dec_impl/2019/2031/oj*

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conclusions) is published for each BREF. The adoption of a CID and the BAT conclusions is mandatory in the permitting and licensing process.

The CID for the food, drink and milk industries[22] was published on 11th November 2019 by the European Commission. The EPA's role is to ensure that the relevant industries apply all relevant BAT conclusions as soon as practicable, but not more than 4 years after the CID is published. Licence Conditions and/or Schedules must be updated or reconsidered within 4 years of publication of a relevant CID. The overall objective of reconsidering and updating permit conditions is to ensure that the operation of installations is in line with the latest developments in the best available techniques.

In the absence of a CID, installations should continue to have regard to the BAT Reference Document and the national Best Available Techniques Guidance notes that are available on the EPA website.

The BAT conclusions available on the EPA website are as follows: slaughterhouses and animal by-product, Intensive rearing or poultry or pigs, emissions to storage, energy and efficiency, food, drink and milk, and industrial cooling systems.

Currently, the EPA had published 47 BAT guidance notes for a number of sectors (Table 2). These guidance notes are issued by the EPA so as to provide guidance on the determination of Best Available techniques (BAT) in relation to:

- applicants seeking Integrated Pollution Prevention and Control (IPPC) licenses under Part IV of the Environmental Protection Agency Acts 1992 to 2007,
- existing Integrated Pollution Prevention and Control (IPPC) Licensees, whose licence is to be reviewed under the Environmental Protection Agency Acts 1992 to 2007,
- applicants seeking Waste Licenses under Part V of the Waste Management Acts 1996 to 2008,
- existing Waste Licensees, whose licence is to be reviewed under the Waste Management Acts 1996 to 2008.

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Table 2: The BAT guidance notes available from the Irish EPA. Guidance notes with significance to the seafood sector are in **bold**.

BAT Guidance Notes for Different Sectors	
Ferrous metal processing	Pesticides, pharmaceuticals & specialty organic chemicals
Ferrous metal foundries	Board manufacturing
Waste (landfill)	Electroplating operations
Waste (transfer & materials recovery)	Extraction of minerals
Manufacture of integrated circuits	Manufacture of sugar
Initial melting and production of iron & steel	Manufacture of synthetic fibres
Production of paper pulp. Paper & Board	Manufacture or use of coating materials
Brewing, malting and distilling	Pig production
Disposal or recycling of animal carcasses & animal waste	**Waste (IPPC)**
Animal slaughtering	Wood treatment & preservation
Cement & lime	Asbestos
Ceramic & diamond	Crude petroleum & handling storage
Dairy	Fellmongering & tanning
Energy (LCP)	Forges
Fish meal & fish oil	**Manufacture of vegetable & animal oils & fats**
General inorganic & alumina	Roasting, sintering or calcining
Glass - including glass fibre	Glass production
Metals & plastics	Extraction of peat
Nonferrous metals & galvanising	Organo tin coating
Oil & gas refining	Chemical
Organic chemical	Asbestos, Glass, mineral fibre
Textile's processing	Carbonation etc of coal
Use of solvents	Manufacture glass fibre or mineral fibre
Vegetable & animal raw materials	

These guidance notes are periodically reviewed and updated in line with any changes in legislation or advances in technology. At the time of their writing, they are considered to reflect best practice for that particular segment. As part of the note series, the EPA encourages proactive dialogue between operators and stakeholders. This dialogue plays a key role in keeping industry, operators and the EPA as being aware of advances or changes in practice and requirements. Given the comparatively small size of Irelands seafood processing and FMFO sectors, this communication channel is crucial.

As part of the application, a licensee must demonstrate to the satisfaction of the Agency, during the licensing process, that the installation/facility will be operated in such a way that all the appropriate preventative measures are taken against pollution, through the application of BAT and justify the application of other than the most stringent ELV in the range.

The BAT hierarchy as stated in the Guidance notes requires that, in the identification of BAT, emphasis is placed on pollution prevention techniques rather than end of pipe treatment. The IPPC Directive 96/61/EC and the Environmental Protection Agency Acts 1992 to 2007 (section 5(3)) require the determination of BAT to consider in particular the following, giving regard to the likely costs and advantages of measures and to the principles of precaution and prevention:

(i) the use of low-waste technology,

(ii) the use of less hazardous substances,

(iii) the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate,

(iv) comparable processes, facilities or methods of operation, which have been tried with success on an industrial scale,

(v) technological advances and changes in scientific knowledge and understanding,

(vi) the nature, effects and volume of the emissions concerned,

(vii) the commissioning dates for new or existing activities,

(viii) the length of time needed to introduce the best available techniques,

(ix) the consumption and nature of raw materials (including water) used in the process and their efficiency,

(x) the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it,

(xi) the need to prevent accidents and to minimise the consequences for the environment, and

(xii) the information published by the Commission of the European Communities pursuant to any exchange of information between Member States and the industries concerned on best available techniques, associated monitoring, and developments in them, or by international organisation, and such other matters as may be prescribed.

The same parent legislation that is applied in Spain also determines the regulation and control of ABPs in Ireland. EU Regulation 1069 of 2009, as amended by EU Regulation 142 of 2011, controls the collection, transportation, storage, handling, processing and use or disposal of all ABPs. As stated in the preceding sections, this legislation divides ABP material into three categories based on its potential risk to animals, humans or the environment and sets

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out how each category should be used or disposed of. The newly published SI[23] 187 of 2014 on ABPs transposes EU Regulation 1069 of 2009 and implements Regulation 142 of 2011. Within SI 187/2014 it states that any person who commits an offence with regards to the use and disposal of ABPs can, on summary conviction, face a fine of €250,000 and/or an imprisonment term of 12 months.

The use or disposal of ABP is strictly controlled so as to protect both public and animal health. The regulation of ABPs is handled by a number of government bodies:

- Department of Agriculture, Food and the Marine: Responsible for most ABP processing plants and the largest meat plants.
- Sea-Fisheries Protection Authority: Responsible for marine ABPs.
- Local Authority Veterinary Service: Responsible for ABP issues in smaller local abattoirs.
- Health Service Executive: Responsible for retail outlets, i.e., butchers.

As stated by the Sea Fisheries Protection Agency, regardless of the category, ABPs must be collected and transported in sealed new packaging or covered leak-proof containers or vehicles. To ensure traceability of the ABPs, all consignments must be accompanied by a fully completed commercial document as specified in EU Regulation 1069 of 2009.

The majority of ABPs of fish origin are classified as Category 3, which includes:

- Fish material that is not destined for human consumption
- Finfish by-products arising from processing activities (excluding mortalities)
- Shellfish that have been previously fit for human consumption but have now passed their shelf life.

Sludge from seafood processing in Ireland is also managed under the main articles of EU water protection legislation:

- Urban Wastewater Treatment Directive (Council Directive 91/271/EEC; European Community, 1991)

[23] Statutory Instrument (SI) is defined as an order, regulation, rule, scheme or byelaw made in exercise of a power conferred by statute under the Statutory Instruments Act 1947. They are also referred to as secondary, delegated or subordinate legislation.
https://www.irishstatutebook.ie/eli/2014/si/187/made/en/print#

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- Directive on Nitrate Pollution from Agricultural Sources (Council Directive 91/767/EEC, or Nitrates Directive; European Community, 1991)
- Water Framework Directive (Directive 2000/60/EC).

There is an increasing interest by operators of freshwater aquaculture facilities to valorise the sludge they produce as part of their solid's recovery. There is strong support for the Department of Agriculture Food and the Marine (the core administrator of ABP regulation in Ireland) to permit an increased use of ABPs in the feedstocks for anaerobic digestion (AD). Currently, there are 8 AD plants in Ireland with ABP approval that process manures, food waste, fish waste and industrial sludge.

The legal framework established to govern the potential of eutrophication resulting from discharges is primarily the Local Government (Water Pollution) Act (1977) and the Local Government (Water Pollution) (Amendment) Act (1990). This allows Local Authorities to monitor the discharge from "trade" premises and to enforce water management plans on these premises. Commercial activities that discharge trade effluent to the public sewer require a licence under Section 16 of the Local Government (Water Pollution) Acts 1977 and 1990. Those who discharge to surface waters require a Section 4 license under the same Acts.

In more recent times, since the implementation of Council Directive 2000/60/EC, the Water Framework Directive (WFD), there have been several SIs transposed into Irish law. The most significant of these being S.I. 272 of 2009, the European Communities Environmental Objectives (Surface Waters) Regulations, 2009. This statutory instrument laid down the measures and environmental quality standards (EQS) required to achieve the environmental objectives as established for surface waters as per EU Council Directive 2000/60/EC (i.e., the Water Framework Directive). It laid down the criteria for calculating the ecological status and potential of a water body based on biological elements (invertebrate fauna, phytobenthos, macrophytes, phytoplankton and macroalgae) and the underlying physico-chemical conditions supporting the biological elements, i.e., thermal conditions, oxygenation conditions and nutrient conditions.

2.3 Portuguese Legislation

The concept of by-product at the EU level is regulated by Directive No. 2008/98/EC, of the European Parliament and of the Council, of 19th November[24], regarding WFD which defines, in article 5, the conditions under which a product can be considered a by-product. At national level, the Decree-

[24] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098

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Law No. 73/2011, of 17th June[25], related to General Waste Management Regime (GWMR), transposes the WFD to national legislation. The goal of the law is to reinforce the prevention of waste production and promote its reuse and recycling in order to prolong its use before returning it in suitable conditions to the environment. In addition, it considers important to promote a full organized market of waste as a way to consolidate the recovery of waste, with advantages from the economic point of view as well as to encourage the use of specific waste with high potential of valorisation. The concept of by-product is defined in article 44-A with four conditions to be verified cumulatively:

a) There is certainty of subsequent use of the product or object.

b) The product or object can be used directly, without any further processing other than normal industrial practice.

c) The production of the product or object is an integral part of a production process.

d) The product or object meets the requirements to follow environmental and health safeness issues and does not entail adverse global impacts from an environmental or human health point of view in subsequent specific use.

Condition c) covers all processes where a product is deliberately produced (i.e., a factory production line, agricultural activities, or construction activities) and due to production processes to which exist a BREF, under the IPPC regime, it is considered that BATs are an integral part of the production process.

Once the conditions are verified, a production residue can be considered a by-product, thus not being subject to rules related to GWMR. The analysis of the conditions and the decision regarding the classification of a certain product to be a by-product is under responsibility of the governmental organization *Agência Portuguesa do Ambiente*, I.P (APA), underneath the Ministry of Environment and Climate Action of the Portuguese government.

