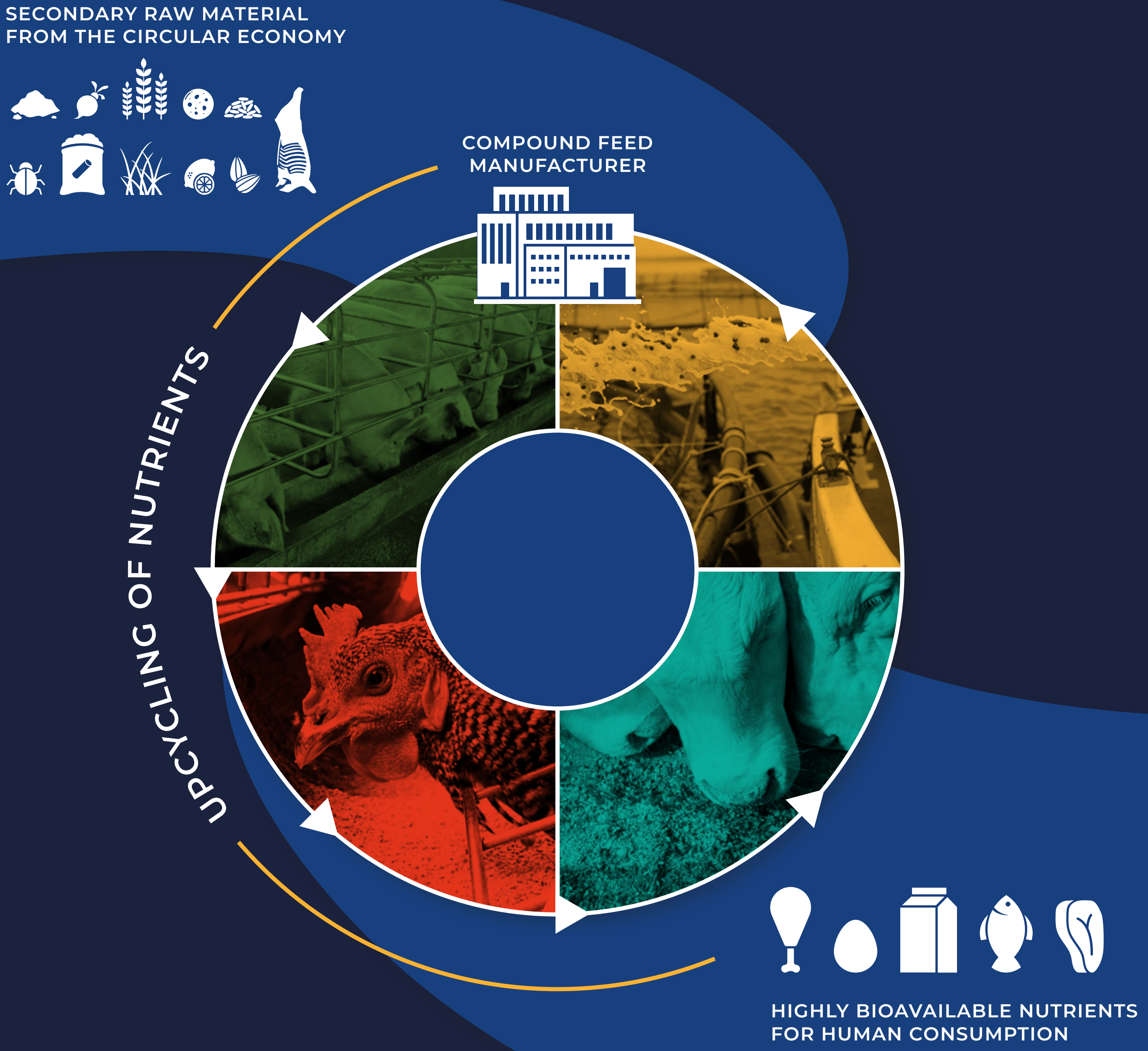
FEFAC
Experts in Animal Nutrition

CIRCULAR FEED

OPTIMISED NUTRIENT RECOVERY THROUGH ANIMAL NUTRITION



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About FEFAC

The European Feed Manufacturers' Federation (FEFAC) was founded in 1959 by five national compound feed associations from France, Belgium, Germany, Italy and the Netherlands. FEFAC represents 21 national Associations in 21 EU Member States as well as associate members in the UK, Switzerland, Turkiye and Norway, and the European associations EMFEMA and EFFPA.

INTRODUCTION

The European feed industry takes great pride in its knowledge, understanding and technical capacity that it has built up over many years in how to recover nutrients from other (industrial) processes in the food and biofuel chain. This is fundamental to our sector and ensures our contribution of feed production to raising food-producing animals as part of a circular food system, thus keeping nutrients in the food systems which would otherwise be lost. Historically, domestic farm animals were reared with what humans did not eat, either grass or residues from food processing activities. In fact, the very origin of the European feed industry stems from the recovery in a professional way, of wheat bran from flour millers, for which there was no human food market.

This 'historic' role in the bio-economy gives our sector a key responsibility in driving sustainable food systems by continuing to innovate in the upcycling of nutrients through feed for food-producing animals. With five concrete ambitions in its Feed Sustainability Charter 2030 released in September 2020, FEFAC committed to further drive sustainable feed production. The second ambition of the Charter is to Foster Sustainable Food Systems Through Increased Resource & Nutrient Efficiency, which initiated a journey through the concepts of human inedible feed, non-food grade feed ingredients and now 'circular feed' as the next level. This brings us back to our origins, as driving circularity in food systems is our license to produce.

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The concept of circular feed, as presented in this publication, provides the 'state of the art' perspective describing the strength of nutrient recovery through animal nutrition. In addition, we believe that the circular feed concept can co-exist with the feed conversion ratio, which is a more traditional resource efficiency indicator that considers 'only' the 'input-output' efficiency from a kg feed into a kg animal product. The circular feed approach takes into account how the feed ingredient originated and what the level of competition is with direct food production. It could be argued that the feed conversion ratio is an indicator that is more appropriate to describe the resource efficiency of poultry and aquaculture systems, while porcine and ruminant systems have more capacity to absorb 'low grade – non-human edible' nutrients emerging from the circular economy. This is the benefit of our highly diverse EU livestock farming systems and species that each of them makes its contribution to optimised resources use, while making the best use of locally and globally available nutrient sources!

Although the circular feed concept is a rather recent development, the feed industry has been recovering secondary raw materials from the circular economy for many decades. In this publication we have therefore included the large range of feed ingredients from our Resource Efficiency Champions publication from 2019 as current day examples of nutrient recovery through animal nutrition, referred to in that publication as "co-products". At the time FEFAC took the opportunity to showcase these co-product examples to illustrate how compound feed manufacturing helps to make plant-based and animal production complementary.

