AgriTech

Insects as feed

Alternative proteins – the trend towards meat, dairy and feed substitutes.
Sustainable farming – fueling demand for more sustainable protein production methods.

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THEMATICS

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Insects as Feed

With rising income levels and a multiplying global population, the demand for meat and seafood is likely to increase with 70 percent to 2bn tonnes by 2050 from 1.2bn tonnes currently. The increase in demand, also requires more feed ingredients that are high in protein, such as soybean meal and fish meal but both face sustainability questions that limit their potential for growth. In the search for alternatives, insect meal is the forerunner, given its high quality protein profile.

- Insects as feed could play a crucial role in supporting conventional meat productivity improvements. Insect meal has the same high quality claims and are providing similar functionalities as fish meal – improving animal health and production efficiency. As such insects are considered an exceptional source of protein for pets, farmed and aquacultured animals.
- In order for insect proteins to reach their full potential, legislation is required to include all waste as insect feed. Using waste to rear insects is particularly interesting because it plays into the idea of a “circular food production system” — one in which waste products can be reinvested into the system so that more food and less waste is produced.
- This could also tilt both the environmental and cost balance to the benefit of the insect meal industry. In our base case we expect the industry to measure 1 million tonnes (USD2.5bn) by 2030 and geometric expand to 7.3m tonnes (USD13.1bn) by 2045. Current total fish meal and oil production is about 6m tonnes.

EXECUTIVE SUMMARY

In the next 10 years, the demand for meat and fish is likely to grow by 30% to 1.6bn tonnes per annum from 1.2bn tonnes and in the next 30 years by 70% to 2.0bn tonnes. In part, this is because the world population is growing. In part, it is because there is a growing appetite around the world for animal-based proteins that comes from the increase in income in developing countries. The build up in demand for meat and seafood, also requires more feed ingredients that are high in protein, such as soybean meal, fish meal and fish oil. Both fish meal and soybean meal are environmental friendly protein sources but they do face sustainability questions that limit their potential to feed the growing demand from livestock, poultry and fish farming.

Already today fisheries agencies around the world manage forage fish by adjusting fishing pressure to achieve long term maximum sustainable yield. As a result, the inclusion of fish meal and fish oil in feed recipes has shown a clear downward trend, and has partly been replaced by vegetable substitutes like soybean meal and rape oil. Fish meal and fish oil are limited resources and will increasingly be used as strategic ingredients at lower concentrations and for specific stages in production. The situation is slightly different for soybean meal, which is the largest source of protein for livestock and poultry feed. Although soybean meal is beating all other meals on energy use and climate change impact, the crop comes with significant sustainability concerns given that growth in production area is causing deforestation, especially in Brazil. This environmental pressure together with efforts from the EU and China (the two largest importers of soybeans) to diminish trade reliance, is driving investigation of crops (canola meal, lupin and other pulses, algae, brewer's spent and also insect meal) that can serve as full or partial replacements.

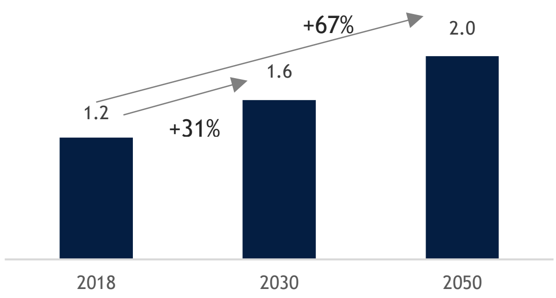
Of the alternatives, insect meal is the forerunner, given its high quality protein profile. Insects are part of the natural diet of both wild pigs and poultry. They constitute up to ten per cent of a bird's natural nutrition, rising to 50 per cent for some birds, such as turkeys. However, fulfilling the insect protein potential for use in animal feed will require legislation to broaden the range of feedstocks, including waste, that can be used to farm insects. Given that insects can be reared on food waste, insect meal could provide a solution for a number of waste streams, including manure, catering waste, unsold products from supermarkets or food industries etc. This could also tilt the environmental and cost balance to the benefit of insect meal (Currently about 10 per cent of the food made available to consumers is lost through waste. Including waste at the level of agriculture production, processing and distribution it is about 1/3 that is lost). Using waste to rear insects is particularly interesting because it plays into the idea of a "circular food production system" — one in which waste products can be reinvested into the system so that more food and less waste is produced (animals only use about 60 per cent of the energy and protein in animal feed, the rest of which they excrete).

In the EU in particular, regulations are changing to the benefit of insect proteins. Since 2017 insect protein has been allowed in the EU for aquafeed where it mostly competes with fish meal. Adoption of insect protein in animal feed is set to accelerate after the EU agreed that from 2022 onwards processed animal proteins (PAPs) and insects are allowed to feed non-ruminant animals including pig, poultry, horses and pets. (The ban on feeding PAPs to ruminants, such as cows and sheep, will continue.)

Currently the insect industry is geared towards providing high quality proteins in pet food and as an alternative for fish meal/oil in aquaculture. However, as prices decline and insect meal becomes more competitive to soybean meal, we expect insect meal to enter into certain segments of the piglets and poultry markets. Using different penetration scenarios we believe that the potential of the insect industry is between 7.3m tonnes (USD13.1bn) and 14.9m tonnes (USD20.9bn) in the next 20 to 30 years. That compares with a current market size of the fish meal & oil industry of 6m tonnes. A demand of 10m tonnes of insect meal would require 650 insect meal production facilities with a capacity of 15,000 tonnes of insect meal (DM) per annum.

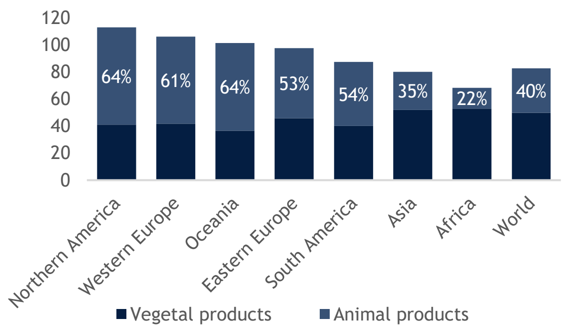
Key 6 graphs

Fig. 1: Global demand for animal food (bn tonnes/year)



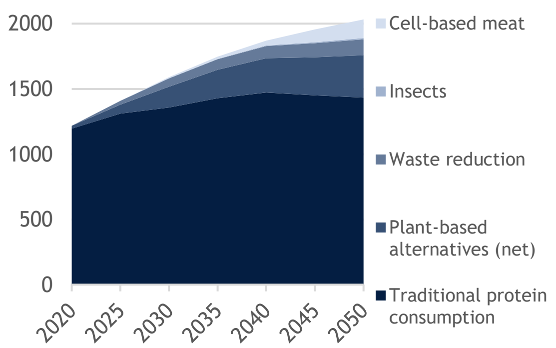
Source: Bryan, Garnier & Cie est

Fig. 2: Sources of protein supply (g/capita/day)



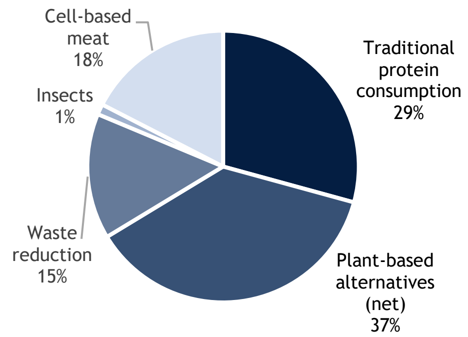
Source: FAOSTAT

Fig. 3: Global protein consumption (billion kg)



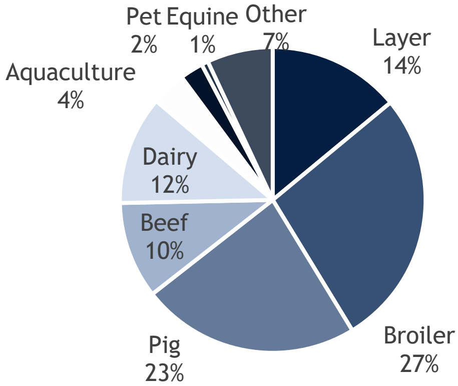
Source: Bryan, Garnier & Cie

Fig. 4: Source for additional protein production (2020 to 2050)



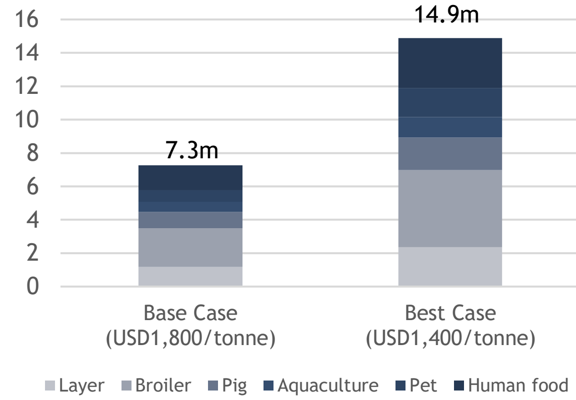
Source: Bryan, Garnier & Cie

Fig. 5: Global compound feed market of 1.1bn tonnes



Source: Alltech

Fig. 6: Potential volumes for the insect industry (m tonnes)



Source: Bryan, Garnier & Cie estimates

Section 01

The growing demand for food, feed and proteins

The growing demand for food, feed and proteins

Animal products including beef, pork, poultry and fish, are recognized as a source of high quality food providing proteins, other nutrients and energy. Farmed animals convert plant and other raw materials into food products for people.

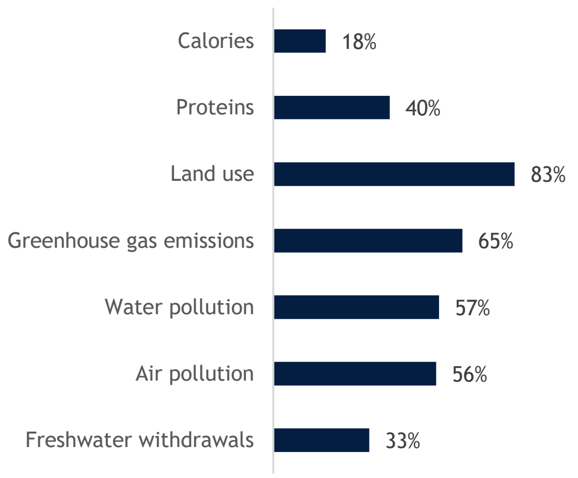
However, livestock farming has a significant environmental impact and could pose a hurdle to provide for the growing demand for food and proteins. There are three big environmental issues with the production of meat and dairy: 1) land use, 2) feed and water sourcing, and 3) climate change. Meat production demands a disproportional larger part of agricultural land, preventing food production to keep up with demand. And the environmental impact on land and water degradation, biodiversity loss, deforestation, greenhouse gasses, climate change, is slowing down agricultural productivity.

Livestock farming is an inefficient use of land and water and produces the majority of agriculture's greenhouse gas emissions.

Since food, water and land are scarce in many parts of the world, livestock is an inefficient use of resources. Our analysis shows that while globally, meat and dairy provide just 20% of calories and 40% of protein, it uses the vast majority – 75% - of agricultural land. (Approximately 40% of the world land mass is used for agriculture and of that 60% is for livestock and 40% for crops. From the 40% used for crops, 60% is eaten directly by people and another 40% is used for animal feed.)

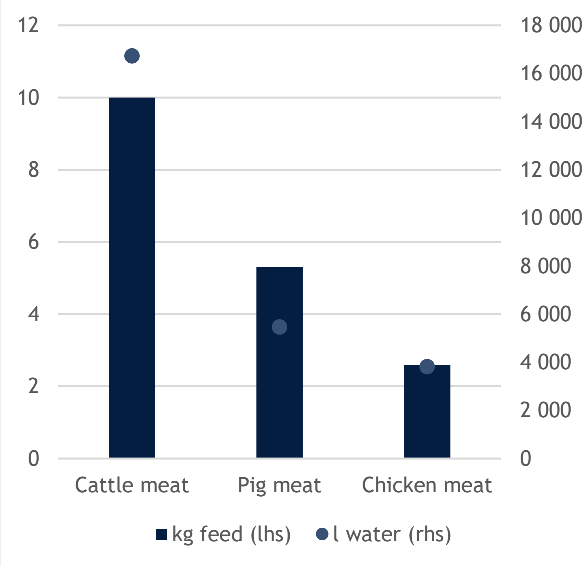
Furthermore, livestock farming produces 65% of agriculture's greenhouse gas emissions mostly (40%) through enteric fermentation (burps) and the rest (25%) through manure. That meat production is highly inefficient for producing food and proteins, is particularly true for red meat. The production of one kilogram of beef requires 10 kilograms of grain – to feed the animal – and roughly 17,000 litres of water. Pork is less intensive and chicken even less. To produce pork meat, 5.3kg of grains and 5,500 litres of water are necessary. For chicken that is 2.6kg and 3,600 litres. Indeed beef stands out for its unproductive water use, producing one of the lowest calories (172kcal) and proteins (16g) for a cubic meter of water. And pork is the second lowest on calories (261kcal) and third lowest on proteins (38) per cubic meter of water. By contrast vegetal crops are more productive. Especially the potato stands out for its productive water use, yielding more food per unit of water than any other major crop. For every cubic meter of water applied in cultivation, the potato produces 5,811 calories (kcal) of dietary energy, compared to 3,569 in maize, 2,381 in wheat and just 1,772 in rice. For the same cubic meter, the potato yields 158 g of protein, double that of wheat and maize, and five times that of rice.

