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ONE EARTH

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ONE EARTH

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List of Abbreviations and Acronyms	
D4.1	Deliverable 4.1
EU	European Union
PUFAs	Polyunsaturated Fatty Acids
TAGs	Triacylglycerols
PLs	Phospholipids
EE	Ethyl esters
VFAs	Volatile Fatty Acids
EPA	Eicosapentaenoic acid
DHA	Docosahexaenoic acid

1 Executive Summary

Deliverable 4.1 (D4.1) reviews the current technical, regulatory and market landscape for ONE EARTH target compounds, including feather- and whey-derived peptides, marine collagen, fermentation-based Polyunsaturated Fatty Acids (PUFAs) and recovered phosphorus. The analysis shows that these compounds are technically feasible and relevant in terms of potential use, but their successful uptake depends on clear specifications, early regulatory alignment, credible sustainability and traceability, and realistic cost structures.

Based on the findings, D4.1 proposes concise technical and regulatory requirement ranges for each compound family and application. These will be used by partners in WP1, WP2, WP3, and WP4 as practical design guidelines for feedstock selection, process development and product formulation, ensuring that upstream work is aligned with real market expectations and future compliance needs.

2 Introduction

2.1 Background of ONE EARTH

ONE EARTH aims to develop and evaluate innovative bio-based solutions for producing nutraceutical/cosmetic, adhesive, agriculture (fertilizers), and aquaculture (fish feed) products by utilizing residual animal-derived biomass. Its core objective is to establish integrated circular value chains, where marine biomass is repurposed into terrestrial products and terrestrial biomass is transformed into aquaculture products, thus promoting a sustainable and "self-reinforcing" carbon cycle.

2.2 Objectives of Deliverable D4.1

The objective of Deliverable D4.1 is to define the technical, functional, regulatory, and market requirements for the target compounds selected within the ONE EARTH project and identify potential gaps. These compounds, derived from residual animal-based feedstocks, are intended for application in cosmetics, nutraceuticals, adhesives, aquafeed, and biofertilizers.

- Identify and characterize the physicochemical and biochemical specifications required for the safe and effective use of the target compounds in downstream applications.
- Compile end-user and producer expectations regarding quality, safety, functionality, and sustainability, with special attention to alignment with the One Health approach.
- Map the applicable regulatory frameworks (e.g. REACH, Novel Foods, EU Fertilizing Products Regulation) and define threshold limits for certain contaminants.
- Conduct a systematic review of scientific literature and patents, focused on industrial-scale processing technologies relevant to the valorization of ONE EARTH feedstocks.
- Benchmark existing and emerging market solutions and products derived from comparable biological sources.

2.3 Methodology Overview

This deliverable adopts a multi-step methodology to define and consolidate the requirements for the target compounds selected under ONE EARTH project. The approach integrates technical, regulatory, and market intelligence, ensuring that the specifications and feasibility analysis are grounded in real-world constraints and opportunities. The methodology is structured as follows:

2.3.1 Identification of Target Compounds and Use Cases

Target compounds were selected based on their relevance to the valorisation of selected feedstocks (chicken feathers, fish scales and bones, cheese whey) and their alignment with the application domains of Work Package 4 (e.g., cosmetics, food supplements, adhesives, fertilizers). The target compounds include hydrolysed keratin peptides, marine collagen peptides, polyunsaturated fatty acids (PUFAs) and phosphorus-rich mineral extracts.

These were mapped against existing and emerging product categories from both a technical application and end-user perspective.

2.3.2 Regulatory and Technical Requirement Collection

A structured desktop review of applicable regulatory frameworks (e.g. REACH, EU Novel Foods, EFSA/FDA, Fertilising Products Regulation (FPR) 2019/1009) was conducted. This was complemented by cross-checking of technical datasheets and certificates of analysis from commercial suppliers and through consultation with domain experts and end-users within the consortium (producers, formulators, regulatory stakeholders).

2.3.3 Literature and Patent Review

A systematic review of scientific literature and patent databases (6.1.1.1) was performed, applying pre-defined inclusion and exclusion criteria. Only studies addressing industrial-scale or pilot-ready technologies were retained.

2.3.4 Market Benchmarking and Product Survey

Commercially available ingredients from similar feedstocks or offering equivalent functionality were identified using online catalogues and supplier databases (e.g., Alibaba, INCIdecoder, UL Prospector), and product datasheets from international suppliers (e.g., Rousselot, Peptan, Keraplast, DSM).

Benchmarks were used to define performance baselines, regulatory acceptance, and market gaps.

2.3.5 Consolidation into Specification Sheets and Compliance Matrix

For each compound, a specification table was created, capturing physico-chemical parameters, purity requirements, solubility, safety thresholds (e.g., heavy metals, microbial loads), and applicable regulatory status. This structured approach ensures traceability between requirements and evidence, aligning with the objectives of Task 4.1 and enabling informed decision-making for the subsequent stages of WP4 and WP5.

3 Identification of Target Compounds

3.1 List of Compounds Selected for Valorisation

In the scope of ONE EARTH, specific compounds have been selected for valorization to generate high-value bio-based products. The project focuses on:

- Polypeptides extracted from chicken feathers and fish scales and bones using microbial and enzymatic processes.
- Polyunsaturated fatty acids (PUFAs) obtained from Volatile Fatty Acids (VFAs), produced *via* anaerobic fermentation of cheese way and from algae cultivation.
- Phosphorus-rich compounds derived from fishbones combined with organic residues through an innovative thermochemical process.

3.2 Expected Applications

The valorized compounds within the ONE EARTH project will be directed towards a range of industrial applications. Polyunsaturated fatty acids (PUFAs) will be utilized in the development of nutraceuticals, cosmetics, and aquaculture products such as fish feed. Polypeptides, derived from chicken feathers and fish scales, will be incorporated into nutraceutical, cosmetic, and bio-adhesive products. In parallel, phosphorus-rich fertilizers, obtained through the processing of fishbones and organic residues, will be applied to the development of agricultural fertilizers.

4 Requirements from End-Users and Producers

4.1 Physicochemical Specifications

For the application of the selected compounds developed within ONE EARTH, specific physicochemical specifications will be set to guarantee quality, safety, and functionality of the final products. In the case of polyunsaturated fatty acids (PUFAs), it is essential to provide a detailed characterization of the fatty acid profiles, including the relative abundance of key compounds such as oleic, linoleic, EPA and DHA. Other important parameters to be defined include purity, concentration, and oxidative stability parameters (such as peroxide value, anisidine value, and total oxidation value), which should remain within acceptable limits to prevent degradation. In addition, moisture content, microbiological safety, and contaminant levels (including heavy metals, dioxins, PCBs, PAHs, and residual solvents) must comply with European standards.

One aspect to be considered regarding the functionality of PUFAs is that their bioavailability is different for each lipid class, i.e. it depends on whether they are bound to triacylglycerols (TAGs), phospholipids (PLs) or ethyl esters (EE).

PLs are essential components of fish cell membranes and also have a central role in the digestion of other lipids, acting as emulsifiers in the intestinal lumen, and in the formation of lipoproteins that transport lipids across the intestinal mucosa and in the blood and lymph as well as stress response and reproduction (Tocher, 2003; Tocher et al., 2008). Some fish may have a limited capacity of *de novo*

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synthesis of PLs at larval and juvenile stages, so diet becomes an essential source of these compounds (Tocher et al., 2008). For instance, European sea bass larvae benefit from increased dietary PL contents in the diet compared to larvae fed diets rich in neutral lipids, i.e. TAGs (Gisbert et al., 2005). In these diets, DHA was predominant in PLs, whereas EPA was more abundant in neutral lipids. In larval cod, the % DHA in tissue PLs strongly and positively correlates with the % of DHA in dietary PLs, and also with larval dry weight (Olsen et al., 2014).

The higher nutritional value of PLs is related to the pathways of lipid digestion. PUFAs are predominantly esterified at the sn-2 position both in PLs and TAGs. Phospholipase A2 removes the fatty acid at the sn-2 position in PLs, releasing a free fatty acid (FFA) and a lyso-phospholipid. In contrast, TAGs are cleaved by 1,3 lipases, so PUFAs are more frequently retained in the resulting monoacylglyceride. In both cases, FFAs join the FFA pool in enterocytes, where they are incorporated into *de novo* synthesised PLs by re-acylation of the lyso-phospholipids. Thus, PLs become the most important source of DHA in most fish larval stages as observed in Atlantic cod and halibut (K. Li et al., 2018; Olsen et al., 2014) and salmon (Jaxion-Harm, 2021). However, there are also exceptions to these nutritional requirements, particularly among freshwater fish species (Huang et al., 2022; S. Wang et al., 2022). Therefore, attention has been drawn in last years to sources of phospholipids, such as krill oil, driven by this expected higher bioavailability of DHA.

For polypeptides derived from chicken feathers and fish scales and bones, molecular weight distribution and amino acid composition may be determined. Purity levels, solubility in relevant media, and stability against heat, pH variation, or oxidation are also important specifications. As with PUFAs, polypeptides must comply with strict limits for contaminants and microbiological safety.

4.2 Functional & Application Requirements

In addition to physicochemical specifications, the selected compounds shall meet specific functional and application requirements to ensure their suitability for use in target products.

For polyunsaturated fatty acids (PUFAs), key requirements include maintaining functional stability throughout processing and storage, as well as ensuring compatibility with various delivery formats. PUFAs are prone to oxidation and may require protective strategies to retain quality. From an application perspective, PUFAs should also demonstrate consistency in sensory profile (e.g., absence of off-flavours or odours) to ensure consumer acceptance.

For polypeptides, functional requirements are linked to their structural and biochemical properties. Peptides should display water solubility or dispersibility, allowing for efficient incorporation into final products. Ease of formulation, handling, and consistent performance in the final product are crucial for market acceptance.

