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Date: **30th April 2025**

Deliverable 3.5

Final Report on Feather Biorefinery Concepts for EU Poultry Sector

This project has received funding from the Bio-based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 101023306

Technical References

Project Acronym	UNLOCK
Project Title	Unlocking a new feather bioeconomy for keratin-based agricultural products.
Project Coordinator	Sarah Montes, CIDETEC
Project Duration	48 months

Deliverable No.	3.5 Final report on feather biorefinery concepts for EU poultry sector
Dissemination level [1]	Public
Work Package	Work package 3: Setting the basis for the feather economy: designing the novel value chains
Task	Task 3.2 Design of integrated biorefinery concept or other processing layout tailored to local circumstances
Lead beneficiary	Farrelly Mitchell
Contributing beneficiary(ies)	Farrelly Mitchell, Bioextrax, Processum, Cedrob, CIDETEC
Due date of deliverable	30/04/2025
Actual submission date	12/05/2025 (23/07/2025 resubmission)

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Authors
1	24/04/2025	Farrelly Mitchell	D. Traas, P.B. Farrelly
2	25/04/2025	CIDETEC	S. Montes (revision)
3	30/04/2025	Farrelly Mitchell	D. Traas (revision)
4	23/07/2025	Farrelly Mitchel	D. Traas (new version)

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Summary

This deliverable, titled 'Final Report on Feather Biorefinery Concepts for EU Poultry Sector', describes the various analyses conducted on the biorefinery concepts developed under Project UNLOCK. In particular, the report considers technical, economic and environmental analysis of the three demo cases prepared within the Project, and benchmarks each aspect against the 'as-is' scenario of feather rendering. The report also applies the results of the social LCA to the biorefinery concepts, and details the EU regulations that must be complied with when it comes to feather treatment and processing.

Disclaimer

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1. Introduction

Within Project UNLOCK, three methods of feather treatment have been explored – steam explosion, mechanical grinding, and microbial fermentation. The purpose of the research carried out under Task 3.2 (Design of integrated biorefinery concept or other processing layout tailored to local circumstances), and the results included within this deliverable, was to conceptualise the biorefinery models developed at a commercial scale, and to conduct technical, economic, and environmental analyses of these models, to determine their potential feasibility as a business case in the future. For benchmarking purposes, this analysis is also conducted for the current method of feather treatment, feather rendering, which hydrolyses the feathers for use in animal feed or fertiliser. As well as considering technical, economic and environmental aspects, this report also details the potential social impacts of the biorefinery concepts, and lays out the EU regulations that these feather treatment processes must comply with.

In order to make fair comparisons, and given that the processes developed under Project UNLOCK have not yet reached a commercial scale, numerous assumptions were made throughout the course of the analysis. For example, it was assumed for the economic analysis that any biorefinery concepts would be located adjacent to a slaughterhouse, and that each process has a production capacity of 1 MT per hour. Any assumptions made are detailed, as relevant, throughout the report.

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2. Technical Analysis

Steam Explosion

Steam explosion is commonly employed as a technique for processing wood into its three main components: cellulose, hemicellulose, and lignin. Under UNLOCK, this process was investigated as a method of feather treatment to facilitate further processing and use of the steam exploded materials in bio-based agricultural plastics. While RISE Processum are responsible for this research within the project, Cedrob have previously expressed potential interest in investing in this area, hence its consideration within this report as a demo case. The steam explosion of feathers exhibited promising results throughout the course of the project.

Process Description

The steam explosion process is characterised by the exposure of material to hot steam (typically between 180 to 240 °C) under pressure (ranging from 1 to 3.5 MPa). Following this, an explosive decompression ensues, rupturing the structure of the material. The rapid release of pressure induces a physical tearing effect. In the context of keratinous materials, the steam explosion process results in disulfide bond cleavage, leading to decreased mechanical properties, moisture regain, and molecular weight, primarily attributed to the diminished concentration of beta keratin in the steam-exploded chicken feather solution (Vadillo et. al, 2023). Such changes affect the keratinous materials' secondary structure due to the intense physical process parameters.

Process Scale

A key consideration in the conceptualisation of any industrial process, is the appropriate scale. The approach to determining scale can consider various factors, including the availability of raw materials, the capital costs involved, the impact of economies of scale, and the market demand for the products produced. Within Project UNLOCK, the steam explosion process was conducted within a small-scale batch reactor, before being scaled up to a 30kg per hour continuous reactor. For the

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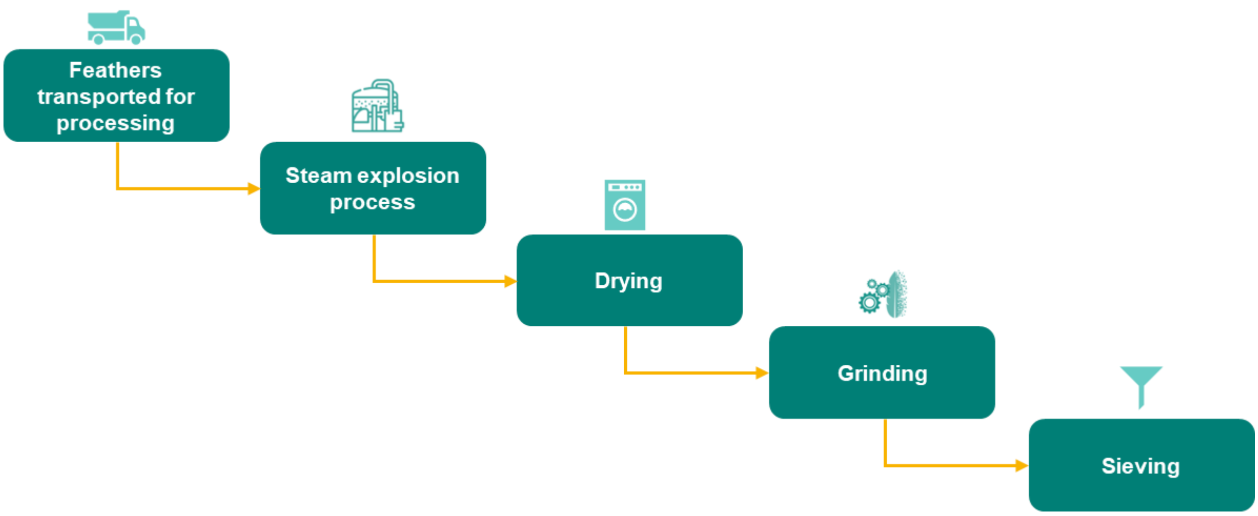
purposes of the examination of a commercial scale reactor, a 3 MT per hour continuous reactor was considered. A reactor of this scale would have the potential to produce over 23,000 MT of steam exploded feathers per year, which is a significant figure and would mean that 3.7% of all feathers produced in the EU would be processed in such a plant. Therefore, for the purposes of the analysis within this report, a more modest scale of 1 MT per hour was assumed, which, while still significant, would allow for a more realistic simulation of the processing of feathers at a commercial scale. It is also important to consider the potential for such a biorefinery to treat lignocellulosic biomass such as wood, which would reduce the feather treatment requirement for capacity utilisation. Given that this research is focused on feather treatment, the potential impact of this on project viability could not be incorporated into the economic or environmental analysis.

