Authors: **Farrelly & Mitchell**
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EUs Feather-based Economy: The Challenges Ahead

UNLOCK Deliverable 2.3

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

UNLOCK EUs Feather-based Economy: The Challenges Ahead

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[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)

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1	29/04/22	FARRELLY & MITCHEL	Michelle Riblet and Daniel Traas.
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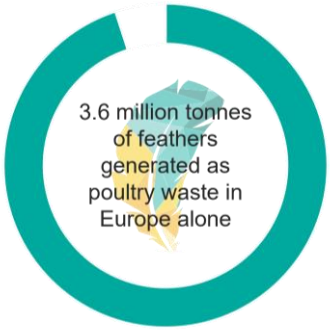
1. Introduction

1.1 Project Background

The European Union is one of the largest producers and traders of poultry products globally and produces around 13.4 million tonnes of products each year. Given the scale of production, the European poultry industry consequently produces a substantial amount of waste (European Commission, 2022), including poultry feathers.

Poultry feathers contain up to 90% keratin, which is a potential, high-quality protein, with biodegradable properties. Keratin can be used as a source of raw materials for biodegradable products such as bioplastics, which can be applied to agricultural or commercial settings. Additionally, several technologies can be used to convert other biological components of feathers into high value-added products.

Biomass, which is derived from plant and animal materials, including organic waste, is projected to play a key role in meeting global sustainability targets. To achieve resource-efficient biomass use, European bioeconomy strategies increasingly consider the concept of circular bioeconomy (Stegmann *et.al.*, 2020). The Bioeconomy Strategy proposed by the European Commission is a part of the European Green Deal, as well as industrial, circular economy and clean energy innovation strategies. These strategies focus on a sustainable circular bioeconomy to achieve their goals.



A new Circular Economy Action Plan launched in 2020 aims to accelerate the EU sustainability transition and move from a fossil-fuel based economy to a circular bioeconomy. Adopting this new bio-based economy model implies that the EU will reduce its reliance on polluting and increasingly scarce carbon emitting resources and move towards biobased resources as a primary source of raw materials. The vision behind this bioeconomy is to build new value chains that utilise resources more efficiently and make industrial processes sustainable and more cost effective, with the support of biorefinery technologies. Poultry feathers, one of numerous by-products of the poultry processing industry, have the potential to contribute as biodegradable inputs into the circular bioeconomy.

Despite their interesting properties, poultry feathers and keratin have very limited use as raw materials in a commercial setting (currently used as feather meal for animal feed and fertilisers). This is mainly due to the lack of technologies for extracting and processing keratin and a lack of widespread markets for feather valorisation to produce high added value products.

Project UNLOCK aims to release the potential of feathers to foster circularity in agriculture. This EU funded project comprises of a consortium of 15 organisations with

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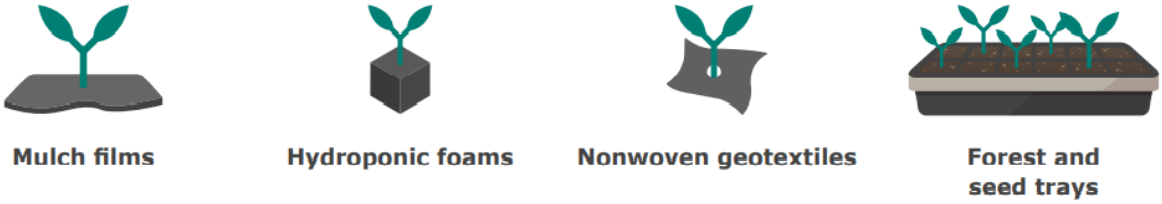
the specific objective of designing and demonstrating an economically and environmentally sustainable supply chain for the feather-based bioeconomy by generating innovative bio-based functional materials for agricultural applications such as forest/seed trays, non-woven geotextiles, mulch films and hydroponic foams.



To unlock the full potential of feathers as a raw material for functional molecules, there are a number of technical, logistical and market hurdles to be resolved in the supply chain to enable commercialisation and easy market uptake of keratin-based products. To understand these hurdles in the process of increased valorisation of poultry feathers, a thorough understanding of the EU poultry value chain, the feather feedstock and the current waste management practices for poultry feathers is required. Work Package 2 of Project UNLOCK aims to achieve this and is the key to guiding the future direction in designing and demonstrating this sustainable supply chain.

Under Work Package 2, two key studies were recently completed, as follows:

- an analysis of feather waste sources and management in the EU which provides a high-level overview of the poultry breeding, meat processing and animal by-product (ABP) rendering in five target countries in the EU, namely France, Germany, Spain, Italy and Poland.
- a quantitative assessment of feather waste streams which details the analysis of the poultry slaughtering throughputs, their regional locations and the subsequent feather feedstock availability (post slaughtering) in these countries.

These studies concluded that an average of 621,200 tonnes of feathers are available annually within the EU with a high demand for this biomass being primarily converted into end products such as animal feed and fertiliser.

This report focuses on identifying and defining the main hurdles for the establishment of feather-based value chains in the regions with strong poultry industry presence, the magnitude of these hurdles and the potential mitigating strategies to address these hurdles.

The key hurdles identified and discussed in this report relate to two key stages of the poultry feather value chain, which are (i) feather management at slaughterhouse, storage and transportation and (ii) keratin exposure stage. These stages are summarised in figure 1 below.

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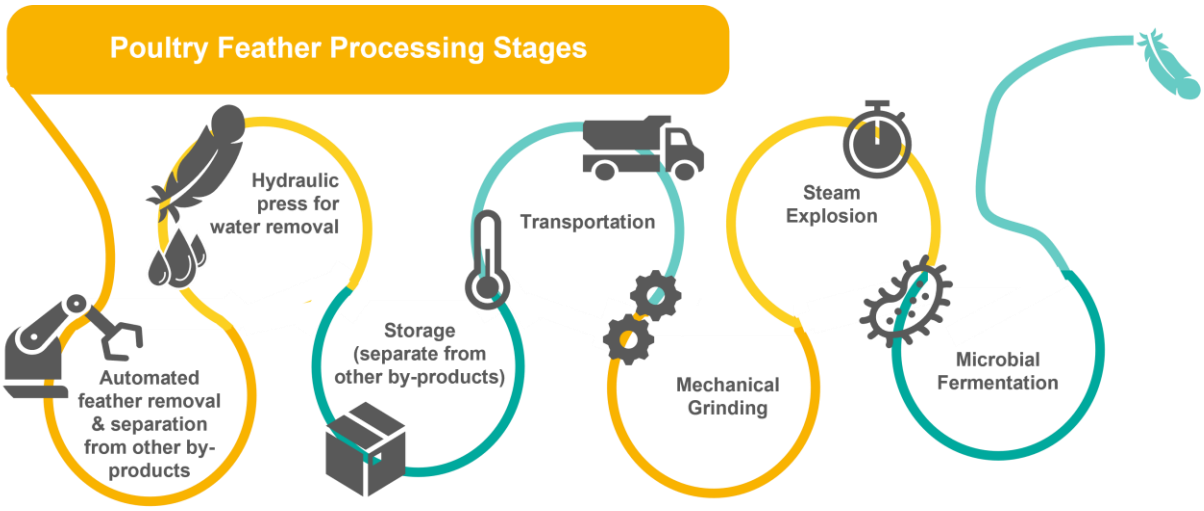
Figure 1 Poultry Feather Processing Stages



1.2 Study Objectives

The objective of this study was to investigate the supply chain hurdles in the establishment of feather-based value-chains in the poultry sector. In particular, key areas such as logistics, infrastructure, quality feather availability and related EU legislations were investigated. This study investigated the magnitude of these challenges using a traffic light approach methodology and potential mitigation strategies to help minimise the effect of these obstacles.

It is recommended to read the results presented in Deliverable 2.1 *'Analysis of Feather Waste Sources and Management in the EU*[1] as a background for this report. The results from this task will inform the direction of work under Work Package 3 (Setting the Basis for the Feather Economy, Designing the Novel Value Chains).

[1] Public Report. Note: Deliverable 2.2 *'Quantitative Assessment of Feather Waste Streams'* a confidential report under Project UNLOCK is also recommended as background material for this report for Project UNLOCK consortium members.