In raising the profile of the circular feed concept at the EU level, we are also trying to identify solutions to address current and future challenges and 'bottlenecks' limiting access to a wider range of circular nutrient sources. The European Commission Farm to Fork Strategy, published in May 2020, provided additional stimulus on how we can make more use of alternative feed ingredients and how we can lower the environmental footprint of animal products through increased use of circular feed, as less reliance on agricultural land will result in lower GHG emissions related to feed production. The new dynamics caused by the Russian invasion of Ukraine in February 2022 reinforce strategic feed security considerations to improve EU feed autonomy by reducing the EU's feed import reliance, especially on high protein feed sources.

FEFAC believes that the impact assessment of the forthcoming EU Sustainable Food Systems Framework must make a critical review of unnecessary measures in the EU regulatory framework that restrict circularity in EU food systems through animal nutrition, as they may stem from legislation-making in times of crisis. In this publication, FEFAC identifies a selection of regulatory obstacles that should be re-assessed in order to facilitate the safe recovery of nutrients that are currently destined for outlets of lower circular economy potential. In addition, the Sustainable Food Systems Framework should also ensure that feed applications of nutrients emerging from the circular economy are not deviated towards bioenergy use because of misguided incentives provided through renewable energy policy-making.

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THE CIRCULAR FEED CONCEPT

Nutrient recovery and reducing nutrient losses lie at the heart of the circular feed concept. It's about retrieving nutrients in the most sustainable way possible and ensuring nutrient transfer and upcycling from one organism to the next in a way that minimises losses. In this intra-organisms, one-nutrition approach, the feed industry plays a key role in closing nutrient cycles and optimising the bioavailability of nutrients for human consumption. Products derived from livestock farming such as meat, fish, dairy and eggs are an excellent source of nutrient-dense and highly bioavailable food for humans. The feeds consumed by farm animals do not possess this intrinsic quality necessary for humans. This is particularly the case in dairy production where cows, as ruminant animals, can synthesise their own amino acids within their bodies to fortify the milk, acting as a kind of bioreactor. It is worth noting that in principle the handling of nutrients at livestock farm level is more efficient and certainly less wasteful than is the case with human beings, as the nutrients 'lost' through animal manure can still be recovered as fertiliser for crop production.

Circularity in feed production is a concept that is still in the process of being defined. It is not always possible to take direct inspiration from existing circular economy models from other industries, where, for example, in plastics production eco-design-based indicators such as recyclability and product lifespan are essential. It is clear though that the concept of countering linear resource depletion through increased circularity and the use of secondary raw materials can work in feed production and can help address the challenge of competition with direct human consumption, which is often referred to in the public debate.

FEFAC would therefore propose the following product-based definition for circular feed, as part of the ongoing debate at a scientific and public level on the key sectoral criteria for sustainable food systems;

> *“Non-food-grade ingredient recovered as a secondary raw material from the (local) circular economy with a low land-use footprint”*

The definition can be broken down into several components, which jointly form the circularity metric. The different dimensions of the components allow for a non-binary approach, where it could be concluded that certain feed ingredients are of a higher circularity level than others.

- **Food/feed grade status**
- **Land use ratio**
- **The proximity of origin to feed mill**
- **Nutrient digestibility**

Food/feed grade status

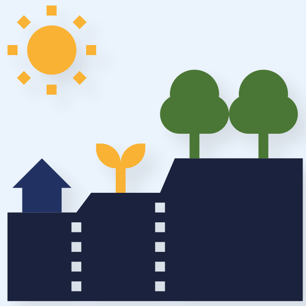
Food grade means that the quality of the material is of such a nature that it meets the expectations of the human consumption market. The concept of ‘human inedible feed’, as defined by FAO, is linked to this. The notion of food/feed grade status however provides a better understanding of the quality of the biomass used by the feed industry, rather than what is ‘consumable’ by a human being from a literal point of view. When a product is feed grade, it is not considered suitable for placement on the human consumption market due to quality characteristics or simply because there is no food business operator placing the material on the human consumption market.

From FEFAC’s analysis included in the 1st Feed Sustainability Charter Progress Report it can be concluded that practically none of the raw materials used in feed production in general, are of food grade nature. Typically, ingredients sold for direct human consumption command a higher market price than if they go to feed, so the market drives this direction. However, there are cases that food grade feed ingredients are sold to a feed operator, but this is normally the result of surpluses for which demand from the human consumption market no longer exists. Nonetheless, a feed ingredient of feed grade nature has higher circularity potential than a feed ingredient that is of food grade nature.

Proximity to the feed mill

The notion of ‘circular economy’ has a geographic dimension, where in general the closer the origin of the raw material to the point of final use (i.e. local), the “more circular”. This proximity is illustrated by the fact that feed mills are located close to their livestock farmer customers, which from a starting point favours local use of resources. In view of European feed production, the sourcing of feed ingredients emerging from the European continent is a means to boost the European circular economy and therefore the European feed autonomy. The proximity of the feed material to the feed mill is an element that is included in the scope of the PEFCR Feed for Food-Producing Animals, where the emissions related to feedstuff transport are part of the environmental footprint of compound feed production, even if the overall impact on GHG reduction may be relatively limited.

Land use ratio



The principles of circular economy point toward the use of secondary raw materials, meaning they are produced from other (industrial) processes that are geared towards the production of a different product. In terms of agronomic resource depletion, the key element here is arable land use. The less arable land that is dedicated to the production of a feed ingredient, the more the feed ingredient is a product of the circular economy and in principle also the lower the carbon footprint.

To quantify the low carbon footprint related to respective land use ratio of a feed ingredient, the principles of economic allocation from LCA-based methodologies such as the PEFCR Feed for Food-Producing Animals could help as it will indicate the extent to which the feed component of a crop is the economic driver for cultivation. This does not exclude the fact that even if the feed component is a key driver of crop cultivation, feed production still plays a role in adding value to the bioeconomy and contributes to sustainable arable land use. It is for example known that feed crops are often grown on arable land that cannot deliver the nutrients necessary for food grade production and feed crops have a role as a rotation crop in good agricultural practices.

Nutrient digestibility

When considering the circularity of a feed ingredient, the nutritional characteristics matter. These will determine how digestible the feed ingredient will be and to what extent it can be expected that the nutrients contribute to the nutritional profile of the animal product (while bearing in mind of course that the farm animal plays a crucial role here). In other words, the circularity of a feed ingredient is also determined by the extent to which the nutrients can be absorbed by the farm animal and are not lost through manure. For example, an increasing focus on nitrogen and phosphorus losses will further drive the attention for the digestion and excretion of these key nutrients at livestock level.