Process Flow

Figure 1 below details the key steps in the steam explosion process.

Figure 1. Steam Explosion Process Flow.



Mechanical Grinding

Within Project UNLOCK, mechanical grinding is a process whereby feathers are ground into smaller particle sizes, before being sterilised through the drying process, for application in nonwoven geotextile manufacture. Through UNLOCK, Cedrob have

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invested in grinding and sterilisation facilities, hence its consideration here as a demo case.

Process Description

Compared with steam explosion and certainly microbial fermentation, mechanical grinding is a relatively straightforward process. Following collection from the slaughterhouse, the feathers are washed, before being fed into the grinding machine. The demo case prepared under UNLOCK is capable of producing 200 – 300kg of ground feathers per hour. Following grinding, the wet feathers are conveyed to a dryer, which using heat, sterilises the feathers in according with the EU animal by-product regulation as they are dried. From here, the ground feathers are bagged before transport for use in end-product manufacturing.

Process Scale

As aforementioned, scale is a key consideration in the conceptualisation of any facility. Within UNLOCK, the demo case was developed to produce 200 – 300kg per hour of ground feathers. However, for the purposes of this task, it was assumed that commercial scale for the process would be 1 MT per hour, in order to align with the scales considered for steam explosion and microbial fermentation, and to allow for fair comparison of these processes from an economic and environmental perspective.

Process Flow

Figure 2 below details the key steps in the mechanical grinding process.

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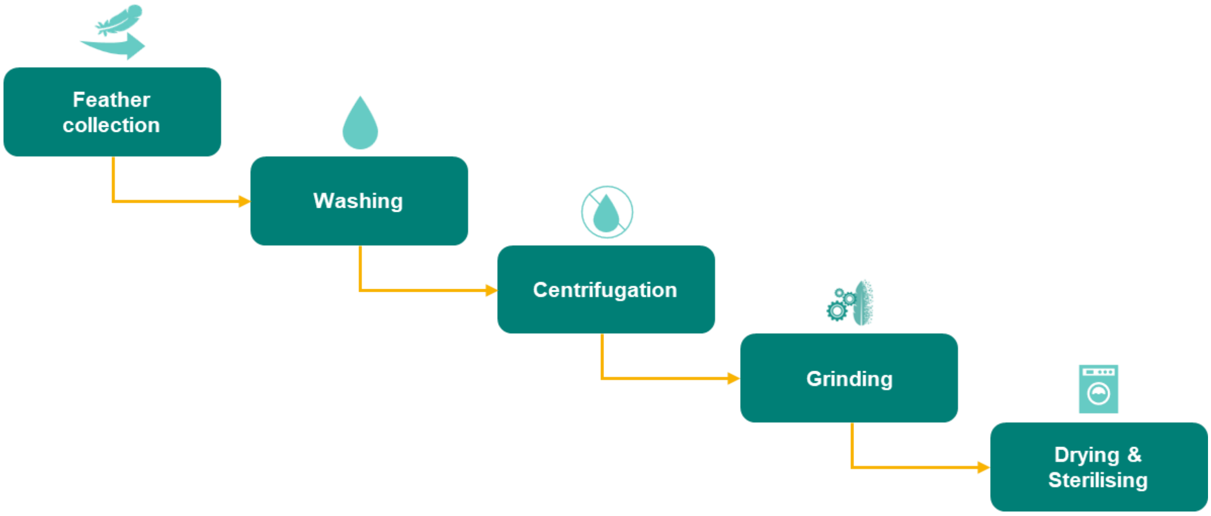
Figure 2. Mechanical Grinding Process Flow.



Microbial Fermentation

Microbial fermentation is a technique being investigated within Project UNLOCK as a method of extracting keratin microfibers from feathers. These microfibers have been used in the trial production of hydroponic foams. Bioextrax have developed this process using a fast-growing, pure bacterial strain, which produces natural enzymes that subsequently partially hydrolyse the keratin.

Process Description

Microbial fermentation is a complex, novel process that has been developed by Bioextrax for the treatment of feathers. Simplified, the process involves the sterilisation of feathers (but not sanitisation), fermentation within the bioreactor, before centrifugation and drying. The process yields two main products, keratin microfibers, used in hydroponic foam production, and hydrolysed protein, a valuable by-product with applications in animal feed.

Process Scale

Through Project UNLOCK, the microbial fermentation process has been scaled up from a 6L lab-scale bioreactor, to a 60L reactor, and ultimately to a 500L reactor. For the purposes of the TEE analysis being conducted of the biorefinery concepts, Bioextrax recommended the consideration of a 1 MT per hour facility. This is in line