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2. Methodology

This research has been conducted using deep dive desktop analysis, in parallel with interactions with key industry stakeholders, consortium members of Project UNLOCK and experts through a consultation process.

The analysis of the existing hurdles, their magnitude and potential mitigating factors is primarily based on information collected through desktop research, direct consultation with stakeholders involved in poultry processing and rendering industries, and finally inputs from field experts.

The analysis examined challenges related to logistics, modes of transport, infrastructure, feather quality and availability. Related EU legislation was studied and potential solutions were discussed with industry experts to mitigate these challenges. Challenges identified were classified using a traffic light approach, explained in section 3 of this report, to indicate the magnitude of each challenge.

Figure 2 below, provides an overview of the approach and methodology.

Figure 2 Our Approach & Methodology

Source: Farrelly & Mitchell

2.1 Secondary and Desktop Research

In order to allow for an assessment of the practices and hurdles in feather waste management, the desktop research extracted and analysed available data and information from publications and national statistical databases.

Statistical data and figures were obtained from a number of secondary sources including national government bodies for agriculture, national statistics authorities and the European statistical database ‘Eurostat’.

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2.2 Industry Stakeholder Consultations

Key industry experts were consulted for the purpose of gathering in-depth knowledge and understanding of the existing feather waste management practices, the existing hurdles along the poultry feather value chain and to discuss potential mitigating strategies.

This was achieved through a combination of site visits, workshops with industry experts and leveraging industry connections to gather critical information and informed insights.

In particular, the consultation aimed at gathering data and information in relation to existing processes and equipment in place for feather waste management across the poultry value chain.

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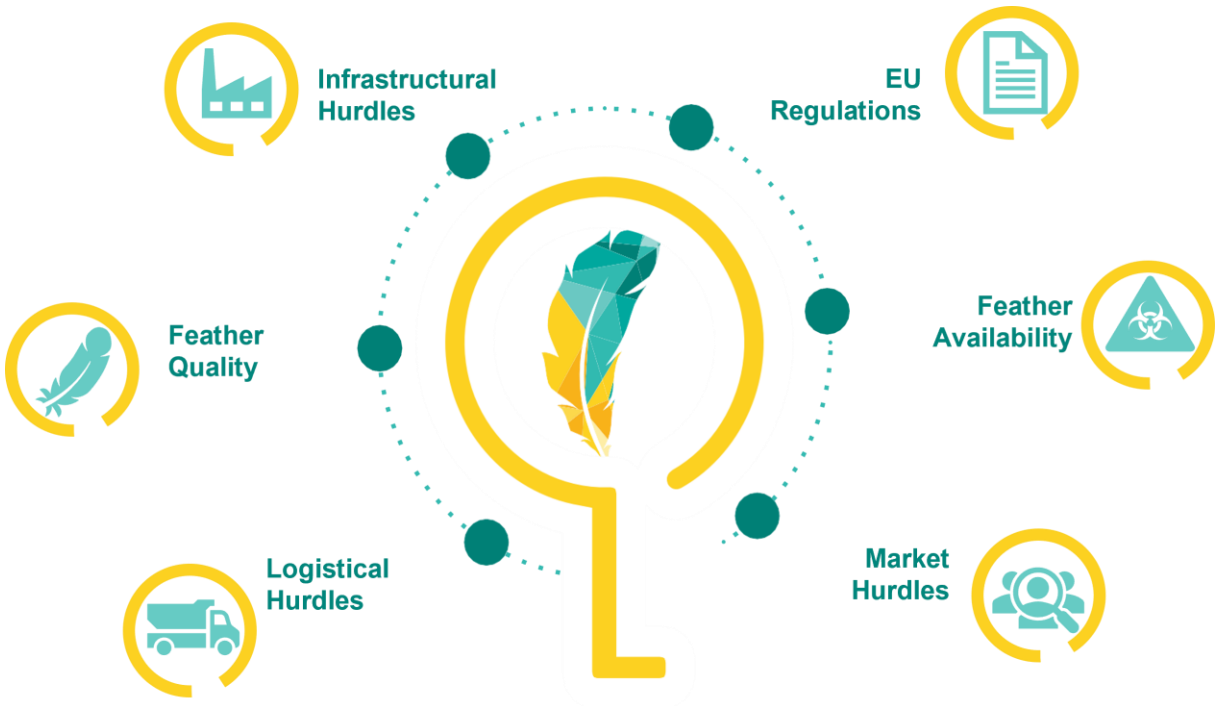
3. Results & Discussion

Results from consultations with a number of large stakeholders in the European poultry industry are included within this report. In total, contributions from 11 stakeholders are referenced, from countries including Poland, Ireland, Italy and Spain. Some operate highly integrated business models and others operating solely as slaughterhouses or renderers. Site visits were conducted to gain an insight into the day-to-day operations of poultry processors and to witness first-hand the hurdles facing the feather value chain.

The hurdles presented are categorised under Logistical Hurdles, Infrastructural Hurdles, EU Regulations, Feather Quality, Feather Availability, and Market Hurdles as outlined in Figure 3 below.

Figure 3 Poultry Feather Value Chain Hurdles



The results are summarised in table 1 below and have been further classified using a traffic light system to define the hurdles according to:

i. their threat to the value chain; and
ii. difficulty to overcome.

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Red signifies either a hurdle which is extremely difficult to overcome or indicates that a hurdle presents a very pronounced threat to the operation of the value chain.

Amber signifies a moderate hurdle which, for example, requires less investment or effort to overcome than a red hurdle, or presents less of a threat to the successful establishment of a new feather value chain.

Green represents a hurdle which is among those easiest to overcome or has minimal threat to the successful operation of the supply chain.

Table 1 Poultry Feather Value Chain Hurdles

Section	Hurdle	Difficulty to Overcome	Threat to Value Chain
Logistics	Carbon Footprint of Transport	🔴	🟡
	Rising Transport Costs	🔴	🟡
	Long Supply Chains	🔴	🟡
Feather Quality	Contamination	🟡	🔴
	Moisture Content	🟡	🔴
	Collection and Transport Practices	🟡	🟡
Infrastructure	Cost of Investments and Diversification Risks	🔴	🔴
EU Regulations	Gaps in EU Legislation Governing Feather By-Products and Bioplastics	🟢	🔴
Feather Availability	Avian Influenza	🔴	🟢
	Competition for Feather Availability	🔴	🟡
Market Hurdles	Competition from Other Bioplastics	🔴	🔴
	Consumer Acceptance	🟡	🟢

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3.1 Logistical Hurdles

Logistical hurdles exist in the path to the establishment of a new feather value chain in the EU as summarised in Table 2. The problems of the carbon footprint and rising transport costs involved in the supply chain are exacerbated by the long distances between different actors in the industry. These challenges, as well as some potential solutions, are described in more detail below.

Table 2 Severity of Logistical Hurdles in Feather Value Chain

Section	Hurdle	Difficulty to Overcome	Threat to Value Chain
Logistics	Carbon Footprint of Transport	🔴	🟡
	Rising Transport Costs	🔴	🟡
	Long Supply Chains	🔴	🟡

3.1.1 Carbon Footprint of Transport

As industries and society, as a whole, becomes more environmentally aware, consideration of the carbon footprint of supply chains is becoming an increasingly important imperative for businesses. EU laws and policies are also becoming a factor, in particular the recent European Climate Law (Regulations (EC) No 401/2009 and (EU) 2018/1999) which sets a legally binding target of net zero greenhouse gas emissions by 2050.

The carbon footprint of the supply chain is especially important in this scenario. The creation of a new feather value chain is part of a circular economy which promotes the recycling of otherwise waste streams to limit the environmental footprint of the poultry industry. Therefore, in keeping with the goals of the project, it is essential that the transport carbon footprint is examined and reduced where possible. One key performance indicator (KPI) of Project UNLOCK is to reduce emissions in the feather value chain by 20%, including from road transport.

Heavy duty vehicles are responsible for about 25% of CO_2 emissions from road transport in the EU and for roughly 6% of total EU emissions each year. It is the duty of every sector to reduce these emissions as much as possible.

The average regional delivery 4x2 axle truck in the EU emits 84 grams of CO_2 per tonne per kilometre (Ragon, 2021). Based on stakeholder consultations, the average distance between slaughterhouses and renderers is approximately 200km and, with each truck carrying 10 tonnes, this equates to approximately 168kg of CO_2 emissions per load.