EXAMPLES OF EXISTING AND EMERGING PRACTICES OF NUTRIENT RECOVERY

The examples of circular feed displayed on the following pages have predominantly been taken from the FEFAC publication *Resource Efficiency Champions* from 2019. These “recovered nutrients” illustrate how the compound feed sector can maintain a large range of bio-resources in the food chain.

CITRUS FRUIT PROCESSING

Squeezing value from the peel

Billions of litres of juice from citrus fruit such as oranges, lemons and grapefruit are consumed globally. After the juice has been extracted, a solid residue made up of the peel and seeds remains. Called citrus pulp, this is a valuable feed co-product. Fresh pulp can be fed to animals locally, but very often it is pressed and dried into pellets, usually at the fruit pressing facility itself, before being exported globally as a commodity (particularly from Brazil and the United States).

Citrus pulp is rich in energy and fibre, with good digestibility for ruminant species. Like sugar beet pulp, its highly digestible fibre content induces good rumination in cows’ stomachs, leading to the production of large quantities of saliva that have a buffering effect on the pH of the rumen. Citrus pulp containing oranges gives a sweet and aromatic flavour to the feed, aiding palatability. When the pulp contains lots of lemon or grapefruit pulp, the taste is usually more bitter.

In dairy cattle, citrus pulp is known to maintain milk quality, especially milk fat. It is particularly well suited to ruminants, which are able to digest high-fibre feeds, and is a good example of how an additional element of agricultural crop production can be kept in the food chain. Due to its high fibre content and the presence of the anti-nutrient limonin, citrus pulp is much less suitable for pigs and is rarely used in poultry.

What is meant by palatability?

Taste! Farm animals (especially young piglets) can be picky eaters and compound feed manufacturers need to ensure that they create nutritionally balanced diets that will be eaten. Taste is a factor in this process. It is also important to produce homogenised feed so animals do not go through their feed trough selectively. This is why compound feeds are often created as pellets.

Raw materials

Citrus fruit

Recovered nutrients

Dried citrus pulp pellets

Consumer products

Fruit juice

WHEAT AND RICE MILLING

Origins of the compound feed industry

It is appropriate to begin with the examples of recovered nutrients that result from wheat milling, as this is where the European compound feed industry has its origins in the early twentieth century. In fact, compound feed manufacturing was initially carried out by flour millers themselves, which is where the term 'feed mills' comes from. Surplus particles from grinding grains to produce flour were initially considered to be a waste product, but conserving these and diverting them as co-products for feed has become an integral part of the manufacturing process for one of the biggest industrial food ingredient sectors. During the production of non-whole-wheat bread, breakfast cereals and pasta, only the endosperm (flour) is used, leaving the hard outer layer (bran) behind.

Wheat bran can have different definitions and compositions depending on the region where it is produced. Flour millers generally have good links with nearby feed markets, supporting local or regional supply chains. In bread manufacturing wheat bran is used in wholemeal bread, so people are generally aware that bran is richer in protein (14–19%), fibre, minerals (particularly calcium and phosphorus) and oils than the endosperm. These nutritional traits are also beneficial to the feed industry. Wheat bran can be consumed by all types of farm animals, although the amount fed to poultry should be limited, as the high fibre content can impact digestibility. The inclusion of wheat bran in feed for sows and ruminants is extremely common. It is associated with improved milk fat yield in the latter.

Rice grains are also surrounded by bran, human consumption of which is a lot less common than consumption of wheat bran. This is despite claims that roughly 80% of the nutrients are in the bran, even though it only makes up 10% of the grain. **Rice bran** is separated from the endosperm in a process that converts brown rice to white rice. As with wheat bran, it contains a useful amount of protein and fibre. The oil in rice bran usually still has a role in food production so it is very common to come across defatted rice bran as a feed material. Rice bran is also a good source of B and E vitamins and certain trace minerals such as manganese and zinc. As with wheat bran, rice bran is particularly suitable for dairy cattle due to its high fibre content.

Feed safety

Feed safety requirements are applied horizontally across all feed materials, whether they are made from co-products or primary raw materials. Manufacturing processes have to control for good hygiene, hazard analysis and critical control points (HACCP) and chemical residues, in line with Regulation (EC) No 183/2015, Regulation (EC) No 767/2009 and Directive 2002/32/EC.

Raw materials | **Recovered nutrients** | **Consumer products**


Paddy rice


Rice bran


White rice


Brown rice


Whole wheat grain


Wheat bran


Pasta


Bread

SUGAR PRODUCTION

Beet pulp pellets, molasses and pressed pulp

Sugar that is used as table sugar or as an ingredient in food and drink products comes from sugar beet and sugar cane. The European Union is the world's biggest producer of beet sugar. This is refined by being cut into small strips or slices, and the sugar is then extracted as juice using water at approximately 70°C. The remaining **beet pulp** is rich in fibre and energy and has outstanding feed value for different types of livestock. It is most commonly used in dairy feed due to its ability to promote milk yield and increase fat levels, as well as reducing the risk of acidosis in the rumen (which is caused by excessive grain starch). In its dried form, beet pulp is an international commodity that is transported by trucks or ships. Dried beet pulp is sold as either unmolassed pellets or as molassed pellets.

During further refinement and crystallisation of the sugar juice, a syrupy co-product called **molasses** is produced. Molasses provides a rapid source of energy and is rich in certain minerals, but its feed qualities go beyond the nutritional benefits. It is a highly valued energy-rich taste enhancer which increases the palatability and homogeneity of compound feed. The viscosity of molasses makes it unsuitable for feeding directly to livestock, but it has good pellet-binding qualities that can control the many fine particles that are part of compound feed processing, preventing post-production pellet deterioration. Molasses is commonly used in ruminant feed, but is also included in pig feed, and to a limited extent poultry feed. Molasses from both beet and cane has a similar nutritional value: the main difference is that cane molasses is typically imported to Europe from overseas, whereas beet molasses is produced within Europe.

Pressed beet pulp is also sold as a fresh product. This can either be fed directly to animals or be ensiled (conserved by being put into a silo or silage clamp). It is a high quality feed for all ruminants.

The incredible powers of ruminants

Ruminants are the only animals that are capable of digesting many co-products, particularly those that are rich in fibre. As a result they play an essential role in creating a food use for agricultural biomass that would otherwise be wasted.