Fig. 7: Contribution of farmed animal products



Source: Bryan, Garnier & Cie, Poore and Nemecek

Fig. 8: Feed (kg, lhs) and water input (litres, rhs) to produce one kilogram of different animal products



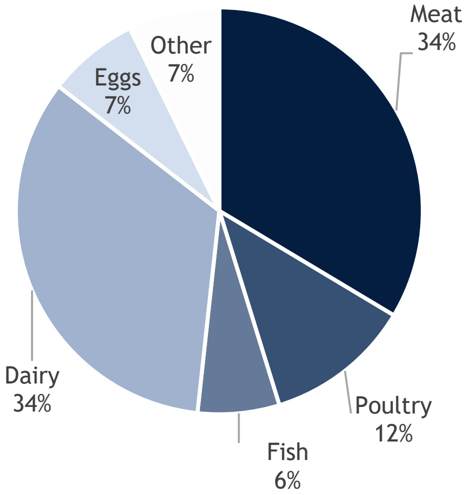
Source: Bryan, Garnier & Cie

Demand for protein is likely to increase by about 30% in the next 10 years and 70% in the next 30 years

We calculate that in the next ten years (by 2030), demand for animal proteins will increase by 30% and in the next 30 years (by 2050) by 70% driven by:

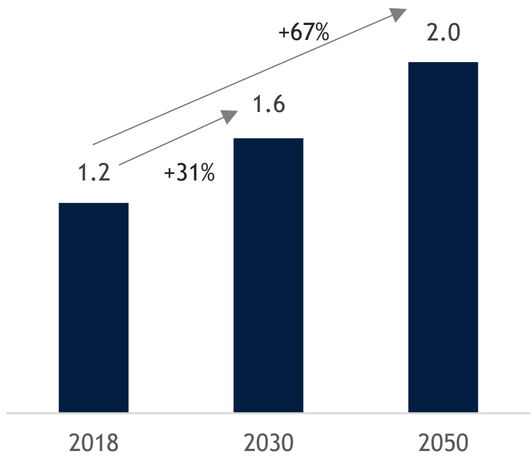
- Population growth: according to the most recent estimate by the World Bank, there are 7.8 billion people - and that might reach 9.7 billion by 2050 (+25%).
- Rising income in developing countries and adaption of the "western" animal protein rich diet: According to the latest data from FAOSTAT, the average 2018 world food supply measured 2,927 kcal/capita/day. Estimates for 2050 range from 3,100 to 3,250 (averaging a 10% increase). And the expected share of animal-based products will rise to 22% in 2050 (from 18% in 2020). Kcal derived from animals would increase to 702 by 2050 from 525 in 2018 (+34%).
- Increased demand for sustainable, organic grown food are putting additional pressures on global natural resources.

Fig. 9: Composition of animal food (kcal/capita/day)



Source: FAOSTAT

Fig. 10: Global demand for animal food (bn tonnes/year)



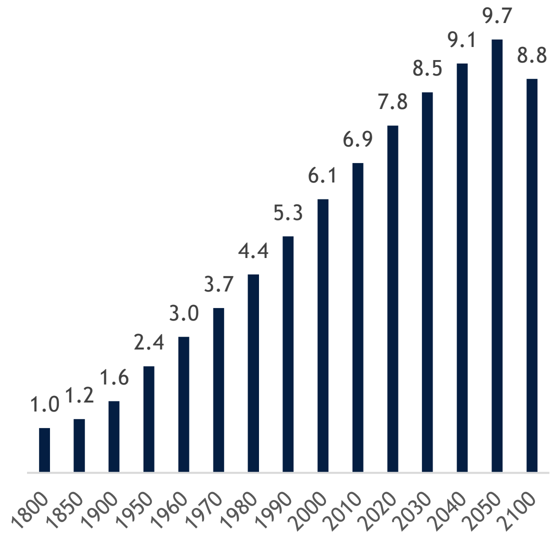
Source: Bryan, Garnier & Cie est

The increase in demand for meat and seafood, also requires more feed ingredients that are high in protein, such as soybean meal, fish meal and fish oil. However, given the finite land resources, allocating land to grow soy for animal feed instead of food, cannot continue at the same rate. Whilst the expansion of pasture for beef production is the leading driver of deforestation in Brazil, soy still plays a significant role taking into account its indirect impacts (i.e. croplands replacing pasture). More than three-quarters (77%) of global soy (350mt) is fed to livestock for meat and dairy production. Most of the rest is used for biofuels, industry or vegetable oils. Just 7% of soy is used directly for human food products such as tofu, soy milk, edamame beans, and tempeh.

Also producing fish meal and fish oil is resource intensive, as about 20% of wild-caught fish is used for feed production. This has led to forage fish such as anchovies and herring being overfished, and some populations have collapsed. Unfortunately, this has implications for the entire food web since larger fish depend on forage fish for food. Yearly world landings of fish, shellfish and crustaceans are around 90mt. Of this, around 70mt are used as food for human consumption and around 20mt are destined for non-food use. Of the 20mt for non-food use, the FAO states that 15mt are channeled into fish meal (5mt) and fish oil (1.25mt) production (70% of fish meal and 75% of fish oil production is used to feed farmed fish). The rest is largely used for ornamental purposes, fingerlings, bait, pharmaceutical uses, and as raw material for direct feeding in aquaculture.

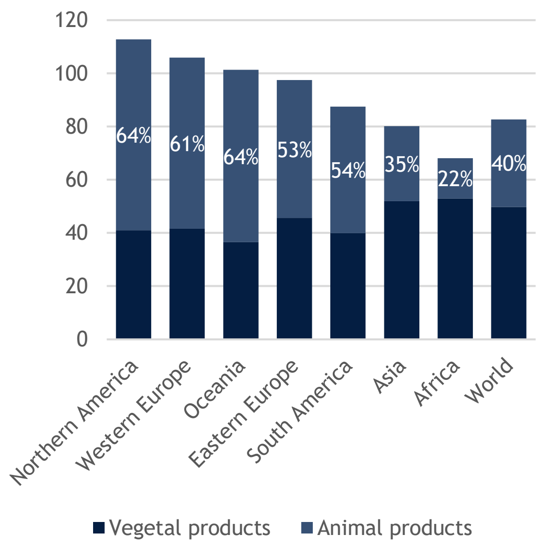
The EU is largely reliant on imported soy for feed. The EU produces 3mt soy beans and imports 33mt of soybean, -meal and -oil. For fish meal and -oil there is not the same imbalance. Each year the EU produces around 575.000t fish meal and 175.000t of fish oil. This constitutes around 15-20%% of the global production and more than EU consumption (450.000t fish meal).

Fig. 11: World population



Source: World Bank, The Lancet

Fig. 12: Sources of protein supply (g/capita/day)



Source: FAOSTAT

Protein demand from a growing global population

Although on average 40% of world protein supply is from animal products, the numbers vary greatly by region in function of the average living standards. In North America, Western Europe and Australia, over 60% of protein supply comes from animal products compared to only 35% in Asia and 22% in Africa. As income increases the amount of animal-based products in diets tend to go up. Hence, the expectation is that by 2050, the share of animal-based products in the total food supply will rise to 22.1% (from 17.9% in 2018) and that the kcal derived from animals would increase to 702 by 2050 from 525 in 2018 (+34%). Combining these findings with the expected evolution of the global population, should, over the next 30 years, lead to a 70% increase in demand for animal products. That in turn should not only increase demand for pasture but also demand for animal feed grown on arable land (for all grains about 50 to 60% is used in feed – and even 77% of soy). Given the scarcity of agricultural land, it is unlikely that supply will be able to match demand with the current agricultural set-up.

We expect that about 30% of the increased need for proteins over the next 30 years will be supplied for by the existing meat and dairy industry given the significant potential for increased efficiency supported by insects and algae proteins as additives and precision feed

Nevertheless, we estimate that about 30% of the increased need for proteins over the next 30 years will be supplied for by the existing meat and dairy industry. Science and technology are driving productivity gains and we believe here is still a significant potential for increased efficiency by implementing best practices on a global scale (seasonality considerations, supplementation, fertilization of pastures, AI, increasing feed, genetic improvement, precision feeding etc). As a result we expect further upside for production per animal in both developed as in developing countries. In developed countries, production per animal is likely to be supported by increases in genetics allowing for a better feed conversion ratio and the use of by-products. In developing markets there is a significant catch-up to the level of production per animal in developed countries. Currently, meat production per animal in Asia and Africa is about half to where it is in North America (44% for cattle, 61% for poultry, 65% for pigs) and dairy production is only a fraction of developed country levels. In Africa beef meat per animal is 152 kg and in Asia it is 167 kg. That compares with 296 kg in the European Union (up from 162 kg in 1961) and 362 kg in the USA (up from 215 kg in 1961). In Africa dairy production per animal is 190 kg and in Asia it is 840 kg compared to 6,100 kg in the European Union and 10,200 kg in the USA. If global productivity levels would be as high as in the USA, meat production would by 25% higher than it is today and global milk production would be 8x higher! Given global supply chains coupled with the urgency to increase productivity (given growing developing countries demands), we would indeed assume that over the next 30 years productivity improvement would lead to a 20% increase in protein production. Because improvements in FCR through selective breeding, demand for feed will increase less and should be partially matched by increased crop yields but also will need to be supported by insect and algae proteins as additives and precision feed.

Additionally a decline in food waste or use as feed stock (directly or indirectly through insects) could provide 15% of the increased need for proteins

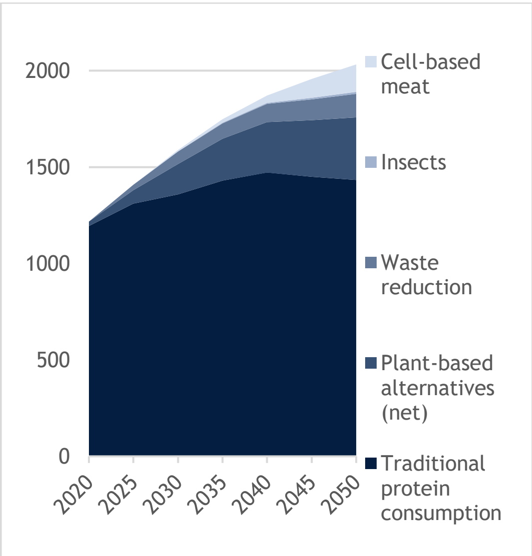
Additionally we expect a decline in food waste and loss or use as feed stock, to provide 15% of the increased need for proteins. Currently almost 20% of the food made available to consumers is lost through over-eating (10%) or waste (9%), a study from scientists at the University of Edinburgh suggests. Furthermore insects are able to use by-products of the food chain as feed and genetic companies are developing animal breeds that will be able to use better that same food waste and loss.

Alternative proteins source could supply the other half of the increased need (we expect 29% from plant-based alternatives 18% from cultured meat and 1% from insects).

After increased productivity in the existing meat and dairy industry (29%) and the use of food waste (15%), the remaining 56% of increased demand for proteins should be provided by alternative protein sources (we expect 29% from plant-based alternatives, 18% from cultured meat and 1% from insects). Indeed, novel technologies and disruptive innovations from plant-based and insect proteins to cultured meat, should be offering an alternative for the traditional products. From those technologies, the plant-based alternative is further advanced and is making big strides to become cost competitive while at the same time being able to improve food sustainability and offer a more healthy alternative to meat. For insects, we expect that consumers are most likely to accept it as an ingredient (e.g. in bars and flour) but their main usage is likely to be in feed (for the conventional meat industry) as an alternative to fish and soy meal.

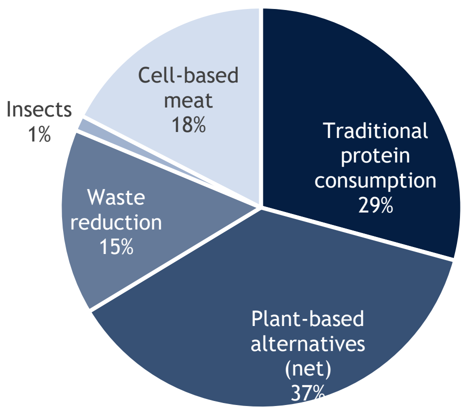
Cultured meat technologies is still facing significant barriers to commercializing: lowering costs and improving taste. Careful attention to texture and judicious supplementing with other ingredients could address taste concerns. And in order to accomplish cost-competitiveness, innovation is needed in four critical areas: cell line development, cell culture media, bioreactors and bioprocessing, and scaffold biomaterials. We expect growth in cultured meat to accelerate from 2035 onwards and together with the continued growth in plan-based alternatives, could start denting traditional protein production from 2040 onwards.

Fig. 13: Global protein consumption (billion kg)



Source: Bryan, Garnier & Cie

Fig. 14: Source for additional protein production (2020 to 2050)



Source: Bryan, Garnier & Cie

The 70% increase in demand of proteins for food and the resulting increase in demand for feed, coupled with the accelerating urbanization, climate change and increased biofuel production represent major risks for long-term food security and competition for land use. AgriTech is developing different solutions. One of those is the development of novel feed proteins, including algal, yeast, bacterial-derived and insect-derived proteins. Among them, insect-derived proteins are the most promising as the natural diets of many animals, both farmed and wild, already include insects.