Another report released under UNLOCK calculated feather feedstock availability in Europe as 698,557 tonnes per year. Assuming all of these feathers are sent for

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rendering, this means that the transport of feathers from slaughterhouse to renderer alone would emit over 11,700 tonnes of CO_2 per annum.

To put this figure in perspective, 1 hectare of Sitka spruce forest on peaty mineral soils sequesters in the region of 3.4 tonnes of CO_2 per annum. This means that to offset the emissions from transport for this supply chain alone, over 3,450 hectares of forestry would have to be planted. This highlights just how much carbon is released from transport within supply chains and why the EU has targeted a significant emissions reduction for heavy goods vehicles (HGV) by 2030.

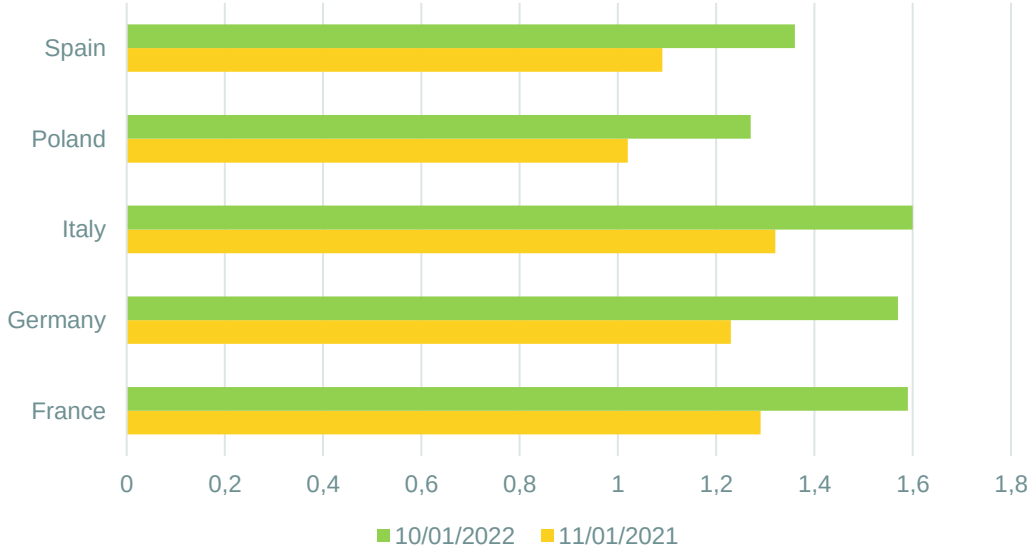
3.1.2 Rising Transport Costs

The cost of transport within supply chains is coming increasingly into focus as fuel costs continue to rise. Diesel prices increased 24% year-on-year from January 2021 to January 2022, increasing from an average of €1.19 per litre over the 5 target countries, to an average of €1.48 as illustrated in figure 4 below.

Considering the distance from slaughterhouse to renderer averages 200km and the average 12 tonne HGV uses 26.44L of diesel per 100km travelled, the cost in 2021 would have been €62.92, rising to €78.26 in 2022 (Wang *et al*, 2019).

In recent months, prices have increased dramatically due to the war in Ukraine, leading to further costs to hauliers squeezing margins for supply chain operators, and emphasising further the need for a solution to overcome this financial hurdle.

Figure 4 Comparison of Diesel Prices in Target Countries 2021-2022



Source: www.tolls.eu

Potential Solutions to Carbon Footprints and Rising Transport Costs

One potential solution is the move towards renewable transport options including electric and hydrogen-powered vehicles. Although these options are becoming increasingly popular for car users, a serious alternative to fossil fuel-powered HGVs is

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yet to be offered. This option to reduce the environmental and economic cost of transport remains a number of years away.

Another alternative to the current practices involves the introduction of additional processes at the slaughterhouse, discussed further under Section 3.2 Feather Quality. If the feathers are dried at the slaughterhouse to produce compacted and dried feathers, lower weights per volume of feathers are transported resulting in a more efficient transport process. In addition to reducing the environmental and economic cost of the transport, this has additional benefits in terms of feather quality.

3.1.3 Long Supply Chains

The issues discussed above are exacerbated by the existence of long distances between the various actors in the supply chain. This was highlighted by numerous stakeholders in consultations throughout Project UNLOCK. Lengthy distances between the slaughterhouses who supply feathers and the renderers who process the feathers impacts a number of key aspects within their businesses. This includes:

- Financial costs (increased transport costs)
- Sustainability impacts (increased carbon footprint)
- Input material quality (keratin breakdown within feathers)

It is therefore desirable to decrease the distances travelled. However, there is no straightforward method to achieve this. Greater integration within business models was shown during consultations to reduce the distances between slaughterhouses and renderers, but the potential solutions mentioned above are more likely to be more suitable to the majority of business models.

It is important to mention that other environmental and economic costs relating to transportation arise at later stages along the supply chain.

Post rendering, processed feather meal is transported to a final stage for compound mixing and packaging into retail packs of animal feed or fertiliser before transport to their end-use location.

This final step will be similar for most end products including bioplastics. All steps taken to reduce supply chain length or to reduce environmental and economic costs of transport must be considered within this new value chain.

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Table 3 Summary of Solutions to Logistical Hurdles

Carbon Footprints & Rising Transport Costs	Difficulty to Overcome 🔴	Threat to Value Chain 🟡
	Future Solution: Renewable energy transport Current Solution: Additional processes at slaughterhouse to reduce weight (via reduction in moisture content) of feathers transported (may be low priority investment with significant impacts on emission reduction)	Carbon footprints are a serious issue, however, to meet increasing demands on food, in particular protein, the poultry value chain will need to continue operations while solutions are being developed
Long Supply Chains	**Difficulty to Overcome 🔴**	**Threat to Value Chain 🟡**
	Solutions involve shortening the supply chain, i.e., through actors integrating in the supply chain, for example, slaughterhouses assuming responsibility for feather rendering onsite, with significant investment costs	Long distances between actors do not prevent the supply chain from operating, although they do lead to increased carbon footprints and transport costs

3.2 Feather Quality

A critical consideration within this value chain is the availability of quality feathers. It is essential that any degradation of the feathers is avoided where possible, to allow maximum yields of keratin to be obtained during processing. The biological nature of feathers means that they are vulnerable to decomposition for a number of reasons following removal from the epidermis of the bird. Preventing this decomposition and maintaining feather quality, is a challenging but essential step in creating a new, high-value, feather supply chain. Table 4 summarises key hurdles identified.

Table 4 Severity of Feather Quality Hurdles in Feather Value Chain

Section	Hurdle	Difficulty to Overcome	Threat to Value Chain
Feather Quality	Contamination	🟡	🔴
	Moisture Content	🟡	🔴
	Collection and Transport Practices	🟡	🟡

There are a number of steps that processors can take to ensure feather quality is maintained. Good practices to minimise microbial growth and keratin breakdown include:

→ Avoiding contamination of the feathers with other animal by-product (ABP) materials such as offal, blood, and heads
  - In the case that this does occur, the feathers are washed to remove contaminants

→ Reducing moisture content of the feathers to lowest possible levels as moisture provides a growth medium for microorganisms

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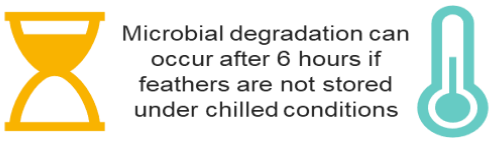
However, many of these steps are currently not undertaken within feather waste streams as they are not required for current end-products manufactured. Also, it may not make financial sense for the processor to invest in additional processes for low-value feathers.

If the feathers are clean and dry, then they can be stored for extended periods of time without degrading. However, if this is not the case, then other precautions to help reduce keratin breakdown include:

→ Maintaining the temperature of the feathers to under 5 degrees during transport and storage.
→ Minimizing transport and storage times before processing as microbial degradation of feathers can occur in as little as 6 hours if they are not stored under chilled conditions.



3.2.1 Contamination

As mentioned previously, contamination of feathers with other ABPs can lead to microbial degradation of the feathers, leading to keratin breakdown. Following feather removal, feathers are often mixed with other animal by-products such as blood, offal, and heads.