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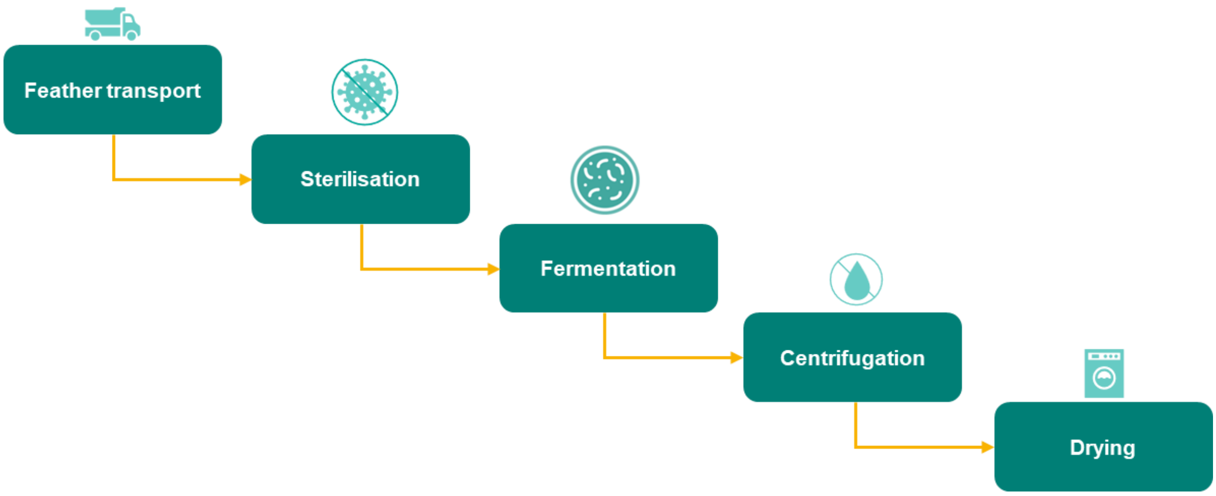
with the potential scales considered for steam explosion and mechanical grinding, and allows for comparison of economic and environmental results.

Process Flow

Figure 3 below outlines the microbial fermentation process flow.

Figure 3. Microbial Fermentation Process Flow.



Rendering

Rendering is a common process for converting animal by-products, such as feathers, into useful materials, such as feather meal. Feather meal is a protein-rich feed ingredient that can be used for in pig feed or pet food, or in fertilisers. Rendering

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involves heating the feathers under high pressure and temperature to hydrolyse the keratin, the fibrous protein that makes up most of the feather structure. The resulting product is then dried, ground, and packaged for distribution. Rendering is a widely adopted method for feather valorisation because it is relatively simple, low-cost, and efficient. However, rendering also has some drawbacks, such as the loss of amino acids, the formation of odours, and somewhat high energy consumption.

Process Parameters

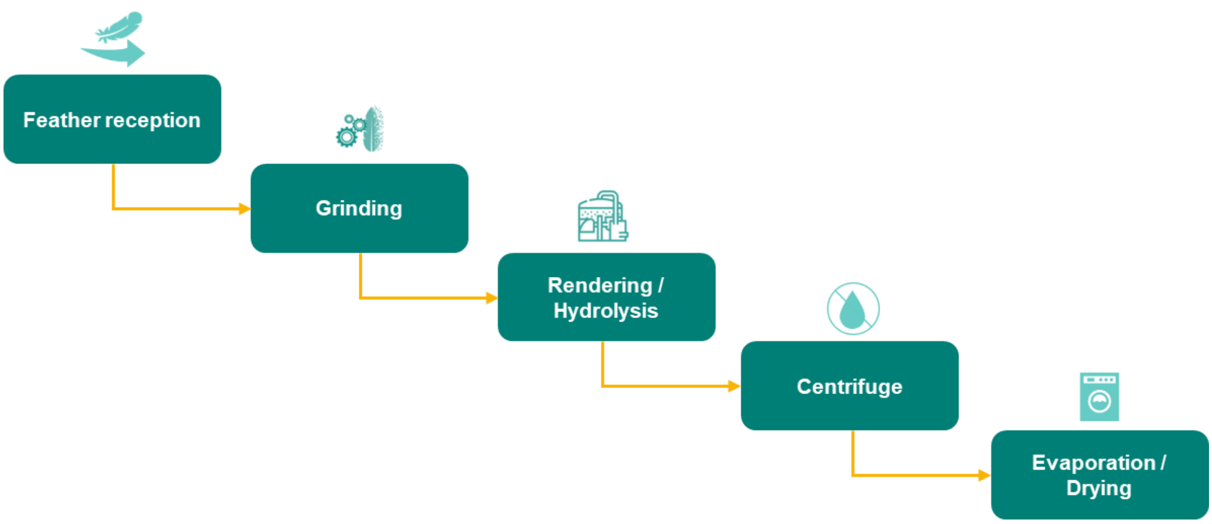
Given that feathers are typically mixed with water and blood at the slaughterhouse, moisture reduction in the form of centrifugation is required before processing. This brings the moisture levels from around 80% to around 62%.

The steam hydrolysis process has a typical duration of between 20 and 40 minutes, at between 2-3 bars of pressure. Hydrolysed feather meal generally has increased protein volume and digestibility when hydrolysis time approaches 40 minutes. Pressures above 2.5 bar lead to a decrease in protein content and digestibility (Sinhorini et. al, 2020).

Process Flow

Figure 4 below outlines the typical feather rendering process flow.

Figure 4. Feather Rendering Process Flow.



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3. Economic Analysis

Economic analysis is an essential component in the design of biorefinery concepts. While each aspect of TEE (technical, economic & environmental) analysis is important, as are social and regulatory considerations, any business case must be shown to be feasible from an economic perspective.

It has been shown that biorefineries are very sensitive to the production scale as an indicator of success. Typically, a high number and high quantity of high added-value products indicates potential success on a low scale, where larger scales are required for lower value outputs. NPV and production costs are very sensitive to scale given the fact that energy consumption and equipment prices do not rise at the same rate as production scale increases. Furthermore, the availability of raw materials and the demand for outputs are two significant limiting factors on scale.

For the purposes of this research, initial economic feasibility is estimated for the three demo cases, and compared with the ‘as-is’ scenario of rendering for feather meal. In order to do so, certain assumptions have been made, including:

- Assumption that each business demo case would be located adjacent to a slaughtering plant.
- Based on this, certain resources will be shared, including common areas, utilities, and administrative staff.
- The same level of administrative staff is assumed for the three demo cases.
- The same cost of transporting the intermediate products to customers is assumed.

Given that this is analysis of biorefinery concepts that are not yet implemented, the assumptions made lead to a number of limitations of the analysis conducted. This includes:

- Both capital and operational costs are estimated and not based on actual quotations received from equipment suppliers.
- Scales were standardised to 1 MT per hour using the power law equation.

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- Actual market demand for the intermediate products has not been determined, therefore scales may be in excess of actual demand for the products produced.
- Selling prices are also estimated and may not be reflective of actual market willingness to pay.