4.3 Customer and Market Needs

The development of bio-based compounds within the ONE EARTH project responds to customer and market needs in the nutraceutical, cosmetic, aquaculture, and agricultural sectors.

In the nutraceutical and cosmetic markets, consumers are increasingly demanding products that are natural, sustainable, and derived from safe and traceable sources. PUFAs and bioactive peptides fit these expectations by offering bio-based alternatives to synthetic ingredients or fish-oil-derived products, while also reducing pressure on conventional resources. For industry actors, reliable supply chains based on valorization of residual biomass provide both a cost advantage and a sustainability benefit that can be communicated to consumers.

5 Regulatory Requirements

5.1 Relevant Regulatory Frameworks

5.1.1 REACH

The REACH Regulation (EC) No 1907/2006 is the cornerstone of chemical safety legislation within the European Union. It applies to substances manufactured, imported, or used in quantities greater than 1 ton per year, and is enforced by the European Chemicals Agency (ECHA). Under REACH, manufacturers and importers must assess and manage risks posed by chemicals and provide appropriate safety information to users.

Based on the current definitions and usage scenarios, the target compounds of the ONE EARTH project do not fall under full REACH registration requirements, as they meet the criteria for exemptions under Annex V of REACH. These exemptions include naturally occurring, non-chemically modified substances, polymers, and substances regulated under sector-specific frameworks such as food, feed, cosmetics, and fertilizers.

5.1.2 Food regulations

The EU Novel Food Regulation (Regulation (EU) 2015/2283) establishes the procedures for the authorization and use of foods and food ingredients that were not consumed to a significant degree within the European Union prior to 15 May 1997. The legislation ensures that such products undergo a safety assessment before entering the EU market. Novel Foods encompass a wide range of categories, including ingredients produced through new technological processes, food derived from innovative sources, and compounds obtained from animal by-products through previously unused methods. For the ONE EARTH project, this regulatory framework is particularly relevant to activities related to nutraceutical applications. In particular, polyunsaturated fatty acids (PUFAs) produced *via* microbial fermentation or extracted from algae species not yet authorized in the EU could fall within the scope of Novel Food legislation. Likewise, polypeptides obtained from chicken feathers or fish scales may be subject to Novel Food assessment if their production processes or intended uses are considered novel.

Other key regulations ensuring safety include Regulation (EC) No 853/2004 laying down specific hygiene rules for food of animal origin and Regulation (EC) No 2073/2005 on microbiological criteria on foodstuffs and Regulation (EU) 2023/915 of 25 April 2023 and repealing Regulation (EC) No 1881/2006 on maximum levels for certain contaminants in food.

5.1.3 Cosmetics Regulation

The Cosmetic Products Regulation (CPR) (EC) No 1223/2009 establishes mandatory requirements for all cosmetic products placed on the European market. The central focus of the legislation is to protect human health by ensuring product safety. For that purpose, it sets out standards concerning final products and their ingredients (lists of banned and restricted substances, impurity limits, labelled warnings for end users, etc.). All cosmetics must undergo a safety assessment before entering the market. Key requirements include maintaining a Product Information File (PIF) with detailed information about product composition, manufacturing process, stability, microbiological quality, relevant safety or efficacy tests and labelling.

Some of the ingredients developed during the ONE EARTH project will be incorporated into cosmetic products and must therefore comply with the provisions of the Cosmetic Products Regulation (CPR). It is essential that these new ingredients are thoroughly characterized (e.g., physicochemical identity, impurity profile) and proven to be safe for their intended cosmetic use. This requirement may directly influence the design and selection of the target compounds—for example, polypeptides with specific molecular weight limitations will be used to minimize the risk of hypersensitivity reactions in consumers (Burnett et al., 2018).

5.1.4 Aquafeed

EU regulations on fish feed aim to ensure that aquaculture products are safe, traceable, and sustainably produced. EU regulations for fish feed prioritize hygiene and safety, addressing aspects such as ingredients, additives, and labeling to protect both consumer and animal health. Key legislation includes Regulation (EU) 183/2005, which focuses on feed hygiene; Regulation (EU) 767/2009, which governs the marketing of feed; Directive 2002/32, which addresses undesirable substances; and Regulation (EC) No 1069/2009, which regulates the use of animal-derived ingredients in fish feed.

Feed ingredients (liquid and powder PUFAs) developed during the ONE EARTH project will be incorporated into aquafeed and must therefore comply with EU regulations regarding feed hygiene and undesirable substances. These new raw materials must be thoroughly characterized, including an assessment of contaminants such as heavy metals, dioxins, and toxins (mycotoxins), as well as antinutritional factors, to ensure they are safe for feeding the fish.

5.1.5 Adhesives

Several European regulations are essential for the safe production, use, and marketing of adhesives. These laws ensure that adhesives meet strict safety, environmental, and consumer protection standards.

Two key European regulations are especially important for adhesives: REACH (Registration, Evaluation, Authorization and Restriction of Chemicals, Regulation (EC) No 1907/2006) and CLP (Classification, Labelling and Packaging of Substances and Mixtures, Regulation (EC) No 1272/2008).
The REACH Regulation ensures that all chemical substances used in adhesives are properly registered, evaluated, and assessed for potential risks. It requires manufacturers and importers to provide information on the properties and safe use of these substances. This helps protect human health and the environment from harmful effects of chemicals throughout the product's life cycle. Important is Annex XVII of the REACH Regulation, which governs restrictions and prohibitions on certain hazardous substances, mixtures, and articles. It contains a list from which the EU can restrict or completely prohibit the manufacture, placing on the market, and use of substances. Annex XVII includes, for example, regulations on microplastics and CMR substances. The CLP Regulation (1272/2008) —

Classification, Labelling and Packaging of Substances and Mixtures — complements REACH by defining how substances and mixtures, including adhesives, must be classified, labeled, and packaged. It ensures that users are clearly informed about possible hazards, enabling safe handling and storage.

When it comes to special applications there are various regulations that should be considered:

Detergent regulation 648/2004: This regulation ensures that detergents are safe for users and the environment by controlling their composition, labeling, and biodegradability.
Aerosol directive 75/324/EWG (2013/10): This directive sets safety and labeling requirements for aerosol adhesive products to prevent accidents and ensure safe use.
Biocidal products 528/2012: Raw materials which are used as biocides need to comply with this regulation. It ensures that products are effective and safe for people, animals, and the environment.
Drinking Water Directive 2020/2184: When adhesives are used for DWD application, this directive guarantees that drinking water across the EU is clean, safe, and of high quality for human consumption.
Construction Product Regulation 2024/3110: This regulation ensures that construction products meet consistent safety, performance, and sustainability standards throughout the EU.
General Product Safety Regulation 2023/988: This is a general law, which applies to all products incl. adhesives. It makes sure that all products sold in the EU are safe for consumers, and that unsafe products can be quickly removed from the market.

5.1.6 Fertilisers

The Fertilizers Products Regulation (EC) No. 2019/1009 establishes mandatory requirements for all fertilizers placed on the European market. This regulation, which was implemented by the European Commission, is a comprehensive set of rules that govern the availability of fertilizers within the European Union. It is a crucial regulatory framework, as it ensures that fertilizers products meet the necessary standards for safe and effective use. The objective of this Regulation is to ensure that products benefiting from the free movement of goods within the Union fulfill requirements providing a high level of protection of public interests, such as human, animal, and plant health, safety, and the environment. To that end, this Regulation should be applicable to products covered by this Regulation.

The distinct functions of various products necessitate divergent safety and quality requirements, which are adapted to their respective intended applications. Consequently, it is imperative to categorize EU fertilizing products into distinct product function categories (PFCs), each of which should be subject to specific safety and quality requirements.

An EU fertilizing product may exhibit multiple functions, as delineated in the product function categories established in this Regulation. In instances where only one of the aforementioned functions is claimed, it is sufficient for the EU fertilizing product to comply with the requirements of the product function category that describes that particular function. Conversely, in instances where multiple functions are claimed, the EU fertilizing product should be regarded as a blend of two or more components EU fertilizing products. In such cases, compliance should be required for each component EU fertilizing product with respect to its function. Consequently, a particular product function category should encompass such blends.

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An EU fertilizing product is defined as a substance composed exclusively of component materials categories (CMCs) that meet the criteria established for one or more of the CMCs enumerated in the designated Annex.

5.2 Application-specific impurity thresholds

Table 1 Application-specific impurity thresholds (e.g. heavy metals, aflatoxins, pesticides)

Substance	Nutraceuticals (Reg. 2023/915, ANNEX I)	Cosmetics (Reg. 1223/2009, EN ISO 17516:2014)	Fish feed (Directive 2002/32/EC)	Adhesives (EC) No 1907/2006), (EC) No 1272/2008)	Fertilizers (Reg. (EU) 2019/1009)
Heavy metals					
Arsenic (As)	n/a	Annex II/43: Prohibited*	Maximum content in 10 mg/kg (ppm) relative to a feed with a moisture content of 12%	n/a	Inorganic As PFC** 1(A), (B), (C); PFC 2, 3(A,B), 4, 6: 40 mg/kg dry matter PFC 1(II): 1000 mg/kg dry matter
Lead (Pb)	3,0 mg/kg (Food supplements)	Annex II/289: Prohibited*	5 mg/kg (same conditions as above)	Annex XVII of REACH restricts lead to 0.1% by weight.	PFC 1(A), (B), (C); PFC 2, 3 (A),(B), 4, 6: 120 mg/kg dry matter PFC 1(II): 600 mg/kg dry matter
Chromium (Cr)	n/a	Annex II/97: Prohibited*	n/a	hexavalent chromium cannot exceed 100 ppm (100 mg/kg)	Cr(VI): < 2 mg/kg dry matter
Cadmium (Cd)	1.0 mg/kg (3,0 mg/kg for seaweed derived products)	Annex II/68: Prohibited*	1 mg/kg (same conditions as above)	RoHS directive, sets a limit of 100 ppm (0.01% by weight)	PFC 1(A): 1,5 mg/kg dry matter PFC 1(B), (C); 3 mg/kg if P_2O_5 < 5%; 60 mg/kg if P_2O_5 > 5% PFC 1(II): 200 mg/kg dry matter