> *"The EU beet sugar sector has a long tradition of maximising value from all products arising from the sugar process, minimising waste as far as possible. As well as common household white sugar, the EU sugar industry is also a major producer of feed materials stemming from sugar beet and sugar cane. Sugar industry co-products such as pulp and molasses are generally highly valued feed materials as a result of their sweet taste and high energy content."*

CEFS EU SUGAR

Raw materials | **Recovered nutrients** | **Consumer products**

Sugar beet

Sugar beet pulp

Molasses

Sugar

BEER BREWING

Creating a nutritious alcohol-free feedstuff for animals

The beer production process includes the filtration to produce liquid wort of a mixture produced by the steeping in water of malted and/or unmalted cereals, further filtration or whirlpooling following the boiling of the sweet wort to which hops have been typically added, and the further fermentation of the wort through the addition of yeast. The solid residues extracted during the processes have been used, amongst other uses, as nutrient rich animal feed since before the Industrial Revolution, when farms and monasteries in Europe brewed their own beer and fed the resulting co-products to their livestock. Depending on the type of beer being brewed, 15–20 kg brewers' grains and 2–4 kg brewers' yeast is generated for each hl (100 litres) of beer produced. With close to 40 billion litres of beer brewed in Europe each year, the role of brewery co-products in feed is significant.

Brewers' grains, whether dried or not, are an excellent feed material that are rich in proteins and highly digestible fibre, making them particularly beneficial to cattle and other ruminants. The fibre supports the functioning of the rumen (the biggest chamber of a ruminant's stomach), complementing forage-based diets that are high in starch and lack readily fermentable fibre. With crude protein content ranging from 19–31% on a dry matter basis, brewers' grains are also a good source of protein. Due to their high moisture level they are perishable, so livestock activity in the proximity of a brewery is also desirable if the brewers' grains are not dried.

Brewers' yeast is the component that converts sugars and starches into alcohol during beer brewing. The yeast must be deactivated by e.g. heat treatment or organic acids to be suitable for use as animal feed. Brewers' yeast is rich in protein (36–50% on a dry matter basis), and has a valuable amino acid profile that is similar to soya. It is an extremely versatile feed for all types of farm animals. When used in poultry feed, it is recognised as an excellent source of B vitamins.

> *"Whilst brewing high quality beer is a brewer's main focus, reducing wastage and minimising environmental impact is also key. Ensuring that secondary materials such as brewers' grains and brewers' yeast have a sustainable outlet as protein, fibre and vitamin-rich animal feed is integral to the brewing sector's constantly improving environmental performance. They form part of the circular beer economy – a virtuous circle from grain to glass and back again."*

The Brewers of Europe

Raw materials | **Recovered nutrients** | **Consumer products**

Cereals

Brewers' grains pellets

Brewers' yeast

Beer

GRASS BIO-REFINING

Optimising the nutritional content of grass

With almost a billion tonnes of annual grass production, grass is the number 1 source of protein consumed by farm animals in Europe, representing almost 30% of the total crude protein consumption. It is a well-known fact that this feed material can only be digested by ruminants such as cattle, thanks to their multiple stomachs. The nutritional characteristics of grass (as well as roughage) make its protein and fibres indigestible for monogastric animals, such as pigs and poultry.

Thanks to research and innovation in bio-refining, the cultivation of grasses, together with clovers and alfalfa, a solution is provided to diversify the market outlets, beyond the common main purpose as cattle feed. In the bio-refining process, fresh grass is crushed and pressed into two fractions; press cake and grass juice. From these two outputs, a range of products with different nutritional features are produced, serving different sectors of the bio-economy;

- a fibre fraction used as feed for cattle and from a longer-term perspective refined into prebiotic feed for monogastric animals, but also used for bioenergy or fibre input for i.a. packaging or textiles;
- a protein concentrate that is suitable for use in monogastric feed;
- fructo-oligosaccharides that can be used in feed or cosmetics
- a nutrient-rich 'whey' that can be used in bioenergy or as a fertiliser

The bio-refining of grass represents an optimisation of the nutrient use of a plant that plays a key role in carbon sequestration. In the case of conversion from cereals production to permanent pastures, it estimated that a reduction of 1–2 ton CO_2-eq per hectare is possible, with also a reduction in nitrogen leaching of 30–50 kg per hectare.

Compared to the consumption of grass in its entirety by cattle, the bio-refining process allows for a better digestibility of the protein still remaining in the fibre fraction that is used as cattle feed, allowing for a reduction in nitrogen and phosphorus excretion. The grass protein concentrate that comes out of the bio-refining process is suitable for consumption by monogastric farm animals such as poultry, pigs and fish. Its nutritional profile is estimated to be of similar composition to soybean meal, meaning it could play a role in boosting the EU (protein) feed autonomy. The expectation is that with the full exploitation of the refining process, there is potential to reach up to 5–15% more proteins than present in soy.

More research and development is needed to unlock further potential. This includes both the plant breeding aspects of the best suitable varieties for bio-refining purposes as well as the bio-refining process itself to extract the highest level of proteins from the biomass. Bio-refining is also being investigated for other (residual) plant materials, meaning more examples of new protein sources may emerge in the future.

Although the representation of the feed outlet in bio-refining is not directly comparable with more 'typical' cases where the feed industry absorbs a co-product resulting from a process that is geared towards a consumer product of higher value, these kinds of innovative examples illustrate how the feed industry helps animal production to become a more optimised component of the European circular bio-economy.

Raw materials

Grass

Recovered nutrients

Fibre fraction

Protein concentrate

Nutrient-rich whey

STARCH AND ETHANOL PRODUCTION

High-performance bio-refining serving many sectors

Starch is a high-value product that is used in a wide range of sectors including food, pharmaceuticals, fuel, paper and textile manufacturing. It can be produced using wet and dry milling processes. Milling separates starch, fibres and proteins from cereals such as maize, wheat, barley and rye, as well as starch potatoes which are specially grown for the purpose. Different feed co-products are produced at different steps of the milling process. Wet milling separates and purifies the main components of the grain, namely protein, starch, fibre, solubles and oil (depending on the type of cereal). Wet milling of maize generates several valuable feed co-products: maize gluten feed; maize gluten meal; and maize germ meal. **Maize gluten feed**, which usually has **maize germ meal** blended into it, is a medium-protein, medium-energy feed material. It is widely used as an ingredient in ruminant diets because of its relatively high levels of digestible fibre. **Maize gluten meal** contains 60–75% crude protein. Although lower in the essential amino acid lysine compared with soya, it is rich in another essential amino acid, methionine.

Wheat gluten feed, wheat gluten meal, wheat germ meal and wheat gluten are obtained from the wet and dry milling of wheat. **Wheat gluten feed** is composed of bran and gluten, and may have wheat germ added to it. It is a fibre-rich ingredient that contains nutritious protein and starch that is used in feed for ruminants, pigs and poultry. **Wheat gluten meal** is a wheat protein concentrate with high protein digestibility (containing 75–80% crude protein).

Wheat germ meal consists mainly of wheat germ, together with some bran and 'middlings' or 'shorts'. It contains at least 25% protein and 9% fat. It is rich in digestible protein and contains vegetable oil, along with essential fatty acids. Wheat germ meal is an excellent source of vitamin B1 and vitamin E. **Wheat protein** contains even more protein (80%) and is used in aquafeed or in hydrolysed form in calf milk replacers. During the processing of starch potatoes, potato protein and potato pulp are obtained. **Potato protein** is a high-quality and highly digestible protein source, rich in the essential amino acids lysine, methionine and cyst(e)ine, and particularly suitable for piglet diets. Dried **potato pulp** provides a digestible fibre source for ruminant and monogastric animals.