The main conclusions of the economic analysis for each demo case are outlined below. The breakeven selling prices were also calculated in the analysis and are included in the analysis.

Steam Explosion

From a technical perspective, the treatment of feathers using steam explosion showed positive results throughout the course of Project UNLOCK. The economic analysis of this biorefinery concept was focussed on two aspects – sensitivity analysis of the selling price, and analysis on the impact of raw material used.

Firstly, Farrelly Mitchell considered the use of raw feathers (feathers collected directly from the slaughterhouse) as the input into the steam explosion process. However, under UNLOCK, the main raw material used for the steam explosion process was washed, ground feathers (produced from the mechanical grinding process). This distinction has significant implications on the economics of the business case, as raw feathers were assumed to have an associated cost of €100 per MT, but ground feathers would have an associated cost of, at a minimum, around €800 per MT. The impact of this was clear – the project shifted from generating feasible profitability and returns with a selling price of €750 per MT of steam exploded material, to barely producing positive returns selling price of €1,250 per MT. The breakeven selling price analysis also highlighted this – at €482 per MT using raw feathers as input material, or €1,206 per MT using ground feathers as the input material.

This analysis has given weight to the consideration that in conducting future trials, efforts should be made to achieve positive results utilising raw feathers as the raw material, improving cost and resource use efficiency.

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Mechanical Grinding

Through Project UNLOCK, Cedrob have developed a demo case facility for mechanical grinding in one of their poultry slaughterhouses in Poland. As mentioned in the technical analysis, the capacity of this is 200 – 300 kg per hour, which was scaled up to 1 MT per hour for the purposes of economic analysis and comparison.

The economic analysis of this business concept highlighted water treatment as a key issue. As the feathers are washed prior to grinding, this involves a large volume of water, which requires treatment following the process. At present, the estimated cost of this water treatment for every tonne of ground feathers produced, is €423. Cedrob have expressed that this cost may be able to be reduced, however, to an estimated €100 per MT, if the water was to be recycled through the slaughterhouse to collect the feathers and other by-products of the slaughtering process.

For this reason, sensitivity analysis on this component was conducted. It determined that, even at a selling price of €1,000 per MT of ground feathers, the grinding business case would not be feasible, if for every tonne produced, a cost of €423 was incurred to treat the waste water from the process. Breakeven analysis was also conducted. This showed that at a waste water treatment cost of €423 per MT produced, a selling price of €1,093 would be required for the project to breakeven. This was reduced to a selling price of €708 per MT when the waste water treatment cost was reduced to €100 per MT.

Microbial Fermentation

As mentioned in the technical analysis, the microbial fermentation process for the treatment of feathers was successfully scaled up to a 600L batch reactor during Project UNLOCK. For the purposes of the examination of a biorefinery concept for the business case, Bioextrax recommended considering a scale of 1 MT per hour.

At the outset of Project UNLOCK, a selling price of €2,000 per MT was recommended for the keratin microfibers produced from the microbial fermentation process. At the scale of 1 MT per hour, the project was shown to produce positive profitability and

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returns, at this selling price. In fact, the breakeven selling price was calculated to be €567 per MT.

Discussion

The results of the economic assessment show that the projects are reliant on currently unproven selling prices to achieve profitability. The results also unveiled a number of areas where the biorefinery concepts would require adjusting in order to improve the attractiveness of the business case. Regarding mechanical grinding, it was shown that waste water treatment has a major impact on the cost of production, and through the recycling of water prior to treatment, this cost can be reduced, allowing the business case to achieve profitability at lower prices. Furthermore, the steam explosion analysis showed the impact that using treated, ground feathers had on profitability and returns, compared to using raw feathers. It is recommended that any future trials consider the implications of this and strive to achieve positive results using raw feathers, in order to reduce the cost of production, and increase resource use efficiency.

While the economic analysis has been conducted assuming a standard scale of 1 MT per hour across the board, the demand for the intermediate products would have to be at a level that requires such a level of production. The analysis, however, fails to consider the potential of these biorefinery concepts to process additional materials, such as wood biomass for steam explosion, feather meal for mechanical grinding, or protein for microbial fermentation, which would help to improve the utilisation of the plants, and generate additional income streams, assisting in achieving economic feasibility. Nonetheless, the outcomes of what is a high-level analysis at this stage of the processing techniques and technologies is promising.

In truth, based on the results of the economic analysis and the developing nature of the bio-based plastics market, the most promising avenue for feather processing would not be in standalone refineries as proposed in this report, but for feathers to be processed in existing plants. This is especially applicable to steam explosion, where significant volumes of feathers could be processed in a continuous reactor, facilitating the input of feathers into the novel value chains, without incurring significant investment costs and risks.

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4. Environmental Analysis

For the purposes of environmental analysis of the biorefinery concepts, Farrelly Mitchell conducted a life cycle assessment of the biorefinery processes. The scope of the assessment is from gate to gate, i.e. from the point of feather collection at the slaughterhouse, to the bagging of intermediate products at the end of the biorefinery processes. It was simulated at a commercial scale, with the function units standardised to 1 MT across the board. The results of the LCA are also compared below with an LCA conducted on feather meal rendering by Campos et. al (2019).

The purpose of this exercise is to understand the environmental impact of the biorefinery concepts themselves. While another LCA focused on the end-products developed in UNLOCK has been conducted in WP6, the scope of this is wider, and narrowing the scope to the biorefineries alone, provides a more specific view on their impacts.

For each of steam explosion, mechanical grinding, and microbial fermentation, global warming potential, acidification potential, eutrophication potential and water scarcity impact were calculated, and compared with feather rendering, as shown in Table 1 below.