Cobalt (Co)	n/a	Annex II/1645: Prohibited*	n/a	n/a	Micronutrient: content declared in label respecting the minimum required by FPR-PFC
Nickel (Ni)	n/a	Annex II/1093: Prohibited*	n/a	nickel release rate must not exceed 0.5 g/cm2/week after two years of normal use.	PFC 1(A), (B); 3(A); 4; 6: 50 mg/kg dry matter PFC 2(A), (B): 90 mg/kg dry matter PFC 1(C); 3(B); 100 mg/kg dry matter PFC 1(II): 2000 mg/kg dry matter
Mercury (Hg)	0,1 mg/kg (Food supplements)	Annex II/221: Prohibited*	0,2 mg/kg (same conditions as above)	Banned under EU Mercury Regulation (EU) 2017/852	PFC 1(A), (B), (C); PFC 2, 3 (A) (B), 4, 6: 1 mg/kg dry matter PFC 1(II): 100 mg/kg dry matter
3-monochloropropanediol (3-MCPD), 3-MCPD fatty acid esters and glycidyl fatty acid esters					
Glycidyl fatty acid esters, expressed as glycidol	1000 µg/kg (fish oils and oils from other marine organisms placed on the market for the final consumer or for use as an ingredient in food)	n/a	n/a	n/a	n/a
Sum of 3-monochloropropanediol (3-MCPD) and 3-MCPD fatty acid esters, expressed as 3-MCPD	2500 µg/kg (fish oils and oils from other marine organisms)	n/a	n/a	n/a	n/a

Dioxins and PCBs					
Sum of dioxins (pg WHO-PCDD/F-TEQ/g)	Maximum 1,75 pg/g fat Marine oils (fish body oil, fish liver oil and oils of other marine organisms placed on the market for the final consumer)	n/a	1,75 Maximum content in ng WHO-PCDD/ F-TEQ/kg (ppt) (1) relative to a feed with a moisture content of 12 %	n/a	n/a
Sum of dioxins and dioxin-like PCBs (pg WHO-PCDD/F-PCB-TEQ/g)	Maximum 6,0 pg/g fat Marine oils (fish body oil, fish liver oil and oils of other marine organisms placed on the market for the final consumer)	n/a	5,5 Maximum content in ng WHO-PCDD/FPCB-TEQ/kg (ppt) (1) relative to a feed with a moisture content of 12 %	n/a	n/a
Sum of non dioxin-like PCBs (ng/g)	Maximum 200 ng/g fat Marine oils (fish body oil, fish liver oil and oils of other marine organisms placed on the market for the final consumer)	n/a	40 Maximum content in µg/kg (ppb) relative to a feed with a moisture content of 12 %	n/a	n/a
Polycyclic aromatic hydrocarbons					
Benzo(a)pyrene	Maximum 2,0 µg/kg Oils and fats placed on the market for the final consumer or use as an ingredient in food	≤ 5 µg/kg (ppb) Not applicable based on raw materials' production process.	n/a	≤ 5 µg/kg (ppb)	CMC*** 3 – Compost, 1e (ii); CMC 5 – Digestate other than fresh crop digestate: no more than 6 mg/kg dry matter of PAH16****
Sum of benzo(a)pyren, benz(a)anthracene, benzo(b)fluoranthene and chrysene	Maximum 10,0 µg/kg Oils and fats placed on the market for the final	n/a	n/a	n/a	CMC 3 – Compost, 4a; CMC 5 – Digestate other than fresh crop digestate:

	consumer or use as an ingredient in food				no more than 6 mg/kg dry matter of PAH16****
Nitrosamines					
Nitrosamines	n/a	< 50 ppb (applicable for raw materials and final products)	n/a	n/a	No declaration required
Microbiological criteria					
Escherichia coli	Absence in 10 g	Absence in 1 g or 1 ml	n/a	n/a	Escherichia coli or Enterococcaceae: 1000 in 1 g or 1 ml
Pseudomonas aeruginosa	n/a	Absence in 1 g or 1 ml	n/a	n/a	No declaration required
Staphyloccocus aureus	Absence in 25 g	Absence in 1 g or 1 ml	n/a	n/a	No declaration required
Candida albicans	n/a	Absence in 1 g or 1 ml	n/a	n/a	No declaration required
Salmonella enterica	Absence in 25 g	n/a	Absence	n/a	Salmonella spp: Absence in 25 g or 25 ml
Residuals					
Relevant solvents will be addressed based on manufacturing processes	To be defined	To be defined	To be defined	To be defined	n/a
Pesticides	Compliant to Regulation (EC) No 396/2005				
Veterinary medicinal products	Compliant to Regulations (EC) No 37/2010 & No 470/2009				

*Traces of prohibited substances are permitted in cosmetic products provided that such presence complies with the requirements described in Article 17 of Regulation (EC) No 1223/2009; "*The non-intended presence of a small quantity of a prohibited substance, stemming from impurities of natural or synthetic ingredients, the* *manufacturing process, storage, migration from packaging, which is technically unavoidable in good manufacturing practice, shall be permitted provided that such presence is in conformity with Article 3 (Safety)*"

** Product Function Category (PFC).

*** component Material Category (CMC).

****Sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenzo[a,h]anthracene and benzo[ghi]perylene.

6 Literature and Patent Review

6.1 Review Methodology

To identify the most relevant industrial processes and regulatory developments applicable to the target compounds of the ONE EARTH project, a structured review of scientific literature and patents was conducted. This review aimed to inform specifications and compliance benchmarks for valorization pathways involving fish by-products, cheese whey, and poultry feathers.

6.1.1 Methodological Framework

6.1.1.1 Database Selection

The primary database used for literature retrieval was Google Scholar, chosen for its broad coverage of peer-reviewed academic literature. Complementary searches were performed in established scientific journals and databases such as PubMed, ScienceDirect and MDPI, while additional data was extracted from EU regulatory databases such as COSING, SCCS opinions, EFSA reports and AI-assisted search platforms such as ChatGPT to identify emerging information and ensure up-to-date coverage.

6.1.1.2 Search Strategy and Scope

The search strategy was structured around the core compounds and feedstocks investigated in ONE EARTH (PUFAs, peptides, bioadhesives, fertilizers, etc.) and their associated application sectors (nutraceuticals, cosmetics, aquaculture, agriculture). Keyword combinations (e.g.,'fish scales collagen peptides nutraceutical,' 'chicken feather hydrolysate cosmetics,' 'PUFA fish feed') were applied to refine results.

6.1.1.3 Eligibility Criteria

Studies were screened using pre-defined inclusion and exclusion criteria (see Table below).

Table 2 Inclusion and exclusion criteria for the literature review

Criteria	Inclusion	Exclusion
Publication Date	2000–2025	Prior to 2000
Language	English	Other languages
Technology Readiness	TRL ≥ 5 (pilot-scale or higher)	Laboratory-scale only (TRL < 5)
Sector Relevance	Cosmetics, Food/Nutraceuticals, Feed, Fertilizers	Energy, construction, or unrelated sectors
Feedstock Type	Residual animal biomass (feathers, whey, fish bones/scales)	Virgin biomass or synthetic raw materials
Document Type	Peer-reviewed articles, patents, industry whitepapers	Editorials, blog posts, non-technical commentary

6.1.1.4 Screening Process

Step 1: Title and abstract screening (automated + manual filtering)
Step 2: Full-text assessment of eligible documents
Step 3: Data extraction for compounds, technologies, regulatory references, and commercial benchmarks

6.1.1.5 Review Management

The reference management software Zotero was used to organize bibliographic data, manage PDFs, and ensure proper citation. Shared Zotero libraries were created to facilitate collaboration among partners, allowing tagging and annotation of references by compound type, application area, and data relevance. This approach ensured transparency, traceability, and harmonized data handling across the review process

6.2 Recent Developments in Industrial-Scale Processing

6.2.1 Peptides from Chicken Feathers

Chicken-feather hydrolysates are used primarily in hair care (repair/conditioning) and skin care (conditioning/moisturising). Commercial offerings cluster into low-MW (<1 kDa) penetration peptides, mid-MW (~1–3 kDa) balanced conditioners, and higher-MW (≥3–10 kDa) film-formers. Low-MW compounds may increase hair volume, and high-MW peptides may repair damage on freshly relaxed textured hair (Malinauskyte et al., 2021). Most suppliers sell either a defined cut or a multi-fraction blend to balance penetration, feel and durability. In a detailed paper by (Mokrejš et al., 2017), which includes an excellent video on preparing keratin hydrolysate, a 2% or 4% mixed-molecular-weight formulation was reported to reduce TEWL significantly—by about 15–30%.

Deodorised/low-odour grades are increasingly common to improve organoleptics in leave-on products (D. Wang et al., 2024). Recent process work at industrial scale emphasises enzymatic keratinolysis with thermo/alkali-tolerant keratinases and optional chemical (Schieder et al., 2024) or physical assists (e.g., ultrasound) to boost yield and control MW windows, aligning with greener "biorefinery" approaches (Moktip et al., 2025).

Racemization risk under basic (alkaline) hydrolysis

Strongly alkaline workflows used to solubilise/cleave keratin (e.g., NaOH, sulfide/sulfite "sulfitolysis") can induce α-carbon epimerization *via* base-catalysed enolate formation, causing partial L→D racemization. The extent rises with pH, temperature, and time, potentially altering bioactivity and declared amino-acid profiles—hence why modern cosmetic/ingestible processes prefer enzymatic or milder acid routes when "L-configuration preserved" is part of the value proposition. Mechanistic foundations and food-protein data sets are long-established (Friedman & Liardon, 1985), (Andino et al., 2023).