Ethanol is best known as an ingredient in spirits, such as vodka, but is increasingly also used as a biofuel. Distiller's grains are the 'spent grains' that are left over following the fermentation process that is used to distil ethanol from cereals. They are a highly valued feed co-product that is rich in protein, fibre, fat and soluble sugars, and are traded globally as **dried distillers grains (DDGs)**. DDGs are mostly produced from maize, but can also be obtained from wheat, barley, rye, or a combination of all three, sometimes depending on cereal prices. The nutritional characteristics and quality of DDGs varies depending on the production process and the grain used, but they are generally suitable for all types of farm animals. DDGs are a good source of phosphorus, zinc and potassium, and their fibre component is beneficial in reducing ruminal acidosis in high-grain rations.

Raw materials

Maize

Wheat

Potatoes

Recovered nutrients

Wheat protein

Potato protein

Dried distillers grains

Maize gluten feed pellets

Consumer products

Starch

Ethanol

INDUSTRIAL FERMENTATION BIOMASS

The circular story of micro-organisms

Industrial fermentation uses micro-organisms such as bacteria, yeasts and fungi to create an increasingly wide range of substances. Examples include amino acids, vitamins, carotenoids, flavourings, enzymes, organic acids and alcohols. Producers of detergents, cosmetics, pharmaceuticals and bioethanol depend on industrial fermentation, with some outputs also destined for food manufacturing.

The elements of interest for the animal feed industry result from the metabolic activity of the micro-organisms. These are grown under carefully controlled conditions, either in liquid or solid-state bioreactors, and fed with a source of carbohydrate and nitrogen, such as sugar or molasses. The primarily products are either excreted by the micro-organisms into their surrounding medium (from where they are isolated and concentrated) or produced inside them and extracted from their cells. Both the **spent medium** and the **microbial biomass** that remain at the end of the separation process have considerable value as feed. These biological processes save significant amounts of resources and energy compared with chemically-based processes, as well as delivering both the desired end products and accompanying co-products under highly sustainable and circular conditions.

The efficacy of industrial fermentation is also inspiring a growing sector that focuses primarily on generating **microbial biomass** from various microorganisms and renewable carbon sources, without the objective of producing specific metabolites. The output from this process and the co-products produced are both known as **single cell proteins** (SCP). They consist of crude or refined protein that is derived from the cells of microorganisms such as yeast, fungi, algae, and bacteria, which are grown on various carbon sources for synthesis. SCP contains over 40% crude protein and is also rich in lipids and vitamins.

Fermentation biomass is one of the richest sources of proteins and amino acids, both in terms of content (approximately 75% protein) and amino acid profile (well-balanced without amino acid profile gaps). It is particularly suited to aquaculture or poultry feeding, as it does not have digestibility limitations, anti-nutritional factors, or a limiting amino acid profile. Different forms of fermentation produce specific co-products, each with potential for future development.

What are essential amino acids?

There are 20 amino acids. Depending on species, about 10 can be synthesised de novo through an animal's metabolic pathway and the rest of them must be acquired through feed and are known as 'essential amino acids' (lysine, threonine, tryptophan, methionine, leucine, isoleucine, histidine, valine, arginine and phenylalanine), or 'semi-essential amino acids' (cyst(e)ine and tyrosine, which are synthesised from essential amino acids). The amino acid composition of plant protein sources varies widely, along with their digestibility. Relying solely on crude protein as a source of essential amino acids results in significant spoilage. Instead, industrial compound feed production uses supplementation to achieve the desired amino acid profile through feed additives in the compound feed.

Raw materials

Micro-organisms grown in industrial fermenter

Recovered nutrients

Microbial biomass granules

Consumer products

Food and feed additives

OILSEED CRUSHING AND VEGETABLE OIL REFINING

The main source of vegetable protein

The oils extracted from soybeans, rapeseed, sunflower seeds and linseed are high-value food ingredients, and are also significantly used in the production of biodiesel. The meal that results from oil extraction contains a high concentration of protein. Oilseed meals represent the most important source of proteinaceous feed materials for food-producing farm animals. Traditionally, oil was obtained by mechanically crushing seeds (a process called 'expelling'), resulting in cakes. Today, crushing followed by solvent extraction has become the most common method as it yields a higher proportion of oil compared with protein meal separation. Toasting is used to reduce the presence of any anti-nutritional factors that could have a negative impact on the digestibility of the protein meals, while also minimising the risk of biological contamination.

The oil from soybeans, rapeseed, sunflower seeds and linseed is the product with the highest economic value, but it can be argued that the protein content of soybeans has become a key driver for cultivating them. As a result of market factors, soybean meal has become the principal source of protein for the feed industry worldwide, setting the benchmark for all other vegetable protein sources. In a context of driving the circular economy, it is therefore hard to argue that the feed industry is recovering nutrients through its demand for soybean meal. Although use of sustainably produced soybean meal will always remain a part of industrial compound feed manufacturing, it must be acknowledged that an increased use of circular feed in principle will also help to reduce the of at least imported soybean meal.

Rapeseed meal is the most common alternative to soybean meal, as well as the most important EU-grown vegetable protein source. With a higher fibre content and lower amino acid availability than soya, rapeseed meal is more suitable in ruminant feeds than in monogastrics or fish, which is also the case for sunflower meal.

The use of **sunflower and linseed cakes** in feed for ruminants has a long history, dating back to the seventeenth century. One of their beneficial traits is the absence of intrinsic anti-nutritional factors, meaning that they do not need further specific treatment for feed use. Sunflower cake has high levels of the amino acid methionine, making it a very useful feed material for egg-laying birds. Innovation in processing technology has made it possible to develop sunflower meal with higher protein concentrations, allowing for direct replacement of soybean meal in feed formulation.

Raw materials

Rapeseed

Sunflower seeds

Recovered nutrients

Rapeseed meal

Sunflower oil cake pellets

Consumer products

Vegetable oil

Biodiesel

GELATINE PRODUCTION

Unlimited possibilities from a few ingredients

The history of gelatine dates back thousands of years, with gelatine-like mixtures produced in Egypt during Pharaonic times. Written records show that fish and fruit specialities prepared with gelatine were considered to be delicacies and served at feasts. Gelatine is indispensable in modern cuisine, as well as in the cosmetic and pharmaceutical industries.