In Portugal, ABPs that need specific treatment are defined as "not intended for human consumption" and are under specific legislation from EU, the Regulation (EC) No. 1069/2009 of 21st October 2009[26,27]. This regulation defines safeness rules to use by-products not intended for human consumption, as well as the obligation to collect cadavers of animals that die in the establishments where they are held (livestock establishments). It revokes the

[25] https://dre.pt/dre/detalhe/decreto-lei/73-2011-670034
[26] https://eur-lex.europa.eu/legal-content/PT/TXT/PDF/?uri=CELEX:02009R1069-20191214&qid=1634913693263&from=EN
[27] https://dre.pt/dre/legislacao-consolidada/decreto-lei/2017-156697732-156696154

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Regulation (EC) No. 1774/2002 of the European Parliament and of the Council, of 3rd October 2002[28] (concerning ABPs).

ABPs mainly arise from animals' slaughterhouses for human consumption (slaughterhouses), production of food (dairy products and processed meat products), and disposal of animals that died in facilities or that have been slaughtered for control of communicable diseases. ABPs not intended for human consumption can be classified into three categories, according to their origin and risk of danger to human or animal health. Most of the ABPs produced in the seafood sector are under category 3 material (i.e., blood, remains of raw or prepared products, shells).

According to Regulation EU No. 142/2011 of the Commission, of February 25, 2011[29], which applies in Regulation No. 1069/2009, ABPs not intended for human consumption must be sent to licensed units to carry out their treatment, by elimination or a process of transformation into by-products that do not jeopardize human or animal health. This Regulation describes seven standardized processing methods. The most common method of treatment/processing of ABPs not intended for human consumption is method 1 (pressure sterilization), which consists of the previous reduction of animal by-products particles to dimensions not exceeding 50 mm, heating them to a temperature above 133 °C for at least 20 minutes without interruption at a pressure of not less than 3 bar. The heat treatment can be used alone or in the sterilization phase before or after the process.

The final products, resulting from the treatment by defined processing methods, are essentially animal fats and feeds, which can be used in the following products:

- Production of pet food ("pet-food").
- Production of compound feed for livestock (feed).
- Production of organic fertilizers and soil organic improvers.
- Fuel (for incineration and steam generators).
- Production of biogas or biodiesel.
- Leathers and skins for the tanning industry.
- Wool and feathers for the textile industry.
- Production of fish oil and fish meal.
- In the case of shellfish shells or shells of crustaceans and eggshells, used under conditions determined by the competent authority that prevent risks to public and animal health.
- Production of animal fat (processing animal fat to obtain grease for the manufacture of foodstuffs).

[28] https://eur-lex.europa.eu/legal-content/PT/TXT/?uri=LEGISSUM%3Af81001
[29] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:054:0001:0254:EN:PDF

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Facilities that produce ABPs not intended for human consumption include 1) livestock/aquaculture farmhouses (i.e., aviaries, pig farms), 2) slaughterhouses, 3) establishments that produce meat or seafood products (i.e., sausages, preparation of food/pre-cooked meals), and 4) establishments that sale to the public (i.e., butchers, fishmongers).

In establishments where ABPs are produced there are established aspects that need to be checked, as for example:

- Existence of appropriate containers to store materials resulting from the activity.
- If the destination and means of transport of these materials are licensed for this purpose (i.e., ABPs must be transported in sealed containers or vehicles with cover which must be washed after each use).

Operators whose activity generates ABPs, must send them to approved or registered ABP establishments or facilities to receive the category of by-product in question. Facilities receiving ABPs must ensure that they come from approved, registered establishments or installations and that their transport, has been carried out by registered carriers.

Important issues for the implementation of Directive 2010/75/EU[30] in the food, drink and milk sector are emissions to water, energy and water consumption. Applicable BATs to seafood processing can help to reduce water consumption, waste, or emissions to air. In FM and FO production, the BAT indicates the use of fresh raw materials (low total volatile nitrogen) and incinerating unpleasant smelling air with heat recovery.

Most seafood processing machinery installations depend for their operation on large quantities of water, primarily for washing and cleaning purposes, but also as a medium for storage and refrigeration of fish products before and during processes. The processing industry for marine species often uses seawater in part of the cleaning process, which is considered important to improve the quality of the product. Seawater used for this purpose is normally filtered and treated with UV disinfection to inhibit spread of bacteria.

The waste by-product material from processing activities is often mixed with the water by the action of the machines, which produces a highly polluted effluent. Fish processing wastewater is known to contain organic contaminants in soluble, colloidal and particulate form. The biodegradable organic matter is mainly in the form of proteins and lipids, and the concentration and volume of wastewater from fish processing varies widely, depending on the fish to be processed, ingredients used (i.e., brine, oil, tomato sauce), unit processes involved, and the source of the water. Furthermore, facilities that produce animal by-products must have floors with grids with an

[30] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32010L0075

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appropriate mesh size, which allows the retention of larger solid materials, in order to prevent their dragging (when cleaning equipment and floors) for effluent treatment system (whether in the case of Wastewater Treatment Stations/municipal or other treatment system existing in the establishments). The processing wastewater is generally treated using physico-chemical methods (primary treatment), biological methods (secondary treatment), or a combination of both. Primary treatments include processes such as equalisation, screening, sedimentation, pH adjustment, flocculation, flotation and microfiltration. The biological processes (aerobic and anaerobic) are known to be more appropriate for removal of dissolved organics and nutrients. A stepwise approach to wastewater treatment commonly yields the best results in the most economical way. The primary treatment deals with the removal of wastewater solids and colloids, as they should be removed quickly and with low-shear technologies to avoid dissolution of oil and organics into the water. It is followed by a wastewater treatment to collect substances lost during the process as it is the last possibility for pollution control and a good opportunity for recovering valuable substances.

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3. BREF AND THE SEAFOOD SECTOR

The possible BATs for the seafood sector are collected in the BREFs of food, drinks and milks industries (December 2019) and the BREF of slaughterhouses, animal by-products and edible co-products Industries (draft of June 2021) (Figure 6).

Figure 6: Cover pages of the reference BREFs used in the report.

The BREF documents on slaughterhouses, animal by-products industry and edible co-products (SAE[31]), and BREF document on food, drink and milk industries (FDM[32]) are based on an exchange of information carried out in accordance with Article 16 (2) of Council Directive 96/61/EC:

The "general approach adopted by the Council and the representatives of the governments of the Member States meeting within the Council in its Resolution of 1st February 1993 (4), considers integrated pollution control a priority, as it contributes considerably to progress towards a more sustainable balance between human activity and socio-economic development on the one hand, and the resources and regenerative capacity of nature on the other".

The BREF is structured in a way that first describes the techniques generally applicable to all industries where general information and good maintenance and operation practices are used. These are considered general techniques as

[31] https://eippcb.jrc.ec.europa.eu/reference/slaughterhouses-and-animals-products-industries
[32] https://eippcb.jrc.ec.europa.eu/reference/food-drink-and-milk-industries

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they can be applied to almost all activities. All techniques are described in the documents under the following subject headings: Description, Environmental benefits achieved, Cross-effects, Performance data, Applicability, Economic data, Driving force for application, Reference facilities and Reference documentation. The objective of the technical working group has been to include sufficient information to evaluate the applicability of the techniques in general and in specific cases. The standardized structure allows techniques to be compared both qualitatively and quantitatively. This information is essential for the determination of BATs. Some techniques are highly technical in nature and others are simply good operating practices, including management techniques.

BATs documents aim to consider the principal criteria of environmental performance of the techniques, while also considering operational aspects like costs. In addition, any technique to be considered as BATs must be based on solutions that are commercial, properly integrated in the industry and validated.

3.1 General considerations on the application of BATs in a seafood processing plant in BREF documents

For the seafood industry, there is one mandatory condition for any technique, and that is it must guarantee the food safety of the product at any point in the process where it is applied. The economic viability of the BATs identified, must be studied for each specific installation and according to the characteristics of the installation, considering factors such as the dimension of the facility, the type of products processed or age of the installation itself. In addition, some local factors may determine the technical viability of a given BAT.

In all BREFs, the techniques listed and described in the BAT conclusions are not described as prescriptive or exhaustive. Furthermore, they emphasize that other techniques may be adopted if at least an equivalent level of environmental protection is ensured. Unless otherwise specified, the BAT conclusions are generally applicable. Therefore, the aspects that can determine the applicability of BAT in each facility in accordance with its particular circumstances will be food safety, economic viability and local conditions and those of the installation itself. Similarly, the technical characteristic of each installation is another important factor that the authority in charge of granting the IEA, must consider when determining the emission limit values. Likewise, the BAT conclusions do not establish ELVs, but do report emission levels associated with the use of BAT.

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3.1.1 Slaughterhouses, animal by-products industry and edible co-products

The SAE BREF document is currently being redrafted from the version published and adopted in May 2005. Significantly, conclusions from Chapter 5, which included recommendations for additional BATs for by-product processing (FM and FO production, biogas production, composting, gelatine production, etc.) have now been eliminated and are based exclusively focusing on the description of techniques for minimizing emissions to air and water. Chapter 5 has been completely rewritten and is now presented in a level-based format, where 26 BAT conclusions are described (Figure 7).

The first level shows the sections containing the BATs (1-20) for all SAE facilities; the second level is divided into BATs specific to slaughterhouses (BAT 21-23) and conclusions specific to the processing of edible by-products and co-products (BAT 24-26) and the third level corresponds to a description of the different techniques recommended to reduce emissions to water and air from all facilities. Appendix I, provides greater detail on each of the BATs.