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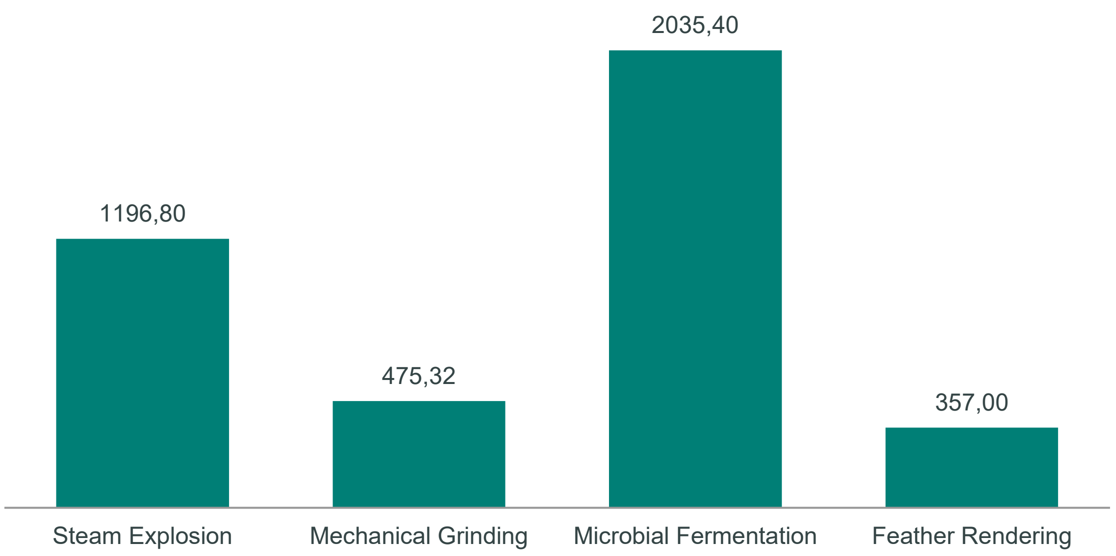
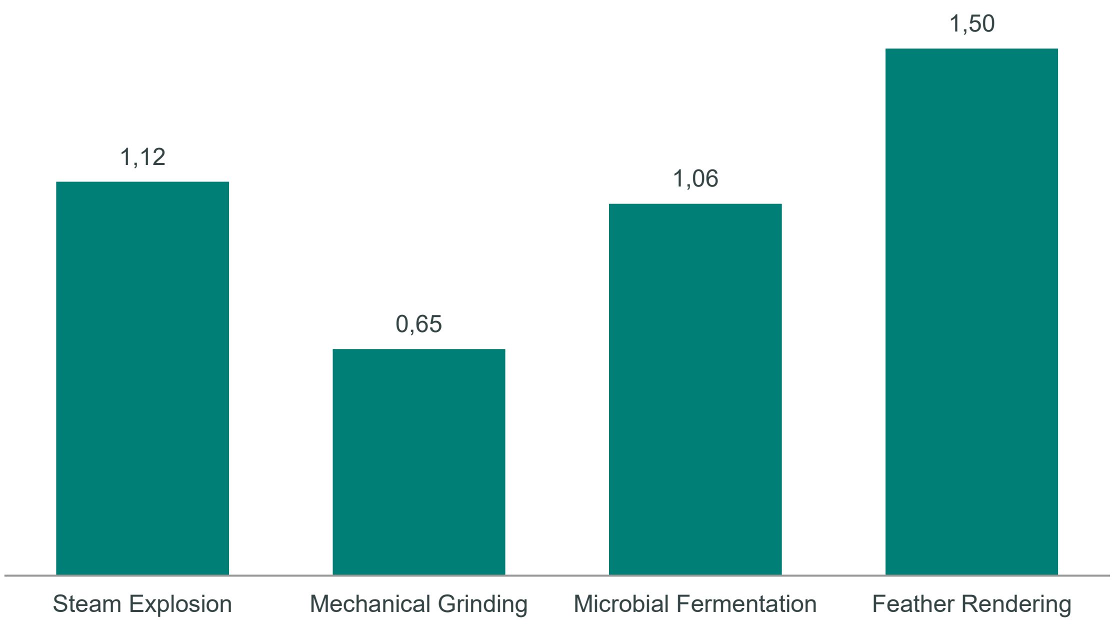
Table 1. LCA Result Comparison and Benchmarking.

Global Warming Potential [kg CO_2 eq.]



Acidification Potential [kg SO2 eq.]