Edible gelatine is produced from raw materials that originate from healthy animals which have been slaughtered in a slaughterhouse, and whose carcases have been found fit for human consumption following ante-mortem and post-mortem inspections. The co-products from edible gelatine production include highly valued feed ingredients. These can be safely used in feed for both food-producing[1] and non-food-producing animals, and are in full compliance with Animal By-Products Regulations (EC) No 1069/2009 and 142/2011.

Dicalcium phosphate dihydrate is a valuable source of calcium and phosphorus for food-producing farm animals that is obtained from the gelatine manufacturing process. Crushed bones are degreased and demineralised using diluted hydrochloric acid before the calcium phosphate is precipitated. The end product is suitable for use in feedstuffs for pets, poultry, pigs and aquafeed. Scientific studies have shown that the use of processed bone phosphates as a source of phosphorous in poultry diets contributes to sustainable animal husbandry, as it reduces reliance on limited rock phosphates and minimises the excretion of phosphate into the environment due to its superior digestibility.

The edible gelatine manufacturing process also generates large amounts of **animal fats**. Fat is an essential nutrient in livestock diets and, like other nutrients such as protein, fibre, starch and sugar, is important to ensure optimum performance. It also makes feed more palatable and represents a high-value energy source. **Gelatine process derived proteins** are dried animal proteins which result from the production of edible gelatine obtained from raw materials according to Regulation (EC) No 853/2004. Gelatine process derived proteins are a source of highly digestible amino acids including lysine, valine, arginine and leucine suitable for animal diets.

> *"The gelatine manufacturing process does not only create a valuable food ingredient. By maximising the value of by-products, it also supplies the feed industry with high value protein products, greases and minerals. As such, gelatine manufacturing has a positive impact on overall environmental sustainability, and supports the circular economy."*

GME
GELATINE MANUFACTURERS OF EUROPE

1 Subject to certain restrictions laid down in Regulation (EC) No 999/2001

Raw materials	Recovered nutrients		Consumer products

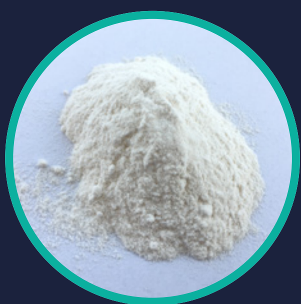

Hides and skins


Animal fat


Gelatine process derived proteins


Gelatine


Bones


Dicalcium phosphate


Collagen hydrolysate (collagen peptide)

DAIRY PROCESSING

No need to cry – no milk is spilled!

Most people know that cheese is produced from milk, but fewer are aware that following the coagulation process induced by the added rennet or the lowering of the pH value a liquid co-product called **whey** remains. Depending on the method used and which animals the milk has come from, different types of whey are produced, including sweet whey and acid whey. Whey products contain little or no fat, which is used in the cheese, and instead have a concentration of lactose, protein and minerals. Processing of liquid whey leads to the creation of different products, both for use in human food (such as food supplements and sports drinks) and animal feed. The latter include whey powder, whey protein concentrate, fat-filled whey and whey permeate, which typically have variable lactose to protein ratios. **Whey powder** is a logistically handy solution given the size and growth of the cheese industry.

Whey-derived products are most commonly used as a milk replacer feed material for infant ruminants such as calves and lambs. They are highly palatable and digestible dairy-based feed components that stimulate appetite and feed intake, while promoting gut health and animal performance. Whey has an excellent amino acid profile and is relatively rich in calcium, phosphorus, sodium, potassium and chloride. It contains no anti-nutrients.

Skimmed milk, usually in powder form, is also a well-known milk replacer feed material for infant ruminants, although its use has decreased steadily in Europe over the past decade because of its role in human food products. Skimmed milk is milk from which most of the fat has been removed for butter production and contains very little fat, although all the protein remains. This has a high biological value and is very digestible. Skimmed milk is a good source of water-soluble vitamins, although most of the fat-soluble vitamins (A and D) are removed with the fat. In recent years **skimmed milk powder** has gradually been replaced by alternative vegetable feed materials, while the amount of milk replacers fed to young ruminants, such as veal calves, has increasingly been replaced with concentrated feed and roughage.

The evolution of animal nutrition science

The early days of animal nutrition science focused on individual elements such as crude proteins, crude fats, crude fibre and minerals. Nowadays feed formulations are based on factors including the proportion of digestible amino acids, the bioavailability of minerals, and the net energy released. The science continues to evolve, and research into the interactions between nutritional constituents of different feed ingredients continues to be studied, along with other factors such as the neutralisation of anti-nutritional factors and the effect of certain micro-ingredients.

Raw materials

Milk

Recovered nutrients

Whey

Skimmed milk powder

Consumer products

Cheese

Butter

MEAT PRODUCTION/ANIMAL BY-PRODUCTS

Creating valuable ingredients for the feed industry

As well as providing meat, animals are a source of high value co-products such as leather and gelatine. A wide range of animal by-products that are not destined for human use can also be processed animal by-products not destined to human consumption. The animal rendering industry processes a range of by-products into useful materials for the feed industry. The resulting feed materials are all made from animal materials that are classified as 'fit for human consumption at the point of slaughter' (referred to as 'category 3 animal by-products' in the EU context) and are processed in accordance with the requirements of the Animal By-Products Regulations (EC) No 1069/2009 and 142/2011.

Rendering uses heat and pressure to sterilise and stabilise animal materials, making them suitable for storage and reprocessing. The two main products of rendering are animal fat and processed animal protein (PAP). Several other niche products that are used in the feed industry are also derived from animal by-products. The use of these feed ingredients, including restrictions for certain species, is also defined by Regulation (EC) No 999/2001.

Rendered products are particularly beneficial to feed producers for a number of reasons. Firstly, they are a source of highly digestible nutrients like proteins, fat and minerals. Moreover, European legislation is the most rigorous in the world, so feed ingredients are consistently high-quality and safe. Feed producers can also rely on a consistent supply of ingredients produced within Europe.

There are environmental benefits too: these materials have a low carbon footprint because most of the environmental impact is attributed to the main product (meat and dairy), not the animal by-product.

Processed animal protein (PAP) from non-ruminant livestock has been approved for use in aquaculture since 2013, and is particularly suitable for inclusion in the feed of carnivorous fish such as salmon. PAP contains essential amino acids, including lysine and methionine, as well as fats and minerals such as calcium and phosphorous. It is also highly palatable and digestible for fish, and has no anti-nutritive constituents. In 2021 the EU passed the reauthorisation of porcine PAP in poultry feed, of avian PAP in pig feed and of porcine & avian PAP in insect feed.

Animal fat is an important ingredient for the feed and pet food industry. It is the most commonly used type of fat in the feed industry and has both nutritional benefits and physical properties that are important for feed producers. Animal fat is suitable for use in feed for all types of animals. Tallow is the only hard fat produced in Europe. Liquid poultry oil, which is another important animal by-product, resembles the linolenic content of rapeseed oil.