Insect meal to fill the need for more feed

Especially the pet food and the aquafeed markets are currently looking towards insects and microalgea as an alternative protein sources given that availability of fish meal is limited, prices are high and volatile and they want to improve their sustainability claims. But also in the poultry and pig industry, demand for alternative high-quality protein is rising.

Edible insects (and microalgae) for animal feed products are fulfilling the same functionalities as fish meal/oil (high protein ingredients that improve animal health, weight gain and FCR)

Indeed, insects (and microalgae) can have the same high quality claims and are providing similar functionalities as fish meal/oil. They are considered an exceptional source of protein for pets, farmed and aquacultured animals. Similar to fish meal/oil, insect meal improves animal health and production efficiency.

In our scenario, insect proteins could represent 5.8m (3%) to 11.9m (7%) tonnes out of the 170m tonnes global protein market for animal feed.

In our base scenario we expect that over time (20 to 30 years) insect meal could provide 2.5% of protein content of pig feed, 5% of the proteins for aquaculture and chicken feed and 10% in pet food. In that base scenario, the demand for insect meal would be 5.8m tonnes. (our best case scenario is for 11.9m tonnes). That compares with a current market size of the fish meal and oil industry of 6.0m tonnes and which according to different forecasts is expected to rise to 10.5m tonnes in 2025 and 13.9m tonnes by 2030. In our scenario where insect meal is developed as an viable and qualitative equal alternative, we do not expect the fish meal and oil industry to grow much beyond its current size. Indeed, already over the past 25 years fishmeal production has not increased and the inclusion of fish meal in fish feed for marine fish has dropped to 12% from 50% (and has been replaced with soybean protein concentrate). We believe that in future, insect meal could be a high valued protein source replacing fish meal.

And even a low penetration in human food could add another 1.5m to 3.0m tonnes (but at significantly higher prices).

Furthermore there is an additional market for insects in human food. Although there is a significant aversion to eating insects by Western consumers, insects have historically contributed to the diets and cultural practices of humans and is, according to the FAO, consumed by about 2bn people on a regular basis (…but mostly for snacking). The addition of insects as an ingredient (e.g. in snacks/protein bars for athletes or in flour that than can be used for bread, pizza, pasta etc) is likely to contribute to a more wide spread acceptance. In our base case we expect insect proteins to take up 0.5% of protein demand for human food and in our best case 1.0%. That would add 1.5m tonnes and 3.0m tonnes respectively bringing the total market demand for insect proteins in the next 20 to 30 years, to a range of 7.3m tonnes to 14.9m tonnes and USD13.1bn to USD20.9bn. Given the price differential between feed and food proteins we expect that around 35% of the market would be food applications, with feed applications accounting for 65%.

Section 02

Insects as novel feed protein source

Insects as novel feed protein source

Edible insects are regarded as one of the most sustainable animal protein sources. They are in general, rich in protein and contain essential amino acids, fatty acids, vitamins and minerals.

The ability to convert substrates into a high-protein product positions insects as a novel feed ingredient that could displace proportions of soybean and fish meal. Insects can be farmed in a range of locations, climatic conditions and production scales.

Indeed, given the role that insects play in natural ecosystems as biological waste processors and decomposers, means that they can be reared from a vast range of feedstock substrate materials, potentially allowing for better cost advantages and more sustainable label.

On top of that, the natural diets of many animals, both farmed and wild, include insects. If allowed to do so within the production environment, fish, poultry and pigs would consume insects as part of their natural behavior. Edible insects, such as black soldier fly, mealworms, lesser mealworms as larvae, house cricket and the European migratory locust, look well-suited as part of animal feed and also for human consumption. However, whilst, according to the FAO, the consumption of edible insects is common practice for at least two billion people, it is a staple that for western consumers is rather unusual. Adaption in the feed industry seems to be much swifter.

Generally, insects are reared, euthanized humanely and then processed by crushing to separate the protein and oil content, both of which are considered high-value products. This process leaves a concentrated and dry meal containing 56–82% protein, which is similar to fish meal and soybean meal protein content.   Furthermore, as well as containing healthy fats and oils, contain essential amino acids, fatty acids, vitamins and minerals, offering good nutritional content for feed. The amino acid profile and digestibility of meals is also important in feed formulation. Some studies suggest that insect meals could have competitive amino acid profiles to fish meal, including a range of essential or indispensable amino acids, however, composition and digestibility vary by insect species, life stage, feedstock diet and rearing system.

Available evidence suggests that insect-based feeds are comparable with fish meal and soy-based feed formulae in terms of protein and nutritional properties, with the exception of fish oils, which cannot be sourced from insects but are required in aquafeed.

A key by-product from insect biomass production is the insects' excrement, known as frass, which is high in nitrogen and can be applied to soil as a fertiliser, offering an additional income stream and thus contributing towards the commercial viability of insect farming businesses. A second and potentially high value by-product is chitin, found in exoskeleton skin sheddings, and with potential use in pharmaceuticals, textiles industries and agriculture.

Fig. 15: Proximate composition (percentage of dry matter) of insect and reference substrates

	Housefly pupae	Black soldier fly larvae	Black soldier fly pupae	Yellow mealworm	Fish meal	Soybean meal
Crude protein	62.5%	56.1%	52.1%	52.0%	71.0%	51.6%
Fat	19.2%	12.8%	19.7%	33.9%	9.2%	2.5%
Ash	5.6%	12.6%	13.9%	3.9%	19.9%	6.8%
Total indispensable amino acids	41.8%	37.1%	39.3%	42.3%	41.5%	44.4%
Digestibility Organic matter	83.2%	84.3%	68.1%	91.5%	82.1%	80.6%

Source: Protein quality of insects as potential ingredients for dog and cat foods, Bosch et al. in Journal of Nutritional Science

A literature review completed by a study from the WWF, taking into account a range of environmental factors, suggests that the overall environmental impact of insect production is lower than those of the production of soybean and fish meal

Insect farming and processing requires a feedstock substrate and energy, water and land to operate the farming facility. The extent of the environmental impact will therefore depend on the insect species, substrate(s) used, the use of by-products from insect production, and the power and heat source for the insect rearing facility. Impacts can also vary by geography and location of the insect farm. A literature review completed by a study from the WWF, taking into account a range of environmental factors, suggests that the overall environmental impact of insect production is lower than those of the production of soybean and fish meal (Figure 16). While this review included both grey and academic literature, it is important to note that there is limited literature available and further research is required to quantify the environmental impact of different insect production systems and to determine the rearing conditions required for optimal environmental outcomes. The literature suggests that the greatest reductions in impact will be in land use (compared to soy production) and biodiversity (compared to both soy and fish meal production). This is due to the high risk of habitat conversion for soybean production and the reduction of fish stocks for providing fish meal for use in aquaculture.

Fig. 16: Summary of literature on the environmental impact of insect farming relative to soy and fish meal production.

■ high impact; ■ moderate impact; ■ low impact; blank for negligible or unknown impact

ENVIRONMENTAL IMPACT		SOYBEAN MEAL	FISHMEAL	INSECT MEAL
State indicators (i.e. changes to the state of nature)				
Land use change		High conversion risk	No impact	No land use change at scale
Soil condition		Intensive agriculture	No impact	No impact
Climate impact		Conversion	Relatively low emissions from shipping	Operation of facility
Water removed		If irrigated	Low impact	Operation of facility and substrate moisture adaptation
Nitrogen		If NPK applied to soy or to crops in rotation	No impact	Nitrogen accumulation in frass
Biodiversity		Conversion and intensive agriculture	Reduced fish stocks, by-catch	Low ecological impact
Pollution		Pesticide use and eutrophication	Effluent discharge	Limited evidence
Waste		Limited evidence	Limited evidence	By-products chitin and frass have uses
Pressure indicators (i.e. environmental footprint assessments)				
Land use footprint		Large area required	Small area used	Small area used
Carbon footprint	Direct	Cultivation and shipping	Fishing vessels	Heating requirement
	Indirect	Land use change	Low indirect footprint	Substrate dependent
Water footprint		High water use	Limited evidence	Low water use

Source: The future of feed: a WWF roadmap to accelerating insect protein in UK feeds

Product range

Insects have been farmed for various commodities including food (cockroaches), dies (cochineal beetle), silk (silkworm) and honey (honey bees), fish bait (mealworms), lac for nail polish and wood varnish (lac insects), animal testing (fruit flies), plastic breakdown (caterpillar larvae of the greater wax moth together with the microorganisms in its gut), pet food (crickets), etc.

The urgency to find alternative protein sources for feed has resulted in a high market acceptance and market recognition for insects. For fish, poultry and pigs, insects are already natural feed.

But the urgency to find alternative protein sources for feed has resulted in a high market acceptance and market recognition for insects The most common insect products are:

- Insect Meal: Is the highest added-value product for animal feed to supplement or replace non-sustainable sources of proteins thanks to high protein content (>60%), more particularly for aquaculture. Given its high digestibility it is also well suited for pet food.
- Insect Oil: Insect oil is obtained by the process of defatting insect proteins, is highly digestible and provides a sustainable source of energy for many animals.
- Insect Puree: Puree is a hypoallergenic fresh product combining all the macro and micronutrients of insects, particularly well-suited for wet formulation of pet food
- Fertilizer (Frass): Frass is derived from insect droppings, is rich in nitrogen, phosphorus and potassium, necessary for good plant growth. It eliminates the need for chemical fertilizers and provides eligibility to organic farming.

Key players in the global edible insects for animal feed market include Protix, Ynsect, Agronutris, Aspire Food Group, EnviroFlight, LLC, Enterra Feed Corporation, Entomotech S.L., Kreca Ento-Feed BV, DeliBugs, Haocheng Mealworms Inc, Entomo Farm, NextProtein, Beta Hatch, Nutrition Technologies, Hexafly Biotech, Entobel, HiProMine, InnovaFeed, Nusect, Protenga, and Mutatec.

In countries where eating insects is part of the culinary tradition, they are often eaten whole: snacking them, stir frying, grilling on skewers or popping them into soups or stews. Sometimes they are grinded, used as flavoring and sometimes made into powder and mixed with salts and spices. Western countries without this tradition, have also a more processed approach to food. In North America, Canada, and the EU, insects have been processed into non-recognizable forms, such as powders, flour, burgers and minced meat, fitness bars, pasta, crackers, bread, snacks but also beer and milk alternatives.

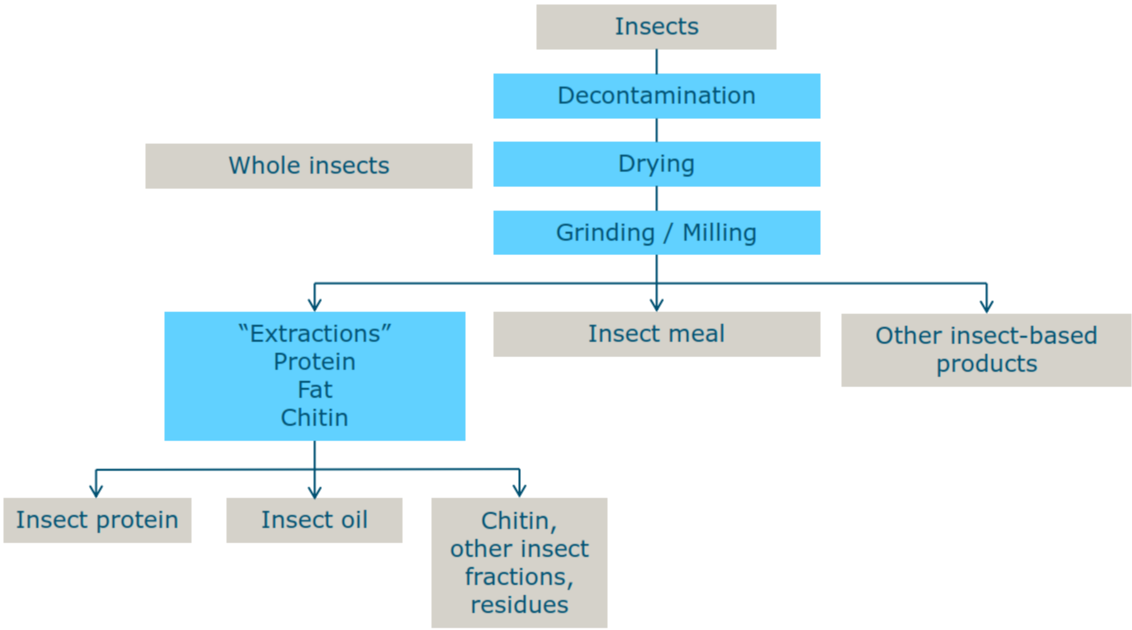
Production process

The production process at an insect farm does not differ from other livestock farms: it rears or buys animals (in this case insects), provides food, water, growing conditions, encourage them to breed, harvest periodically and process them.