Patent filings cluster around (i) enzymatic keratinolysis of poultry feathers using keratinases (often Alcalase/Protamex blends or microbially produced keratinases); (ii) chemical/physical solubilization routes (alkali, sulfite/sulfide "sulfitolysis", reduction/oxidation, high pressure); (iii) deodorization/decolorization (activated carbon, resins, alcohol washes); (iv) fractionation to MW targets for cosmetics (typically 0.5–10 kDa) and feed peptones; and (v) process-intensification/plant design for continuous operation.

Representative patent families & what they protect.

- **1992 — EP0499260 A2 —** Procedure for hydrolyzing keratin — Biodata Oy. Early enzymatic route (sulphite pretreat + protease) for keratin hydrolysates; teaches peptide-length control for feed/cosmetics and is cited by later families (Savolainen, 1992).
- **2010 — US2010/0196302 A1 / EP2170096 A2 —** Keratin hydrolysates, process for their production and cosmetic composition containing the same — Universidade Federal do Rio de Janeiro (UFRJ). Establishes broad microbiological/enzymatic hydrolysis from feathers and topical cosmetic uses (conditioning, film-forming). Enzymatic (Bacillus) hydrolysis of chicken feathers yielding sub-500 Da peptides for hair, skin, and nail cosmetic compositions (e.g., shampoos/leave-ons) (Vermelho et al., 2010).
- **2012 — US2012/0130048 A1 —** Process for extracting keratin — Universiti Malaysia Pahang. Faster, large-scale extraction flow for keratin from poultry feathers; protects throughput-oriented steps/conditions (Gupta & PERUMAL, 2012).
- **2013 — CN103088098 A/B —** Method for producing peptone by taking poultry feather as raw material — Anhui Huaqiang Down Co., Ltd. Microwave puffing → keratinase digestion → carbon deodorization → spray-dry; strong deodorization/decolorization teaching with many parameters (Xia Lunbin & Chen Houqian, 2013).
- **2015 — CN104770574 A —** Preparation method of feather protein powder — Shandong Longkete Biological Technology Co., Ltd. Keratinase-based hydrolysis toward feed-grade powders; useful prior art on enzyme selections and drying (Lujiang et al., 2015).
- **2018 — EP3262952 A1 —** Method for preparing digestible feather or hair meal — Empro Europe NV. Hydrolysis + pressure/heat process controlling solids/liquids to yield digestible feather/hair compositions; notes cosmetic cross-uses (VANOVERSCHELDE & VANOVERSCHELDE, 2018).
- **2018 — US2018/0263259 A1 —** Methods and uses for keratin hydrolysis — International N&H Denmark ApS. Covers enzymatic hydrolysis (apparatus, compositions, kits) to generate highly digestible, palatable keratin hydrolysates (Gade et al., 2018).
- **2019 — US2019/0194297 A1 —** Process for extracting keratin from poultry feathers — Tomorrow Water Co., Ltd. (BKT). Focuses on scalable extraction and separation of keratin from feather biomass with process controls that improve purity and efficiency; protects production flows adaptable to wastewater/biomass-processing infrastructure (Tasaki & Kaneoka, 2019).
- **2019 — WO2019043128 A1 —** Keratin hydrolysate for oral cosmetic use — Bretagne Chimie Fine SAS (BCF Life Sciences). Defines a poultry-derived keratin hydrolysate (≥88% free AAs; low cysteine/tyrosine) and claims oral (nutricosmetic) use to improve hair (anchorage, shine, density/volume) and nails; includes a food-supplement format (Sergheraert, 2019).
- **2022 — US11534383 B2 —** Cosmetic compositions and methods of use — Virtue Labs LLC. Protects leave-on/rinse-off hair treatment compositions comprising keratin/keratin-derived materials (incl. hydrolyzed keratin peptides) with specified carriers and application regimens;

method claims cover repair/strengthening/smoothing of damaged hair fibers via topical application (SHABAN et al., 2022).

- **2024 — WO2024/232842 A1 —** Method of production of hydrolyzed keratin and amino acid from chicken feather and poultry slaughterhouse remains — (Assignee not listed in WO publication). Alkaline, closed, pressurized-reactor process claiming odor suppression and microbial safety at high T/P, with examples using $KOH/Ca(OH)_2$ (ALTIOK, 2024).

Claim types

1. Method/process (pretreatments, enzyme selections, sulfitolysis windows, deodorization trains).
2. Composition (defined MW distributions; amino-acid fingerprints; low odor/color specs).
3. Use-claims (hair fiber repair, skin moisturization/film-forming; feed peptone).

Implications for ONE EARTH positioning.

- Differentiate on enzyme strategy & fingerprint: claims are parameter-heavy; novel keratinase, kinetic control, or sequence-level "peptide fingerprints" linked to hair/skin endpoints create room and stronger claim charts.
- Odor/color problem with greener options: patents hinge on activated carbon/resins. Alternative membrane-based deodorization or tailored adsorption media at distinct pH/ionic strengths can avoid overlap while improving LCA.
- Leverage cross-domain prior-art: feed-oriented patents (digestible feather meal) can act as defensive prior-art for unit ops/conditions, leaving room to claim cosmetic-grade fractionation and structure-function.

6.2.2 Collagen Peptides from Fish Scales and Bones

Fish-processing by-products (scales, bones and skins) are a mature, globally used source of type-I collagen. Marine-derived collagen and its derivatives, such as gelatin and hydrolyzed collagen (HC), are well characterized and consist of versatile molecules offering several advantages, such as application in multiple fields without any religious and hygienic constraints (Dondero et al., 2025). Collagen is typically extracted (acid/alkali pretreatment) and converted to gelatin or hydrolyzed enzymatically to low-molecular-weight peptides. Commercial offerings cluster by source (marine/fish), degree of hydrolysis (average MW), purity, sensory profile, and target application (nutraceutical, cosmetic, technical/adhesive). There have also been isolated specific peptides with various activities, such as antioxidant, tyrosinase inhibitors etc (Siahaan et al., 2022).

Manufacturing Routes (typical)

A detailed review of the marine sources and methods for manufacturing is given in the following review articles (Barzkar et al., 2023), (Farooq et al., 2024) and (Alcolea Ersinger et al., 2025)

Demineralization/pretreatment of scales/bones → 2) Acid/alkali swelling → 3) Thermal extraction to gelatin or enzymatic hydrolysis to peptides → 4) Filtration, decolorization/deodorization → 5) Concentration, fragmentation by membrane filtration & spray-drying.

Enzymatic hydrolysis is tuned to achieve desired peptide size distribution for solubility, bioavailability, and application performance. Typical species feedstocks (tilapia, carp, cod, salmon).

Patent Landscape Scope & trend

Patenting around marine / fish-derived collagen peptides focuses on: (i) enzymatic hydrolysis of scales, skins and bones into low-MW type I collagen peptides; (ii) integrated pretreatment–hydrolysis–polishing schemes delivering low colour and low odour; (iii) narrow MW fractions (1–5 kDa, often ~2 kDa) for nutricosmetic and functional food use; and (iv) co-valorisation of mineral fractions (e.g. hydroxyapatite) from bones and scales. Process/plant design is driven mainly by Chinese, Korean and Japanese assignees, while major international collagen producers concentrate on composition and use-claims in beauty-from-within and joint/skin health.

Representative patent families & what they protect

- **2006 — JP2006160654 A —** Method for producing fish gelatin and fish gelatin — Nitta Gelatin Inc. Foundational marine-collagen patent describing extraction of gelatin/collagen from fish skins and subsequent conversion to collagen peptides; widely cited as prior art for scalable fish-collagen processes(Matsumoto et al., 2006).
- **2010 / 2012 — CN101724677 A/B —** Method for extracting collagen polypeptide and hydroxyapatite in fish scales by cooking hot extrusion — WUHAN PUSAITE Film Technology Cyclic Utilization Co., Ltd. Co-extraction of collagen polypeptides and hydroxyapatite from fish scales via hot extrusion and enzymolysis; protects integrated collagen–mineral valorisation and zero-waste concepts (Duanji et al., 2012).
- **2011 — KR101020312 B1 —** Production method of fish scale collagen peptide — (KITTOLIFE Co., Ltd.). Enzymatic hydrolysis (e.g. alcalase/protamex) of degreased fish scales under controlled pH/temperature followed by membrane fractionation to obtain low-MW collagen peptides (Hyun-pil et al., 2011).
- **2012 — CN102839207 A** — Method for preparing collagen peptide from fish scales — Wenzhou University. Wash/soften/decalcify followed by enzymatic hydrolysis and filtration/drying; broad process claims for fish-scale collagen peptides applicable to tilapia/carp and similar species(Maohong & Xiaowei, 2012).
- **2012 / 2014 — CN102718862 A/B —** Decolorizing and deodorizing method of collagen peptide of abyssal fishes — Jimei University & Nanning Haiwang Health Biotechnology Co., Ltd. Highly parameterised decolorisation/deodorisation (urease deamination, activated carbon, resin, ethanol, spray-drying) for deep-sea fish collagen peptides; sets detailed post-treatment windows (Wuyin & Minjie, 2012).
- **2015 — CN103224971 B —** Fish-skin collagen deodorizing production method — Belt (Yantai) Marine Biotechnology Co., Ltd. Flavourzyme-assisted hydrolysis plus thermal inactivation and activated-carbon treatment to obtain <5 kDa low-odor fish-skin collagen peptides; defines enzyme loadings and deodorisation conditions (Qingli et al., 2015).
- **2017 — CN106608916 A** — Ion-exchange chromatographic deodorization technology for fish collagen peptides — Qingdao Keno Bio & Tech Co., Ltd. Use of ion-exchange columns for

selective removal of odorous components from collagen peptide solutions; protects column media, pH and flow conditions (Mingmei, 2017).