Spray-dried blood plasma is an important ingredient in the diet of young animals, especially piglets that are weaning. The immunoglobins it contains support the piglets' developing immune systems, strengthening health performance and improving feed conversion ratios.

Raw materials | **Recovered nutrients** | **Consumer products**


Carcasses


Processed animal protein


Animal fat


Meat


Spray-dried blood plasma

FOOD MANUFACTURING

The feed formerly known as foodstuffs

During the production of foodstuffs such as bread, biscuits, chocolates, breakfast cereals, crisps and pasta, some of the output typically fails to meet the manufacturer's required standards and becomes a 'former foodstuff', destined for use in animal feed. Food can fail to meet the appropriate standards through production errors that lead to items being broken or incorrectly shaped, coloured, flavoured or labelled. Surpluses of unsaleable goods can also occur following seasonal events such as Christmas or Easter, or after a product line is discontinued. Former foodstuffs can also result from the challenges of daily delivery of certain foods.

When **former foodstuffs** cease to be saleable for human consumption, and after the manufacturer or retailer has considered donating them to charity (for instance to a food bank), any remaining stock is typically still suitable and safe for animal feed production. Different foodstuffs can be collected and converted into an energy-rich feed which can take the place of ingredients that are normally selected for their energy value (such as wheat, barley or maize).

Some former food products like chocolates, crisps and croissants have an oil content that means they may even be considered as 'fat-fortified' compared with cereal grains, offering further nutritional value. Because former foodstuffs have also typically undergone heat processing, the starch and other nutrients are more digestible. In addition, well-preserved former foodstuffs are not troubled by mycotoxins. Former foodstuffs represent a very broad category of feed materials, although as they are destined for food-producing animals they must not contain any meat or fish. It is also important to point out that as they are sourced from food manufacturers and retailers, they are not the same as catering waste.

Processed former foodstuffs are used in feed for all species of farm animals, but they are most frequently destined for pig feed. Some people may have concerns about feeding chocolate to farm animals, but fortunately they metabolise theobromine (a compound that can be fatal to dogs) in the same way as humans. In fact, like humans, farm animals find the sweet content that former foodstuffs typically are made up of very tasty.

> *"Former foodstuffs resulting from food manufacturing can be processed into a high-quality feed that fits perfectly into a balanced diet for healthy animals. Food producers therefore have a consistent and sustainable outlet for any foodstuffs that are no longer suitable for human consumption, and can thereby reduce food wastage"*

FOODDRINK EUROPE

Raw materials | **Recovered nutrients** | **Consumer products**

Food manufacturing

Processed former foodstuffs

Chocolate bars

Biscuits

OTHER RECOVERED NUTRIENTS

Grape seeds and pulp

Co-product of the pressing of grapes for making wine or grape juice. A source of polyunsaturated fatty acids and beneficial antioxidants.

Cotton seed meal

Co-product of oil extraction from cotton seeds. Cotton seed meal is a good source of protein, however lower amino acid availability and presence of anti-nutrient gossypol.

Glycerine

Co-product from the production of fatty acids and esterification. An energy-rich feed material that is particularly suitable for dairy cows.

Palm kernel meal

Co-product of the palm kernel oil extraction process. A high-fibre medium-grade protein feed, most suited to ruminants.

Olive oil cake

Co-product from olive oil extraction. After being defatted and destoned, frequently used as pig feed in areas local to where olive oil is produced.

Groundnut meal

Co-product from peanut oil extraction. Has a high protein and oil content.

Feed beer

Beer that is not destined for human consumption.

Broken eggs

Broken eggs from hatcheries and egg packing stations are typically used to produce egg powder.

OTHER RECOVERED NUTRIENTS

Fish trimmings

These include the food-grade parts left over after fish has been filleted, along with the frames (heads and backbones) and the viscera. Collectively, they make up about 54% of the fish meal used in Europe (2016, IFFO).

Linseed meal

Co-product from linseed oil extraction. The meal is protein-rich and contains omega 3 fatty acids.

Apple pomace

The solid residue that remains after milling and pressing of apples for cider, apple juice or puree production

Malt residuals/culms

Co-product from the malting industry. Provides a good source of protein, energy and fibre.

Wheat middlings

Made up of the elements of the wheat milling process that are not flour (screenings, bran, germ, flour remnants). Richer in digestible fibre and protein than flour itself.

Copra meal

Co-product from coconut oil production. Rich in fibre with mid-range protein levels.

Oat hulls

Co-product of oat rice or oat flake production. Very high fibre content, low in protein and energy. Widely used in the diet of some ruminants.

Hydrolysed feather meal

A protein-rich co-product from poultry processing operations (broiler, turkey and other). For food-producing animals in the EU only allowed in aquafeed.

OUTLOOK ON CIRCULAR FEED VISION

The key question to answer is whether there is scope for increased use of circular feed criteria going forward, given the assumption that this would represent a step towards more sustainable feed and livestock production. In principle, European compound feed manufacturers already make use of all safe nutrients that are available to them, while economically viable. To reach the next level, FEFAC believes the time is right to map the potential additional resources resulting from emerging circular economy practices and innovation and evaluate the drivers and obstacles to their access to the feed outlet, including those of a regulatory nature. This suggests also considering whether the EU regulatory framework applicable to feed production could be amended in a way that could make additional circular feed available, when considered safe. Bearing the Farm to Fork Strategy ambitions in mind, we hope we can count on EU legislators to facilitate a dialogue on this topic and perhaps also take responsibility for setting a feasible roadmap and to establish corresponding mandates to EFSA as a priority. FEFAC would also be willing to cooperate with assessing the quantitative potential of circular feed, taking into account the innovative examples mentioned in this publication, which often already benefit from publicly funded research.

It can be assumed that certain legislative baselines are here to stay. The safety requirements set by the General Food Law with its articles on operator's responsibility and traceability should not be touched, but beyond that there may be opportunities to revisit certain legal articles and re-assess the basis for their restrictions. There may be cases where these regulatory restrictions are no longer justified by safety considerations, considering that a number of them were established at a time when technology, traceability and control capabilities were not at the level of efficiency they have reached now.

One example is the Annex III of EU Regulation 767/2009 on the Marketing of Feed which provides a list of *materials whose placing on the market or use for animal nutritional purposes is restricted or prohibited*. These restrictions have their justifiable origin in terms of direct feeding to farm animals, however, circular economy thinking begs the question of whether the outright exclusion of any feed chain use is strictly necessary. Technological innovation and developments are showing that intra-organism upcycling of what currently could be considered 'waste' holds the potential to produce safe, clean and valuable nutrients with a purpose in animal nutrition. A sustainable food systems approach takes into account the potential for optimised circularity and takes inspiration from non-food production with recognised 'end of waste criteria'.