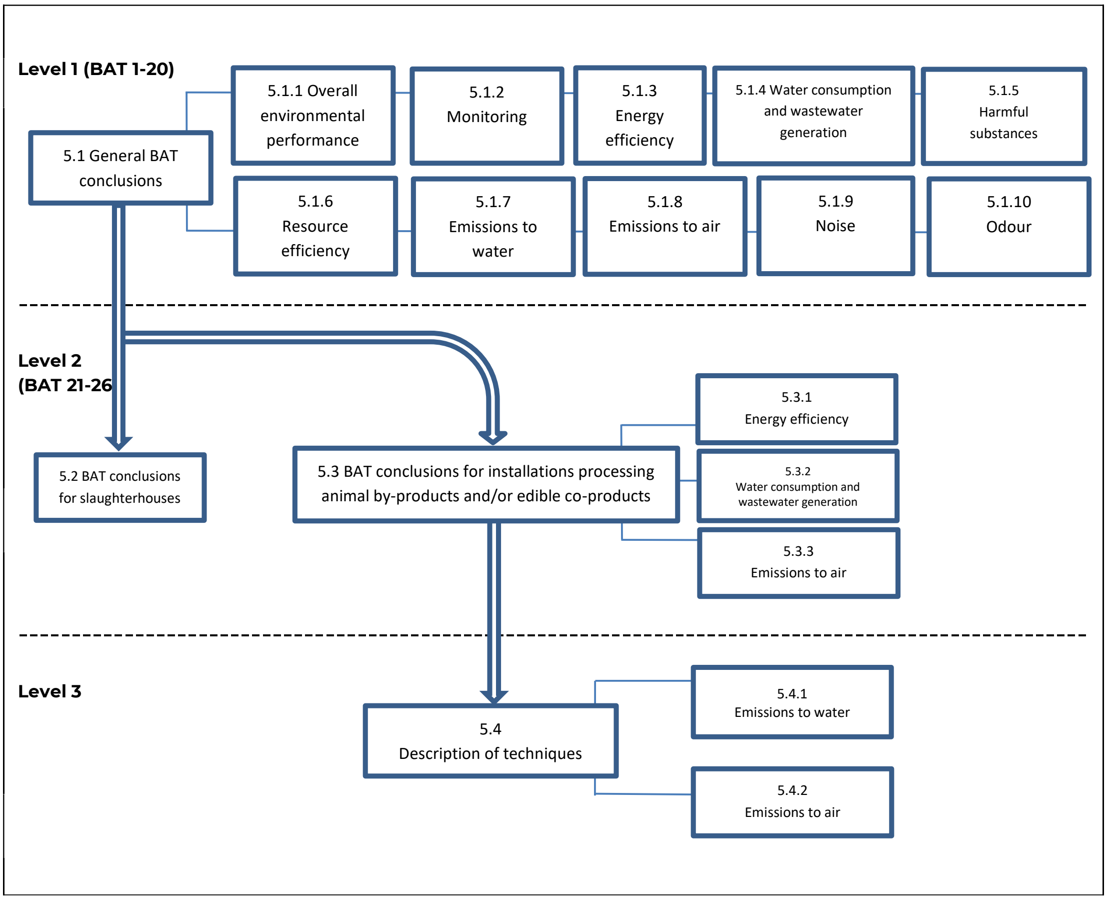

Figure 7: Chapter 5 - Best Available Techniques (BAT) conclusions for the slaughterhouses, animal by-products and edible co-products industries.[33]

[33] https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC113018_WT_Bref.pdf

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In addition to recommendations on how to optimize water management and its reuse, in the general conclusions, there are recommendations for plant cleaning to reduce water consumption and the amount of wastewater generated, leading to increased resource efficiency, etc. In relation to nutrient recovery, some general BATs (such as BAT 12) consist of using one or several techniques. Among the five techniques described, the following are the most relevant for nutrient recovery:

- ***Anaerobic digestion.*** *Treatment of biodegradable waste by microorganisms in the absence of oxygen, resulting in biogas and digestate. Digestate can be used as a soil amendment, by providing a fertilizing effect aimed at improving the quality in terms of structure and composition, adjusting its nutrients and pH. Although it may not be applicable due to the quantity and/or nature of the waste.*
- ***Recycling or recovery of separated waste.*** *Waste is separated, for example, by means of screening, trap doors, collecting bins, drip trays and feeders that are precisely positioned for recycling and recovery.*
- ***Phosphorus recovery as struvite****. Phosphorus contained in wastewater streams is recovered by precipitation in the form of struvite (magnesium ammonium phosphate). This is applicable only to wastewater streams with a high total phosphorus content (>50 mg P/l) and with a high flow rate.*

The other two remaining techniques are related to the correct handling and management of by-product storage, or the use of fats as a substitute for fossil fuels.

Some of the conclusions of the BREF for reducing emissions to water (BAT 13), propose techniques such as hydraulic buffering, which can be a solution to avoid uncontrolled emissions, as it provides adequate buffering capacity to control the wastewater generated. However, this type of application requires a certain evaluation of the risks (nature of the pollutants, effects of further treatment, receiving environment, total quantities of treatment and emission, etc.) to be adopted in the form of the most appropriate measures (control, treatment and reuse). In addition, for applicability in the case of existing facilities, this technique may not be suitable due to insufficient space or inadequate wastewater collection systems.

Another BAT, which may not be suitable for the same reasons as BAT 13, is the application of BAT 14, which involves the use of a combination of different techniques to reduce these emissions to water, combining up to a total of 14 different techniques (equalization, neutralization, physical separation, precipitation, evaporation, chemical oxidation with ozone, aerobic and/or anaerobic treatment, nitrification and/or denitrification, precipitation, enhanced biological phosphorus removal, coagulation and flocculation, sedimentation, filtration and flotation).

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From BAT 24 (second level), specific BAT conclusions are presented for installations processing ABPs and/or edible co-products, which are applied in addition to the general BAT conclusions (BAT 1-23).

For by-product and/or co-product from processing plants which are edible, the use of BAT 24 to increase energy efficiency is based on using an appropriate combination of the techniques specified in BAT 9 (combination of (a) energy efficiency plan and energy audits, and (b) use of general energy-saving techniques) and multistage evaporators. Processes which occur in this technique include the use of evaporators, which remove water from liquid mixtures generated (i.e., during fat melting, rendering) during FMFO production.

In the case of water consumption and wastewater generation (BAT 25), the conclusions are based on the information given in the corresponding sections of “current emission and consumption levels for rendering of ABPs, FM and FO”. In the case of by-products, consumption and emission data are generally expressed as “per tonne of by-products treated”. This also facilitates the examination of the relationships between different processes and their actual consumption and emission levels, while at the same time, avoiding an assessment of data that is erroneous as, for example, in the case of data based on low concentrations that may have been collected after dilution of the effluent by excessive water consumption.

According to this information, maximum emission limits are established for each technique used (Table 3).

Table 3: *BAT-Associated Environmental Performance Levels (BAT-AEPLs) for specific wastewater discharge (m^3/tonne of raw material)*.

Type of installation/process(es)	Specific wastewater discharge [1] (Yearly average)
Rendering, fat melting, blood and/or feather processing	0.05–1.55
Fishmeal and fish oil production	0.20–1.25

[1] m^3/tonne of raw material

It should be noted that special attention has been taken to ensure that the BAT conclusions do not conflict with the rules of Regulation (EC) N° 1069/2009 of the European Parliament and of the Council of 21st October 2009, establishing health rules concerning ABPs not intended for human consumption, which lays down rules for the handling, storage, transport and treatment of ABPs. In addition, consistency has been ensured with other

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pieces of legislation related to, i.e., public health, food safety, animal welfare and workplace health and safety.

3.1.2 Food, drink and milk industries

In food, drink and milk (FDM) industry BAT conclusions, raw materials are considered to be any material brought into the facility, whether already treated or processed for food or feed production (packaging is not included in the product weight).

In order to increase resource efficiency on FDM BREF, BAT 10 proposes the use of several techniques, which are the most important for nutrient recovery:

- ***Anaerobic digestion.*** *Same description as in the previous case.*
- ***Waste utilization.*** *The residues (by-products) are used, for example, as animal feed. May not be applicable due to legal requirements.*
- ***Recovery and reuse of pasteurizer residues.*** *Pasteurizer residues (by-products) are reused in the mixing unit and thus reused as raw materials. Applicable to liquid food products only.*
- ***Phosphorus recovery as struvite.*** *Same description as in the previous case. Also describe its use after appropriate wastewater treatment, the wastewater is used for spreading on land to exploit the nutrient content or to utilize the water.*
- ***Use of wastewater for land spreading.*** *Only applicable in case of demonstrated agronomic benefit, low pollution and no negative effect on the environment (i.e., soil, groundwater and surface water). The applicability of this technique may be limited by the scarcity of available suitable land adjacent to the facility. Applicability may be limited by local soil and climatic conditions (i.e., in the case of wet or frozen fields) or by legislation.*

In the case of phosphorous recovery, the insoluble struvite crystals formed contain an equimolar amount of magnesium, phosphate and ammonium ions. The different struvite precipitation techniques differ from each other mainly by the type of pre-treatment in the preparation of the waste for struvite formation (fermentation, hydrolysis, etc.) and the type of wastewater from which the crystal is to be recovered. Therefore, this technique may be of interest for recovering more nutrients than just phosphorus, and its use in different applications such as fertilizers, where phosphorus and nitrogen are important micronutrients for plant growth and plant development.

Once again in FDM BREF, as in the SAE BREF, the phosphorus recovery technique in the form of struvite is highlighted as the only nutrient recovery technique for wastewater streams with a high total phosphorus content (above 50 mg P/l) and a significant flow. The rest of the techniques described in the BAT are aimed at improving the removal of compounds present for minimize emissions.

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4. GENERAL SECTORAL BATS FOR INDUSTRIAL EMISSIONS TO WATER

For most seafood processing and aquaculture facilities, wastewater generation is the main environmental aspect of concern. This is due to the emissions to water from processing activities and waste streams that result from the processing of by-products for the production of FMs and animal feed.

This aspect is closely related to the level of water consumption of the activity or system and is another aspect of great relevance. Most of the water used in seafood processing facilities forms part of the wastewater. The rest can be incorporated into the final product, can be lost through evaporation, or can leave the facility as part of the solid waste and by-product material. All the techniques to be considered for the determination of BATs included in the BREFs are always oriented towards the application of technologies that achieve a reduction or minimization of the compound generated. In most cases, there is no reference to more efficient use and/or a more circular economy-oriented approaches to the relevant compounds, which can be recovered at later stages and/or which may have a high added value in the future (Figure 8).

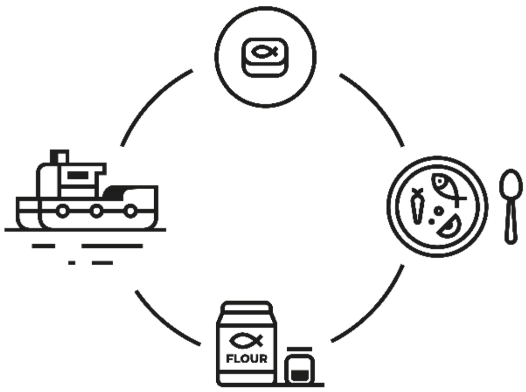

Figure 8: A diagrammatic overview of seafood circularity.