The production process at an insect farm does not differ from other livestock farms: it rears or buys animals (in this case insects), provides food, water, growing conditions, encourage them to breed, harvest periodically and process them. Most insect farms are fully integrated and their production platform is mostly automated. The standard processing procedure usually includes:

- Harvesting and cleaning: Insects at different life stages can be collected by sieving followed by water cleaning (i.e. swimming in water for 24 hours) when it is necessary to remove biomass or excretion. Before processing, the insects are sieved and stored alive at 4 °C for about one day without any feed.
- Killing and inactivation: Insects are killed by freezing which also inactivate any enzymes and microbes on the insects.
- Heat-treatment: Sufficient heat treatment is required to kill pathogens so that the product can meet the safety requirement.
- Drying: To prevent spoilage, the products are dried to lower the moisture content and prolong the shelf life. Longer drying time results from a low evaporation rate due to the chitin layer, which prevents the insect from dehydration during their lifetime. In general, insects have a moisture level in the range of 55-65%. A drying process decreasing the moisture content to a level of less than 10% is good for preservation.

Fig. 17: Elaborate insect processing



Source: Wageningen University & Research

Environmental impact

While there are environmental benefits of using insects compared tot chicken, pig or beef in human food, the conclusions for animal feed are more balanced: there does not seem to be a major environmental benefit to prefer insect meal for feed over fish meal or soybean meal. The benefit compared to fish meal is limited to the risk of overfishing and depletion of forage fish, but all other indicators including energy demand, climate change, land and water use are in favor of fish meal. However, given the increased demand for farmed fish and as a result fish meal and oil, there is no other option than to formulate compound fish feed with insect meal.

The benefit compared to soybean meal is mainly at the land use level (depending on the assumptions of feed input for insect farming), while on cumulative energy demand, climate change impact, acidification and eutrophication the benefit is to soybean meal.

However, given that insects can be reared on food waste, providing a potential solution for a number of waste streams, including manure, catering waste, unsold products from supermarkets or food industries etc., could tilt the environmental balance to the benefit of insect meal.

Insect meal as feed

There is no environmental benefit of insect meal over fish meal or soybean meal: the benefit compared to fish meal is limited to the risk of overfishing and depletion of forage fish, and the benefit compared to soybean meal is mainly at the land use level.

There are not that many studies on the environmental impact of insect meal as an alternative for fish meal or soybean meal. Nevertheless the main conclusion seems that there is no environmental benefit to prefer insect meal over fish meal or soybean meal. The benefit compared to fish meal is limited to the risk of overfishing and depletion of forage fish, but all indicators including energy demand, climate change, land and water use are in favor of fish meal. The benefit compared to soybean meal is mainly at the land use level (depending on the assumptions of feed input for insect farming), while on cumulative energy demand, climate change impact, acidification and eutrophication the benefit is to soybean meal.

The main issues to use insect meal as feed are about using waste streams as feed and scaling up of insect production: “Intensifying industrial insect farming with standard and energy-efficient facilities and developing suitable insect-specific substrates to address nutritional composition and environmental aspects will be essential for insect meal as a future protein source supply for aquafeeds.”

One of the earliest insect meal life cycle assessment (Thevenot et al., 2017), based on data provided by the French mealworm producer Ynsect, concluded that per kg of protein, mealworm larvae meal production had a larger impact on the environment than those of soyabean meal and fish meal as sources of protein in livestock and aquaculture feeds. Not only was the impact larger on cumulative energy demand, climate change impact, acidification potential but also for eutrophication potential, and for land use. The conclusion of the authors was that using mealworm meal in animal feed does not currently decrease environmental impacts of livestock. However, the mealworm diet contributed the most to impacts in all the categories. On the pilot farm that was used for the study (of Ynsect), the insect diet contained a mix of flours from raw materials that can be used directly in animal feed. Since the FCR was 1.98x, feeding mealworm meal to poultry or fish would decrease the economic and environmental efficiency of these production systems. Hence, the conclusion that research efforts should focus on identifying alternative sources of feed for insects that have lower environmental impact. However, the quality and composition of the insect diet can strongly influence the nutritional composition of the insect meal. This directly influences ingredient ratios in animal feed formulation and consequently has a positive or negative influence on environmental impacts of animal supply chains. Furthermore, by increasing competition for raw materials (currently biomass is used in animal feed, biogas production or composting) and byproducts (insect manure, oil, and chitin, which could replace manure from other animals and compost, used cooking oil, and chitin from crustaceans, respectively), the emergence of a new insect supply chain might indirectly worsen environmental impacts of other types of agriculture production.

Fig. 18: Comparison of life cycle impact assessment of one kg of protein of mealworm larvae meal, soybean meal, and fish meal delivered in France.

	Mealworm larvae meal (France)	Soybean meal (Brazil)	Fish meal (Peru)
Cumulative energy demand (MJ)	217.37	31.17	25.62
Climate change (kg CO2 eq)	5.77	4.09	1.69
Acidification (g SO2 eq)	39.38	17.61	6.59
Eutrophication (g PO4 eq)	23.03	16.45	2.63
Land use (m2a)	6.35	4.34	0.01

Source: Alexandre Thévenot, Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects in Journal of Cleaner Production, 2018

While being competitive against animal-derived egg protein and microalgae, BSF meal has a higher environmental impact than plant-based meals and also than fish meal and whey concentrate.

A more recent life cycle assessment of food industry side streams transformation via Black Soldier Flies into intermediate products applicable for feed and food purposes (Smetana et al., 2019) indicated that the fresh BSF biomass from a high productivity pilot industrial scale (Protix, Buhler) is almost twice more sustainable than fresh chicken meat. However, while being competitive against animal-derived egg protein and microalgae, BSF meal had a higher environmental impact than plant-based meals but also than fish meal and whey concentrate.

Fig. 19: Environmental impact comparison of main protein sources used for feed and food (per 1 kg of product)

Environmental impact comparison of main protein sources used for feed and food (per 1 kg of product)

	DM %	Protein, %	GWP, kg CO_2 eq.	OD, mg CFC11 eq.	AC, g SO_2 eq.	EU, g N eq.	ED, MJ	FD, m^3	LU, m^2a
Soybean meal	87.5[1]	49.1[1]	0.34-0.72[1] 6.52[19]	0.2-0.3[1,17]	−1.2 – 3.1[1] 11.4[17]	−81-2[1] (g NO_3 eq.)	5.37[6] 25.5[19]	0.04[6]	3.26[6]
Rapeseed cake	89[1]	34.8[1]	0.37-0.57[6]	0.004-0.05[6]	6.8-7.5[6]	8.9-9.1[6]	3.3-3.8[6]	0.001-0.03[6]	1.5-1.6[6]
Pea protein meal	n/a	n/a	0.44[6] 4-10[8] (pulses)	0.057[6]	21.8[6]	7.94[6]	5.25[6]	0.03[6]	2.85[6]
Fishmeal	90[4]	60-72[5]	0.12-0.58[18] 0.65-1.8[14,3,4,13] 0.48-5.6[15,16] 5.37[17]	0.016-0.073[18] 0.83[3] 0.947-1.03[17,4]	0.12-8.7 [14,18] 7.0[13] 15.9-18.0[4.16] 56.7-62.6[19,3]	−16[4] 0.4-0.87 [3.18]	2.13-17.1[18, 4,3] 21[13] 79.8[17] 120[16]	0.0002-0.0016[18] 0.0036[3] 0.347[4]	0.0005-0.0052[1 8,3] 0.6-1.1[14]
HM (this study)	96.6	56	5.3	0.43	21.3	17.9	84.18	0.0028	1.89
HP (this study)	30	17	1.16	0.091	5.3	4.6	17.9	0.0006	0.48
Fresh meat (chicken)	25-30	23-24	1.62-3.12[10]	1.8[10]	44.25[10]	75[10] (g NO_3 eq.)	18.5-65[10]	0.053-0.155[11]	19.5-31.3[11]
Whey concentrate	86-89[3]	60[3,7] 80[11,kp]	7.48[7] 0.8-7.4[6] 12.1[2] 28–43[8,kp] 40.6[11,kp]	0.01-0.06[9] 3.33[7] 3.8[11,kp]	0.05-1.5[6] 56.6[7]	1.14[6] 37.3[2] 3.59-101[9] 229.3[11,kp]	58.1[2] 83.3[7] 10.7-39.4[6]	0.003-0.066[6] 1.45[2] 9.58[7]	0.26-8.27[6]
Egg protein concentrate[9]	85	80	23.4	1.01	4000	139	183	2.65	40.1
Microalgae[9]	96	55	14.7-245.1	0.9-19.8	260.5-1407.5	40.6-105.3	217.1-4181.3	0.3-3.9	1.7-5.4

Sources: [1] – (Dalgaard et al., 2008); [2] – (Kim et al., 2013); [3] – own calculations, [4] – Danish LCA Food Database; [5] – (Hall, 2011); [6] – ecoinvent 3 and Agrifootprint databases; [7] – (Smetana et al., 2016); [8] - (Nijdam et al., 2012); [9] – (Smetana et al., 2017); [10] – (González-García et al., 2014; Weidema et al., 2008); [11] – (Wiedemann et al., 2017); [12] – (Bacenetti et al., 2018); [13] – (Papatryphon et al., 2004); [14] – (Samuel-Fitwi et al., 2013); [15] – (Cashion et al., 2017); [16] – (Smárason et al., 2017); [17] – (Silva et al., 2017); [18] – (Fréon et al., 2017); [kp] – per kg protein. Note: HP – *H. illucens* puree (fresh insect production); HM – *H. illucens* meal (defatted protein concentrate); DM – dry mass, GWP – global warming potential; OD – ozone depletion; AC – acidification; EU – eutrophication; ED – energy demand; FD – freshwater depletion; LU – land use.

Source: Smetana et al., Sustainable use of Hermetia illucens insect biomass for feed and food: attributional and consequential life cycle assessment, 2019 in Resources, Conservation and Recycling

However, the ability to use non-utilized side-streams (i.e. waste) is a key factor which determines the life cycle impact and as a consequence the further development of the insect industry.

Furthermore, one of the main conclusions seems that the ability to use non-utilized side-streams (i.e. waste) is a key factor which would determine the life cycle impact and as a consequence the further development of the insect industry.

The study also concluded that to assure reduced environmental benefits expected from insects, the industry will need to consciously make steps in upscaling insect production (improved efficiency of feed conversion and processing). And also transforming organic residuals into BSF biomass could result in a lower environmental impacts if composting or anaerobic digestion (as a waste treatment technology) is avoided.

A systematic review of research published on the environmental consequences of using insect meal as an ingredient in aquafeeds (Tran et al. 2021) looked at data from various studies to investigate the consequences of insect meal production and insect meal-based diets with respect to their environmental impact, including global warming potential, energy use, land use, water use, acidification, eutrophication as well as to economic fish-in fish-out ratio and solid waste output production. Analysis indicated that insect meals' production exerted positive effects on land use but was associated with greater energy use and a larger carbon footprint compared to conventional protein sources. Substitution of silkworm meal for fish meal in aquatic animal diets significantly reduced solid phosphorus waste compared to insect-free diets. In contrast, the inclusion of black soldier fly, housefly, mealworm and grasshopper leads, in comparison to insect-free diet, to greater solid nitrogen waste. Reducing the proportion of fish meal and, to a lesser extent fish oil, by various insect meals in aquatic diet formulations significantly reduces economic fish-in fish-out, indicating less marine forage fish required per unit fish yield. The simulated data showed environmental benefit associated with land use of insect-containing aquafeeds compared to insect meal-free feeds, especially insect species of housefly and mealworm. In all, the study suggested a trade-off of using insect meal as an aquafeed ingredient regarding environmental consequence. Since insect meal has excellent potential to supply protein for aquafeeds in the coming years, improvement in insect meal production systems and nutritional composition will be essential to make insect meal a sustainable aquafeed ingredient.

The conclusion of the different research highlights the two pain points of insect meal inclusion for feed: energy efficiency and substrate use. " Intensifying industrial insect farming with standard and energy-efficient facilities and developing suitable insect-specific substrates to address nutritional composition and environmental aspects will be essential for insect meal as a future protein source supply for aquafeeds."

Insects as food

Mostly because their high feed conversion ratio, insects are a feed/food source with a low environmental impact.

Insects are a food source with a low environmental impact due to, amongst others, the limited need for arable land and water, compared with livestock, and low ecological cost (low greenhouse gas and carbon dioxide emissions). The environmental benefits of rearing insects are mostly founded on the high feed conversion efficiency, in comparison with beef, pigs and chicken. Crickets, for example, require only 2 kg of feed for every 1 kg of bodyweight gain. However, different genetics companies are already achieving the same ratios for traditional meat products although these technologies are not yet widely but slowly adopted; e.g. Genus' pork genetics has a projected feed conversion ratio of 1.9x by 2030 vs. 2.2x in 2020 and a global average of 5.3x. However, given that the field of insect science is relatively young, further improvements on the FCR for insects could be expected.

But by far the most interesting aspect is that insects can be reared on organic waste from humans and animals. As such insects can also provide a solution for the processing of organic waste. Several fly species are well suited for biodegradation of organic waste, with the house fly and the black soldier fly being the most extensively studied insects for this purpose.

Insects are also reported to emit less ammonia (urine and manure) than cattle or pigs. One study concluded that rearing of mealworm larvae, crickets and locusts emits about one tenth of the ammonia from pigs (Lange et al. 2021). Furthermore, production of insects requires significantly less land. Small-scale experiments showed that mealworm protein produced on 1 ha of land would require 2.5 ha to produce a similar quantity of milk protein, 2–3.5 ha to produce pork or chicken protein, and 10 ha to produce beef protein (DiGiacomo and Leury, 2019).