In that regard, the EU feed ban on certain processed animal proteins (PAPs) for certain species also has its repercussions in terms of the possible outlets of certain animal by-products, catering waste as well as former foodstuffs containing meat and fish. The reauthorisation in 2021 of porcine PAPs in poultry feed, of avian PAPs in pig feed and of porcine & avian PAPs in insect feed, was a first step towards the re-introduction of these highly nutritive resources for animal feeding. However, there is still a massive amount of Category 3 Animal By-Products that cannot yet enter the feed chain, including meat-containing former foodstuffs. Involvement in the upcycling chain of organisms of lower trophic level such as insects, micro-organisms or algae could however provide an additional perspective, where the safety of the origin of the substrate used to grow these organisms is assessed on a case-by-case basis for the relevant animal species.

Insect farming

Insect farming is a good existing example of a "nutrient upcycling" sector, with currently already converting inputs of lower value into high value outputs in feed for all farm animal species.[1] Currently in the EU, the substrates on which insects are fed can only be of materials of vegetal origin and other products of animal origin which are also authorised for other farmed animals. The European insect sector can maximise its contribution to enhancing circularity in food production and unlock its full potential if the spectrum of inputs authorised in the rearing of insects is diversified. In turn, this would allow for indirect access of the European livestock and aquaculture sector to a large range of valuable biomass, as the bio-conversion properties of insects can upcycle these materials into suitable feed materials. With insects acting as an intermediate organism in the value chain, this would also allow for compliance with the intra-species cycling ban.

Credit: Entogourmet

FEFAC would recommend a step-wise approach in the identification process of eligible substrates, where former foodstuffs containing (cooked) meat and fish could be a good start, provided that the intrinsic safety of the material is confirmed by EFSA and that conditions for safe production and use as feed are defined by the legislator. The production of insect-based animal feed in this way would still be a stellar example of circular feed, as the intra-organism upcycling allows for the nutrient recovery of nutrient-rich biomass that would otherwise have been lost from the food chain, while the frass resulting from insect farming can also be used as a bio-fertiliser.

For more information see **www.ipiff.org**

1 Processed animal proteins (except hydrolysed proteins) are not authorised as feed for ruminants

Algae production

Algae production represents a comparatively new branch of aquaculture, with a variety of bio-economy applications including feed. As plants, algae have a fairly unique capacity to absorb and convert 'waste-based streams' into biomass of high nutritional value, without the need for the use of arable land. There are numerous research projects that are investigating the potential of using wastes such as anaerobic digestate, livestock manure or municipal and industrial waste, as a substrate for the production of algal biomass with a use in animal feed. The use of manure in these kinds of processes can in addition help with improving circularity at livestock farm level, as the nutrients lost at feed digestion stage would in fact be recovered through feed again. In a sustainable food system, the regulatory classification of for example manure should therefore not result in the exclusion of potential use in the feed supply chain. Here again it is not the case to widely open the door to any given project, but to authorise on a case-by-case, controlled, traced and safe projects.

For more information see **www.what-are-algae.com**

Phosphate minerals

Current use of phosphate minerals used in animal feeds comes primarily from rock phosphate mines, located in for example Morocco or Russia. Innovation in recycling, driven by phosphorus recovery obligations in some countries, today enables recovery of phosphorus from sewage sludge incineration ash. The current EU regulatory framework does not allow for phosphates processed from such recovery to be used in animal feeds. If the incineration process ensures sanitary safety and if the incineration and phosphorus recovery processes are placed under supervision of control authorities, EFSA and the EU legislators should clarify conditions for safely and legally allowing use of such recovered phosphates in animal feed production.

For more information see **www.phosphorusplatform.eu/regulatory** and **www.easymining.se**

Single cell proteins

Single cell proteins are often mentioned as a promising protein of the future. Research is investigating a wide-variety of substrates that single cell proteins such as bacteria and yeasts could be grown on. These substrates are in general all waste-based resources of substances that have no direct purpose in animal nutrition. The examples range from gases such as CO, CO_2, ammonia and methane to waste-based streams such as manure. Legislators should anticipate the potential use of single cell proteins in animal feed, as this could also provide viable solutions to emissions-related challenges in livestock farming.

All 'new' food and feed chain actors, both inside and outside the livestock value chain, carry primary responsibility for the safety of their products. When circular feed concepts are considered to be to the benefit of sustainable food systems, there needs to be buy-in from the downstream part of the value chain. There certainly is a degree of sensitivity connected to the topic of circular feed, where the notion of 'waste use in feed' carries a legacy of reputational damage. For the further transition to more sustainable food systems, with reduced emissions in livestock production, using fewer natural resources and increased EU feed autonomy in the context of feeding a growing global population, it is essential that resources are committed to addressing and improving market and consumer acceptance in full transparency. Food actors should be mindful of imposing production specifications on the feed sector that inhibit the optimisation of circularity in feed production. There is also a role for the animal breeding sector, which can facilitate the creation of robust breeds that are more adapted to digest recovered nutrients.

Increasingly, there are production specifications laid down by upstream value chain partners that could restrict feed producers from optimising circularity in feed formulation. An example of a product specification that is often part of a claim on the animal product labelling, is the demand for plant-based animal feed. In Europe, market development for animal protein produced with plant-based feed has increased following the reapproval of certain processed animal proteins as feedstuffs. As a result, former foodstuffs, where often animal by-products, such as milk, eggs or honey, are constituents, are then also excluded.

At the same time, current providers of circular feed should continue their commitment to make efforts to supply the feed sector with high-quality residual biomass flows. FEFAC has already taken note of an increasing trend amongst food actors towards a bioenergy outlet for their residual biomass flows that could provide a nutritional value and purpose in animal feed. From a bio-economy perspective, FEFAC advocates for a hierarchy for nutrient-rich biomass, where the food chain perspective of nutrient upcycling deserves priority over non-food use. Consideration should also be given to stimulating this hierarchy through incentive-based mechanisms similar to carbon credits.

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Disclaimer

This publication provides an introduction to examples of circular feed -products that FEFAC considers to be the most representative and interesting for industrial compound feed manufacturing. For a more detailed (but not exhaustive) inventory of feed materials used in compound feed manufacturing, see the EU Catalogue of Feed Materials. During the compilation of this brochure, FEFAC consulted in-house experts, as well as those from the industries that supply the circular feed examples described. FEFAC does not guarantee the accuracy of any of the information provided, and in particular information on the nutritional value of the feedstuffs and their manufacturing process, which may differ significantly across plants and may be known under different names. A more detailed description can be found in the Best Available Techniques (BAT) Reference Document in the Food, Drink and Milk Industries. This publication is intended to provide a general overview and introduction to the use and potential of circular feed in compound feed manufacturing and should not be used as the basis for a risk assessment or as a manual for feed formulators.

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