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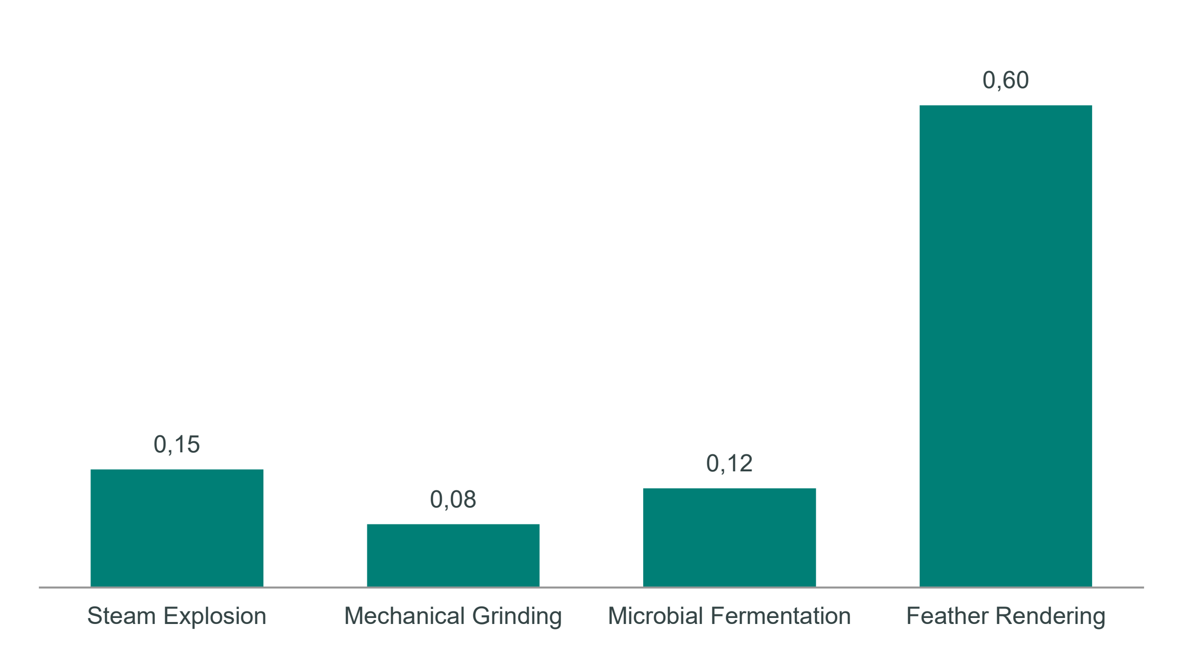
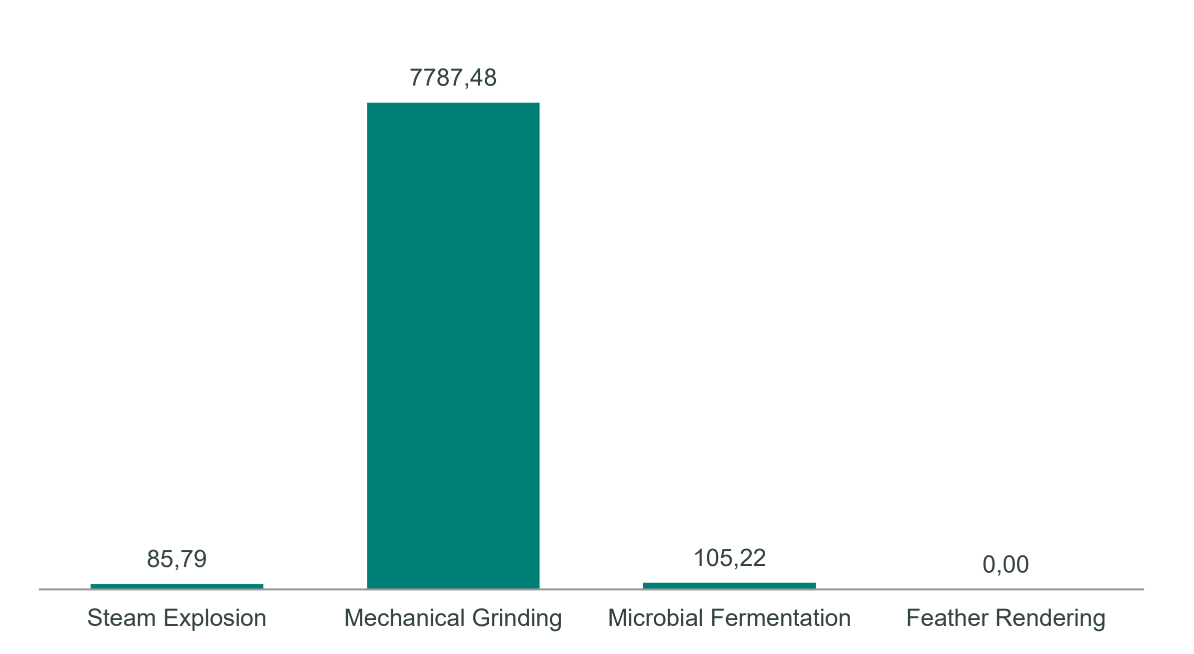
Eutrophication Potential [kg PO_4^{3-} eq.]



Water Scarcity [m^3 world eq.]



Global Warming Potential (GWP)

Of the four processes, microbial fermentation appears to have the highest impact in global warming terms, with feather rendering the lowest. These results, especially that of the steam explosion vs feather rendering, differ from the initial assumption at project

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outset that steam explosion would have lower energy usage. The breakdowns of the contributions to the overall global warming potential figures highlights the need for energy-efficient technologies and the integration of renewable energy sources to reduce environmental impact, which would have a positive impact across all biorefinery cases. Specific to microbial fermentation, enhancing microbial fermentation through process optimisation, biogas utilisation, and carbon capture and utilisation technologies within the fermentation process can either effectively reduce and trap CO_2 before it is released into the atmosphere, further mitigating GWP.

Acidification Potential (AP)

AP is another key environmental impact category examined in LCAs. The results show that acidification potential is highest for feather rendering, and lowest for mechanical grinding. The major contributor to AP is from sulphur dioxide emissions during electricity generation. The relatively consistent AP across the three UNLOCK processes is due to this fact. According to the study on feather rendering, the highest contributor to AP is the wood pellets used for generating process heat. Similar to the case of GWP, a shift to cleaner energy sources is crucial to reduce the AP, through the reduction of sulphur dioxide emissions.

Eutrophication Potential (EP)

The eutrophication potential across the three UNLOCK processes shows similar patterns, with the figure significantly higher for feather rendering. The impacts here again stem from nutrient runoffs associated with electricity generation. Regarding feather rendering, again the highest contributor to EP is the wood pellets used for generating process heat. Mitigations to reduce the EP would involve enhanced wastewater management practices at the point of electricity generation, or transitioning to cleaner energy sources with lower nutrient runoff potential.

Water Scarcity

While water scarcity implications are not insignificant for both steam explosion and microbial fermentation, mechanical grinding has by far the highest impact. This is due to the high volume of water required to wash the feathers prior to grinding. For the other two UNLOCK processes, the water scarcity impact stems from the water involved

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in electricity generation. Therefore, for the washing component of the grinding process, it is essential that water saving technologies are implemented to lessen the impact on water scarcity. This could include water treatment and recycling within the production process, or potentially developing an alternative method of feather collection such as conveyor belts, where the feathers do not become contaminated with blood, reducing the washing requirement. While no figures on rendering were available, water usage within the rendering process is very low.

Limitations

The most significant and obvious limitation of the LCA research is the exclusion of processes before and after the feather biorefineries, for example, the impacts of poultry production or the end use of the products produced. As mentioned, this was intentionally done in order to get a perspective on the impacts of the biorefineries themselves.

Another limitation relates to the feather rendering LCA, which was referenced from existing literature. While the LCAs for UNLOCK's processes were conducted and defined as only relating to the biorefineries, the rendering LCA also includes impacts from the slaughterhouse, which will skew the result comparison.

Finally, the LCA assumes that for each UNLOCK process, the feathers are collected from the slaughterhouse and are processed in accordance with the process flows outlined in the technical analysis. In reality, this may not be the case, as for example, during the project, feathers for steam explosion were first washed and ground, however, within the LCA, the impacts from steam explosion did not include those from the washing and grinding process.

Conclusion

While the environmental impacts of the UNLOCK processes may be higher than initially envisaged, much of the impacts across the categories could be significantly mitigated by a switch to renewable energy sources, and can be improved further by implementation of efficiency measures.