The typical, low-cost collection process is for feathers to be brought to a centralized collection point via a water channel where they are mixed with blood from the kill-line and other ABPs. To avoid this, slaughterhouses can use a conveyor belt to transport the feathers separately, or use vacuum systems or washing machines to remove the contaminants from the feathers following mixing. These practices ensure that hygiene is maintained in order to avoid biological breakdown of the feathers.

The most significant challenge raised through stakeholder consultations was the need to isolate, store and transport feathers separately from other by-products as this takes time and increases costs. Project UNLOCK seeks to make these additional processes worthwhile to the processors by increasing the value of the feathers and creating a viable income from what is currently viewed as a waste stream.

3.2.2 Moisture Content

High moisture content during storage and transport leads to keratin breakdown. Moisture content of feathers is most commonly reduced using a hydraulic press, which reduces moisture from around 80% to between 40-60%. Driers can also be used to minimize moisture, however, these are more costly to install and operate. Reducing moisture content has additional benefits outside of feather degradation, through reducing transport costs by decreasing the weight of the feathers following removal of moisture. As described above, this makes for a more efficient supply chain with lower environmental footprints and reduced costs.

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3.2.3 Collection and Transport Practices

Feathers are generally delivered to ABP renderers daily, or every second day, to prevent microbial degradation. This means that storage costs associated with the feathers are low or non-existent. However, as feathers are often high in moisture content and temperature, degradation can occur within hours.

A key issue surrounding long supply chains is the degradation of feathers during transport. Under current practices, this is a significant problem, where the moisture content within feathers can be as high as 60% and the feathers are transported under ambient temperatures, regularly reaching higher than 20 degrees Celsius during warmer periods. Feather quality deteriorates rapidly under such conditions, with rejections of feather feedstock reported by stakeholders due to feathers being of unusable quality on arrival.

These hurdles can be bypassed entirely by minimizing moisture and other contaminants from the feathers, as shown in Table 5.

Table 5 Summary of Solutions to Feather Quality Hurdles

Contamination	**Difficulty to Overcome** 🟡	**Threat to Value Chain** 🔴
	• Range of options for processors to invest in to prevent feather contamination • Stakeholders frequently cited the need to isolate, store and transport feathers separately as a significant challenge	If high-quality, uncontaminated feathers are not readily available within the value chain, this becomes a serious problem in the context of producing keratin-based bioplastics
Moisture Content	**Difficulty to Overcome** 🟡	**Threat to Value Chain** 🔴
	• Range of options for processors to invest in to minimise water content of feathers, knock on benefits in transport cost reduction • Possible reluctance to invest in equipment	If high-quality feathers are not readily available within the value chain, this becomes a serious problem in the context of producing keratin-based bioplastics
Collection & Transport	**Difficulty to Overcome** 🟡	**Threat to Value Chain** 🟡
	• Overcoming this problem relies heavily on finding and implementing solutions to contamination and moisture content in feathers	The value chain will continue to operate even if collection and transport practices remain unchanged

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3.3 Infrastructural Hurdles

A major hurdle to the development of a new value chain for poultry feathers is the cost of new investments and the risk of diversification to actors within the industry (see table 6).

Table 6 Severity of Investment Cost and Diversification Hurdles in Feather Value Chain

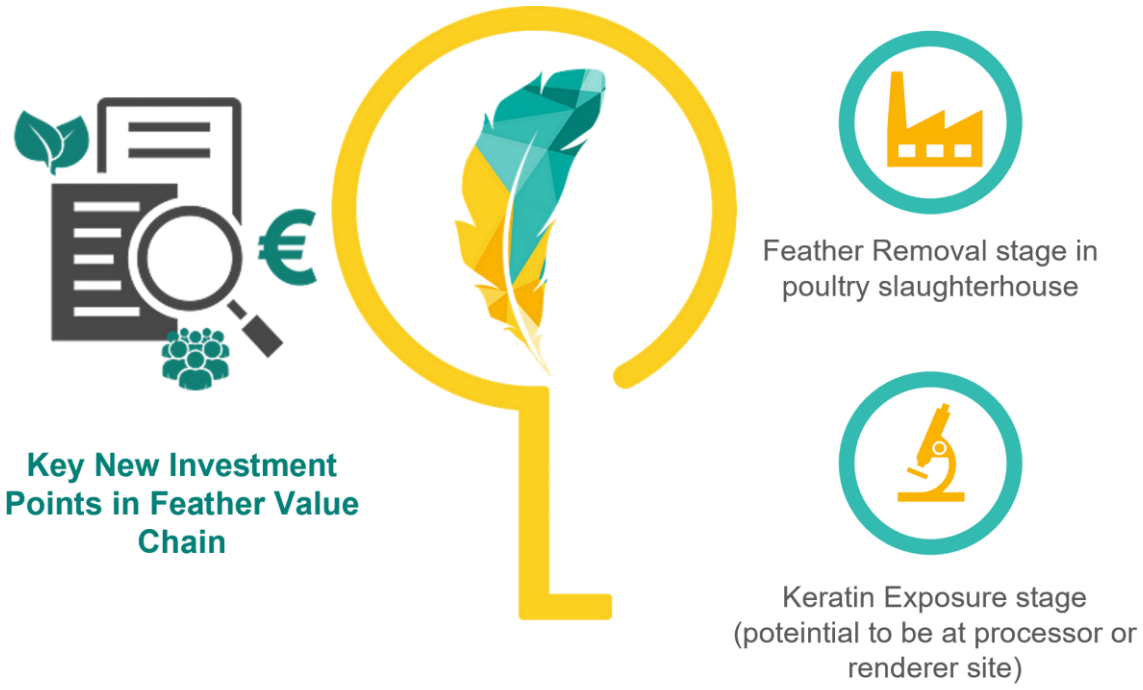
Section	Hurdle	Difficulty to Overcome	Threat to Value Chain
Infrastructure	Cost of Investments and Diversification Risks	●	●

3.3.1 The Cost of New Investments and Diversification Risks

Many businesses will view switching from a current practice, e.g., producing feather meal and fertiliser, to producing an innovative product with no current market, as a significant risk. This is especially relevant with the rising costs of fertilisers and feed due to current geopolitical impacts. Key investment points are as illustrated in figure 5 below.

The price of feed and fertiliser increased 134% and 19% respectively on the year from February '21 to February '22, pre-Ukraine war price rises

Figure 5 Key Investment Points in Feather Value Chain



The stakeholders consulted for Project UNLOCK involved at the poultry slaughtering stage vary in size across the EU, with slaughter throughputs ranging from 34 million to

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210 million birds per annum. These are considered major players within the EU poultry industry.

Stakeholders, in particular those with non-integrated business models and small throughputs, may be slow to invest in new management processes for feathers. For these processors, poultry feather are acceptable in their current form and generate a revenue which, while considered low value, is in high demand across the EU as inputs for the rendering industry.

As outlined in figure 5 above, two key stages within the feather value chain which will require investment are (i) feather management at slaughterhouse and, (ii) keratin exposure stage.

i. Feather Management at Slaughterhouse

Feather management at poultry slaughterhouses will require additional investment in any new feather value chain. As shown in the case study below, current feather management practices within slaughterhouses differ between processors of duck and chicken feathers, with additional steps incorporated during duck processing for optimising feather quality post slaughter. These additional steps require investment in equipment and operational costs for key critical control points including washing and drying.

Case Study: Comparison of Feather Management Practices within Duck and Chicken Slaughterhouses

Feather management practices differ between duck and chicken slaughterhouses, as greater care is required during processing to maintain the quality of higher value duck feathers. The level of investment in equipment for processes such as washing and drying of duck feathers is similar to what will be required by chicken processors in order to guarantee the supply of high-quality feathers into the supply chain.

The site visits undertaken during this study provided a comparative insight into key processing steps in the feather management practices for chicken and duck feathers are illustrated in figure 6 below. Duck feather processes are considered potential solutions for improving quality and limiting degradation in chicken feathers.