- **2022 — CN114015739 A —** A kind of liquid collagen peptide product and preparation method thereof — Nanning Dong Higher Bio-Tech Co., Ltd. Stabilised liquid tilapia-skin collagen peptide system (defined solids, viscosity, sterilisation and filtration steps); relevant for RTD beverages and liquid nutricosmetics (Mingsheng, 2022).
- **2025 — WO2022043476 A1 / EP4203982 B1 —** Combination of collagen peptide and whey protein for use in a condition of the skeletal tissue — Rousselot B.V. Claims synergistic combinations of Peptan®-type collagen peptides with whey protein for inflammation and skeletal tissue recovery (sports, joint, tendon, muscle). Shows Rousselot's strategy of locking multi-ingredient performance claims around its peptides (NOGUCHI et al., 2025).
- **2025 — WO2025/145018 A1 —** Collagen peptide compositions from fish skins and scales and methods for producing same — Thai Union Group Public Co., Ltd. Modern integrated platform for skins/scales: mild pretreatment, targeted enzymatic hydrolysis, polishing and fractionation to high-purity <2 kDa peptides with specified di-/tripeptide content; links process conditions to composition and claimed functional benefit (CHAIKITWISUTTIKUL et al., 2025).
- **2025 — EP4465823 B1 / WO2023213909 A1—** Collagen hydrolysate composition for reducing joint pain after exercise — Rousselot B.V. Protects the Colartix®-type collagen hydrolysate matrix (defined MW distribution, dosage range, and joint-pain endpoint) for post-exercise joint discomfort. Relevant as a **use/composition benchmark** for bioactive collagen peptides rather than process on by-products (PRAWITT et al., 2025).

Assignees & commercial linkages

- Rousselot (Peptan®) Composition/use filings and technical dossiers on ~2 kDa collagen peptides for skin elasticity, hydration, bone & joint support. Marine collagen grades are frequently cited as benchmarks or named actives in third-party patents.
- Nitta Gelatin / Wellnex Portfolios covering collagen peptides (including fish) for joint, bone and beauty-from-within applications; establish typical MW specs, purity, and clinically supported dose ranges.

Marine collagen producers (Thai Union, Belt (Yantai), Qingdao Keno, Nanning Haiwang, etc.) focus on converting fish-processing by-products (skins/scales/bones) into high-purity collagen peptides with defined MW distribution, colour/odour indices and sometimes co-produced mineral streams.

Claim types

1. Method / process claims — pretreatments, enzyme systems, hydrolysis conditions, deodorisation and chromatographic sequences, and plant layouts.
2. Composition claims — defined MW distributions, amino-acid profiles, low odour/colour indices, specified peptide or di-/tripeptide ratios, sometimes plus mineral co-components.

3. Use-claims — oral and topical uses for skin anti-ageing, elasticity, hydration, joint and bone support, nail/hair benefits, and occasionally microbiome or metabolic angles, with defined dosage or inclusion ranges.

Implications for ONE EARTH positioning

- **Differentiation levers**
  - Design novel enzyme consortia and hydrolysis profiles delivering unique peptide fingerprints or sequence motifs.
  - Implement greener deodorisation/clarification (e.g. optimised carbon/resin usage, membrane polishing) with quantified LCA and organoleptic benefits.
  - Integrate co-product valorisation of minerals (hydroxyapatite, calcium–phosphate) from bones/scales for a robust circular narrative.
  - Build claims on robust process–structure–function links (defined MW/sequences ↔ clinically or in vitro supported cosmetic/nutricosmetic endpoints).
- **Freedom-to-operate (high-level)**
  - Many CN/KR/JP patents are highly parameterised; operating outside their specific pH/temperature/time/enzyme windows, or using alternative polishing technologies, can provide room.

6.2.3 PUFAs from Cheese Whey

6.2.3.1 Fermentation of whey to Volatile Fatty Acids (VFA)

What's new at scale: Continuous/semicontinuous acidogenic fermentation of cheese whey with pH-programming and in-line VFA capture (e.g., gas-permeable membranes) yields controllable C2–C6 profiles suitable as feedstock carbons.

- (Molinuevo-Salces et al., 2024)— Cheese-whey → VFA with pH control; demonstrates gas-permeable membrane recovery concept (process + separation window).
- (Urbina et al., 2025)— Acidogenic fermentation of dairy by-products to custom VFA streams (parameter mapping; meso/thermo conditions).
- (Chalima et al., 2017) review — Waste-to-VFA production and VFA utilization by microalgae; factors affecting VFA production and downstream bioprocesses.

6.2.3.2 Fermentation to PUFAs from VFA

What's new at scale: Oleaginous microbes can consume acetate/short-chain VFAs to produce omega-3-rich single-cell oils; *Schizochytrium* sp. routes to DHA, *Yarrowia* sp. routes to EPA are the best-documented platforms.

Funded by the European Union

- (Y. Li et al., 2023)— *Schizochytrium limacinum* grown on acetate; transcriptomics + fermentation performance show acetate as viable carbon toward DHA.
- (Zhang, E, et al., 2025)— *S. limacinum* valorizes VFA-rich effluents; butyrate/mixture carbons enable DHA production while polishing wastewater metrics.
- (Narisetty et al., 2022)— *Yarrowia lipolytica* engineered for robust acetate utilization; demonstrates acetate-to-lipid conversion and sets up EPA-type routes.

  (Patel et al., 2020) review— Industrial DHA from *Schizochytrium;* strain/medium strategies relevant when coupling to VFA carbons.

Representative patent signal

- US7932077 B2 (DuPont/Danisco) — Engineered *Y. lipolytica* pathways for high-EPA oils (desaturase/elongase cassette logic; industrial feasibility) (Damude et al., 2011).

6.2.3.3 Esterified PUFAs (processing, advantages vs. crude oils)

Esterification of PUFAs is widely used to stabilise, concentrate and functionalise omega-3/omega-6 lipids compared with crude oils or free fatty acids. Ethyl esters and re-esterified TAGs produced *via* chemo- or lipase-catalysed routes allow higher EPA/DHA loading, reduced off-flavours, improved oxidative stability and easier downstream formulation in capsules, emulsions and functional foods. Recent reviews and studies on omega-3 processing and structured lipids (Aguilera-Oviedo et al., 2021; Castejón & Señoráns, 2020; Xie et al., 2023) show that enzymatic esterification/transesterification under mild conditions efficiently generates PUFA-rich esters and TAGs with better shelf-life and processability than corresponding crude fish oils or free PUFAs.

A related strategy is esterification of PUFAs with phytosterols, particularly β-sitosterol, to obtain sterol–PUFA esters that combine the cholesterol-lowering properties of phytosterols with the cardiometabolic and anti-inflammatory potential of long-chain PUFAs. Chemical and enzymatic routes have been reported for β-sitosteryl–PUFA (e.g. linoleic, α-linolenic, EPA/DHA) esters, yielding products with lower melting points, improved dispersibility/solubility in lipid and food matrices, and enhanced formulation flexibility compared with crystalline β-sitosterol plus separate PUFA oil (C. Liu et al., 2019; W. Liu et al., 2021; Qianchun et al., 2011; Zhang, Yan, et al., 2025) These systems can be positioned as structured lipids with synergistic functionality (sterol + PUFA) and as a technically credible alternative to unmodified marine oils in high-value nutraceutical concepts.

Representative process/purification papers & patents

- (Oterhals et al., 2010)— **Modeling of short-path distillation** to remove POPs from fish oils (temperature/feed-rate/working-fluid effects).
- (Olli et al., 2013)— Experimental **short-path distillation** achieving efficient removal of a broad set of POPs from fish oil.
- WO2013178936 A2 — **Method for continuously enriching an oil produced by microalgae with ethyl esters of DHA.** Molecular distillation to enrich DHA-EE from microbial/algal oils (PATINIER & Looten, 2013).

- WO2013178937 A2 — **Method for continuously enriching an oil produced by microalgae with ethyl esters of dha** — Multistage supercritical CO_2 extraction to enrich DHA-EE (scalable high-purity route) (Perrut et al., 2013).

6.2.4 Phosphorus Fertilizers from Pyrolysis of Fish Bones & Chicken Feathers

Phosphorus fertilizers are derived from the pyrolysis of fish bones and chicken feathers, which are classified as by-products according to Regulation (EC) No. 1069/2009. The products obtained must comply with the provisions of the Fertilizers Products Regulation (EC) No. 2019/1009.

Specifically, pyrolysis products could fall within a new CMC of FPR 2019/1009, namely CMC 14 "PYROLYSIS AND GASIFICATION MATERIALS" through a Delegated Act by amending Annexes II, III and IV to Regulation (EU) No 2019/1009 of the European Parliament and of the Council for the purpose of adding pyrolysis and gasification materials as a component material category in EU fertilizing products. The CMC 14 is concerned with the subject of pyrolysis and gasification materials.

Specifically, an EU fertilizing product may contain pyrolysis or gasification materials obtained through the thermochemical conversion under oxygen-limiting conditions of exclusively one or more input materials, including animal by-products or derived products within the scope of Regulation (EC) No 1069/2009. The pyrolysis or gasification reactor may only process input materials, which are not contaminated with material streams, or input materials, other than animal by-products or derived products within the scope of Regulation (EC) No 1069/2009 which have been contaminated with other material streams unintentionally in a one-off incident, resulting only in trace levels of exogenous compound.

The pyrolysis and gasification materials shall have a molar ratio of hydrogen (H) to organic carbon (H/Corg) of less than 0.7, with testing to be performed in the dry and ash-free fraction for materials that have an organic carbon (Corg) content of less than 50%.