Land, water and feed use: Insects are significantly more efficient than other livestock in terms of feed conversion because they are cold-blooded and rely on their environment to control metabolic processes, such as body temperature. This advantage from insects is accentuated as a much higher amount of insects is edible: 80-100% compared to 40% for cows and 55% for pigs and chicken. Furthermore, depending on the species or processing method, they contain an average amount of protein (dry matter, DM) that varies between 50% and 82%, as well as being rich in nutrients such as calcium, iron, and zinc (Jansson and Berggren, 2015).

For producing beef, water is needed for growing its feed, to make the animal drink, clean the structure and process the meat. In the end, 1 kg of beef would have required 15,500 litres. On the other hand, the production of insects as food needs very few water. This is largely because insects such as crickets are designed with a tough exoskeleton which prevents them from drying out. They are also designed to derive much of their water from their feed diet and their digestive systems are highly efficient at conserving water rather than excreting it. (insects don't pee!). As they need less feed, less water is required to grow this feed. In the end, producing 1kg of crickets require only 300l of water! However for mealworms it is over 4,000 litres. Nevertheless, for beef, the water footprint per gram of protein is five times larger than of mealworms, while the least water-impacting food item, excluding mealworms (23 litres per gram of protein), is represented by chicken meat (34 litres per gram) compared to 112litres for beef and 57 litres for pork (Miglietta et al., 2015)

Edible insects require less feed to grow. For producing 1kg of meat, a cow need to eat 10kg of feed. For producing the same amount of insects, they will have eaten only 2kg. Moreover, insects are able to eat a large variety of feed and they can be fed on leftover such as bran and vegetables scraps.

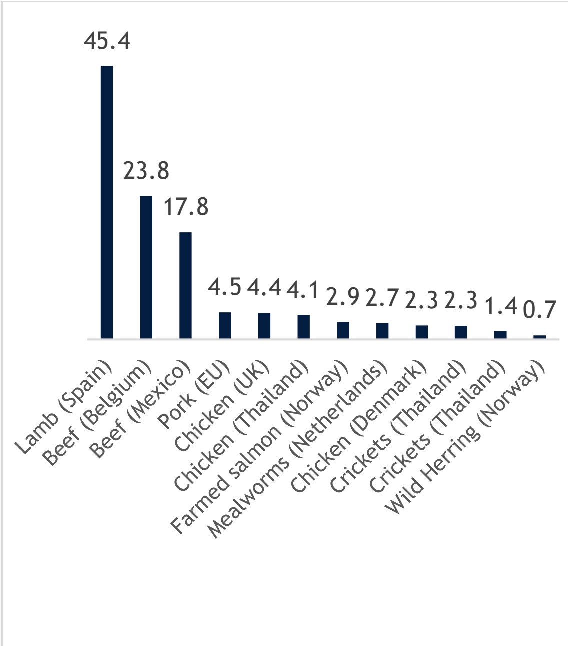
Fig. 20: Amount of land, feed and water needed to produce 1 kg of live animal weight

	% edible	Feed (kg)	Land (m2)	Water (litres)
Beef	40%	10.0	250	15,500
Pig	55%	5.0	70	6,000
Poultry	55%	2.5	70	4,250
Mealworm	80%	2.5	35	4,340
Cricket	80%	1.5	40	310

Source: Hoekstra (2012), Hoekstra and Mekonnen (2012), Mekonnen and Hoekstra (2010, 2012), Oonincx and de Boer (2012), and van Huis (2013)

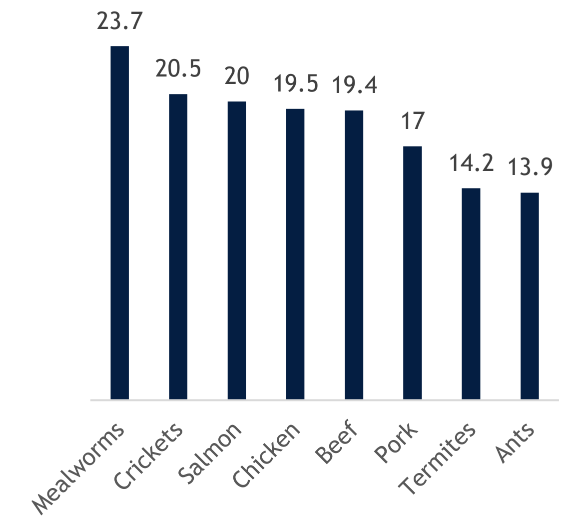
Greenhouse gasses: There is consensus that the biggest contributor to global climate change is greenhouse gas emissions, predominantly CO2, nitrous oxide and methane, from fossil fuels and agricultural and industrial processes. The agricultural sector contributes the most to GHG emissions, with livestock accounting for an overall 18% of CO2 equivalents. Studies comparing livestock emissions found that insects GHG emissions of g CO2-eq/kg mass gain compares favorably to any other livestock. On a per kg product basis, beef has by far the highest GHG emission with 23.8 kg CO2-eq/kg, pork 4.5 kg CO2-eq/kg, chicken 4.1 kg CO2-eq/kg, and crickets 1.8kg-eq/kg. The reason behind this is that as efficient as insects are in converting calories to edible biomass, they also expend a portion of these calories powering a life's worth of biological processes. The fact that insects do not rely on such a controlled environment or as much feed significantly cuts down on emissions to begin with. Additionally, no insect (with the exception of cockroaches and termites) produces methane, and none produce ammonia.

Fig. 21: CO2kg-eq emissions associated with producing one kg from different livestock



Source: Afton Halloran, University of Copenhagen, Denmark

Fig. 22: Protein content per 100g



Source: University of Missouri

A secondary benefit is that insects have been shown to be able to eat a wider variety of feeds including agricultural waste and food waste.

Circular Food Production: One important secondary benefit for insect farming is the kind of feed that can be used. Specifically, insects have been shown to be able to eat a wider variety of feeds including agricultural waste and food waste. For instance, during its larval stage, BSF larvae are voracious consumers of a wide variety of organic material, ranging from fruits and vegetables to animal remains, and manure. Small-scale waste management using BSF larvae has already been tested with a variety of organic by-products, such as rice straw, grains, faecal sludge and manure, and kitchen waste. Harvested larvae are high in protein (41–44%) and lipid (15–49%) content, which can be used as animal feed and biodiesel production; however, the use of the larvae is dependent on their nutritional makeup which is directly a result of what they feed on. (Scala et al., 2020).

This is particularly interesting because it plays into the idea of a “circular food production system” — one in which waste products can be reinvested into the system so that more food and less waste is produced. Indeed, animals only use about 60 per cent of the energy and protein in animal feed, the rest of which they excrete.

Frass: Despite being highly efficient in converting biowaste into biomass, insect production itself also yields a waste stream consisting in moulting skins (exuviae) and, more importantly, insect faeces (“frass”). In natural conditions frass deposition to soil has a great impact on soil fertility due to its high nutrient and labile carbon content (major food source for soil microbes). Therefore, several companies are already (preparing to) selling frass as a fertilizer. Even though some farmers have reported beneficial effects of frass to plants, there is however currently very limited information on the ability of frass produced by insect farms to improve soil fertility and, ultimately, plant growth. Research would be also relevant given the need to find cost-effective and environmental-friendly alternatives to conventional mineral fertilizers whose production relies on fossil fuels and finite resources. A 2020 greenhouse study from

Houben et al. found that frass (from mealworm) has a great potential to be used as a partial or a complete substitute of mineral NPK fertilizer. Due to its rapid mineralization and its high content in readily-available nutrient, frass had a similar effectiveness to supply N, P and K and sustain biomass production than NPK fertilizer. However, as the authors conclude, further in situ researches are required because temporal mineralization in controlled conditions may be different from mineralization in field. A 2020 Kenyan field study from Beesigamukama reported that an application of BSF frass fertilizers increased grain yields by 71% to 96% during the short rain season and 49% to 101% during long rain compared to the control. On the other hand, grain yields increased by 50% to 87% during the short rains and 32% to 77% during the long rains season due to commercial fertilizer. Maize grain yields did not vary significantly at equivalent rates of the commercial organic and BSF frass fertilizers. The authors believe that the increased maize plant height, chlorophyll concentration, and nitrogen and phosphorus uptake observed in plots treated with black soldier fly frass fertilizer compared to plots treated with the commercial organic and mineral fertilizers could be attributed to better supply and availability of nutrients from the frass fertilizer. Furthermore, it is suggested that the high release of nutrients resulting from the high mineralization rate of black soldier fly frass fertilizer and high availability of mineral nitrogen in the top 20 cm of soil might have partly contributed to better synchrony of nutrients supply for maize growth, chlorophyll formation and high yields.

Use of antibiotics: Current farming practices encourage the development of antibiotic resistant bacteria given that animals are given antibiotics to mitigate the development of pathogens that comes from holding animals tightly together. Due to the biological differences between insects and humans, the kind of pathogens they transmit are less likely to be transferred to humans. So, farming them in close quarters holds less risk. Insect farming has the added benefit in being done in close to sterile conditions (or at least highly controlled ones) which would prevent the development of pathogens in the first place. Nevertheless, there are many insects that are the primary or intermediate hosts or carriers of human diseases. Pathogens that are capable of being transmitted by insects include protozoa (eg. malaria, Chagas' disease), bacteria (eg. plaque, typhoid fever, cholera, Lyme disease), viruses (eg. dengue, yellow fever), and such helminths as tapeworms, flukes, and roundworms.

Animal Welfare: Farming livestock is often considered inhumane given that these animals are established sentient beings capable of feeling pain. Article 13 of the Treaty on the Functioning of the European Union states that all animals, regardless of their role – pets, sport animals, farm animals, to name a few – deserve their welfare requirements to be taken into full regard. Animal well-being is based on the pursuit of the so-called “Five Freedoms”, first among these, freedom from hunger and thirst, discomfort, pain, fear and distress. However, EU policy makers have left out invertebrate animals – and thus insects – from the scope of the EU animal welfare legislation that normally apply to European animal breeders. This means that today insect producers are exempted from any EU legal obligations in the area of animal welfare. Nevertheless, the European industry association for insect producers, IPIFF, promotes good welfare practices in husbandry including those five freedoms.

Insects are considered highly nutritional; the majority of them are rich in protein, healthy fats, iron, and calcium, and low in carbohydrates.

Nutrition: Insects are considered highly nutritional; the majority of them are rich in protein, healthy fats, iron, and calcium, and low in carbohydrates. In fact, researchers from the FAO (2013) claim that insects are just as – if not more – nutritious than commonly consumed meats, such as beef. They are also more nutritionally dense than macro livestock. They have crude protein levels of 40–75% which is, on average, 50% higher than soybeans, 87% higher than maize, 63% higher than beef and 70% higher than fish. The omega-3 and omega-6 fatty acid levels in mealworms are comparable to that of fish. Other insects with ideal fatty acid ratios are house crickets, short-tailed crickets, Bombay locusts and scarab beetles. Mealworms have a higher content of calcium, vitamin C, vitamin A and riboflavin per kg than beef. And a serving of silkworms and palm weevil larva have 224.7% and 201.3% of the daily suggested thiamine intake compared to chicken which has just 5.4%.

Barriers to overcome and other considerations

Although there is still significant research to be done on the specific impact of insect products in feed, most barriers that the insect industry has to overcome, concern the use of insect products as food.

Research

Although research is increasing, there are still significant knowledge gaps and conflicting theories including the environmental impact of insect industrialization, benefits of insect feed ingredients, etc…

Edible insects have emerged in the past decade as a potential solution to a suite of pressing environmental and human health issues, including climate change, malnutrition, food insecurity, and environmental degradation resulting from agro-industrial production. Although research is increasing (from 14 peer-review articles in 2012 to over 100 in recent years), there are still significant gaps and conflicting theories including the environmental impact of insect industrialization, benefits of insect feed ingredients, microbial complexity of industrial insect rearing for human consumption, the impact of external production factors such as feed and temperature on the quality of insect feed/food, standardization of insect products, product safety and shelf life, etc…

One particular important field that need further research is the specific benefits of insects as a feed ingredient. Indeed, although most research seems to agree that fish and soy meal can be replaced by insect meal, it is unclear if there are limits to the replacement rate. A study exploring the use of different black soldier fly larvae ingredients in trout production, published in the journal Aquaculture, found that the maximum of black soldier larvae meal is 13% and for oil is probably just over 10%. Higher levels of substitution were found to slow growth of fish. Also whole-body crude protein and amino acid content of rainbow trout was inversely correlated with dietary inclusion of black soldier larvae meal but not with black soldier larvae oil (Dumas et al. in Aquaculture, 1 July 2018). Furthermore, insects can be considered as safe from a microbiological point of view but can contain residues of pesticides and heavy metal (Baiano, 2020)

Consumer acceptability

European and North American consumers, despite some differences between countries, tend to prefer eating ingredients of a given food in original form, and reluctance remains toward consuming insect-based food. Nevertheless the U.S. Food and Drug Administration reports that there may be 60 fragments of insect in 100 g of chocolate for example, and the idea of eating insects is far from new, but the very slow uptake in Western countries suggests that there are considerable cultural barriers to their widespread adoption. Nutritional arguments are not thought to be enough to overcome the 'disgust factor' and convert Westerners to insect-based dishes. However, processed insect ingredients in protein bars of flour, could be successful.