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Figure 6 Poultry Feather Removal Process - Chicken & Duck Slaughterhouse Case Studies

Scalding

Scalding: Loosening of feathers for easy removal

Pre-Plucking

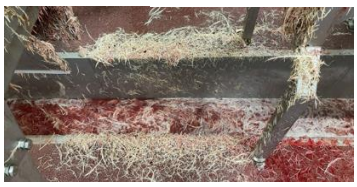
Plucking

Feather removal: Rotating rubber fingers for feather

Post-Plucking

Mixing

Feather Collection Stage: feather collected post plucking, mixed with water (from plucking machine and kill-line) which facilitates movement of the feathers. Contamination with other ABPs can occur at this point.



Pressing

Screw Pressing: Water mixed feathers enter screw-press for moisture removal (approx. 50%)

Storage and Removal: Transfer of feathers to the storage truck before collection by licensed ABP rendering plant

Scalding

Scalding: Loosening of feathers for easy removal

Feather removal: Rotating rubber fingers for feather

Wax-coating of carcass, for the removal of any remaining fine feathers or quills by another set of rubber fingers. This step is usually not undertaken for chicken feathers

Feather Collection Stage: feather collected post plucking, mixed with water (from plucking machine and kill-line) which facilitates movement of the feathers. Contamination with other ABPs can occur at this point.

Mixing

Feathers & blood/water mix collection in the tank 0.5 to 1.0

Washing & Drying: Feathers are washed in the washing machine (0.5 tonne capacity) for removal of oils & contaminants. Washed feathers are dried @ 126°C for complete

Washing & Drying

Feather Sorting: Sorting by weight (quality) before distribution to customers.

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Duck feathers are graded into 4 categories with markets for these feathers ranging from high-value luxury items such as bedding and clothing, to medium value items such as furniture and cushions. The final grade feathers are destined for low value markets via the rendering industry.

This operation demonstrates the additional feather management practices in place at duck slaughterhouses which are critical for ensuring higher revenues are generated from this by-product.

Consideration must be given to the inclusion of key steps such as washing and drying into the current feather management practices for poultry feather as these steps can:

- significantly reduce or prevent degradation of the feathers during storage and transport due to reduced contamination and moisture content;
- significantly reduce transport costs by reducing feather volumes and weights (due to reduced moisture content) during transportation for rendering; and
- increased revenues generated from high quality chicken feathers for use as inputs into the bioplastics industry.

Stakeholder discussions indicated that investment by smaller poultry processors is likely to be limited due to the perceived lower return on investment.

Investment by larger poultry processors is a possibility due to larger annual throughout provided return on investment can be demonstrated.

Lack of investment by industry would result in lower availability of the high-quality feathers required for further processing into bioplastics.

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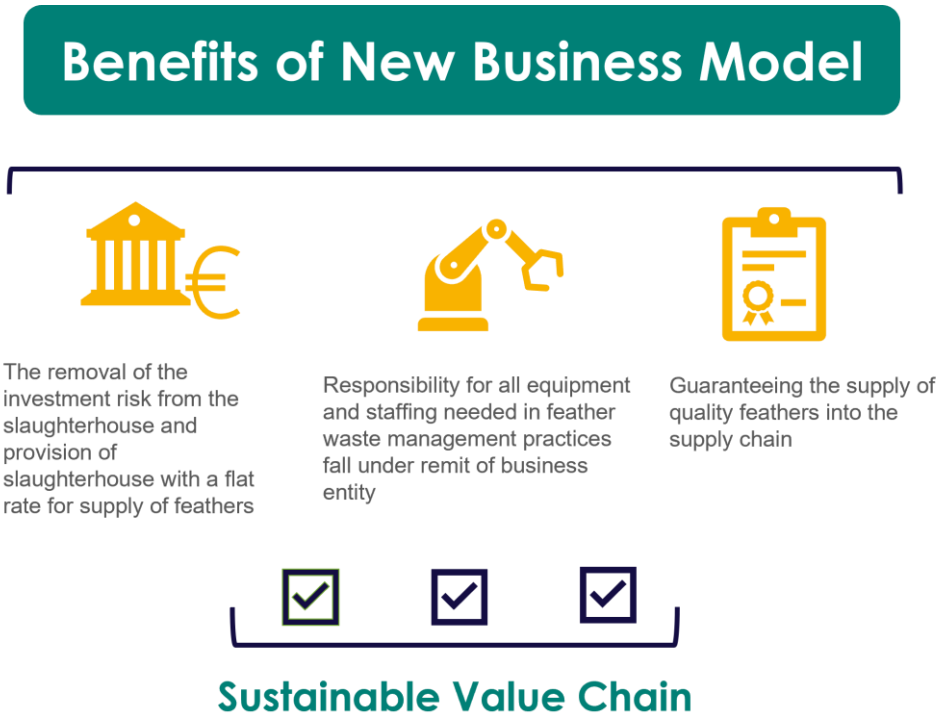
Business Model Case Study

One potential solution to this is the creation of a business model where a business entity establishes a partnership with slaughterhouses. This partnership allows the business to establish its operations within poultry slaughterhouse and assumes full responsibility for the feather management practices. Processing equipment and staff are provided by the business entity which would handle the feathers from post plucking stage until removal from the processing site.

Figure 7 New Business Model Benefits



A number of businesses are operating under this model which has proved successful in the valorisation of ABP products.

Under Project UNLOCK, workshops will be held to show the benefits of these new end-products to potential processors and end-users with the aim of encouraging investment within the industry. These solutions will be discussed further in upcoming reports.

ii. Keratin Exposure Stage

Beyond investments in maintaining feather quality as detailed above, significant additional investment at the next stage of the value chain will also be required. This stage of the process for feathers can be described as keratin exposure, where the feathers are treated in order to make the keratin available for use in bioplastic manufacturing. There are three processes that can be undertaken to do this, which are 1) mechanical grinding, 2) steam explosion, and 3) microbial fermentation.

1) Mechanical grinding is the most basic of the three processes being examined in Project UNLOCK. This involves the conversion of feathers into fibrous pulp.

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If successful, this would allow for a simpler process while still achieving a high value-add product. However, to be achieved at scale, such equipment and additional expertise would require capital investment.

2) Steam explosion is a physico-chemical treatment technique used for biomass conversion processes. Through Project UNLOCK, its application for feathers is being optimised to obtain high-quality keratin to be used in bioplastics. Continuous steam explosion reactors at the scale required would involve capital investment by renderers, as well as additional investments in expertise.
3) Microbial fermentation is the final technique for the pre-treatment of feathers being researched under Project UNLOCK. This method selectively breaks down the non-fibre parts of the feathers allowing the recovery of fibres in their native form. These fibres are strong, have low-density and possess good resilient properties while also being biodegradable. Scaling this equipment up to industrial levels would have similar implications to investment costs as mechanical grinding and steam explosion explained above.

Although any of these new processes will require investment, Project UNLOCK seeks to make these viable and worthwhile for industry stakeholders as these processes have inherently lower running costs and environmental footprints when compared to existing chemical hydrolysis processes for feather meal production. Furthermore, the bioplastics created have a far higher value than feather meal, creating additional value and incomes for businesses.

Table 7 Summary of Solutions to Investment Cost and Diversification Risk Hurdle

Investment and Diversification Risks	Difficulty to Overcome	Threat to Value Chain
	Substantial investments required in equipment and expertise at both slaughtering and rendering stages, while also being exposed to risk of moving into unfamiliar and newly establishing market	Buy-in from current stakeholders in the poultry industry, through investments in improved feather management and processing, is essential to the successful establishment of the value chain

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3.4 EU Regulations

A robust regulatory framework governing animal by products (ABP regulations) exists providing stakeholders with clear direction on criteria for further processing of ABP products such as poultry feathers.

In contrast, there is currently no EU law in place applying to bio-based, biodegradable and compostable plastics in a comprehensive manner. Therefore, in the European Green Deal and new circular economy action plan, the European Commission announced a policy framework on the sourcing, labelling and use of bio-based plastics, and the use of biodegradable and compostable plastics. The EU Commission are currently at the stakeholder consultation stage for a "Policy framework on biobased, biodegradable and compostable plastics".

It is important that new EU legislation on bioplastics take account of input materials such as ABP and align with the existing regulations governing the specific categories of ABP. The ABP legislation is a co-regulation of the European Council, the European Parliament and the EU Commission and lays down the general principles for the use of ABPs. All three institutions must agree to any change in this Regulation and thus change is unlikely.