An example of the application of the circular economy in the context "waste to industry" in the seafood sector, could be the use of waste from the shrimp processing industry for obtain resources with high added value, that achieve a reduction or minimization of the compound generated. As a way to recover and transform the remains of the exoskeleton of crustaceans, that are usually treated as waste, high added value products such as chitosan or phenolic compounds derived from lignin can be obtained by extracting their chitin. The mechanical, filmogenic and antimicrobial properties of chitosan can be used in industries such as food, pharmaceutical, cosmetic, etc. in the form of films or alternative forms of packaging (Figure 9). In addition, the polymeric films obtained from chitosan generate waste that can be treated as organic waste, since its degradation is carried out in short periods of time, resulting in a more responsible use of resources in a sustainability approach.

Figure 9: Example of shrimp processing industry under a CE approach (www.biobridges-project.eu)[34].

Water availability is influenced by factors such as climate, hydrogeology, and general demand for water use which is also influence by its price. These will also influence when considering whether or not consumption is a key environmental issue at the installation level. The Water Framework Directive requires water pricing policies to provide adequate economic incentives to promote more efficient consumption so that the water resource is not wasted. In general, the BREF document only identifies BATs to achieve minimization of water consumption. This wastewater treatment consumes large amounts of energy and sometimes chemicals are used, which can also cause odour problems.

Every time the water is exposed to a production channel or a type of ABP, both during the production process and during cleaning, it carries with it a series of contaminants such as fats or fluids derived from blood, which causes a considerable increase in the biological load to the wastewater treatment plant. Also, when fats are melted in hot water, any subsequent separation process is made more difficult. This consideration of minimizing both the consumption and the pollution of the water that is released, produces a series of environmental benefits, since an increase in the volume of water used has a direct impact on a greater volume of wastewater that will have to be

[34] https://www.biobridges-project.eu/news-events/news/enhancing-the-shelf-life-of-fish-products-through-packaging-material-made-from-fish-and-marine-waste/

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subsequently treated in wastewater treatment plants (on-site or at municipal facilities).

Processing companies in this sector, have wastewater with a high organic pollutant load, in addition to other secondary and auxiliary materials which have been added in the manufacturing processes. The addition of auxiliary services, such as nutrient recovery treatments can help to reduce these impacts. The existing differences in the characteristics of the wastewater generated in the different facilities depend, among other factors, on the type of product to be processed, the equipment and technology used for the production process, the cleaning methodologies, and the chemical products used.

Industrial wastewater, as well as all wastewater discharged and used for any commercial or industrial activity, has been defined by Directive 91/271/EEC on Urban Wastewater Treatment. The effluent pollutant load depends on the type of seafood being processed. For example, the load generated from processing blue fish species (i.e., anchovy, sardine, mackerel) generally is higher than that generated from white fish species (i.e., hake, cod, monkfish). This difference is due to the high fat content and the fact that blue fish species are not normally eviscerated on fishing vessels.

Another characteristic of the processing of fishery and aquaculture processing products that significantly influences the effluent pollutant load is the high rate of spoilage of fish and fish by-products. As the quality of the raw material deteriorates over time, the yields decrease, and product losses contribute to higher waste loads. The wastewater stream can be increased by the elimination of body fluids, such as blood and other liquid constituents from the internal organs of the fish (i.e., fish gills and guts). Clearly, the existence of these substances in the effluent will depend on the correct gutting of the fish on the catching vessels and the precision with which this operation is carried out, since even if the fish arrives headless and gutted it may contain traces of the internal organs and blood.

These raw material losses can end up in wastewater streams if appropriate segregation measures are not taken. These wastewater streams may contain muscle trimmings, bones and viscera soluble substances. For example, in canning lines a considerable concentration of fats and proteins from the cooking processes are lost and may not properly be exploited as a form of nutrient recovery.

The contribution to the final discharge of this collection of liquid streams (blood, internal fluids, etc.) is minimal in terms of flow rate if the large volumes contributed by other operations are considered. However, their contribution in terms of pollutant load is very high, as each of these discharges individually has very high chemical oxygen demand (COD) concentrations.

Operations such as salting and washing of salted parts have the greatest impact on the efficiency of the final effluent treatment. This operation can contribute to high concentrations of salt in the wastewater, which can reduce treatment quality and adversely impact on biological treatment or depuration systems/stages.

The emission levels associated with the best available techniques (ELVs-BAT) for emissions to water given in BAT conclusions refer to concentrations (mass of substances emitted per volume of water), are expressed in mg/l. The ELVs-BAT for emissions to water, apply at the point where the emission is discharged from the installation.

The ways that these ELVs-BAT can be determined are:

- In the case of a continuous discharge, the average values are expressed every working day, i.e., 24-hour flow-proportionate samples. Time-proportionate pool samples may be used if sufficient stability of the flow rate is demonstrated. As an alternative, point samples may be taken, provided that the effluent is properly mixed and homogeneous.

- In the case of batch discharge, the average values over the duration of the discharge, will be taken as flow proportionate replicate samples or, assuming that the effluent is adequately mixed and homogeneous, as a point sample taken pre-discharge.

In the SAE BAT conclusions, in the case of COD, the calculation of the average reduction efficiency is based on the WWTP effluent and influent load. The mains sources in seafood wastewater that influence COD levels are organic in nature and can include blood, viscera and cooking waters (Table 4). Solid's concentrations can be influenced through the level of bones, residues or organ meats that find their way into the wastewater streams. In terms of other nutrients such as phosphates and nitrogen forms, these can be influenced through the levels of viscera and blood.

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Table 4: Main parameters, sources, techniques and possible use of organic compounds in wastewater of seafood processing sector (Adapted from SAE BREF conclusions).

Parameters	Principal Sources	Main Techniques	Potential uses
Organic material	blood, cooking waters, viscera, washing waters, etc.	Equalisation, Neutralisation, physical separation.	FM, FO, peptides,
Suspended solids	guts, fish bones, fish residues	Coagulation, flocculation, filtration, flotation.	FM, FO, peptides, collagen, gelatine,
Fats and oils	cooking waters	Fat separators	FO, fuel
Phosphates	cooking waters, viscera and blood	Precipitation	Fertilizers.
Nitrogen	viscera and blood	Nitrification and/or denitrification	Fertilizers, Biochar, Compost
Salt	salting and washing/peeling	Precipitation, Evaporation	Fertilizers

The emission levels given below are considered to be appropriate to protect the aquatic environment and are indicative of the emission levels that would be expected to be achieved when applying the techniques that are generally considered to be BAT. The values do not necessarily represent the levels currently available in the industry but are based on the recommendation of the Technical Working Group (TWG)[35]. It should be highlighted that the ELVs-BAT are applied at the emission exit point of the installations, and therefore only on the emission levels associated with the BATs for direct discharges to the receiving water flow, regardless of the type of raw material to be processed or the type of installation (Table 5). These ranges have suffered a considerable reduction with respect to the acceptance values within the old SAE BREF, it is also noteworthy that the new BREF does not include fats and oils.

[35] These working groups are set up by the European IPPC Bureau.

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Table 5: Associated emission levels (AEL) with BAT for minimizing wastewater emissions from slaughterhouses, animal by-product facilities and edible co-products (draft SAE BREF version of June 2021).

Parameter	New BAT-AEL (mg/l) (1) (2)	Old BAT-AEL (mg/l) (1) (2)
Chemical oxygen demand (COD) (3) (4)	25–100 (3)	25 – 125
Biological oxygen demand (BOD) (2)	-	10 – 40
Total organic carbon (TOC) (3)	7–35	-
Total suspended solids (TSS)	4–40 (5)	5 – 60
Total nitrogen (Total N)	2–25 (6)	15 – 40
Total phosphorus (Total P)	0.25–2.5	2 – 5
Fats and oils	-	2.6 – 15

(1) The averaging periods are defined in the General considerations.
(2) No BAT-AEL applies for biochemical oxygen demand (BOD). As an indication, the yearly average BOD_5 level in the effluent from a biological wastewater treatment plant will generally be ≤ 20 mg/l.
(3) Either the BAT-AEL for COD or the BAT-AEL for TOC applies. The BAT-AEL for TOC is the preferred option because TOC monitoring does not rely on the use of very toxic compounds.
(4) The upper end of the BAT-AEL range is 120 mg/l for installations processing animal by-products and/or edible co-products, only if the abatement efficiency is ≥ 95 % as a yearly average or as an average over the production period.
(5) The lower end of the BAT-AEL range is typically achieved when using filtration (i.e., sand filtration, microfiltration, membrane bioreactor).
(6) The BAT-AEL may not apply when the temperature of the wastewater is low (i.e., below 12 °C) for prolonged periods.

Wastewater in FMFO processing installations is normally produced from the water content extracted from the raw material during processing and from seawater used (in cases where it is used) in washing and cooling processes in the scrubbers and evaporators. These wastewaters contain high loads of organic matter, suspended solids, nitrogen, phosphorus, dimethylamine and trimethylamine. Concentrations of sodium hydroxide and sulfuric acid in wastewater are derived from the use of detergents.

The highest emission levels occur in industries that do not usually have flow and level optimization, segregation, water reuse and dry cleaning. However, as can be seen in the new BREF (Figure 10), it is interesting to highlight that the 4 plants with the highest values (wastewater discharges >10 m^3/tonne product produced) have a specific waste management plan.