They shall have no more than:

(a) 6 mg/kg dry matter of PAH16 (**);

(b) 20 ng WHO toxicity equivalents (***) of PCDD/F (****) /kg dry matter;

(c) 0.8 mg/kg dry matter of ndl-PCB (*****);

(d) 30 g/kg chlorine (Cl-) on a dry matter basis;

(e) 2 mg/kg dry matter of thallium (Tl), in case more than 5% of pyrolysis or gasification additives relative to the fresh weight of total input material have been applied.

NOTES:

(**) Sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenzo[a,h]anthracene and benzo[ghi]perylene.

(***) van den Berg M., L.S. Birnbaum, M. Denison, M. De Vito, W. Farland, et al. (2006). The 2005 World Health Organization Re-evaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-like Compounds. Toxicological sciences: an official journal of the Society of Toxicology 93:223-241. doi:10.1093/toxsci/kfl055.

(****) Polychlorinated dibenzo-p-dioxins and dibenzofurans.

(*****) Sum of congeners PCB 28, 52, 101, 138, 153, 180.

7 Market & Ingredient Landscape

7.1 Commercially Available Ingredients from Selected Feedstocks

To understand the positioning of ONE EARTH compounds within current markets, existing commercially available products derived from the same feedstocks (chicken feathers, cheese whey, fish scales and bones) or producing similar compounds (peptides, PUFAs etc.) were reviewed.

This review considered suppliers worldwide and included data from product catalogs, regulatory databases, and commercial platforms such as Alibaba, UL Prospector, Knowde, SpecialChem and manufacturer websites. Products selected reflect established market presence, regulatory approval, and relevance to the application areas of cosmetics, nutraceuticals, fish feed, and adhesives.

This benchmarking provides a valuable context for positioning ONE EARTH's target compounds within existing supply chains and end-use formulations.

7.1.1 Peptides from Chicken Feathers

7.1.1.1 Cosmetic ingredients

Representative cosmetic ingredients identified in our scan (non-exhaustive):

- Vari®-Ker 100 (Variati S.p.A.) – feather-derived low-molecular-weight peptides (<1,000 Da) positioned for hair "restructuring," with an AA profile rich in serine, proline and glutamic acid; suitable for shampoos and treatments.
- Greentech / trading platforms (e.g., Alibaba listings) – feather keratin powders/hydrolysates with variable specification; suitable for hair, nail, skin, and food supplements.

Functional positioning for formulating cosmetics

- Shampoo & light leave-ons: favour <1 kDa fractions for better cuticle ingress and rinse-off retention; pair with cationic polymers/quats for deposition.
- Masks/conditioners: include 3–10 kDa (optionally with a small 10–30 kDa tail) for film formation, combability and breakage reduction; blend with a cationic system for substantivity.
- Face/hand creams: use 1–3 kDa narrow cuts (or blends with a small <1 kDa tail) for a soft, non-tacky feel and measurable hydration.
- Organoleptics: specify deodorised grades (carbon/β-cyclodextrin/membrane polished) and finish products at pH 5.0–6.0 with EDTA 0.05–0.1% to minimise amine-type off-notes and colour drift.

Implications for ONE EARTH

The category is technically validated yet fragmented. ONE EARTH can differentiate with standardised MW fingerprints (SEC-HPLC % bands), low-odor specifications (TVB-N/amine limits), and application-level performance data (e.g., tensile & combing on bleached hair; corneometry/TEWL in skin). Two immediately relevant SKUs are proposed for partners:

1. CF-Pep L (0.4–0.9 kDa, deodorised) for shampoos/serums (0.2–0.5%).
2. CF-Pep M/H (2–8 kDa with 10–20% 10–20 kDa, deodorised) for masks/conditioners and creams (0.3–1.0%).

7.1.1.2 Food-supplement ingredients

Representative nutraceutical ingredients (feather-sourced) identified in our scan (non-exhaustive):

- Kera-Diet® (BCF Life Sciences) – extensively hydrolysed feather keratin positioned for nutricosmetics.
- KeraGLO® (NutriScience Innovations) – food-grade hydrolysed keratin from poultry feathers, promoted as "extensively hydrolysed" for higher digestibility/absorption; used in capsules, powders, tablets, liquids; marketing specs note high free-AA content.
- Food-grade feather keratin hydrolysates (various) e.g Greentech – multiple Chinese suppliers list feather-origin hydrolysates for dietary supplements; specifications vary widely (degree of hydrolysis, ash/metals, microbiology).

Form/organoleptics & quality specifications for ONE EARTH benchmarking:

- Form factor: spray-dried powders with low odour, low ash, good solubility; target capsule or sachets.
- Specs to standardize/compare: free AA % (vs. peptides), MW distribution (SEC-HPLC), total sulfur AAs (Cys/Met), TVB-N/amine limits (odour proxy), heavy metals, microbiology (including absence of Salmonella/Staph), and allergen/origin statements.
- Positioning & use levels: hair/skin/nails benefits; ~0.5–1.0 g/day typical in marketed concepts and trials; combine with minerals/vitamins as appropriate (e.g., Zn/biotin/Se).

Implications for ONE EARTH

Extensive hydrolysis (higher free-AA fraction) and low-odor processing / deodorised. A complete regulatory dossier (source traceability, HACCP/GMP, contaminants) will be needed. Benchmarked targets and dose form benchmarks above can work as a guide.

7.1.1.3 Adhesive ingredients

There are no commercially available adhesives specifically marketed as being derived from chicken feather-based peptides, though this is an active area of research and development. Several research institutions are working on creating sustainable bio-adhesives from chicken feather keratin, a protein that can be hydrolyzed into peptides, with the goal of replacing petroleum-based adhesives. While some research groups have successfully produced experimental adhesives, these products are not yet available on the commercial market.

Why this is an area of development:

- Waste reduction: Chicken feathers are abundant waste products from the poultry industry and using them for adhesives can provide an economic value to waste.
- Sustainability: The goal is to create a renewable and biodegradable alternative to traditional synthetic adhesives, which are often petroleum-based and can release harmful formaldehyde.
- Strong material properties: Keratin, the protein in feathers, has a strong fibrous structure and can be processed into adhesives with good bonding strength.

Examples of research:

- Fraunhofer Institute: Researchers have developed a process to enzymatically hydrolyze keratin into soluble oligomers, which can then be used to create adhesives.
- IPB University: A team developed an organic adhesive from chicken feathers and cow bone waste, demonstrating the potential for using waste materials to create adhesives.
- Bio-based binder research: Other studies have focused on using keratin hydrolysate as a bio-based binder for products like particleboard, showing its potential for industrial applications, though these are not yet commercial products.

7.1.2 Collagen Peptides from Fish Scales and Bones

7.1.2.1 Cosmetic ingredients

Representative cosmetic ingredients identified in our scan (non-exhaustive):

- Crotein MCAA and Collasurge (Croda) (Aqua & Collagen Amino Acids) very low MW (~150 Da); highly hygroscopic, penetrates stratum corneum and undamaged hair cuticle for from-within moisturisation; great in lightweight serums, toners, and strengthening hair treatments.
- Crotein M (Croda) (Hydrolyzed Collagen) medium MW (~12 kDa); substantive humectant/conditioner for skin and hair; boosts hair plasticity and manageability; fits conditioners, 2-in-1s, and leave-ons where slip and breakage reduction matter.
- Collasol M PE (Croda) (Aqua & Soluble Collagen) very high MW (~300 kDa); forms a surface moisture reservoir/film that smooths feel, helps elasticity appearance, and reduces TEWL; ideal for skin creams/serums and premium conditioning masks where film-forming and sensory payoff are desired.
- MARI COLL NPNF (TRI-K) (Hydrolyzed Collagen) for hair-care (conditioning/repair)

- Naticol® x3Peptide (Weishardt) (Hydrolyzed Collagen) Collagen tripeptide-enriched; very low MW peptides (≤~300 Da fraction) for firming/anti-wrinkle and scalp vitality concepts; pairs well with niacinamide/HA; best in serums, eye gels, scalp tonics (use 0.1–1%).
- Naticol® 1000 (Weishardt) (Hydrolyzed Collagen) low-MW (~2 kDa) film-forming humectant for skin and hair; boosts immediate moisturization without tack, improves hair manageability; great in lightweight gels, essences, leave-in sprays (use 0.2–3%).
- Naticol® 4000 (Weishardt) (Hydrolyzed Collagen) low-MW (~4 kDa) medium-MW for cushiony feel and barrier support; enhances slip and combability in rinse-off and leave-on; suits creams, masks, conditioners where a bit more body is desired (use 0.2–5%).
- Naticol® CySkin (Weishardt) (Collagen peptides + L-cystine complex) beauty-tone/radiance positioning; supports antioxidant and smoothing claims; works in brightening serums, day creams, spot ampoules (use 0.2–2%).

Chemistry & Specifications (what is typically marketed)

- Type: Predominantly Type I collagen/peptides from fish scales/skins/bones.
- Form: Fine powder; occasionally liquids.
- Molecular weight: Common bands ~0.3–5 kDa for peptides; gelatin ~50–300 kDa.
- Assays: ≥90% protein on dry basis (peptides), moisture ≤8–10%, ash ≤2–5%, fat ≤1%.
- Amino acid profile: High glycine, proline, hydroxyproline; negligible tryptophan.
- Solubility & sensory: Neutral odor "marine-mild" grades; low viscosity in solution for peptides.
- Contaminants: Heavy metals and microbiological specs aligned to cosmetic standards.