There are two distinct psychological reactions to insects as a food source for humans. In countries where entomophagy is the norm, insects are seen as a valued protein source and knowledge on which species are edible is considered local wisdom passed down between generations. Conversely, in Western cultures, insects can invoke negative reactions: 'deeply embedded in the Western psyche is a view of insects as dirty, disgusting and dangerous'. This view of insects as inedible is perpetuated by the Western media through TV shows such as 'Fear Factor' and 'I'm A Celebrity…Get Me Out Of Here!' where contestants are forced to eat raw insects to advance in the competition and show their daring. One study reported that in Western societies, only 12.8% of males and 6.3% of females were likely to adopt insects as a substitute for meat (Verbeke 2015) and another that 19% of individuals were prepared to eat insects as a meat substitute (Hartmann & Siegrist 2017). This presents the additional hurdle of how to increase acceptance of entomophagy in Western cultures.

To date, no socio-demographic factors have been linked to the willingness to eat insects (Hartmann & Siegrist 2017). Rather, the main influential factors seem to be neophobia, familiarity, interest in the environment, convenience and attachment to meat (Verbeke 2015; Gere 2017). The more neophobic, uninterested in the environment and attached to a diet that contains meat the person is, the less likely they are to be prepared to eat insects.

Although acceptance of insects as a human food in Western cultures is low, there is significantly more support for insects as an animal feed.

However, if insects are presented in a convenient, appropriate and familiar form (e.g. insect flour in a cookie), the more willing an individual may be to try it. Although acceptance of insects as a human food in Western cultures is low, there is significantly more support for insects as an animal feed. Two-thirds of 415 farmers surveyed in Belgium found it acceptable to use insects in animal feed (Verbeke et al. 2015). The PROteINSECT project reported that 66% of consumers consider fly larvae as suitable feedstuff, over 80% want to know more about insects as feed, and 75% were happy to eat animals fed on insects (PROteINSECT 2016). Perhaps the first step to increasing consumer acceptability of entomophagy is through increased use in animal feed.

High levels of chitin

Chitin can be a source of allergy but can also improve the immune defence

Formulations from insects may be high in protein, although the true protein levels can be overestimated when the substance chitin, a major component of insects' exoskeleton, is present. Critically, many food allergies are linked to proteins so consumption of insects could trigger allergic reactions. These can be caused by an individual's sensitivity to insect proteins, cross-reactivity with other allergens or residual allergens from insect feed, e.g. gluten.

One of the sources of allergies could be chitin. Chitin is primarily a structural material in organisms. It is the second most abundant biopolymer in the world, after cellulose. Chitin is the main component of fungal cell walls. It forms the exoskeletons of insects and crustaceans. It forms the radulae (teeth) of mollusks and the beaks of cephalopods. Chitin also occurs in vertebrates. Fish scales and some amphibian scales contain chitin.

In insects and plants, chitin and its derivatives provide protection and immune defense to organisms. And when they are digested by humans, chitin and its degradation products are sensed in the skin, lungs, and digestive tract, initiating an immune response and potentially conferring protection against parasites. Because they stimulate an immune response, chitin and chitosan may be used as vaccine adjuvants.

Other potential uses of chitin are that it may have applications in medicine as a component of bandages or for surgical thread. Chitin is used in paper manufacturing as a strengthener and sizing agent. Chitin is used as a food additive to enhance flavor, as an emulsifier and as a preservation agent. It is sold as a supplement as an anti-inflammatory agent, to reduce cholesterol, support weight loss, and control blood pressure. Some chitin derivatives have even been found to have antioxidant properties. Chitosan may be used to make biodegradable plastic. Chitin also has a broad application within the medical field. For example, contact lenses, artificial skin, and even dissolvable surgical stitches are derived from some form of chitin. It's valuable qualities establishes chitin as a unique and extremely sought after biopolymer.

Different studies show that chitin content in the tested insects can vary largely in a range of 6% to 13% of chitin, depending on species, sex, and stage of development.

Fig. 23: Nutritional potential of selected insect species reared on the island of Sumatra (g/100g)

	Citin	Crude protein	Fat
Giant mealworm larva	6	46	35
Common mealworm pupa	12	51	32
Common mealworm larvae	13	52	31
Field cricket nymph	7	56	32

Source: Marie Borkovcová, 2017

Regulations

Over the past few years, insect use in animal feed and products for human consumption has slowly been growing. However, the industry is hindered by the lack of a clear legal framework and companies operating in this field have done so under significant regulatory uncertainty. Only in the EU, lawmakers have been clarifying regulation for use of insects for human or animal consumption. But in the US, Asia and Africa, for different reasons, regulation on the use of insects is non-existent.

A European regulatory framework for insect food and feed is developing

EU Law regulates the conditions for food and feed business operators, such as insect producers, to produce and commercialize their products in the European Union. There are legislation that defines general principles and standards in the area of food and feed safety. According to these, producers of insects, like any other food or feed business operator, are responsible for ensuring the safety of the marketed products. As a consequence insect producers are obligate to register or ask approval of their activities at their national competent authority and follow hygiene standards at the different stages of production covered.

In the EU there are restrictions on the feed that may be given to farmed animals, including insects.

EU decision makers have also established restrictions on the feed which may be given to ‘farmed animals’ – i.e. animals that are kept for the production of food, feed or other derived products (e.g. wool or hides). These restrictions also apply to insects intended for human consumption or for animal feed use. Consequently, such insects may only be fed with materials of vegetal origin. Some exceptions are however admitted for materials of animal origin such as milk, eggs and their products, honey, rendered fat or blood products from non-ruminant animals. The feeding of farmed animals with other slaughterhouse or rendering derived products, manure, or catering waste is however prohibited. The same ban applies to the use of unsold products from supermarkets or food industries (e.g. unsold products in reason of manufacturing or packaging defects) if these contain meat or fish.

Furthermore, obligations lie with insect producers to ensure that their animals are kept in good health so as to prevent the spreading of diseases among their production flock. To this end, EU policy makers have established the responsibilities of animal breeders in the area of health and biosecurity in the so-called ‘EU Animal Health Law’.

Third countries producers intending to export insects or their derived products – as food or feed – into the European Union must comply with similar– or equivalent – standards as those established in the European legislation.

European insect producers must conform with EU environmental legislation: Notably, Regulation (EU) No 1143/2014 restricts the insect species that are eligible for farming purposes – i.e. by establishing a list of ‘invasive alien species’. The objective of this legislative text is to prevent the introduction in the environment of species that may threaten upon surrounding biodiversity or ecosystems, in the event of accidental release of farmed insects. Today, the only listed insect species in this legislation – and therefore prohibited –is the Asian predatory wasp – i.e. vespa velutina.

EU policy makers have left out invertebrate animals – and thus insects – from the scope of the EU animal welfare legislation that normally apply to European animal breeders. This means that today insect producers are exempted from any EU legal obligations in the area of animal welfare.

In the EU, currently only the yellow mealworm, the migratory locust and the house cricket are allowed for human consumption…

On 13 January 2021, the European Food Safety Authority (EFSA) published an opinion that mealworms are safe for human consumption. And on 3 May 2021, The European Commission approved the marketing and consumption of dried yellow mealworms, of the Tenebrio molitor species, as a novel food (the EC defines a "novel food" as one that hadn't been consumed to a significant degree by humans in the EU prior to May 15, 1997).

Following a second positive opinion (July 2021), on the 15th of November 2021, the European Commission has authorized dried and frozen migratory locust (Locusta migratoria) as Novel Food.

Later in 2022, the European Commission has published the second of frozen, dried and powder yellow mealworm (Tenebrio molitor) and the first authorization of dried, ground and frozen house cricket (Acheta domesticus) respectively on the 8th and 11th of February 2022 (following the 3rd and 4th EFSA opinions in August 2021). The authorizations entered into force respectively on the 28th of February and on the 2nd of March 2022.

… and only 8 species of insects can be given to farmed fish.

Other insects can only still only used in animal feed. Since 2017, the European Commission allowed introducing feeds derived from some insects into animal diets (EU Rer. 2017/893). This regulation has permitted the use of processed animal proteins (PAPs) from insects in the diet of farmed fish limited to seven species (Black Soldier Fly, Common Housefly, Yellow Mealworm, Lesser Mealworm, House Cricket, Banded Cricket, Field Cricket and (since November 2021) Silkworm.

Since September 2021, insect-derived proteins are allowed for pig and poultry feed, next to pet food.

And since September 2021, insect-derived proteins are allowed for use in pig or poultry feed, together with pet food (e.g. dogs, cats, birds or reptiles) and fur animals (e.g. mink). (In April 2021, the EU Member States voted positively on the authorization of insect processed animal proteins (PAPs) in poultry and pig feed. This proposal represents a relevant milestone for the European insect sector, as it marks one of the key steps in the authorization process. In line with the EU procedures, the entry into force of this proposal took place on the 7th of September 2021.)

Some European Union Member States have developed their own legislation. In Belgium, The Federal Agency for the Safety of the Food Chain has produced a specific regulation for edible insects, although no insects bred outside of the European Union are accepted. They updated their regulation in 2018 according to the EU transitional period which extended the legality of products nationally authorized before 2018, provided they applied for an EU permit by 1 January 2019. Through their national federation, Belgian companies sent applications for Novel Food to the EU for three insects: crickets, mealworms and locusts.

The Netherlands is home to some mealworm and cricket farms designed to breed for human consumption. These include the leader, Protifarm (and its subsidiary Kreca), as well as some start-ups active in the marketing and production of edible insects. Its legal basis is not clear, though, and the public body responsible for food safety (NVWA) has refused to comment.

The Danish Veterinary and Food Administration believes that whole insects (including flour, if coming from whole insects) do not fall under the EU novel food legislation. As a result, imports from non-EU countries is possible for those insects falling under the transitional period (mealworm and house crickets, for example). Denmark is jumping ahead with edible insect initiatives.

Finland has followed the Danish example in 2017, releasing rules for import and sales of edible insects. As for the other countries which allowed edible insect prior to 2018, in 2018 they are in the transitional period. It is not clear what will happen in 2019.

The control of food in Germany is a task for the 16 federal states. The Federal Office of Consumer Protection and Food Safety (BVL) fulfils only some coordination functions, so its position is not legally binding and it is aligned with the EU commission decision: insects or parts of insects are novel food and cannot be sold in Germany until a procedure for novel food approval has been finalized. But in March 2018 Metro Group announced the launch of a mealworm pasta.

Norway is not an EU member, but belongs to the European Economic Area and therefore follows a number of European regulations. Still, their interpretation of edible insects is that when they are whole (as opposed to parts or isolates of insects), they do not fall under the novel food law. Import would be accepted if custom is cleared in an EU country. This is the position of the Norwegian food agency.

For years, the British Food Safety Agency has shown a favorable position on the sale, consumption and import of edible insects. After Brexit its is most likely that insects will be allowed to keep on being sold on the market.

In December 2016, the Swiss council passed an edible insect law (which took take effect May 1, 2017) allowing the sale and consumption of three species: crickets (Acheta domesticus), European locusts and mealworms. Among the requirements, the insects must have been bred for human consumption and after slaughter must be treated according to the criteria of food security (high temperatures, freezing, etc.). The rules released by the food agency (OSAV) are very strict and complex. In the case of import from non-EU countries, they requires the insect to be whole, shipped only by plane to Zurich or Geneva, and accompanied by lab test and certificates.

In the US, the use of insects as food or feed is not prohibited

In the US, regulators have taken a more hands-off approach.

In the United States, however, federal regulation of insects for human consumption or as feed for animal consumption, has largely been characterized by regulatory inaction, which is creating a high level of uncertainty. And unlike in the EU, there does not seem to be a legal initiative on the table in the US to provide some legal clarity.

On a Federal level, insects used as food fall under FDA oversight. The USDA's Food and Safety Inspection Service (FSIS) regulates meat, poultry and eggs. Everything else defaults to FDA regulation (e.g. sea food, game). The USDA may be involved in insect farming through their Animal and Plant Health Inspection Service (APHIS) agency (e.g. for import of a new species).

Most of FDA's attention, however, has not been focused on regulating insects as human or animal food, but rather on regulating insects as "filth." The agency has traditionally prohibited insect parts in food, treating them as adulterants under the Federal Food, Drug, and Cosmetic Act (FDCA). FDA has typically responded to edible insect inquiries by stating that insects are considered food if they are to be used for food or as components of food. This response has been viewed by some observers as an informal acceptance of the use of insects in or as human food. Under this regulatory framework, insect food products and insect-based food products would be subject to all relevant sections of the FDCA and must be processed using current good manufacturing practices. Insect-specific processing standards are particularly important to ensure edible insects' safety, as the biological and chemical hazards of using farmed insects for human consumption depend on how the insects are reared and processed.