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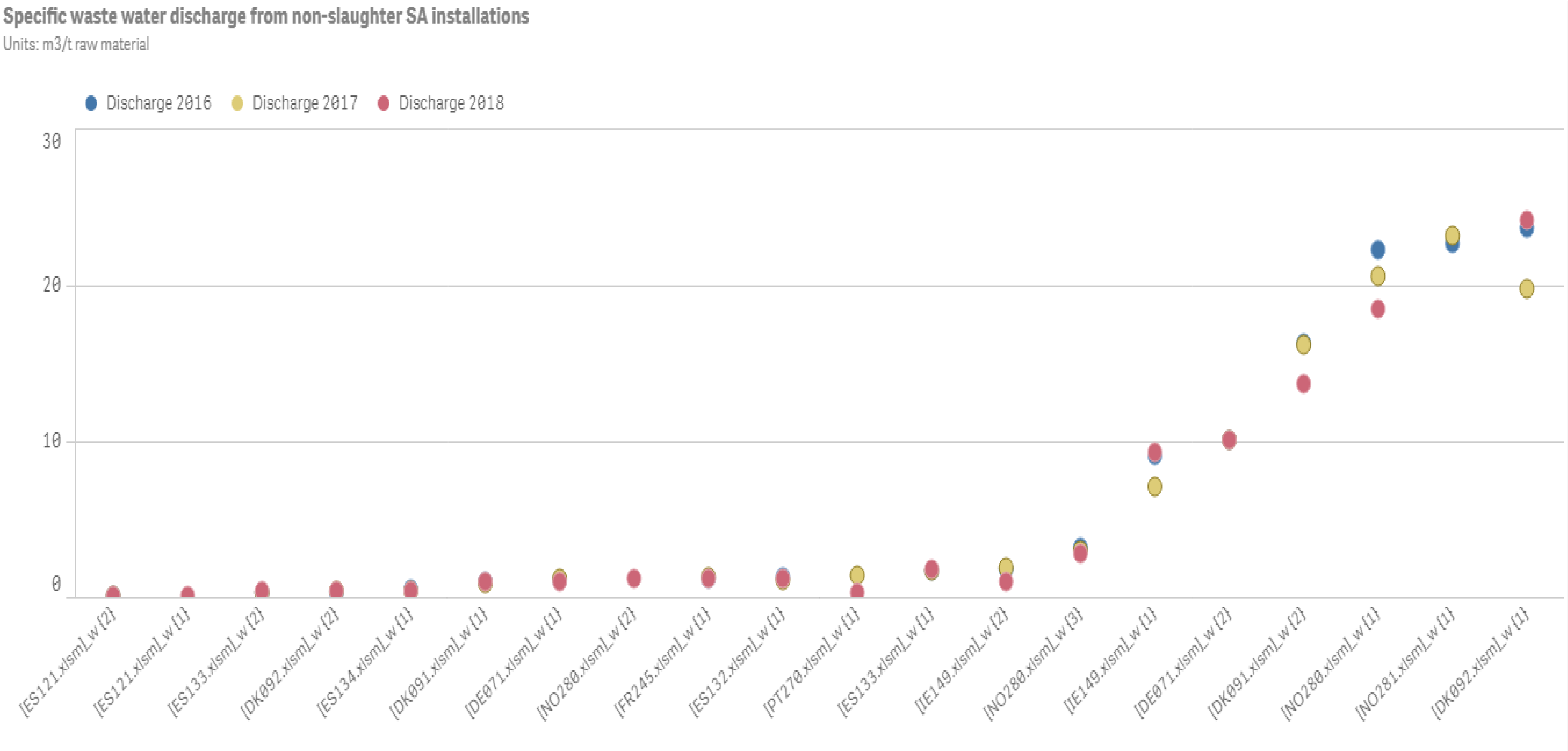

Y-axis indicates the m^3/tonne of raw material produced. Y-axis indicates the study sites.

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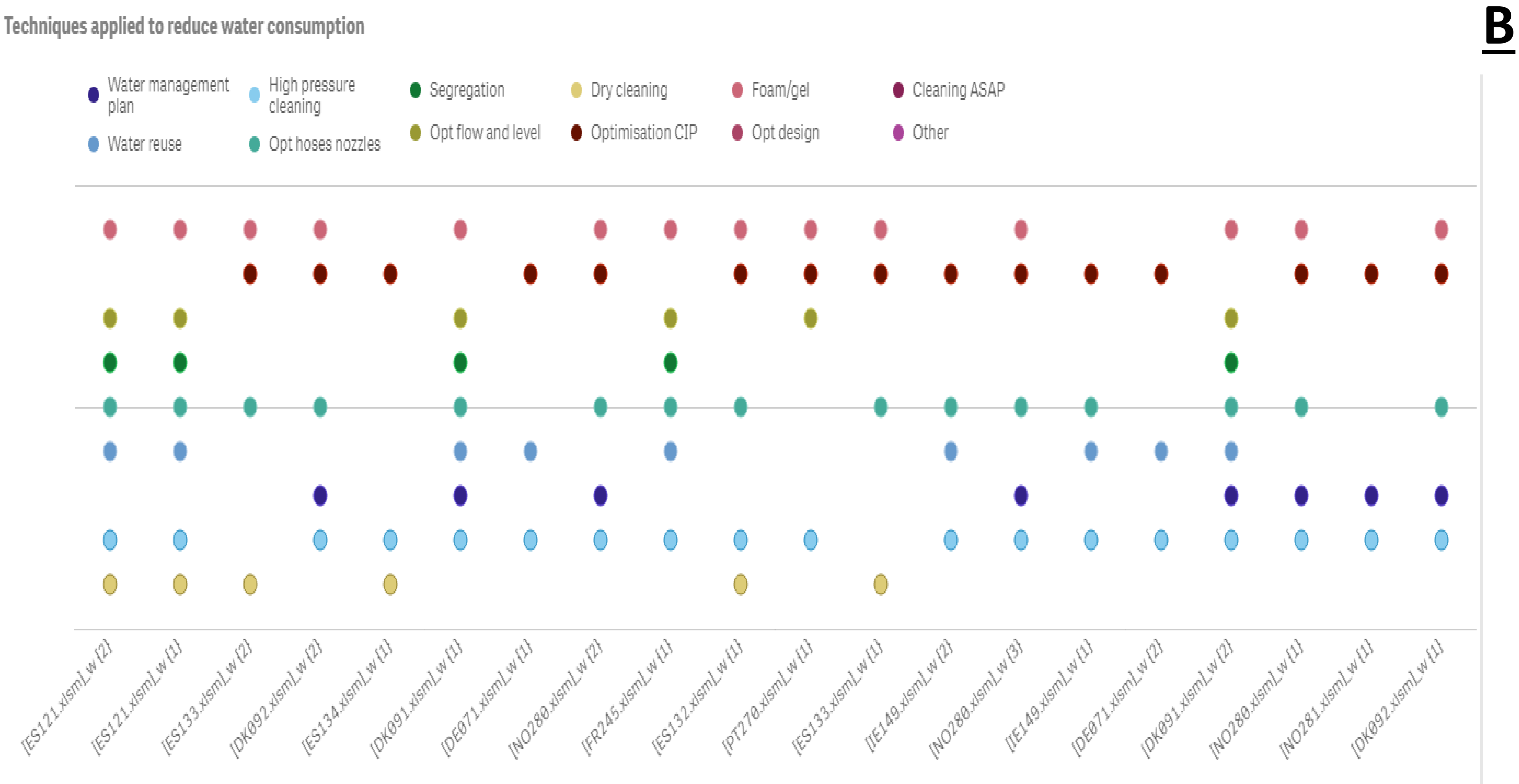

Figure 10: Reported data from installations on specific wastewater discharges in m^3/tonne of raw material from fishmeal and fish oil production (A) total discharge types and (B) techniques applied to reduce water consumption are also shown. SA in the image A, refers to slaughterhouses and animal by-products.

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Biological wastewater treatment is a depuration alternative that can be adopted in many situations, such as in the case of effluents with high BOD values, when discharge limits are very restrictive, or when discharge costs are very high. This type of treatment is described in the BAT conclusions as more appropriate for installations with a high organic load in their effluents and where there are no pronounced variations in their production (i.e., seasonality or quality of the raw material or other reasons), as these systems are somewhat sensitive to changes in the composition and volume wastewater that they receive. The selection of technologies and techniques will need to be based on investment and operational costs and considerations.

There are two main systems for biological treatment: aerobic and anaerobic systems. In the seafood industry it is more common to install aerobic treatment systems. The basic principle of aerobic treatment of organic waste is the conversion of organic solids into CO_2 and sludge with a high biomass rate. The conversion is carried out with high O_2 input to the reactor, using mechanical agitation or diffusion. The most common and versatile method for the treatment of industrial wastewater is activated sludge. However, the most suitable type of treatment system depends, among other factors, on the available space and operating conditions. After the aerobic treatment, the sludge generated is purged and a portion of it is recirculated to the biological reactor to replace biomass losses that are produced throughout the system (i.e., return activated sludge).

The implementation of a sludge treatment system will be necessary in the case of aerobic installations, because sludge generation through this system is generally abundant. The treatment system usually consists of a thickening unit and a dewatering system by means of a press, filter or centrifuge to concentrate the sludge.

Some examples of BAT solutions for aerobic treatment include the installation and use of drains with filters and/or collectors to prevent solids mixing with wastewater; the use of systems known as «*cleaning-in-place*» or CIP, etc.

In the case of the FDM BREF, the levels associated with the BATS (ELVs-BAT) that are applicable to direct emissions to the receiving water body, applied directly at the outlet emission point of the facility, are also included. In this case they only include values for COD, total suspended solids, total nitrogen and total phosphorus (Table 6).

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Table 6: Emission levels associated with BAT for minimizing wastewater emissions direct to receipt chamber[36]**.**

Parameter	BAT-AEL (daily average) (1)
Chemical oxygen demand (COD) (2)(3)	25–100 mg/l
Total suspended solids (TSS)	4–50 mg/l (4)
Total nitrogen (Total N)	2–20 mg N/l (5)(6)
Total phosphorus (Total P)	0.2–2 mg P/l

(1) The BAT-AELs are not applicable to emissions from dry pet food and compound feed production.
(2) There are no BAT-AELs applicable to biochemical oxygen demand (BOD). As a guideline, the average annual level of BOD5 in the effluent of a biological wastewater treatment plant will generally be ≤ 20 mg/l.
(3) The BAT-AELs for COD can be replaced by a BAT-AELs for TOC. The correlation between COD and TOC is determined on a case-by-case basis. The BAT-AELs for TOC is the preferred option since its monitoring is not dependent on the use of highly toxic compounds.
(4) The lower end of the range is typically reached when filtration (i.e., sand filtration, microfiltration, or membrane bioreactor) is used, while the upper end is typically reached when sedimentation alone is used.
(5) The upper end of the range is 30 mg N/l as a daily average only if the reduction efficiency is ≥ 80 % annual average or averaged over the production period.
(6) The BAT-AELs may not be applicable when the wastewater temperature is low (i.e., below 12 °C) for extended periods.

The recommended value for COD is the same in both BREFs. However, there are slight differences in other parameters. For example, a slightly higher value up to 50 mg/l is recommended for TSS (10 mg/l more in the maximum limit) and there is a reduction in the maximum limits for TN (from 25 to 20 mg/l) and TP (from 2.5 to 2.0 mg/l) and in the lower limit for TP emissions (from 0.25 to 0.2 mg/l).