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5. Social Assessment

Introduction

Biorefineries should be environmentally, economically, and socially sustainable. It is therefore essential that social factors are considered in the design of biorefinery concepts. For example, food security is a major social factor often mentioned with biorefineries, given the competition for land and other resources to produce raw materials for biofuels. This factor is not of concern to Project UNLOCK however, given the nature of feathers as a typical waste stream within the poultry value chain.

This section presents a synthesis of the social impact assessment conducted within WP6 (Assessment of environmental, social and economic impacts of processes / products and compliance with EU legislation) of the UNLOCK project, focusing on the three biorefinery processes for feather valorisation: steam explosion, mechanical grinding, and microbial fermentation. The assessment uses the SOCA v3 methodology in OpenLCA, which expresses social impacts as "medium risk hours" across stakeholder groups. The analysis identifies where social risks are concentrated, how they arise, and what implications this holds for process selection and supply chain management.

Methodological Overview

Social Life Cycle Assessment (S-LCA) in UNLOCK evaluates risks to four main stakeholder groups: workers, value chain actors, local communities, and society. Social risks are quantified as "risk hours" - a measure of the time stakeholders are exposed to medium-level social risks related to indicators such as sanitation, health expenditure, labour rights, and corruption. The vast majority of social risks are associated with the production phase of each process, particularly the sourcing and processing of materials and energy, rather than the end-of-life or disposal stages.

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Steam Explosion

Process Context

Steam explosion is a physical-chemical pretreatment applied to feathers to break down their structure, making them suitable for further processing into biobased materials. The process involves high-pressure steam followed by rapid decompression. The main social risks associated with this process are not from the feathers themselves, but from the utilities and energy sources required for operation.

Key Social Risks

- **Energy Source:** The social risk profile is primarily determined by the type of energy used to generate steam. If coal-based energy is used, this introduces significant social risks, particularly in regions outside Europe where coal is a primary energy source. These risks manifest as increased health expenditure in local communities (due to pollution and poor air quality) and as broader societal health burdens.
- **Worker Safety:** Operating high-pressure equipment presents occupational health and safety risks for workers, though these are generally less significant than the upstream energy-related risks.
- **Local Community Impacts:** The operation of steam explosion facilities may affect local water use and emissions, but these risks are minor compared to those embedded in the energy supply chain.

Table 2. Summary of Steam Explosion Social Risks.

Risk Category	Main Source	Relative Contribution
Health expenditure	Coal-based energy	Moderate to High
Worker health & safety	High-pressure equipment	Low to Moderate
Community health	Energy supply chain	Moderate

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Implications

To reduce social risks, the steam explosion process should prioritise renewable or low-risk energy sources and maintain strong occupational safety protocols.

Mechanical Grinding

Process Context

Mechanical grinding involves washing, grinding, and drying feathers for use in products like geotextiles. The process is relatively straightforward but relies on external equipment and energy.

Key Social Risks

- **Energy Use:** As with steam explosion, the social risks are largely tied to the energy source for drying and sterilization. Coal-based or fossil energy increases health risks in communities and adds to the societal health burden.
- **Value Chain Integrity:** Risks of corruption and anti-competitive behaviour can arise in the procurement of equipment and materials, especially if supply chains are not transparent or are located in high-risk regions.
- **Worker Safety:** Risks are generally lower than in steam explosion, but safe operation of grinding and drying equipment remains important.

Table 3. Summary of Mechanical Grinding Social Risks.

Risk Category	Main Source	Relative Contribution
Health expenditure	Energy for drying	Moderate
Corruption / competition	Equipment / material supply	Moderate
Worker health & safety	Equipment operation	Low

Implications

Social risks can be mitigated by choosing renewable energy sources, ensuring transparent procurement, and maintaining good workplace safety standards.

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Microbial Fermentation

Process Context

Microbial fermentation uses bacteria to break down feathers and extract keratin microfibers for use in foams and other products. The process involves bioreactors and can produce valuable byproducts.

Key Social Risks

- **Energy Source:** The fermentation process is energy-intensive. If powered by fossil fuels, especially coal, it increases health-related social risks in both local and broader communities.
- **Feedstock Sourcing:** While feather sourcing itself is low-risk, the use of additional biobased fibres or feedstocks can introduce social risks depending on their origin (e.g., land use, labour rights).
- **Worker Rights:** The operation of bioreactors and handling of biological materials require proper worker protections, but these risks are generally manageable with good practices.

Table 4. Summary of Microbial Fermentation Social Risks.

Risk Category	Main Source	Relative Contribution
Health expenditure	Fossil-based energy	Moderate
Feedstock sourcing	Additional bio-based fibres	Moderate
Worker health & safety	Bioreactor operation	Low

Implications

Improving energy efficiency, using renewables, formalizing labour practices, and managing water use are key to reducing social risks in rendering.

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Key Recommendations

- **Prioritize Renewable Energy:** Transitioning from coal-based to renewable energy sources in all processes will significantly reduce health and community risks.
- **Supply Chain Transparency:** Map and audit suppliers, especially for additional materials and equipment, to avoid corruption and labour rights violations.
- **Material Efficiency:** Reduce the use of high-risk materials and optimize process efficiency to lower the overall social risk footprint.
- **Worker and Community Protections:** Maintain high standards for workplace safety and engage with local communities to address any operational impacts.

Conclusion

The social impact assessment for feather-based biorefinery processes in UNLOCK highlights that the main social risks are embedded in the upstream supply chains for energy and additional materials, rather than in the feather processing itself. Across all processes, the overwhelming majority of social risks are not linked to the feathers themselves, but to the energy and additional material supply chains required for processing and product formulation. For example, in the UNLOCK demonstrators, less than 10% of total social risk hours were attributable to the processed feathers, with the remainder stemming from other materials (such as biopolymers or biobased fibres) and the energy used in production. By focusing on responsible sourcing, energy transition, and transparent supply chains, biorefinery projects can meaningfully reduce their social risk profiles and contribute to a more socially sustainable bioeconomy.

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6. Legal Requirements

A robust regulatory framework governing animal by-products is in place within the EU, providing clear guidelines on the processing and treatment of ABPs, such as poultry feathers. The ABP Regulation determines the circumstances under which ABPs are to be disposed of, and also the conditions under which ABPs may be used for applications, including animal feed or soil improvers.