When insects are added to processed food (used as an ingredient) for both human and animal consumption, insects are subject to food additive regulations (GRAS) that is subject to premarket review and approval by FDA, unless the substance is generally recognized, among qualified experts, as having been adequately shown to be safe under the conditions of its intended use, or unless the use of the substance is otherwise excluded from the definition of a food additive. Furthermore, the regulation also states that general recognition of safety has to be based upon scientific procedures that require the same quantity and quality of scientific evidence as is required to obtain approval of a food additive. That makes it very unlikely that private companies with an internal GRAS dossier on file would likely not pass FDA review due to the stringent scientific requirements. That the FDA has not enforced GRAS rules is based on their enforcement discretion that could be based on:

- Population intake of edible insects is low; therefore, risk is also low.
- There is currently no evidence of people being harmed by consuming insects.
- State and local regulators don't have the technical capability to enforce GRAS compliance.

This inaction could change if there is evidence that the consumer is being harmed by edible insects. The FDA has removed the GRAS status for Partially Hydrogenated Oil as the research has shown that the ingredient is harmful. Also a higher levels of insect consumption could trigger regulatory action.

Elsewhere rules are equally relax or non-existent

And also in other parts of the world, regulators have been less concerned.

In Canada, crickets are not considered as a novel food, and today the largest breeder in North America is located in Canada and serves some local start-ups, including One Hop Kitchen. If, however, an insect lacks a history of safe consumption, it might fall back into the novel food category pending an evaluation by the Bureau of Microbial Hazards in the Food Directorate.

Australia and New Zealand share an agency for the maintenance of food safety, Fsanz. This agency has addressed some cases like the super mealworm, the domestic cricket and the moth, deciding that they are not novel foods, even though they cannot be considered traditional foods either. In particular, they have yet to encounter food safety problems and consequently have not been put to the consumption limits or import.

Other parts of the world, such as Asia and Africa, are traditionally more comfortable with the presence of insects in the food-chain. However, this is not reflected in the law, and the regulation on insects ranges from sparse to non-existent. While local producers of insect-related products might be able to sell their wares on local markets with relative ease, the export to industrialized countries might prove challenging as long as there is no clear legal framework in place.

Southeast Asian countries have a tradition of entomophagy, but do not have regulations relating to the breeding, sale and export of insects. Thailand, the world's largest breeder of crickets, has released the guidelines for cricket farming (GAP – Good Agricultural Practice) in 2017. Also in China, insects are a common culinary ingredient in many regions, but there are still no mentions of this in food law. An exception, though, is silkworm pupae, which was included in 2014 in the list of foods allowed by the Ministry of Health. China is the world's largest producer of silk (500.000 tonnes of silkworm pupae per year). In South Korea the Korean Food and Drug Administration classified crickets (the Gryllus bimaculatus species) and mealworms as normal foods, without restrictions. It is expected that other insects will be added soon to the eligibility list.

Economics of insect farming

The vast majority of commercially successful, mostly small scale, insect farms are labor intensive and use basic techniques including growing insects in containers or pens (about 2 sqm) and feeding them with chicken feed that contains 14-21% proteins. Industrial insect farming is a relatively new practice, and so far is mainly focused on feed production. Currently, a few industrial enterprises are in various stages of development for insect farming. There are some industrial-scale farms producing insects for human consumption in Asia, especially China and Thailand, but in the US, Europe, and Canada, major companies like Protix, InnovaFeed, Agronutris, Beta-Hatch, and Ÿnsect are turning instead to raising insects for livestock and as an alternative for fish meal.

For large-scale production, critical elements including research on insect biology, suitable rearing conditions, and diet formulas are required. To achieve commercial mass production, current farming systems need automation of some key processes to make them economically competitive with the production of fish meal for feed and with meat from livestock. Most of the venture-backed startups are using methods that are zone-based automated environments, where software controls the temperature, humidity, feeding, air circulation and most of the safety and inspection procedures. There are myriad benefits of automation for insect farming: some that are broadly applicable like labor costs and contamination risks, and some are specific to insects such as preventing cannibalism and immediately addressing problems like mold.

Fig. 24: Small scale cricket farming in Thailand

Source: FAO

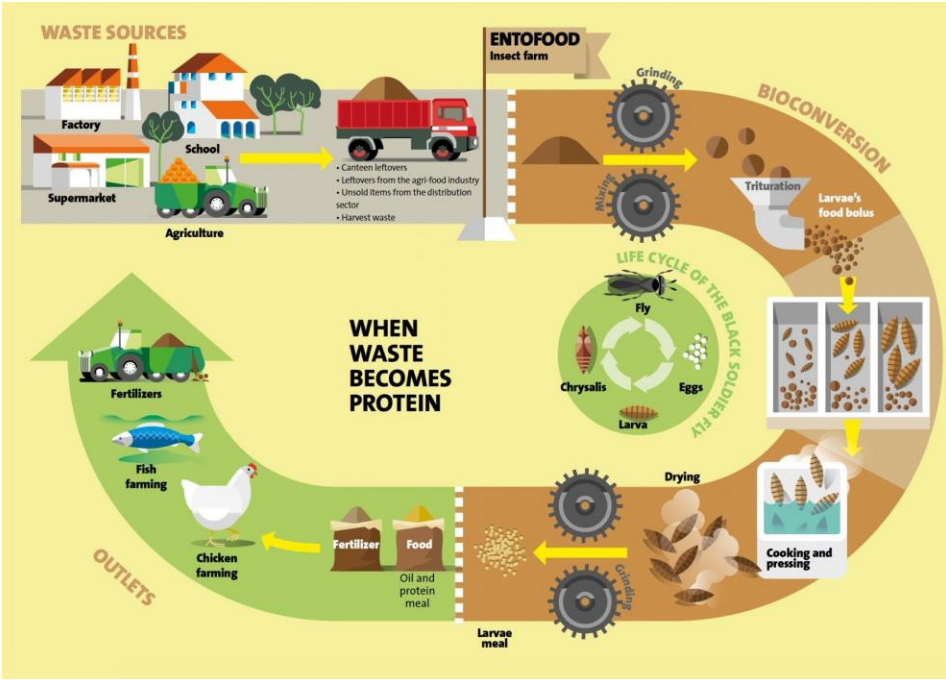
Fig. 25: Automated mealworm farming in France

Source: Ÿnsect

For small scale production the barriers to entry are low and returns relatively high, with basic technology and production area requirements, and rapid breeding cycles. For these small scale enterprises, gross margins are around 40%. But industrial production is on a different scale: all 20,000 Thai farmers produce about 7,500 tonnes of crickets; while the exiting factory of Ÿnsect in Dole is producing around 500 tonnes of proteins and the new one in Amiens after an investment of EUR150m will have a capacity of 100,000 tonnes of insect products (of which 25,000 tonnes proteins). The Ÿnsect process is underpinned by technology protected by around 30 patents, representing 40% of the total patent portfolio of the top 10 insect protein companies worldwide. InnovaFeed's plant in Nesle had an initial 15,000 tonne capacity but the factory is already being ramped up to 70,000 tonne (of which 20,000 tonnes proteins) requiring an additional investment of EUR50m. And Protix new facility of 15,000 tonnes proteins is requiring a EUR60m investment.

Revenues from insect farms come from the transformation of insects to protein meal (price is determined by the protein content), oils, fats, purées (the intermediary stage presenting soluble protein concentrations) and frass, the faeces used to substitute chemical fertilisers.

Fig. 26: Insects at the heart of bioconversion



Source: Entofood Veolia

Feed is an important cost element. It takes 2.1kg of feed to produce a kg of crickets (input may be lower with other insects), whereas it takes 2.6kg, 5.3kg and 10 kg to produce 1 kg of chicken, pork or beef, respectively. Indeed, it does not only take less food for insects to gain biomass but also a higher proportion (80% to 100%) of its biomass is edible (60% of a cow, 74% of a chicken and 73% of a pig). For insects to be used as feed, different (organic waste) side streams can be considered. However, when insects are used for human consumption, the agricultural products need to be feed grade or even food grade when insects are not degutted. It may even be that waste streams should not be considered. Furthermore, the feedstock needs to be cheap (or ideally free of charge), locally available, of consistent quality and supply, and above all free of pesticides and antibiotics.

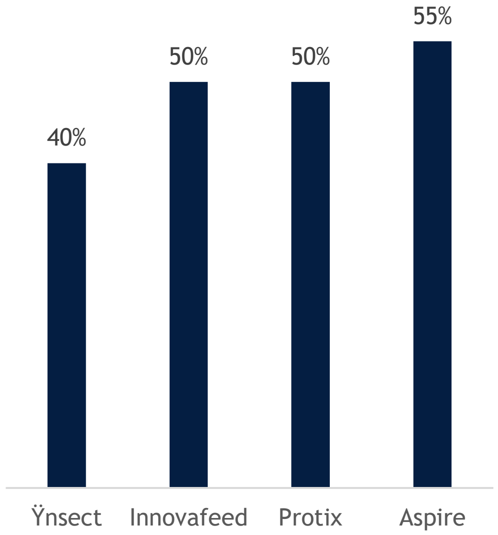
Other cost considerations are climate (In Western Europe and North America insects need heated conditions to optimize growth and hence controlled environments) and the type of species used. Species that will be mass produced need to have a high intrinsic rate of increase (short development cycle, high survival of immatures and high oviposition rate); a high potential of biomass increase/day (weight gain/day); a high conversion rate (kg biomass gain/kg feedstock) the ability to live in high densities (kg biomass/m2); and low vulnerability to diseases (resistance).

Further considerations to make include: Is the species amenable to large scale automation such that labor costs can be reduced? Can the species be contained in non-native areas? Is there a possibility of genetically improving species by selective breeding to get high quality strains? Parental genetic lines need to be preserved in case of culture crashes.

Most industrial insect companies are looking to achieve EBITDA margins between 40% and 55%, assuming selling prices of USD2,000 to USD3,000 per tonne, which is a significant premium over fish meal prices (USD1,500 per tonne).

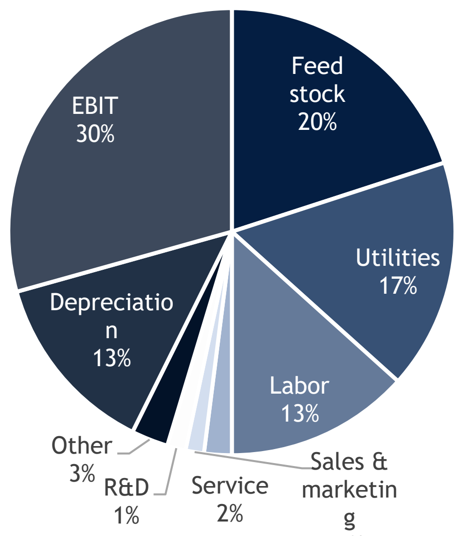
Most industrial insect companies are looking to achieve EBITDA margins between 40% and 55% assuming, depending of the species (BSF, mealworms, crickets), selling prices of insect meal/oil at USD2,000 to USD3,000 per tonne (price range also depends on market addressed and differs in aquaculture vs petfood or food applications). Under those selling price assumptions, feedstock, utilities (heating and ventilation), labour and depreciation seem to be the main cost elements, accounting for an estimated 20%, 17%, 13% and 13% of revenues with design improving efficiencies, especially in heating, ventilation and labour. This leaves an EBITDA margin of 43% and EBIT margin of 30%.

Fig. 27: Expected EBITDA margin different insect companies



Source: Bryan, Garnier & Cie

Fig. 28: Profit and Loss example of an insect company



Source: Bryan, Garnier & Cie

The place of insect meal and oil in the animal feed industry

There is currently no official and complete international database on what livestock eat. However, Anne Mottet et al., Livestock Policy Officer for the FAO, estimate that livestock consume 6 billion tonnes of feed (dry matter) annually. The three major feed materials are grass and leaves (2.7bn tonnes), followed by crop residues such as straws, strover or sugar-cane crops (1.1bn tonnes). At global level, human-edible feed materials represented about 14% of the global livestock feed ration and 86% is made of materials that are currently not eaten by humans. Grains made up only 13% of the ration and represent 32% of global grain production. Of that 6.0bn tonnes of feed, 1.1bn tonnes is compound feed.

Of the 6.0bn tonnes of teed, 1.1bn tonnes is compound feed and of that 170m tonnes is proteins.

Compound feed refers to the feed that is manufactured in order to produce a balanced feed that can meet farm animals' physiological requirements at different growth stages and production uses. It goes well beyond the mixing and milling of feed materials and is beased on scientific nutrition expertise. Compound feed is a mixture of raw materials and supplements sourced from either plant, animal, organic or inorganic substances, or industrial processing, with or without containing additives. The raw materials that are used in manufacturing process are soybean, corn, barley, wheat, and sorghum, etc.. Vitamins, minerals, and amino acids are the most common additives blended to form compound feed. This commercial feed manufacturing generates globally an estimated annual turnover of over USD450bn (i.e. averaging USD400 per tonne). The global data on compound feed, collected by Alltech, indicates feed production by species as: broilers 27%; pigs 23%; layers 14%; dairy 12%; beef 10%; other species 7%; aquaculture 4%; and pets 2%.