General techniques to reduce water consumption and the volume of wastewater discharged are presented in section 1.4 of the conclusions of this FDM BREF. To reduce the amount of waste for disposal, BAT 19 recommends use of one of the 2 techniques described below:

- **Recovery and (re) utilization of yeast after fermentation:** After fermentation, the yeast is collected and can be partially reused in the fermentation process or can be reused again for multiple uses, i.e., for animal feed, in the pharmaceutical industry, as a food ingredient, in an anaerobic wastewater treatment plant for biogas production, etc.
- **Recovery and (re) use of natural filter material:** After chemical, enzymatic or thermal treatment, natural filter material (i.e.,

[36] https://eippcb.jrc.ec.europa.eu/sites/default/files/2021-06/SA-BREF-20210629.pdf

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diatomaceous earth) can be partially reused in the filtration process. Natural filter material can also be used (i.e., for soil conditioning).

In seafood BATs special attention must be paid to gelatines. The sludges from the treatment of gelatine manufacturing wastewater and the sludge generated during processing are regarded as excellent fertilizers and soil conditioners. These sludges are defined as rich in calcium, nitrogen and phosphorus contents and have potential for use as fertilisers, if the needs of the soil match the nutrient level of the sludge. One of the economic advantages of using sludge as fertilizer is that there are lower operational costs when compared to those associated with waste management and the removal of the waste.

There is a general trend in the BREF conclusions to reduce emissions, through the tightening of standards and reducing the monitoring intervals and the emission loads permitted. This current strategy in the BREFs does not provide the attention that is required to a promote the recovery of nutrients that are lost during the treatment process, with the notable exception of phosphorus (i.e., recovery of phosphorus as struvite). This approach should be redirected and aligned with a more environmentally efficient strategy such as the change of paradigm of depuration or circular economy. Given the emerging role that a circular economy will play in all European industries and sectors it would be timely that the future BREFs, consider energy use in wastewater treatment to meet ELVs and rather to focus on the valuable resources that can be derived or captured in BATs, with value-add opportunities. Likewise, this also depends on the sector itself to implement and realise these opportunities. Industry must redefine their production strategies, towards more diversified offerings within the fishing and aquaculture sector, in order to successfully valorise or capitalize on the value in their waste streams.

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5. EMERGENT TECHNOLOGIES FOR NEW STRATEGIES IN NUTRIENT RECOVERY

It should be considered that in the fisheries and aquaculture industries there are two main types of potential valuable products, which are often not adequately valued:

1. the effluents, sludge and wastewater coming from water processes (i.e., cooking effluents),
2. different biological discards and by-products resulting from industrial processing.

Studies on the valorisation of liquid effluents (wastewater) are very limited. However, it is possible to extract pigments, proteins or aromatic substances from these compounds (Tremblay et al., 2020). Regarding the sludge, alternative management could generate new resources, generating valuable elements such as carbon and different nutrients (Gherghel et al., 2019).

BREF documents describe emerging techniques that may be used in the seafood sector. For these techniques, efforts should be made to include only those techniques that are at an advanced stage of development and such that there is a high probability that they may become BAT in the near future. In relation to the emerging techniques described the reason they are understood to be novel, a description of the same and their potential environmental performance in comparison with the existing best available techniques should be described. For example, the emerging technique provides a higher level of environmental protection (or at least the same level of environmental protection) as those already proposed and that there are higher cost savings than those that would be obtained with the current BATs. Additionally, operational considerations such as the time until they become commercially available should be included. This is covered and explained in Article 3, point 14, of Directive 2010/75/EU to define any technique as an "emerging technique". The techniques listed in this section will be taken into consideration in future revisions of this document.

5.1 Bioreactors and biofilms

Within the SAE BREF there are two general techniques and one technique for facilities processing ABPs and/or edible co-products. Two of these techniques are not yet commercially applied and are in the research or development stage. These techniques are the use of (i) heterotrophic microalgal bioreactors to convert organic matter, nitrogen and phosphorus in wastewater into biomass suitable for energy production (i.e., biodiesel) and (ii) the use of microbial fuel cells that use bacteria as a catalyst for converting organic matter into electricity, meaning that the use of energy recovery from organic material and can achieve a significant reduction of COD, BOD, TSS and total

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nitrogen content in wastewater. The last of these is (iii) hydrothermal liquefaction technique, specific for by-product plants. It is a method of decomposition and valorisation of biomass, comparable to gasification and pyrolysis to convert biomass into a thermally stable fuel product, also known as biocrude, which can then be thermocatalytically upgraded to obtain hydrocarbon fuel blends.

These three techniques are aimed at increasing energy recovery in seafood supply chains. Moreover, as mentioned above, the current draft BREF generally focuses on waste and energy minimization, and not on value added reuse of nutrients for purposes other than energy. In this sense, apart from those already mentioned, there are different proposals both at laboratory scale and already in a commercial state.

Through research at a European project level, different combinations of technologies have been tested which may be of interest for evaluation as future BATs. For example, the potential of two technologies based on biofilm processes (aerobic granular sludge and hybrid bioreactors) was installed and demonstrated in a fish canning industry located in the Rías Baixas (Galicia), where almost 80% of the Spanish fish canning companies are concentrated, under the LIFE SEACAN[37] project. Biofilm processes have been successfully applied in various industrial sectors but have not yet been used on a full production scale for canned fish effluents. Preliminary tests conducted on a smaller scale, reveal remarkably high effluent quality with a simultaneous reduction in energy consumption and the associated carbon footprint compared to conventional wastewater treatment technologies. In these tests, energy consumption was reduced by at least 20%; effluent quality improved by removing up to 90% of nitrogen and 95% of organic matter; and carbon footprint reduced by 25%.

Another example is the development of a pilot scale system for the valorisation of wastewater from the fish canning industry, within the framework of the FISHPOL[38] project (Sustainable system for the valorisation of fish canning wastewater for biopolymers production). The system uses the organic matter present in the wastewater from the fish processing industry to obtain value added products such as polyhydroxyalkanoates (PHAs), a type of biopolymers also known as bioplastics. This process is proposed as an alternative to the wastewater treatment systems in operation in the sector, which often have limited disposal capabilities and are characterized by their lower environmental impact. The overall pilot scale system consists of an acidification reactor, a second unit of enrichment to select the PHA cumulative microorganisms and a third unit where the maximization of PHA accumulation is carried out by means of the previously enriched mixed

[37] http://www.life-seacan.eu/
[38] https://biogroup.usc.es/?q=node%2F3182&fbclid=IwAR2IEPvIPtyZE08OBUdSz4boykJmIb-h6Tgg8DArQKMPNZgc527G0xg6oQM

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cultivation. The operation of this system is completed with the integration of a nitrogen removal system to ensure the reduction of the eutrophication potential of the final effluent produced.

5.2 Integrated multitrophic aquaculture

In aquaculture facilities, the AQUAVAL[39] project (Valorisation of water use in aquaculture using multi trophic systems) aimed to develop technological solutions for the treatment of water used in freshwater systems. The technological solutions aimed to create a complete treatment system to eliminate pollutants and valorise effluents in accordance with the principles of the circular economy. The treated water was tested for specific concentrations for recycling/reuse at the production facility or discharge into natural water sources, using biological treatment technologies where the biomass was cultivated in the form of granules and enriched in microbial populations capable of recovering nutrients and eliminating micropollutants. Nitrogen was removed from the water in systems other than the biofilters currently used, and a bivalve filtration unit was maintained with the output water from the technology described above, in order to test the growth capacity of the bivalves and improve the efficiency of the proposed system.

New projects as ReFish-to-Food[40] explore innovative forms for obtaining new sources of protein from fishery by-products and discards. For that, a new technology based on the anaerobic digestion and dark fermentation processes will be developed to obtain the single cell protein (SCP) using as raw material sub-products from the seafood processing industry. It is expected that results obtained in the ReFish-to-Food project could improve different aspects as characterizing almost five suitable sub-products identifying their physic-chemical characterization and their bioC and bioH2 production potential; assessing the environmental profile of the SCP production using LCA; making available to the companies a new and more sustainable protein resource to integrate into their current products and demonstrating synergies between a seafood processing industry, which generates sub-products, and a protein marketer company.

As an alternative potential solution to liquid wastes for aquaculture and fish processing, the cultivation of high nutritional value microalgae in IMTA systems presents great potential. Ammonium (NH^{+4}) from protein metabolism is the main nutrient in aquaculture effluents. Generally, in intensive aquaculture systems, solids are removed by sedimentation or screening, and ammonium is converted to nitrate (NO_3), through nitrification in bacterial filters. Therefore, current effluent treatment technology depends on expensive bacterial systems and does not add value to the process beyond

[39] http://www.waterjpi.eu/joint-calls/joint-call-2016-waterworks-2015/aquaval
[40] http://www.anfaco.es/blog_ct/index.php/2022/01/26/

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the removal of nutrient pollutants from the effluent. Microalgae can be used for efficient collection and recycling of nutrients in aquaculture effluents, reducing COD, BOD and removing heavy metals. However, when used for heavy metals removal, reuse opportunities for the algae may be limited. To further enhance the economic strength of IMTA systems, the extraction of high value-added compounds from algal biomass (fatty acids, pigments, polysaccharides, etc.) can be derived. These compounds can be valorised in premium animal feeds (Milhazes-Cunha et al., 2017) or in some instances be feedstocks for biobased plastics or fuels (Laurens et al., 2017).

The use of microalgae produced in wastewater as animal feed, and in particular aquaculture wastewater, is a potential way to valorisation and is governed under Regulations (EC) N° 183/2005 and (EC) N° 767/2009. Furthermore, microalgae are not included in the latest version of the Catalogue of Feed Materials, but at the same time, they are extensively used in the cultivation of bivalves and live feed, both fresh and in the form of commercial products (GAIN, 2019; Cunha & Otero, 2017).

Through this effluent valorisation, small-scale aquaculture could change in the direction of IMTA approaches, including the farming of low trophic level products. IMTA is presented as a very interesting system to achieve maximum optimization of farming methods and techniques, with the ultimate goals of gradually decreasing the impact of aquaculture on the environment and to produce biomass of high environmental and economic value in a sustainable way. However, land-based IMTA systems are strongly affected by Regulation (CE) No 767/2009 on the circulation and use of feed, according to which animal waste may not be fed to other animals, both food-producing and non-food-producing (Article 6, Annex III). This regulation excludes the option of introducing filter feeders or detritivores in the system that feed directly on fish waste, and therefore limits the potential of IMTA to contribute the implementation of the aquaculture in the EU (GAIN, 2019).