Until the new legislation on bio-based, biodegradable and compostable plastics is in place, the current gap remains a hurdle to the establishment of this value chain (see Table 8). Fortunately, as clear animal by-product regulation exists and development of framework legislation for bioplastics is underway, this barrier to entering the sector should soon be removed.

Table 8 Severity of Regulation Hurdles in Feather Value Chain

Section	Hurdle	Difficulty to Overcome	Threat to Value Chain
EU Regulations	Gaps in EU Legislation Governing Feather By-Products and Bioplastics	🟢	🔴

3.4.1 Gaps in EU Legislation Governing Feather By-Products & Bioplastics

The specific objective of Project UNLOCK is the generation of innovative, bio-based functional materials for agricultural applications (e.g., forest/seed trays, nonwoven geotextiles, mulch films and hydroponic foams) from poultry feathers. Understanding of the EU legislation governing the use of poultry feather in these products is key to industry involvement in the production of these types of products.

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Mulch films | Hydroponic foams | Nonwoven geotextiles | Forest and seed trays

Two key pieces of EU legislative frameworks are relevant for Project UNLOCK.

Firstly, the EU framework governing animal by-products, which is in place and embedded within the EU industry for over a decade and, secondly, the EU framework governing bioplastics – currently being developed by the EU Commission. Alignment of these two frameworks is important and will influence the selection of end-products prioritised for development under this project.

Rendering is the process that converts by-products from the meat and livestock industry, such as feathers, into usable materials. Without proper management meat and animal by-products can become hazardous.

As a result, the rendering industry is underpinned by strict EU veterinary principles to prevent the spread of animal diseases and zoonoses. ABP is regulated by EU Council Regulation No. 1069/2009 and its Implementing Regulation (EU Regulation No 142/2011) (referred to as the ABP Regulations).

The objective of these regulations is to promote the sustainable use of animal materials and a high level of protection of public and animal health in the EU. Clause 1 of Commission Regulation (EU) No 142/2011: 'Regulation (EC) No 1069/2009 specifies animal and public health rules for animal by-products and products derived thereof.'

This Regulation determines the circumstances under which animal by-products are to be disposed of in order to prevent the spreading of risks for public and animal health.

In addition, that Regulation specifies under which conditions animal by-products may be used for applications in animal feed and for various purposes such as in cosmetics, medicinal products and technical applications.

It also lays down obligations for operators in handling animal by-products within establishments and plants which are subject to official controls by EU regulators.

With a view to preventing and minimising risks to the public and animal health arising from ABPs and products derived from them, Regulation (EC) No 1069/2009 assigns products to specific categories that reflect the level of such risks and includes requirements on their safe use and disposal, as follows:

- Category 1 ABPs: Defined in Article 8 of Regulation (EC) No 1069/2009. This material is associated with the highest risk and consists principally of material that is considered a TSE risk, i.e. Specified Risk Material.
- Category 2 ABPs: Defined in Article 9 of Regulation (EC) No 1069/2009. This material is associated with medium risk. It includes fallen stock, manure and gastrointestinal tract contents. Category 2 is also the default status of any animal by-product not defined in the ABP Regulation as either Category 1 or

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Category 3 material and includes such material as slaughterhouse drain-trap waste.

- 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.

Feathers from slaughterhouses are likely to be contaminated with a range of pathogenic bacteria including Campylobacter and Salmonella. This legislation clearly sets down the conditions under which feathers as animal by products can be used. The legislation requires that industry must demonstrate that there are processes and procedures in place to ensure that any treatment applied to feathers will be sufficient to eliminate all pathogens which might be present.

Two key scenarios, as outlined below, exist under this legislation, namely,

- untreated feathers, parts of feathers and down; and
- treated feathers, parts of feathers and down

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. Under Project UNLOCK some of the innovative products in which feathers will be incorporated could be close in definition to soil improvers or organic fertilizers and are required to undergo one of these approved treatments before use in certain derived products.

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.

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	-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;

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	(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: (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 1 g

Treated feathers, parts of feathers and down:

(i) 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 that they can be placed on the market 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.
- comply with the standards outlined in Chapters 1 and 11 of Annex IV of Regulation 142/2011.

Biobased, biodegradable, and compostable plastics policy framework:
In March 2022 the EU commission completed a public consultation on biobased, biodegradable, and compostable plastics which aimed to provide insight for preparing a new policy framework on this group of plastics. The aim of this new framework, set for release in summer 2022, is to address emerging sustainability challenges related to the use of the biobased, biodegradable, and compostable plastics by driving innovation, enhancing investment certainty within the internal market, and increasing environmental protection.

It is important that this new legislation clearly sets out the criteria of use of ABP products in bioplastics and aligns with existing definitions, categorizations, and principles under the existing EU ABP legislative framework.

A clear legislative framework on biobased, biodegradable, and compostable plastics is needed to direct the development of such products under this project and to provide clarify and for continued investment in this sector.

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Table 9 Summary of Solutions to Regulation Hurdles

EU Regulation	Difficulty to Overcome 🟢	Threat to Value Chain 🔴
	Commitment to policy framework on biobased, biodegradable and compostable plastics through the European Green Deal, EU Circular economy action plan indicate solutions to overcome this legislative hurdles are in development and being progressed as urgent by the EU Commission	If this hurdle is not overcome, then there is a substantial risk that a new feather value chain as examined under UNLOCK will face challenges, particularly in ensuring commitment from industry to invest in this area

3.5 Feather Availability

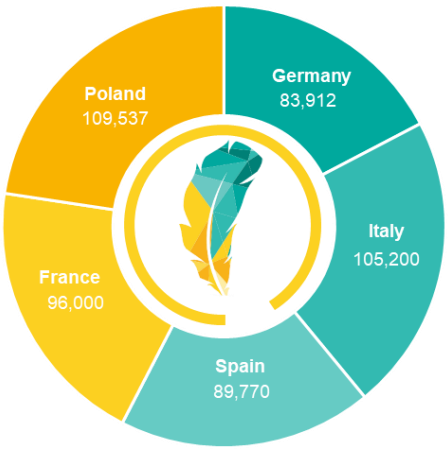
The two key hurdles for consideration in this new value chain are (i) avian influenza and (ii) competition for use of feather in existing or upcoming end-products. These two hurdles are presented below (see Table 10).

Table 10 Severity of Feather Availability Hurdles in Feather Value Chain

Section	Hurdle	Difficulty to Overcome	Threat to Value Chain
Feather Availability	Avian Influenza	🔴	🟢
	Competition for Feather Availability	🔴	🟡

In terms of feather waste supply, an estimated volume of almost 450,000 tonnes of poultry feathers is available annually across France, Germany, Poland, Italy, and Spain, with Poland being the largest supplier (Figure 8). The average EU figure in the period from 2010 to 2020 totalling 621,200 tonnes. The new trading arrangements between the EU and UK have negatively impacted the supply of poultry feathers into the EU, primarily due to increased transportation costs.
However the poultry market is relatively stable, as seen from analysis presented in Deliverable 2.1, indicating that the supply of feather from within the EU, should remain relatively constant.

Figure 8 Average annual feather feedstock availability from target countries (MT)



3.5.1 Avian Influenza

One key disruptor to feather stock availability is disease outbreak in poultry, especially avian influenza, which can decimate flocks. The 2020–2021 avian influenza epidemic, with a total of 3,777 reported highly pathogenic avian influenza (HPAI) detections and approximately 22,600,000

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affected poultry birds in 31 European countries, was one of the largest HPAI epidemics that has ever occurred in Europe (EFSA Scientific Report, Avian influenza overview May – September 2021). This HPAI outbreak disrupted the poultry supply chain in many European countries. The first cases were detected in turkey holdings and later on in laying hens, broilers, backyard flocks, breeder flocks and wild birds. In the period January to June 2021, there were more than 1,200 cases in poultry flocks in 22 different European countries.

The turkey industry in Germany and Poland was particularly impacted by HPAI. Despite the reinforcement of biosecurity measures, several breeding farms and turkey farms saw their flocks decimated. Depopulation measures to control the spread of the disease were successful but had a significant impact on production and resulted in millions of birds being slaughtered.