7.1.2.2 Food-supplement ingredients

Representative food supplement ingredients identified in our scan (non-exhaustive):

- *Naticol®(*Weishardt): Marine collagen peptides of natural origin, soluble, odorless, colorless, neutral in taste, and heat resistant. Different grades and dosages target different applications such as joints, beauty, active aging, sport and gut support, with scientifically proven benefits.
- *Peptan® F (*Rousselot): One of the leading brands of collagen peptides with neutral sensory profile and instant solubility, targeted for mobility, beauty and sport applications. Certified with Friend of the Sea (FOS) Certificate focusing on sustainability.
- SOLUGEL® *Marine (*PB Leiner): SOLUGEL® product range comprises four products, fitting a wide range of consumer applications. SOLUGEL® Optima FD and FP are destined for oral consumption as collagen powder, with neutral organoleptic profile, combined with improved solubility and wettability properties. SOLUGEL® Supra FP and FD have a very low molecular weight (500 Da) enabling instant absorption and are marketed for ready-to-drink applications (shots and beverages).
- CollaSel *fish (Valemis):* High quality fish collagen with neutral sensory profile and average MW 2000 Da. Also available as CollaSel Fish Tripeptide (MW 500 Da) with increased bioactivity in beauty and mobility applications proved by clinical studies.

- Further Food Grade Marine Collagen (Various suppliers): There are several commercially available collagen peptides of marine origin produced worldwide. Molecular weight (MW) typically lies within the range of 1000 – 3000 Da.

Implications for ONE EARTH

Strong market maturity and broad acceptance make fish-derived collagen peptides a low-risk benchmark for nutraceutical and cosmetic use, with clear specs and compliance pathways. The space for differentiation comes from the aspect of sustainability and traceability as available products typically derive from cultivated fish skin, while materials produced within one EARTH's scope derive from valorized by-products, fish scales & bones.

7.1.2.3 Adhesive ingredients

While "fish scale and bone glue" itself isn't a commonly listed product, commercial adhesives derived from fish peptides are available, often as animal-based protein glues or specialized hydrogels. These are made from fish byproducts like skins, bones, and scales, which are rich in collagen that is processed into gelatin to create an adhesive. Specialized products are also emerging, such as hydrogels made with fish skin gelatin and peptides for applications like tissue adhesion.

How they are made and their properties:

- **Collagen source:** Adhesives are made from collagen extracted from fish skins, bones, and scales, which are abundant fishery byproducts.
- **Processing:** The collagen is typically processed by heating in water to break it down into soluble gelatin, which can then be used as an adhesive.
- **Specialized products:** More advanced products are being developed, like hydrogels cross-linked with peptides for specific uses, such as medical tissue adhesion.

Examples of commercial products:

- **Protein glues:** These are commercially available animal glues, including fish glue.
- **Isinglass:** The purest form of fish glue, made from the swim bladders of fish like sturgeon, has been historically used as an artist's adhesive.
- **Specialty hydrogels:** Some research points to the development of fish-based hydrogels, though these may not yet be widespread commercial products, such as those developed for tissue adhesion.

7.1.3 PUFAs from fermentation

7.1.3.1 Cosmetic ingredients

Representative cosmetic ingredients identified in our scan (non-exhaustive):

- PEPHA®-TIGHT CB (dsm-firmenich) – *Nannochloropsis oculata* extract (microalgae) with pullulan; positioned for instant + long-term firming/skin-tightening in serums, eye gels and day creams.
- Algal DHA Oil 40% (Vita Actives) – cosmetic-/nutraceutical-grade *Schizochytrium* oil (high-DHA) supplied as bulk oil for emolliency/skin-conditioning claims and lipid-phase enrichment in creams, balms and sticks.
- Vegan Algal Oil Powder (Nutraceuticals Group) – microencapsulated *Schizochytrium* oil (powder, ~11% total omega-3) for easy dispersion into water-based formats (lotions/serums) and anhydrous powders; useful when oil handling or oxidation is a concern.
- *Yarrowia lipolytica* Ferment Lysate (various cosmetic suppliers) – yeast-ferment lysate (humectant/skin-conditioning) that can complement lipid phases in microbiome-friendly or barrier-support formulas. (INCI: *Yarrowia Lipolytica Ferment Lysate*).

Functional positioning for formulating cosmetics (PUFA focus)

- Barrier & emolliency: add 0.5–2% algal DHA oil to O/W creams and balms for lipid-phase enrichment; combine with antioxidants (e.g., tocopherol) and chelators.
- Light textures/serums: prefer algal oil powders (microencapsulated) to dose omega-3s without greasiness; good in gel-creams/emulsions that target sensitive/soothing claims.
- Tightening/instant effect: use PEPHA®-TIGHT CB at supplier-recommended levels (typically 1–3%) for visual lift; pair with film-formers.

7.1.3.2 Food supplements ingredients

Representative food-supplement ingredients identified in our scan (non-exhaustive):

- life'sDHA® (DSM-Firmenich): Vegetarian DHA from *Schizochytrium*; available as oils and powders for softgels, gummies and foods.
- VivoMega Algae 2050 TG Premium (GC-Rieber): High EPA (20%) and DHA (50%) concentrate on triglyceride (TG) basis made from algae oil. The algae oil is derived from microalgae that originates from the strain *Schitzochytrium sp.*
- Almega®PL (Qualitas/iwi/Algatech portfolio): *Nannochloropsis*-derived EPA-only extract enriched in polar lipids (>15%); clinical evidence for lipid management; positioned as high-bioefficiency EPA.
- Yeast-derived EPA Oil (engineered *Yarrowia lipolytica*): Fermentation EPA developed at industrial scale (DuPont "Harvest™/New Harvest™ EPA" program); demonstrates feasibility of yeast EPA supply for human nutrition (availability varies today).

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Esterified PUFAs (commercial examples & advantages)

Representative esterified formats and where they fit:

- Algal DHA/EPA Ethyl Esters (from *Schizochytrium*; multiple suppliers) – concentrated EE oils produced by trans-esterification (e.g., ≥450 mg/g DHA EE; ≥150 mg/g EPA EE) intended for food supplements. Advantages: high potency per capsule, finer control of EPA:DHA ratios, and often lower viscosity for filling; use with meals to maximize absorption.
- Concentrated DHA Ethyl Ester (microalgal) – clinical literature describes 90% DHA EE concentrates (e.g., MATK-90) with triglyceride-lowering effects. Advantages: very high DHA payload per softgel; suitable for targeted cognitive/eye-health products.
- EPA Polar-Lipid Complexes (e.g., Almega®PL) – EPA enriched in glycolipids/phospholipids rather than neutral TAG/EE. Advantages: improved dispersion and reported bioefficiency at lower doses; vegan alternative to krill-type phospholipid delivery.
- General note on EE vs TAG/PL: EE allow higher concentration and flexible standardization; TAG are closer to native dietary lipids; PL/polar formats may offer better bioavailability and GI tolerance in some studies/formats.

Implications for ONE EARTH

- For cosmetics, prioritize microencapsulated algal powders and PEPHA®-TIGHT CB for light textures + visible effect; include antioxidant systems to protect PUFAs.
- For food supplements, anchor the vegan omega-3 range on life'sDHA® / life's®OMEGA and differentiate with EPA-only polar lipid (Almega®PL); consider EE concentrates when capsule count or potency targets are strict.

7.1.3.3 Adhesive ingredients

Commercially available adhesives derived from polyunsaturated fatty acids (PUFAs) are often bio-based polyurethanes and epoxies, which incorporate oils rich in PUFAs like soybean, castor, and linseed oil. Another emerging product is the high-performance thermoplastic hot-melt adhesive from Arkema (Platamid Renew), which is 100% vegetable oil-based. These are developed as sustainable alternatives to petrochemical-based adhesives, with applications in various industries, particularly for bonding wood and metal.

Types of adhesives:

- **Polyurethane (PU) adhesives:**
    - Developed from vegetable oils such as soybean, castor, and linseed oil, which are chemically modified into polyols to react with isocyanates.

- Show good bonding ability on various substrates and enhanced biodegradability compared to fossil-fuel-based adhesives.

- **Epoxy adhesives:**
    - A new generation of bio-sourced epoxy monomers and polymers are being developed using natural materials like vegetable oils.
    - These offer good chemical resistance and flexibility.
- **Thermoplastic hot-melt adhesives:**
    - Arkema's Platamid Renew is a high-performance hot-melt adhesive made from 100% vegetable oil, making it an emerging option for high-demand applications.

Key benefits and considerations:

- **Sustainability:** Reduces reliance on fossil fuels, aligning with a circular economy.
- **Biodegradability:** Offers enhanced biodegradability compared to traditional adhesives.
- **Performance:** Vegetable oil-based PU adhesives, especially those rich in unsaturated fatty acids, demonstrate good bonding properties and chemical resistance. However, the high unsaturation in some oils may make them more susceptible to oxidation, requiring stability evaluations.
- **Processing:** Some can be processed using standard equipment, such as the Platamid Renew hot-melt adhesive which can be processed into web, film, and filament.
- **Research focus:** Ongoing research is optimizing formulations to ensure the oil content does not negatively impact mechanical strength and evaluating the long-term durability of these materials under different environmental conditions.

7.1.3.4 Fish feed ingredients

Over the past two decades, the aquaculture industry has significantly reduced its dependence on marine ingredients such as fish meal and fish oil, which are primary sources of protein, polyunsaturated fatty acids (PUFAs), and essential minerals for cultured species. To find alternatives for both protein and lipid sources, the industry has increasingly utilized by-products from aquaculture, including trimmed fish, fish hydrolysates, and fish oils. For instance, the availability of PUFAs derived from algal sources, along with revalorized oils from the aquaculture sector, has provided the aquafeed industry with additional options for sourcing these important fatty acids.