This should be reconsidered in near future, because, for example, the implementation of the IMTA would reduce the high cost of feed production for the rearing of spat (oyster larvae), which is one of the major barriers to the expansion of farmed bivalve aquaculture. Further research is needed to propose regulatory exemptions for systems where risks are low and where there is a potential for increased food production with better environmental implications. This will require major changes in policy and legislation to replace the conventional single species approaches to incorporate biculture and policulture through mechanisms such as the EU Aquaculture Advisory Council to develop health and food legislation that directly supports the safety of IMTA products.

Closed and recirculating aquaculture systems (RAS) can often be excluded from certain high value classifications. For example, aquaculture products

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from a RAS, under current legislation cannot be certified as organic (Meisch and Stark, 2019; Warrer-Hansen, 2015), which can limit the acceptance of these systems in markets where organic status is a unique selling point (i.e. Ireland – organic salmon and mussels). However, there is precedent for products from open water IMTA systems being certified as organic in other jurisdictions (Chopin et al., 2014).

5.3 Ammonia recovery

Other examples of industrial applications for the recovery of these nutrients are the AMREWAS[41] project (ammonium recovery and plant-based water purification from nitrogen-rich wastewater) which demonstrated the use of stripper-scrubber combinations for ammonia recovery followed by an aerated reed bed as further purification. The ammoniacal nitrogen was recovered in the form of an ammonium nitrate solution (25%), which can be used by fertilizer factories or applied locally by farmers. The INFUSION[42] project (Intensive treatment of waste effluents and conversion into useful sustainable outputs: biogas, nutrients and water) investigated the environmental impact that can be reduced by producing renewable energy (biomethane), recovering bio-fertilizers (sludge and ammonium salts), using regenerated membranes, and using treated water for irrigation in water-scarce areas.

Nitrogen removal in wastewater treatment has been studied in large-scale plants, using techniques such as nitrification/denitrification (autotrophic nitrification-denitrification with limited oxygen, aerobic nitrification-denitrification with Bacillus), or deammonification techniques such as anaerobic ammonium oxidation and algal-nitrifying bacterial consortium (Beckinghausen et al., 2020). The techniques used for nitrogen recovery can be chemical (struvite precipitation), physical (membrane processes, filtration, adsorption, stripping, etc.), biological (microbial electrolysis cells, microbial fuel cells and microbial desalination cells) or a combination of several processes. (Beckinghausen et al., 2020; Ukwuani et al., 2016; Tao et al., 2015; Booker et al., 1999) Most wastewater treatment plants actually employ energy-intensive nitrogen removal methods that provide no additional benefit other than meeting effluent concentration limits. Ammonia rich water can be used to grow algae or bacteria that could be used in the biogas/biofuels industry, as a food source for animals or humans, or as fertilizer, however, the microorganisms cannot be fully accepted as fertilizer due to the high concentration of metals and other contaminants that may be present in the biomass along with the nitrogen. Therefore, this process must be improved to ensure a product that is an alternative to the direct application of nitrogen-

[41] https://www.detricon.eu/research-projects
[42] https://eurecat.org/es/portfolio-items/life-infusion/

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rich recovery solutions on agricultural fields (Beckinghausen et al., 2020; Walsh et al., 2012).

5.4 Animal by-product valorisation

For solid waste, the by-products of processing, such as heads, skin, fins, bones, guts and scales, could be important sources of new high quality and high commercial value compounds such as proteins, peptides, vitamins, amino acids, collagen, chitin, enzymes, gelatine, glycosaminoglycans, polyunsaturated fatty acids (PUFA), minerals, etc. Furthermore, they can provide important functional and bioactive properties for food, agriculture, cosmetics, pharmaceutical and/or nutraceutical industries (Ghalamara et al., 2020; Al Khawli et al., 2019; Wang et al., 2019; Song et al., 2012). In addition, different processes have been developed to exploit these by-products efficiently in the form of food packaging, silage, fertilizer enrichers, biofuels, etc. (Nawaz et al., 2020).

The use of by-products in human food continues to be a challenge with regards to food safety and their interactions with other ingredients. Several products of interest can be obtained from fish co-products such as protein hydrolysates and polyunsaturated fatty acids from fish heads, omega-3 rich food supplements from liver, etc. (Al Khawli et al., 2019).

Fish oil is also a valuable potential by-product and a source of high-quality nutrients, rich in omega-3 fatty acids. One example of omega-3 fatty acid use has been reported in bakery and pasta products, which are of great interest in their benefits as functional foods (Nawaz et al., 2020). The use of different technologies such as ultrasound combined to assisted enzymatic extraction (UAE), is a promising method to improve the recovery efficiency of oil extraction. The use of UAE before enzymatic hydrolysis in fish heads has been reported to enhance oil recovery, resulting in a higher content of PUFAs and better oxidative stability, as well as a lower apparent viscosity and less sensitivity to temperature changes. The wider use of UAE technologies would make the resultant product ideal for multiple food applications (Al Khawli et al., 2019).

Calcium from fish bones has received considerable attention as a calcium supplement for calcium deficiency. Studies have reported the high bioavailability of calcium from tuna bones in comparison to calcium from other sources such as milk, vegetable and salts (Nemati et al., 2016). However, all previous studies suggested a pre-treatment step was required. This pre-treatment can take the form of heating, boiling, tempering, or chemical treatment before adding it to the food matrix (Nawaz et al., 2020; Gupta et al., 2016). The reason is that the bone matrix is composed of a complex inorganic part and an organic part of collagen fibres which are difficult to break down in a simple enzymatic digestion without prior softening of the bones. Likewise,

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by incorporating boiled fish bones from Nile tilapia into biscuits, it was reported that fish bone fortification was a good source of calcium and other minerals, along with improved fatty acids (Nawaz et al., 2020).

Most of the animal by-products from seafood preservation and processing have long been used in FM production and consequently for animal feed (Cho et al., 2010). This is the natural output produced from fishery waste associated with the processing of various fishery products, although from a circular business economic model perspective, the aim would be to use these products for high value categories (pharma-industry, cosmetics, biotechnology and human food). However, if there is a low availability of material, low quality material, large distances between the supplier and the valorisation plant or poor logistics, prospective high added value opportunities, could be destined for animal feed.

Red and vascularized fish flesh, a by-product of fillet processing, is a good source of high-quality protein that is often used for feed production or discarded without revenues (Herpandi et al., 2011; Nawaz et al., 2020). The use of supercritical fluid extraction makes it possible to reduce the fat content of FM without affecting the quality of the protein. Under certain extraction conditions (10-40 MPa/25-80 °C) and CO_2 flows of 9.5 g/min resulted in a product with 90% fat reduction (Al Khawli et al., 2019). FO can be extracted from fish viscera by pressing, microwave-assisted extraction, supercritical fluid extraction, solvent extraction, autolysis and enzymatic hydrolysis (Wang et al., 2019).

The high cost of FM used in fish feed has encouraged alternative ways of obtaining protein. Fish silage is an excellent protein product and the most available source of amino acids for protein biosynthesis, with high amounts of PUFAs and biological value for animal feed. It is widely used as feed in aquaculture for different aquaculture species. During silage processing, endogenous enzymes hydrolyse proteins and transform them into more soluble nitrogen compounds (Herpandi et al., 2011).

The production of compost reduces the volume of by-products and fishery waste generated and can be used as a natural soil amendment, improving soil texture and fertility, at the same time reducing the use of synthetic fertilizers (Radziemska et al., 2019). For example, the fermentation of squid gladii by *Lactobacillus paracasei* has been reported as a biofertilizers (Wang et al., 2019). In addition, when used as a fertilizer, it can help to increase the carbon storage capacity of the available carbon, potentially minimizing greenhouse gas emissions to the atmosphere (Radziemska et al., 2019).

The recovery of phosphorus (usually as struvite) from sewage sludge is reported after anaerobic digestion of the sludge by different commercial processes, where phosphorus can be used as a nutrient for fertilizers.

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However, although these processes involve low investment costs and can remove heavy metals simultaneously, they usually require specific equipment, have high operating costs and high chemical and energy consumption (Gherghel et al., 2019).

Different fertilizers based on FM are commercially available and some are even authorized for ecological and organic agriculture. For example, composted fish by-products and pine bark have been evaluated as organic fertilizer, with a positive effect on the nitrogen, phosphorus, potassium, sodium, calcium and magnesium content in the experimental plant leaves, although the Ca:P ratio simultaneously worsened (Radziemska et al., 2019). To be a viable fertilizer supplement in the future, biomass recovery must be refined to ensure a consistent and safe quality product. Alternatively, direct application of nitrogen-rich recovery solutions to agricultural fields could be considered (Beckinghausen et al., 2020).

Microwave technology at laboratory scale has been used to obtain Cd, Cr, Cu, Ni, Pb and Zn after anaerobic digestion of sludge, with a total recovery of 95.3-100%. After anaerobic digestion and sludge dewatering, the production of adsorbents for metal ions (Cu^{2+} and Pb^{2+}) has been reported, with improved control of the heating process, energy savings and reduction of equipment and wastes (Gherghel et al., 2019).

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6. CONCLUSION AND DISCUSSION

The further processing of seafood into a wide variety of value-added products is increasingly common in response to the parallel demand for ready-to-eat foods or ingredients that require little preparation before serving. The economic recovery of waste and by-products into valuable compounds, despite being attractive, is not easily implemented because, although it includes a low-cost raw material, it implies a high cost for logistics, storage and transport, as well as utilisation of processes associated with high energy consumption or pioneering techniques for recovering valuable products. In this sense, in order to ensure the economic viability, it is essential to process large quantities of raw material, which in most cases, it is not possible to obtain with the by-products generated by a single company. Additionally, this could be facilitated by creating a "fish by-products bourse" displaying information by time of year, type and characteristics of available by-products.

The new circular economy approach within the seafood industry, where waste streams are minimized as much as possible and unavoidable wastes are reconsidered as useful resources, could be a new way to address the problem of seafood waste, nutrient loss and inevitable food spoilage. The discussion on the mismatch of recovery techniques and applications in use today, highlights the lack of information sharing between the research community, industry, government and potential end users.

Some of the techniques outlined in this document which are suitable for applying circular solutions to seafood waste will be difficult to introduce in processing plants without policies that encourage their use, as well increase their acceptance by respective industries and citizens. For example, currently there is no reliable information to determine the end product market for these recovery technologies, which may lead to a focus on a product that may not have a viable future in the market. Another possibility is the use of processes that allow the transformation of by-products with compositional similarities and origin compatibilities, thus enabling industrial efficiencies in terms of waste recovery and end-product production. Collaboration between stakeholders in the fishery and aquaculture processing industry sector towards new business opportunities should be encouraged, so that together with research they can produce new value-added products that successfully implement the circular economy concept.