Disease outbreak is the most significant disruptor to feather feedstock

In France, duck production was another industry to be significantly impacted by HPAI (AVEC Annual report, 2021). During the period October 2020 to September 2021, 1,282 cases of HPAI outbreaks in poultry were reported affecting 22.6 million birds across Europe, with Poland being the member state reporting significantly higher levels compared to other countries. This is illustrated in Figures 9 and 10 below.

EU legislation (Regulation (EU) 2016/429) required all infected poultry to be slaughtered. By-products from such animals are categorised as high-risk material (Category 1 under the Animal By-Products legislation (Regulation (EC) No 1069/2009) and must be destroyed. Poultry feathers from infected flocks are generally incinerated and unavailable for supply under Category 3 by-products.

The extent of the damage caused by this outbreak highlights the potential for disease to be a hurdle within feather supply chains, by reducing the quantity of quality feathers available. Outbreaks can be limited by improving biosecurity measures. However, due to the nature of the virus, while outbreaks can be reduced, they cannot be eliminated, meaning this challenge will remain for the poultry industry.

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Figure 9 Numbers of poultry affected by HPAI in European Countries from October 2020 to September 2021

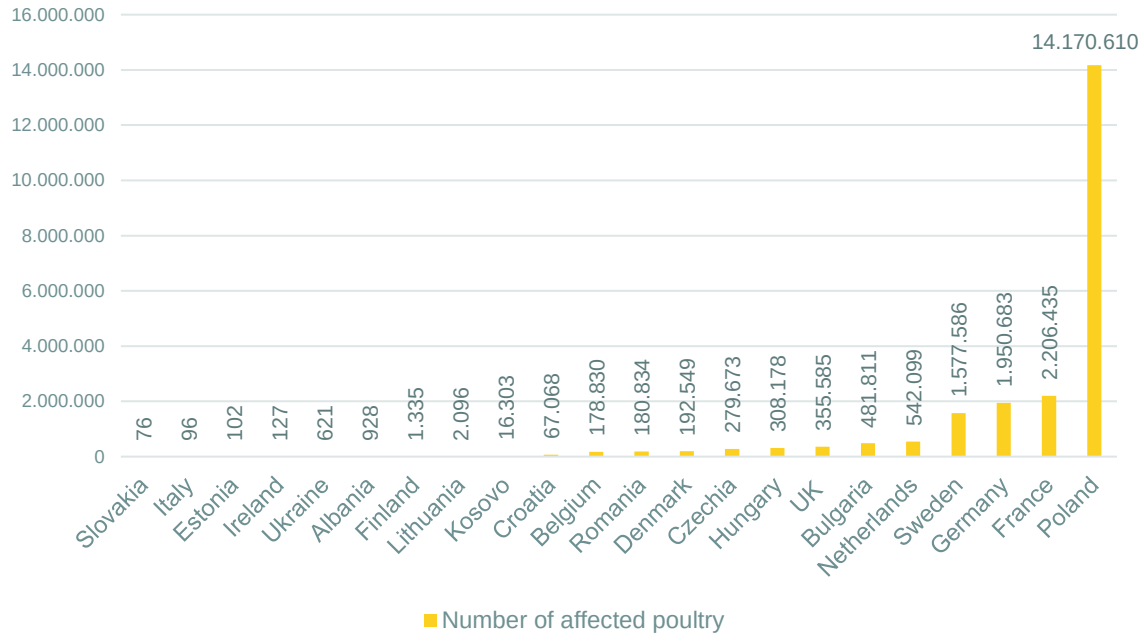
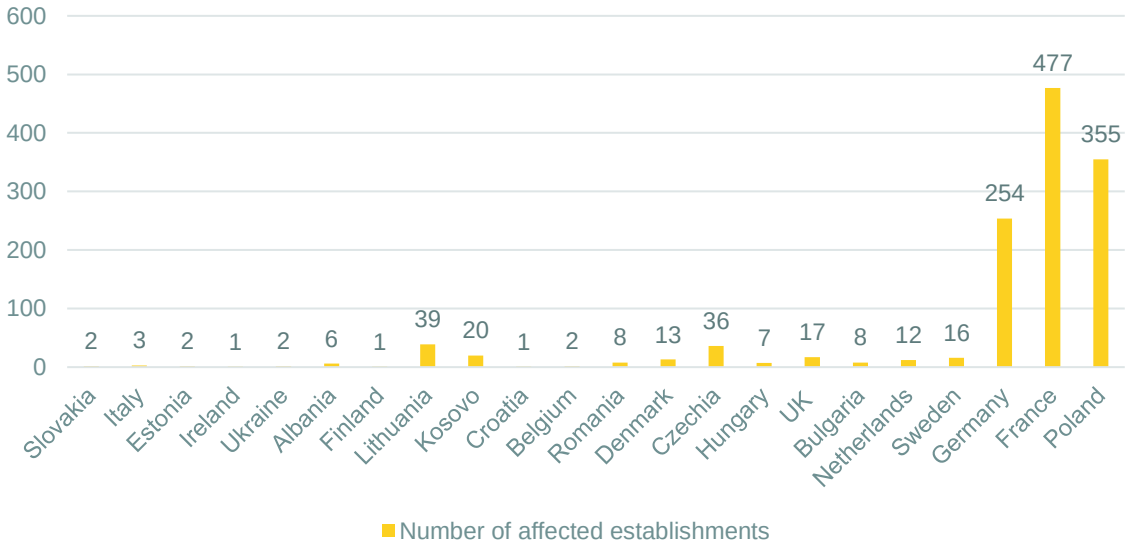


Figure 10 Number of establishments affected by HPAI in European Countries from October 2020 to September 2021



(Source: EFSA[2])

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3.5.2 Competition for Feather Availability

Research conducted under Project UNLOCK indicated that current demand for feathers for rendering is high within the EU. Therefore significant competition for feather availability for a new feather value chain can be expected.

Issues relating to quality feather availability (Section 3.2) or avian influenza (Section 3.5.1) are outlined earlier, however, there are other hurdles which must be overcome in order to achieve the necessary feather availability for a new feather value chain. This includes existing competition from the biogas and animal feed and fertiliser industries.

Interviews with industry stakeholders during research for Project UNLOCK revealed that there is currently a substantial demand for feather waste within Europe, for processing into feather meal. Markets for both animal feed and fertilisers are strong, with financial returns being generated in the existing poultry feather value chain.

Diversion of feathers from this existing profitable market to a new bioplastics market will be challenging. However, industry stakeholders are open to this new market provided evidence is in place to reassure industry stakeholders that this option is viable, offers better financial returns than the existing market and is sustainable long term.

Within this resides another challenge, discussed in more detail under Section 3.4 on EU Regulation, that there is clear regulation in place surrounding the uses of feather products in feed and fertiliser. However, much ambiguity remains about the legality of reprocessing feather waste into biodegradable end products as discussed under Project UNLOCK. This ambiguity may mean processors are less inclined to shift away from the current practices which are generating financial returns for them.

The production of biogas from agricultural waste stream is a product which is becoming increasingly relevant under the topic of renewable energy. EU regulations governing this product are in place. Biogas is an alternative end-use for poultry feathers in which a number of stakeholders indicated they were already involved.

Competition for feathers with existing industries is undoubtedly a hurdle which will have to be overcome when establishing a new value chain for chicken feathers. The solution is relatively straightforward and is at the core of what Project UNLOCK aims to achieve- a higher value for feathers.

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Table 11 Summary of Solutions to Feather Availability Hurdles

Avian Flu	Difficulty to Overcome 🔴	Threat to Value Chain 🟢
	Outbreaks of avian influenza extremely difficult to control due to nature of virus and requirement for widescale application of improved biosecurity measures across regions and national boundaries - high probability that outbreaks will continue as observed in recent years	Even with a serious outbreak of HPAI during 2020-21, feather availability remained high, meaning avian flu is limited in its threat to the value chain
Competition	**Difficulty to Overcome 🔴**	**Threat to Value Chain 🟡**
	Current demand for existing products (feed and fertiliser) remains high - stakeholders unlikely to shift from current practices unless assured about new product price, consumer acceptability and future growth of market	A higher price for feathers should entice processors into a new feather value chain, however the risk remains that some may not switch from current practices

3.6 Market Hurdles

Competition from other bioplastics and gaining consumer acceptance are two of the market hurdles that keratin-based bioplastics will need to overcome in order for the value chain to achieve viability (see table 12). This can be done through gaining end-user trust in products by achieving price competitiveness and through differentiating these sustainable bioplastics from other alternatives currently available.