With the aim of preventing and minimising risks to public and animal health, Regulation (EC) No. 1069/2009 assigns animal by products to specific categories that reflect the level of associated risk. Under this, feathers are classed as Category 3 ABPs, defined as follows:

- Category 3 ABPs: Defined in Article 10 of Regulation (EC) No 1069/2009. It is the lowest risk category of animal by-product. It includes parts of animals that have been considered fit for human consumption in a slaughterhouse, but that are not intended for consumption for commercial or other reasons.

Given that feathers from slaughterhouses can be contaminated with a range of bacteria, including campylobacter and salmonella, the legislation requires that industry actors demonstrate that the feather treatment processes undertaken are sufficient to eliminate all pathogens which may be present. Within the legislation exists two key scenarios, 1) untreated feathers, parts of feathers and down, and 2) treated feather, parts of feathers and down

1) Untreated feathers, parts of feathers, and down

According to Annex XIII, Chapter VII (A) of Commission Regulation (EU) No 142/2011, untreated feathers, parts of feathers and down must be Category 3 materials referred to in Article 10(b) (iii), (iv) and (v) and Article 10(h) and (n) of Regulation (EC) No 1069/2009. If feathers are to be used in certain derived products, such as animal feed, soil improvers or fertilizers they must be processed using one of the permitted methods described in Annex IV, Ch. III of Regulation 142/2011 which sets out the time, temperature and pressure criteria depending on particle size of ABP product to be processed as outlined below.

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Particle Size	Time, Temperature and Pressure
> 50 millimetres	- Core temperature of more than 133 °C for at least 20 minutes without interruption at a pressure (absolute) of at least 3 bars - Batch or continuous systems
> 150 millimetres	- Core temperature greater than 100 °C is achieved for at least 125 minutes, a core temperature greater than 110 °C is achieved for at least 120 minutes and a core temperature greater that 120 °C is achieved for at least 50 minutes - The core temperatures may be achieved consecutively or through a coincidental combination of the time periods indicated - The processing must be carried out in a batch system
> 30 millimetres	- Core temperature greater than 100 °C is achieved for at least 95 minutes, a core temperature greater than 110 °C is achieved for at least 55 minutes and a core temperature greater that 120 °C is achieved for at least 13 minutes - The core temperatures may be achieved consecutively or through a coincidental combination of the time periods indicated - The processing may be carried out in batch or continuous systems
> 30 millimetres	- Core temperature greater than 100 °C is achieved for at least 16 minutes, a core temperature greater than 110 °C is achieved for at least 13 minutes, a core temperature greater than 120 °C is achieved for at least eight minutes and a core temperature greater that 130 °C is achieved for at least three minutes - The core temperatures may be achieved consecutively or through a coincidental combination of the time periods indicated - The processing may be carried out in batch or continuous systems
> 20 millimetres	After reduction, the animal by-products must be heated until they coagulate and then pressed so that fat and water are removed from the proteinaceous material. The proteinaceous material must then be heated in a manner which ensures that a core temperature greater than 80 °C is achieved for at least 120 minutes and a core temperature greater that 100 °C is achieved for at least 60 minutes. - The core temperatures may be achieved consecutively or through a coincidental combination of the time periods indicated - The processing may be carried out in batch or continuous systems
NA	Any processing method authorised by the competent authority where the following have been demonstrated by the operator to that authority: (a) The identification of relevant hazards in the starting material, in view of the origin of the material, and of the potential risks in view of the animal health status of the Member State or the area or zone where the method is to be used; (b) the capacity of the processing method to reduce those hazards to a level which does not pose any significant risks to public and animal health; (c) the sampling of the final product on a daily basis over a period of 30 production days in compliance with the following microbiological standards:

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	(i) Samples of material taken directly after the treatment: Clostridium perfringens absent in 1 g of the products (ii) Samples of material taken during or upon withdrawal from storage: Salmonella: absence in 25g: n=5, c=0, m=0, M=0 Enterobacteriaceae: n=5, c=2, m=10, M=300 in 1g

2) Treated feather, parts of feathers, and down

Annex XIII, Chapter VII (C) of Commission Regulation (EU) No 142/2011 allows the placing on the market, without restriction, of feathers, parts of feathers and down which have been factory-washed and treated with hot steam at 100°C for at least 30 minutes.

In summary, in order for the feathers to be placed on the market or used in further applications, the feathers:

- Must come from an approved slaughterhouse.
- Must be transported hygienically to an approved processing plant.
- Must be treated using an approved processing method as outlined above, which can be demonstrated to be effective.
- Must comply with the standards outlined in Chapters 1 and 11 of Annex IV of Regulation 142/2011.

Implications for UNLOCK's Demo Cases

As demonstrated, in order for feather products to be placed on the market, the feathers must be treated using an approved processing method. For UNLOCK's demo cases, the best route to complying with this is to adopt the final method in the table above, which is to prove the efficacy of processing in sterilising the feathers, and receive approval from the competent authority for said process. This has already been completed by Cedrob for their mechanical grinding and rendering processes, in line with Regulation (EC) No. 1069/2009. Given that sterilisation occurs in both the steam explosion and the microbial fermentation reactors, there is potential to conduct the necessary tests and approve these processes. This would remove the requirement for feather sterilisation at the slaughterhouse, only for the sterilisation step to be repeated in the bioreactors, creating both economic and environmental savings.

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7. Conclusion

This report on the feather biorefinery concepts for the EU poultry sector describes the technical, economic and environmental analyses conducted, as well as considering social and regulatory elements.

The main conclusion of this research is that the requirement for such biorefinery concepts to be developed solely to treat feathers does not currently exist. Considering the cost and risk associated with investing in biorefineries, and the nascent stage of the bio-based plastics market, it is recommended that the processing of feathers is done, at least initially, in existing plants, where possible. This is especially true of steam explosion, which has shown promising results, where feathers can be treated in continuous reactors that until now, have been used to treat lignocellulosic biomass such as wood. The economic analysis also helped to outline areas such as waste water treatment and the raw material used as extremely significant to the economic feasibility.

From an environmental perspective, UNLOCK's processes appear to have a lower impact than the traditional feather treatment method for each of acidification potential, eutrophication potential, and water scarcity, while the rendering performs better from a global warming potential aspect. However, the global warming impact of the UNLOCK processes can be drastically reduced through a switch to renewable energy sources – a step which would also improve the social impact of the biorefineries.

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