Representative PUFA-based ingredients for fish feeds identified in our scan (non-exhaustive):

- Enviro Fish Oil (Pelagia) – rich in EPA, DHA and other long-chain fatty acids. Accepted as organic feed ingredient according to Regulation (EC) No 834/2007 and No 889/2008. Without synthetic preservatives, added natural antioxidants.
- QRILL Aqua Total (Aker QRILL Company) – a natural red-orange-brownish meal derived from Antarctic krill, rich in essential nutrients and free from additives. This product shows natural seasonal variation of fat and protein contents.
- QRILL AstaOmega Oil (Aker QRILL Company) – a specialty performance supplement in the format of an oil of dark red color due to its high content in astaxanthin. Also high in omega-3 fatty acids and cholesterol.
- AlgaPrime™ DHA (Corbion) – oil from heterotrophically grown Schizochytrium, source of DHA. Available in two formats: as a dry powder made of microencapsulated oil and in liquid form as a blend of algae and vegetable oil.
- Algal Oil (Veramaris) – oil with 65 % DHA & EPA obtained from heterotrophically grown microalgae. Successfully tested in white shrimp and Atlantic salmon.
- DHA Natur™ (ADM Animal Nutrition) - highly concentrated, vegetable-based DHA omega-3 source based on heterotrophic algae. Recommended for salmon and trout, applicable to other species. Flax oil (ADM Animal Nutrition) – source of alpha-linolenic acid.

Some of the commercial suppliers of by-products from the aquaculture industry:

- MOWI- salmon oil from by-products of the salmon industry.
- DANFOREL – supply of fish oil and fish protein concentrate processed from by-products from the trout processing industry.

7.1.4 Phosphorus Fertilizers from Pyrolysis of Fish Bones & Chicken Feathers

A comprehensive review of the extant literature on the subject reveals a lack of any reference to commercially available fertilizers derived from pyrolyzed fish bones and chicken feathers. However, in Italy, two products derived from fish and chicken are available and are subject to regulation by the Italian legislation for fertilizers (D.Lgs. 75/2010). The two products in question are referred to as chicken feather meal (i.e. Pennone) and fish bone meal. The former is classified as a nitrogen (N) organic fertilizer, while the latter is classified as a nitrogen-phosphorus (NP) organic fertilizer.

The pyrolysis of fish bones and chicken feathers has the potential to enhance the stability of the fertilizer. Consequently, this would result in a reduction in the rate of fertilizer degradation, thereby minimizing the release of nutrients from the fertilizers. These aspects are critical for ensuring the long-term maintenance of soil health and fertility.

7.2 Comparative Benchmarking of Selected Products

To assess how ONE EARTH's target compounds compare with existing and emerging commercial solutions, several product attributes and performance criteria were benchmarked. The benchmarking covers purity, yield (or content), cost (when available), regulatory status, sustainability credentials, and functional performance in end-use applications. Data were gathered from technical datasheets, supplier disclosures, scientific literature, and market reports.

Table 3 Commercial products benchmarking

Product / Solution	Feedstock	Purity/ active content	Regulatory status	Functionality	Retail Price (B2B) €/kg	Estimated producer's price €/kg
Vari®-Ker 100	Chicken feathers	~80 % hydrolyzed keratin peptides	Approved for cosmetics	Personal care; hair repair		
Hydrolyzed Keratin Protein Powder (Greentech)	Chicken Feather	>90% hydrolyzed keratin peptides	Approved for cosmetics	Personal care; hair repair		40
Crotein MCAA	Chicken Feather	15% Collagen Amino Acids MW ~150	Approved for cosmetics	hair and skin		
Naticol® x3Peptide (Weishardt)	Fish scales / skin	≥25% collagen tripeptides (Gly–X–Y type), produced via specific enzymatic hydrolysis. MW 300 Da	Cosmetics	Skin		
Naticol® 1000 (Weishardt)	Fish scales / skin	low-MW (~2 kDa)	Cosmetics	Hair		

Peptan® Marine (Rousselot)	Fish scales / skin	~90 % collagen peptides (Type I)	EU Novel Foods + Cosmeticapproved	Nutraceuticals; cosmetics	23	16
Peptan® Marine (Rousselot)	Fish scales / skin	~90 % collagen peptides (Type I)	EU Novel Foods + Cosmeticapproved	Nutraceuticals; cosmetics (joint, skin)	23	16
Menifluid (Menichetti)	Plant-based glue, which contains less than 15% animal protein.	Vegetable biomass	Nordic Swan Ecolabel	Adhesives	7	
Leinos 720 Natural latex Glue (Leinos Naturfaben)	Natural latex	Natural latex, water	DIN 53269, 53275, 54324	Adhesives	26	
VivoMega Algae 2050 TG Premium	*Schitzochytrium sp.* microalgae	50% DHA + 20% EPA	Complies with current EU regulations for foods/dietary ingredients	Food supplements		102
EcoPhos® (Ecophos SA)	Fish bones and animal byproducts	Mineral P content typically > 2025 % P_2O_5 equivalent	Meets EU Fertiliser Regulation 2019/1009 for CE mark	Plant Biostimulants; fertiliszer markets		
Algal Oil (Veramaris)	Micralgae	oil with 65 % DHA & EPA	ASC-MSC certified algal oils for aquaculture	Alternative source of PUFAs in aquafeed	9-10	
Salmon oil	By-products from the salmon industry	EPA/DHA -5-8% of total fatty acid	ASC certified	Aquafeed	1.2-1.5	

8 Summary of Technical and Regulatory Requirements

8.1 Consolidated Specification Sheet(s) for Each Target Compound

The following specification sheets summarize the key physico-chemical, microbiological, regulatory, and application-related parameters for the compounds targeted by the ONE EARTH project. These specifications reflect the consolidated requirements gathered from industrial partners, literature, commercial benchmarking, and regulatory constraints. They serve as guiding documents for product development and scale-up.

8.1.1 Target Compound: Hydrolysed Keratin Peptides (from Chicken Feathers)

Table 4 Specification of Hydrolyzed Keratin Peptides (from Chicken Feathers)

Parameter	Specification / Requirement
Appearance	Off-white to light yellow powder or granules
Protein Content	≥ 80% (w/w)
Moisture	≤ 8%
Odor	Mild; no residual feather odor
Solubility (in water)	≥ 90% at 25°C
Heavy Metals	Lead < 1 ppm; Arsenic < 0.5 ppm
Microbiology	TAMC < 1000 CFU/g, Yeasts & Moulds < 100 CFU/g
Applications	Hair care, skin barrier repair, agricultural biostimulant
Regulatory Status	Cosmetic (EU Cosing: Hydrolyzed Keratin); Feed: permitted under EC 767/2009

8.1.2 Target Compound: Marine Collagen Peptides (from Fish Scales/Bones)

Table 5 Specifications of Marine Collagen Peptides (from Fish Scales/Bones)

Parameter	Specification / Requirement
Appearance	White to light beige powder
Molecular Weight	2–5 kDa. For cosmetic applications: MW average ≤ 3.5 kDa
Peptide Content	≥ 90% (w/w)
Solubility	≥ 95% in water
Taste/Odor	Neutral, no fishy odor
Heavy Metals	Mercury < 0.1 ppm; Cadmium < 0.5 ppm
Microbiology	Total microbial count <1000 cfu/g, Pathogen-free; Salmonella absent
Applications	Nutricosmetics, joint health, skin elasticity
Regulatory Status	EU Novel Food-compliant; GRAS in US

8.1.3 Target Compound: PUFAs from Whey Fermentation

Table 6 Specification of PUFAs from Whey Fermentation

Parameter	Specification / Requirement
Appearance	Light yellow to golden oil or oil-blend (liquid)
Fatty Acid Profile	To be defined
Free Fatty Acids	≤ 5% (oleic acid equivalent)
Peroxide Value	≤ 5 meq O_2/kg oil
Moisture	≤ 0.2% w/w
Unsaponifiable Matter	≤ 2%
Heavy Metals	Pb < 0.5 ppm; Cd < 0.1 ppm; Hg < 0.05 ppm; As < 0.1 ppm
Microbiology	Pathogen-free; total viable counts ≤ 10^4 CFU/g
Oxidative Stability	≥ 3 months shelf life under cool, dark storage
Regulatory Status	Pending (novel food, feed) depending on process
Functional / Organoleptic	Neutral to mild odor, encapsulation-compatible

8.1.4 Target Compound: Phosphorus from Fish Bones

Table 7 Specification of Phosphorus from Fish Bones

Parameter	Specification / Requirement
Physical Form	Powder or granules; optionally acid-treated
Phosphorus Content	≥ 20–25% P_2O_5 w/w
Calcium : Phosphorus Ratio	1.5:1 to 2:1
Solubility / Availability	≥ 10% water-soluble; ≥ 30–50% acid-soluble
Moisture	≤ 10% w/w
Heavy Metals	Cd ≤ 60 mg/kg P_2O_5; Pb, Hg, As within EU limits
Microbiology	Pathogen-free; ABP Category 3 compliant
Regulatory Status	EU Fertilizing Products Reg. 2019/1009
Functional Properties	Granular form, low dust, slow/medium release

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9 Conclusions and Recommendations

The literature and market analysis conducted in D4.1 confirms that ONE EARTH targets technically feasible and market-relevant compound families (feather- and whey-derived peptides, marine collagen, PUFAs from fermentation, recovered phosphorus and related streams), aligned with growing demand for sustainable, traceable and high-performance ingredients. At the same time, it highlights key success factors: managing purity–yield–cost trade-offs, integrating regulatory requirements early, substantiating sustainability and traceability claims, and ensuring cost competitiveness against established benchmarks.

Based on this analysis, D4.1 consolidates a set of technical and regulatory requirements and preliminary specifications for each target compound/application. These outputs will serve as a common guidance framework for partners in WP1, WP2 and WP3, steering feedstock selection, process development and product design toward:

- realistic, application-specific specification levels (minimum/target/premium) linking functionality, safety and manufacturability;
- “regulatory-by-design” development aligned with current legislation;
- integrated traceability and sustainability documentation suitable for future LCA and verification;
- techno-economic viability consistent with industrial scale-up.

By operationalising these requirements across the upstream work packages, ONE EARTH strengthens coherence between research, development and future market uptake, and positions its ingredients as credible, competitive and sustainable alternatives in EU and global value chains.

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