According to the main European directives, disposal should be the last solution and thus valorisation of these wastes are required. Therefore, FM and FO would be reserved only for those by-products whose characteristics are not considered as functional products or use for other resources of interest.

It should also be considered that the technical and economic viability of the BATs identified should be studied for each specific installation and according

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to its characteristics, considering factors such as the size of the installation, the type of products processed or the age of the installation itself. In addition, some local factors may determine the technical and economic feasibility of a given BAT. The techniques listed and presented in the BAT conclusions are not prescriptive or exhaustive. Many other techniques can be adopted as long as at least an equivalent level of environmental protection is guaranteed.

Additional aspects that will determine the application of a BAT in a given installation can include food safety, economic viability, local conditions and installation. Also, the technical characteristics of each installation is another important factor that the environmental impact assessment must consider when determining the emission limit values. Likewise, BAT conclusions do not establish ELVs but rather report on the emission levels associated with the use of BAT.

In such an assessment of technologies that enable conversion of waste to useful by-product products, consumption and emission data of the conversion process are usually expressed "per tonne of by-products treated". This facilitates the examination of the relationships between different processes, their actual consumption and emission levels. It should also be noted that the ELV-BATs are applied to the emissions from the installations only. Therefore do not consider the actual concentration reductions achieved, focusing only on the emission levels associated with BAT for direct discharges to the receiving water stream, regardless of the type of feedstock to be processed or the type of installation.

Finally, it should be mentioned that many of the current techniques still focus on lab scale technologies, as opposed to scaling up technologies to full scale and performing full energy and technical economic analysis. As more pilot scale results and information on products and processes enter into industrial practice the opportunities for increased seafood circularity and nutrient recovery will increase. Supporting and enabling a sustainable transition to a circular economy.

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Appendix I

The following section is adapted from Chapter 5 of the Best Available Techniques (BAT) Reference Document for the Slaughterhouses, Animal By-products and Edible Co-products Industries (Draft 1 – June 2021). It presents the 25 BAT conclusions and the different parameters and areas that they cover.

The techniques listed and described in these BAT conclusions are neither prescriptive nor exhaustive. Other techniques may be used that ensure at least an equivalent level of environmental protection.

Unless otherwise stated, the BAT conclusions are generally applicable.

5.1 General BAT Conclusions

5.1.1 Overall environmental performance

BAT 1: In order to improve the overall environmental performance, BAT is to elaborate and implement an environmental management system (EMS).

BAT 2: In order to improve the overall environmental performance, BAT is to establish, maintain and regularly review (including when a significant change occurs) an inventory of water, energy and process chemicals consumption as well as of wastewater and waste gas streams, as part of the environmental management system (see BAT 1).

BAT 3: In order to improve the overall environmental performance, BAT is to elaborate and implement a chemicals management system (CMS) as part of the EMS (see BAT 1).

BAT 4: In order to reduce the frequency of the occurrence of other than normal operating conditions (OTNOC) and to reduce emissions during OTNOC, BAT is to set up and implement a risk based OTNOC management plan as part of the EMS (see BAT 1).

5.1.2 Monitoring

BAT 5: For wastewater streams identified by the inventory of inputs and outputs (see BAT 2), BAT is to monitor key process parameters (i.e., continuous monitoring of wastewater flow, pH and temperature) at key locations (i.e., the inlet and outlet of the pre-treatment, the inlet to the final treatment, the point where the emission leaves the installation).

BAT 6: BAT is to monitor at least once per year: (i) the yearly consumption of water and energy; and (ii) the yearly amount of wastewater generated.

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BAT 7: BAT is to monitor emissions to water with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

BAT 8: BAT is to monitor channelled emissions to air with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

5.1.3 Energy Efficiency

BAT 9: In order to increase energy efficiency, BAT is to use technique (a) and an appropriate combination of the general energy-saving techniques listed in technique (b) below.

(a) Energy efficiency plan and energy audits
(b) Use of general energy-saving techniques

5.1.4 Water consumption and wastewater generation

BAT 10: In order to reduce water consumption and the amount of wastewater generated, BAT is to use techniques (a) and (b) and one or a combination of the techniques (c) to (k) given below:

(a) Water management plan and water audits
(b) Segregation of water streams
(c) Water recycling and/or reuse
(d) Optimisation of water flow
(e) Use and optimization of water nozzles and hoses
(f) Dry cleaning
(g) High-pressure cleaning
(h) Optimisation of chemical dosing and water use in cleaning in-place (CIP)
(i) Low-pressure foam and/or gel cleaning
(j) Optimised design and construction of equipment and process areas
(k) Cleaning of equipment as soon as possible

5.1.5 Harmful substances

BAT 11: In order to prevent or, where that is not practicable, to reduce the use of harmful substances, i.e., in cleaning and disinfection, BAT is to use one or a combination of the techniques given below.

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(a) Proper selection of cleaning chemicals and/or disinfectants
(b) Reuse of cleaning chemicals in cleaning-in-place (CIP)
(c) Dry cleaning
(d) Optimised design and construction of equipment and process areas

5.1.6 Resource efficiency

BAT 12: In order to increase resource efficiency, BAT is to use one or a combination of the techniques given below.

(a) Anaerobic digestion
(b) Prevention of biological degradation of animal by-products and/or edible coproducts
(c) Recycling/recovery of separated residues
(d) Use of animal fat as a fuel
(e) Phosphorus recovery as struvite

5.1.7 Emissions to water

BAT 13: In order to prevent uncontrolled emissions to water, BAT is to provide an appropriate buffer storage capacity for generated wastewater.

BAT 14: In order to reduce emissions to water, BAT is to use an appropriate combination of the techniques given below.

<u>Preliminary, primary and general treatment</u>

(a) Equalisation
(b) Neutralisation
(c) Physical separation, i.e., screens, sieves, grit separators, fat separators, or primary settlement tanks

<u>Physico-chemical treatment</u>

(d) Precipitation
(e) Evaporation
(f) Chemical oxidation with ozone

<u>Aerobic and/or anaerobic treatment (secondary treatment)</u>

(g) Aerobic and/or anaerobic treatment (secondary treatment), i.e., activated sludge process, aerobic lagoon, anaerobic contact process, membrane bioreactor

<u>Nitrogen removal</u>

(h) Nitrification and/or denitrification

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Phosphorous removal

(i) Precipitation
(j) Enhanced biological phosphorus removal

Final solids removal

(k) Coagulation and flocculation
(l) Sedimentation
(m) Filtration (i.e., sand filtration, microfiltration, ultrafiltration)
(n) Floatation

5.1.8 Emissions to air

BAT 15: In order to reduce emissions to air of CO, dust, NO_X and SO_X from the combustion of malodorous gases (i.e., in thermal oxidisers or steam boilers) including non-condensable gases, BAT is to pre-treat the waste gases using technique (a) when necessary, and to use one or a combination of techniques (b) to (d) given below.

(a) Removal of high levels of dust, NO_X and SO_X precursor
(b) Fuel choice
(c) Low-NO_X burner
(d) Optimised Thermal oxidation

5.1.9 Noise

BAT 16: In order to prevent or, where that is not practicable, to reduce noise emissions, BAT is to set up, implement and regularly review a noise management plan, as part of the environmental management system.

BAT 17: In order to prevent or, where that is not practicable, to reduce noise emissions, BAT is to use one or a combination of the techniques given below.

(a) Appropriate location of equipment and buildings
(b) Operational measures
(c) Low-noise equipment
(d) Noise control equipment
(e) Noise abatement

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5.1.10 Odour

BAT 18: In order to prevent or, where that is not practicable, to reduce odour emissions, BAT is to set up, implement and regularly review an odour management plan, as part of the environmental management system.

BAT 19: In order to prevent or, where that is not practicable, to reduce odour emissions, BAT is to use all of the techniques given below.

(a) Regular cleaning of installations and equipment
(b) Cleaning and disinfection of vehicles and equipment used to transport and deliver animal by-products and/or edible coproducts
(c) Enclose animal by-products and/or edible co-products during transport, loading/unloading and storage
(d) Prevention of biological degradation of animal by-products and/or edible coproducts

5.2 BAT conclusions for slaughterhouses

The BAT conclusions presented in this section apply to slaughterhouses. They apply in addition to the general BAT conclusions given in Section 5.1.

5.2.1 Energy efficiency

BAT 20: In order to increase energy efficiency, BAT is to use an appropriate combination of the techniques specified in BAT 9 and of the techniques given below.

(a) Refrigeration management plan
(b) Steam scalding
(c) Jet stream scalding

5.2.2 Water consumption and wastewater generation

BAT 21: In order to reduce water consumption and the amount of wastewater generated, BAT is to use an appropriate combination of the techniques specified in BAT 10 and of the techniques given below.

(a) Dry emptying of stomachs
(b) Dry collection of the contents of intestines
(c) Steam scalding

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5.2.3 Use of refrigerants

BAT 22: In order to prevent emissions of ozone-depleting substances and of substances with a high global warming potential from cooling and freezing, BAT is to use refrigerants without ozone depletion potential and with a low global warming potential.

BAT 23: In order to prevent or, where that is not practicable, to reduce refrigerant losses, BAT is to use one or a combination of the techniques given below.

(a) Refrigeration management plan
(b) Preventive and corrective maintenance
(c) Use of refrigerant leak detectors

5.3 BAT conclusions for installations processing animal by-products and/or edible co-products

The BAT conclusions presented in this section apply to installations processing animal by-products and/or edible co-products. They apply in addition to the general BAT conclusions given in Section 5.1.

5.3.1 Energy efficiency

BAT 24: In order to increase energy efficiency, BAT is to use an appropriate combination of the techniques specified in BAT 9 and of the technique given below.

(a) Multistage evaporators

5.3.2 Water consumption and wastewater generation

Environmental performance levels for specific wastewater discharges:

(i) Rendering, fat melting, blood and/or feather processing
(ii) Fishmeal and fish oil production
(iii) Gelatine manufacturing

Are outlined and specified under this heading.

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5.3.3 Emissions to air

BAT 25: In order to reduce emissions to air of organic compounds and malodorous compounds, including H2S and NH3, BAT is to use one or a combination of the techniques given below.

(a) Condensation
(b) Adsorption
(c) Biofilter
(d) Combustion of malodorous gases, including non-condensable gases, in a boiler
(e) Thermal oxidation
(f) Wet scrubber
(g) Bio scrubber

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Water-Energy-Seafood Nexus:

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