Table 12 Severity of Market Hurdles in Feather Value Chain

Section	Hurdle	Difficulty to Overcome	Threat to Value Chain
Market Hurdles	Competition from Other Bioplastics	🔴	🔴
	Consumer Acceptance	🟡	🟢

3.6.1 Competition from Other Bioplastics

If feather-based bioplastics are to succeed in the marketplace, then they need to be competitive with and have advantages when compared to the other bioplastics already being marketed and used. This is a significant hurdle in creating a new higher-value feather supply chain.

Price competitiveness is an extremely important factor in establishing market share. One product being researched under Project UNLOCK is bio-based mulch films. Currently, bio-based mulch films manufactured using poly-lactic acids, bio polyesters and starches have a far higher cost of production than existing bioplastics manufactured from polyethylene, due to the cost of the raw materials.

In addition, this product has a higher density which results in high quantities of inputs being required to produce the same amount of film.

However, bio-based films hold an advantage over those plastics manufactured from polyethylene, as these either have to be removed from the land and recycled, or are

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oxo-degradable, meaning they are broken down but with the consequence of microplastics being released into the environment.

Introducing keratin obtained from feathers as a raw material in these bio-based plastics may increase the competitiveness of these products on price, which Project UNLOCK seeks to achieve. Given that in this instance, the cost of the raw material, i.e. feathers, is low, there should be scope to achieve price competitiveness if the production costs of the keratin are minimised.

Another method of achieving competitiveness on the open market is for a product to differentiate itself by offering a number of distinct advantages. This could mean using more sustainable materials and offering itself as a climate-friendly option, or by offering products with different biodegradation timelines. For example, one currently available mulch film begins to biodegrade after 5 weeks and is fully integrated into the soil after 9 months. Although the composability quality of this product is clear, beginning degradation after only 5 weeks on the soil is too short a timeframe for many uses, with 7-8 weeks more desirable. This problem can be combatted by increasing the thickness of the film, but this adds additional costs to an already more expensive product.

Research has shown that blending keratin with starch to create biofilms decreases the water solubility of the material, meaning it may have some benefits in terms of extending the window in which no degradation occurs (Tesfaye et al, 2018). Similar issues are being experienced with biodegradable seed trays, in that they begin to biodegrade before they are planted. Again, incorporating keratin into such a formulation may have the potential to extend this time frame. By offering different products with different biodegradation timelines, UNLOCK products could distinguish themselves from the rest of the bio-based plastics market.

Finally, one hurdle may be that feather-based materials may not seem attractive to end-users at first sight and that significant effort may be required to convince end-users of the benefits of using feather-based biodegradable materials. However, end-users may also see the benefit of re-using a waste product to create a valuable agricultural material which may attract customers.

3.6.2 Consumer Acceptance of Newly Developed Products

One hurdle which may arise at the tail end of the value chain is consumer acceptance of newly developed products. This is in reference to both the end-user, which may be a farmer, and the consumer of the farmers' products.

One potential hurdle in this scenario is the veganism movement and what foods can be classed as vegan. If a farmer uses geotextiles, mulch films, or hydroponic foams manufactured from feather keratin, would that disqualify their product from being "vegan"? If so, this is one potential market which could be shut off to farmers.

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End-users will also be hesitant about moving from one product with which they are familiar, to another which they are not, especially if that product is derived from feathers in a completely new process. This will be tackled through the engagement programmes through UNLOCK as mentioned in section 3.3.1.

Table 13 Summary of Solutions to Market Hurdles

Competition	Difficulty to Overcome 🟡	Threat to Value Chain 🔴
	• Price competitiveness with other bioplastics may be difficult to achieve, however ensuring efficiencies in inputs and processing can assist • Research surrounding extended biodegradation timelines compared with other materials should allow keratin-based products to differentiate from the market	If competition with other bioplastics (particularly in terms of functionality and cost) cannot be established, then success of keratin-based bioplastic value chain will be difficult
Acceptance	**Difficulty to Overcome 🟡**	**Threat to Value Chain 🟢**
	Generating acceptance of keratin-based bioplastics will be a challenge among a small cohort of society, and will be addressed through engagement programmes in UNLOCK	Acceptance of a product should develop provided the product is of high-quality and consumer messaging is managed correctly, thus acceptability challenges are considered as a minor treat

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4 Conclusion

This study has provided an insight into the range of hurdles facing the feather value chain in the EU.

Each year, over 620,000 tonnes of feathers are generated by the poultry supply chain within the EU. Consultations with industry stakeholders have shown that slaughterhouses experience high levels of demand for their feathers, for rendering into feather meal, which is increasing demand for both animal feed and fertilisers given current the geopolitical situation. The creation of a new value chain for feathers will encounter many challenges relating to this competition for feathers, as detailed in the report.

Logistical hurdles within the feather value chain are related closely to the length of the supply chains, the subsequent carbon footprints and cost of transport. Certain solutions have wide ranging benefits for feathers quality, such as minimizing water content, while other options including renewable transportation remain in the pipeline. These solutions and others will be investigated further in future reports.

Feather quality is arguably the most important consideration within the value chain. For the processes required for keratin extraction, the feathers must be maintained in good condition with microbial degradation minimised. Ensuring the availability of such high-quality feathers is linked closely to the cost of new investments and diversification risks for actors within the value chain. The price processors receive for feathers will need to be increased substantially before slaughterhouses undertake the investments required to provide the higher quality feathers required in this new value chain.

The existing and future regulatory landscape for feathers and bioplastics is another factor which could negatively impact on the successful establishment of a new feather value chain. Clear animal by-product legislation currently details the capacity for feathers to be used in a range of agricultural products, including, as mentioned, animal feed and fertilisers for which feathers are in demand. Framework legislation on bioplastics is now being drafted and it is critical that the use of animal by products, such as feathers, in more environmentally friendly bioplastics is clearly addressed.

Through primary research for UNLOCK, it was shown that significant demand currently exists for feathers for use in animal feed and fertiliser processing in Europe. This hurdle of feather availability can be overcome by a new feather value chain enticing processors in with higher prices offered for high-quality feathers. Avian influenza can also have a significant impact on availability, especially in the case of a widescale outbreak as experienced in 2020-21.

Finally, market hurdles also have a role to play in future challenges in a feather to bioplastic value chain. Keratin-based bioplastics will face challenges in differentiating themselves from the other products available within the bioplastics marketplace, whether that be on technical specifications, or price differenciation. Minor issues may

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also arise in relation to end-user reluctance to switch from current products, or perhaps unacceptance by specific categories of consumers (e.g. vegan sector).

Many of these challenges mentioned in this report exist currently in the feather value chain, for example, those relating to logistics and feather quality, and will transfer over to a novel value chain as hurdles. Addressing these will have immediate benefits for the existing supply chain, as well as positively impacting future developments within the sector. Others, such as those involving investment and market hurdles, apply only to the establishment of the new feather value chain.

The traffic light system was effectively used to classify the hurdles by their difficulty to overcome and the threat they pose to the value chain. Feather quality issues provide some of the most significant threats to the operation of the value chain, while logistical and infrastructural hurdles will be among the most difficult to overcome.

Research on the hurdles facing the feather value chain has shown that responsibility in navigating the challenges and successfully establishing the sustainable sector lies with various members of the industry. Within the private sector, stakeholders must be willing to invest in their processes to guarantee the supply of high-quality feathers into the value chain and to increase the sustainability of their transport methods.

At government level, regulators must ensure the provision of clear guidelines and legislation on the appropriate conditions and criteria for the use of feathers in the creation of bioplastics. Implementation of biosecurity measures should be strengthened by industry in the wake of the recent avian influenza outbreaks to mitigate future outbreaks of this disease within the poultry sector.

Lastly, support from consumers, as potential end-users of keratin-based bioplastics is imperative. Therefore it is important that consumer awareness of the benefits of these new products in terms of improved environmental sustainability and functionality is correctly managed to promote product acceptance.

This report has detailed the various challenges ahead for EU's new feather value chain, from logistics, to regulation, and some of the potential ways to overcome these, to help ensure a sustainable future for this branch of the EU poultry industry.

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