Fig. 29: Global feed of 6.0bn tonnes dry matter

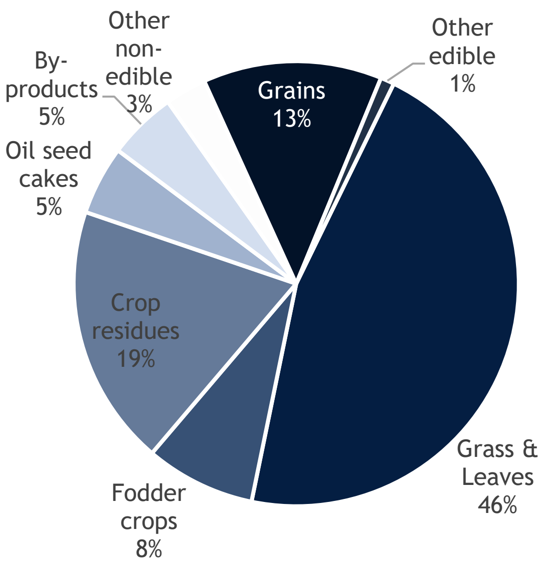
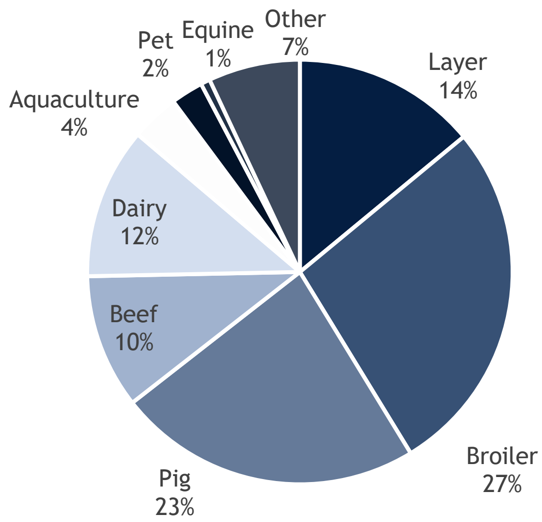


Fig. 30: Global compound feed of 1.1bn tonnes



Fodder crops: grain and legume silage, fodder beets
Crop residues: straw and stover, sugar cane tops, banana stems
By-products: brans, corn gluten meal and feed, molasses, beetroot pulp and spent breweries, distilleries, biofuel grains
Other non-edible: second grade cereals, swill, fish meal, synthetic amino acids, lime
Other edible: cassava pellets, beans and soy beans, rapeseed and soy oil

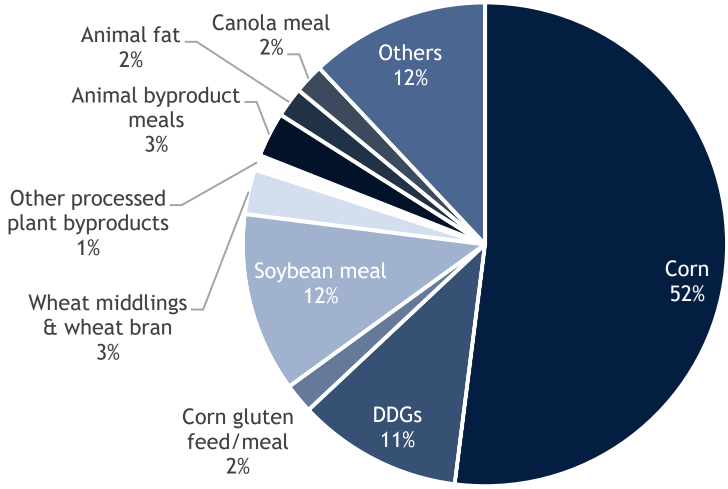
:

Source: Global Livestock Environmental Assesment Model, Gerber et al.

Source: Alltech

A study from iFeeder on the 250m tonnes of compound feed for the US's domestic livestock and pets showed that corn, made up slightly more than half (52%) of the total amount of compounded feed consumed, and when combined with soybean meal (12%) and dried distillers' grains with solubles (DDGs) (11%), represented more than 75% of all feed tonnage consumed in 2019. iFeeder also reported on a number of other ingredients used in animal diets, including wheat middlings and wheat bran (3%), animal byproduct meals (3%), corn gluten feed/meal (2%), canola meal (2%), animal fats (2%) and other processed plant byproducts (1%).

Fig. 31: Total US animal feed composition of 250m tonne, 2019



source American Feed Industry Association, Institute for Feed Education and Research

New feeding strategies are included in the compound feed market and comprise the application of innovative feed ingredients and their mixtures providing functionalities that optimise animal nutrition, health and welfare and reduce environmental impacts and costs of livestock production. It is in this frame work that insect meal/oil has to be placed. Especially the aquafeed industry is looking for alternative protein sources as availability of fish meal is limited and prices high and volatile. Hence the their interest for edible insects. But also in the poultry and pig industry, demand for high-quality protein is rising and also here insects and microalgea could play a role.

Edible insects (and microalgae) for animal feed products are fulfilling the same functionalities as fish meal/oil (high protein ingredients that improve animal health, weight gain and feed conversion ratios)

Indeed, insects (and microalgae) for animal feed products have similar functionalities as fish meal/oil. Fish meal and fish oil are employed as high protein ingredients within the feed given to farmland animals and farmed fishes. They are considered an exceptional source of protein for all farmed and aquacultured animals. Hence command signficant higher prices than other feed. They are rich in essential amino acids, particularly lysine, cysteine, methionine, and tryptophan, which are key limiting amino acids for growth and productivity in notable farmed species. Animal health is improved with fish meal and fish oils in their diet. The inclusion of fish meal & fish oil in animal feed results in improved production efficiencies across all major farmed species. It has the potential for the dietary manipulation of tissue/product composition to produce 'healthier' foods for use in the human food chain. The story around insects meal and oil (and microalgea) is very similar highlighting the increased productivity and health of the animals. Moreover, insects have the great advantage that they can be tailored depending on the species and the feed of that species which would allow it to become cost effective for farmers (as less costly additivies are needed). However that charecteristic could limit the prospects of the insect meal & oil industry in general:

1) Insect meal & oil lacks standardisations: fish meal is measured through its protein content (55% or 60%) and the same standard does not apply to insect meal & oil where there is far greater varibility in protein, fats and minerals. This originates in the flexible nature of insects that can produce more tailored insect meal & oil depending on their feed.
2) Cost of insect meal & oil is currently signficantly higher than fish meal & oil (double), which for specific companies' products could be justified for certain species at certain stages of their growth cycle. However, to compete with fish meal & oil, prices will need to come down to the same level. Current prices of insect meal are around USD3,000/tonne compared to fish meal at USD1,500/tonne, fish oil at USD2,000/tonne and soybean meal at USD450/tonne (source:index mundi). As the different insect meal producers are scaling up we expect that prices for insect meal will fall, over the next 24 months to the USD2,000 per tonne level (still comanding a premium on fish meal due to limited availability). In the medium to longer term and given that most insects can be reared on food waste (and provide a solution for waste management), we expect insect meal prices to drop further.
3) Uncertainty of scaling up: current trails are still with relatively small production units. It remains to be seen if new larger facilities will be able to produce the same quality as the smaller trail plants. Also with variable feed stocks depending on the geography, the caracteristics of a specific insect meal & oil might vary.
4) Uncertain environmental credentials: the insect industry has mainly focussed on the feed conversion ratio, land use and water use ratios to promote the sustainability aspect of insects. However, rearing insects at temperatures of 20 to 25 degrees does require energy. Earlier in this research we have highlighted that insect meal as feed is not necessary a more environmental friendly solution compared to both fish meal and soybean meal.

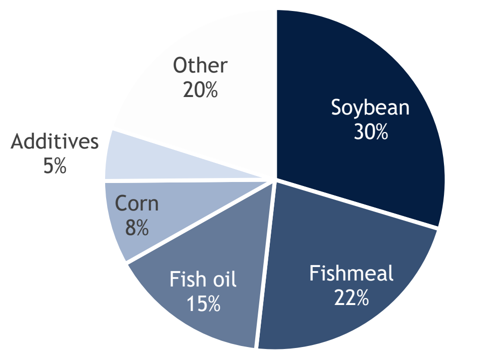
Currently the insect industry is geared towards providing high quality proteins in pet food and aquaculture, which are both very specific and high value added industries.

Currently the insect industry is geared towards providing high quality proteins in pet food and as an alternative for fish meal/oil in aquaculture, which are both very specific and high value added industries. In our base scenario we expect that insect meal could provide an alternative source for the growth and/or replacement of other protein sources to the tune of 5% of the current demand from aquaculture and 10% from the pet food demand. In that base scenario, the insect meal industry for these two segments could be respectively 0.6m and 0.7m tonne (at USD2,500/tonne). In a best case scenario we estimate that the size of the insect meal industry could provide in aquaculture 10% of proteins and for 25% in pet food (but at lower prices i.e. USD1,500/tonne).

Next to the relatively highly priced aquaculture and pet market, we expect a more commoditized insect meal market to develop allowing for insect meal to enter into piglets and poultry markets.

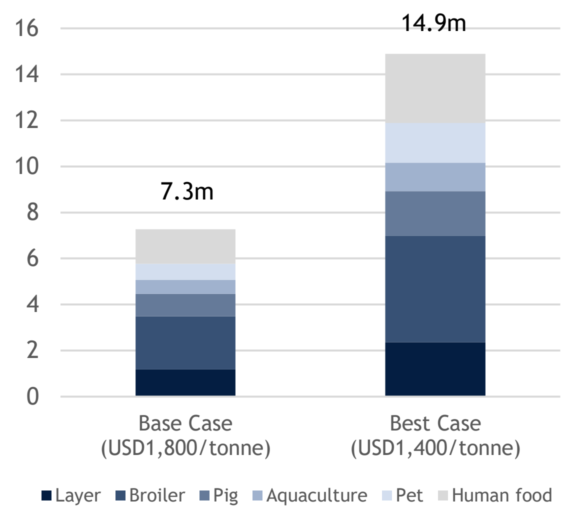
Next to the relatively highly priced aquaculture and pet market, we expect that with efficiencies in production, a more commoditized insect meal market (but still demanding prices of USD1,000 to USD1200 per tonne) develops allowing for insect meal to enter into piglets and poultry markets assuming that additional trials as well as economic analyses prove that the nutritional benefits of insects are at least equal to those of fish meal.

Fig. 32: Global aquafeed market (USD57bn) by ingredient, 2019



Source: Fortune Business Insights

Fig. 33: Potential volumes for the insect industry (m tonnes)



Source: Bryan, Garnier & Cie estimates

Chicken feed is primarily made up of macro ingredients such as cereal grains (eg wheat, barley and sorghum) and oilseed meals (such as soya bean or canola meal) or animal by-product meals. Cereal grains make up between 60-70% of the diet and are the major source of energy in the diet and oilseed or fish meal are the main protein source and make up 20 to 30% of the feed. Scientific research seems to agree that replacing oilseed of fish meal with insect meal does not have a negative impact on chicken growth rates, feed conversion ratios, and mortality. In some geographies replacing soy or fish meal in poultry feed with fly meal (up to 42 percent in the starter diet and 55 percent in the finisher diet) did not have any adverse effects on weight gain, body composition, or flavor of chickens. But it did reduce the cost of feed and improved the cost-benefit ratio by 16 percent and the return on investment by 25 percent (Onsongo et al. on Kenyan chicken farming). With feed accounting for 50% to 70% of production cost for poultry producers, the conclusion is that insect meal could become an interesting alternative to soybean and fish meal, assuming that prices are competitive. However, there is no consensus yet if inclusion of insect meal at a certain stage of their life cycle, has a positive impact on weight gain or mortality. There is some research suggest that replacing 10% of soybean meal with insect meal could be beneficial for weight gain. In our base scenario we have included for the chicken feed segment, a 5% replacement rate and in the more bullish scenario we have retained a 10% replacement rate.

Also for pigs, soybean products are excellent sources of protein because their amino acid profiles complement those of cereal grains. Amino acids in soy protein are more digestible than amino acids in most other plant proteins, which results in less nitrogen being excreted in the manure from pigs fed diets containing soybean meal than if other protein sources are used. Depending on the age (weight) of the pigs, soybean meal is 15% to 25% of their feed with 5% to 10% of that sometimes replaced with fish meal, sunflower meal, corn gluten meal or potato protein. Research showed that a full replacement of fish meal by full-fat black soldier fly larvae meal was possible and did not adversely affect growth and blood characteristics. In our base scenario we have included a 2.5% replacement rate in the pig feed segment and in the more bullish scenario we have retained a 5% replacement rate.

The additional benefit of using locally derived insect protein sources instead of soybean and fish meal is that it is likely to lead to reductions in associated land use, water and emissions. Furthermore as insects can bio-convert waste into a high-protein and high-fat products potentially suitable as animal feed sources, they could contribute to feed and manure waste management. The 1.3bn tonnes of food that globally every year is wasted could be used for around 100m tonnes of insect meal/oil. In the US alone, the 45m tonnes of food waste could be converted in 4m tonnes of insect feed. In the EU, around 90m tonnes of food is waste, allowing the production of 10m tonnes of insect feed. Hence, there is ample food waste supply to allow for cheap feed for the insect industry and it should not be a limiting factor for the sector to reach its full potential.

Insect meal market outlook

In our scenario, insect and algae proteins could represent 5.8m (3%) to 11.9m (7%) tonnes out of the 170m tonnes of global protein market for animal feed.

Adding the different feed applications for insect meal/oil, our base scenario calls for 5.8m tonnes of insect meal production and our best case scenario for 11.9m tonnes. That compares with a current market size of the fish meal & oil industry of 6.0m tonnes and which according to different forecasts is expected to rise to 10.5m tonnes in 2025 and 13.9m tonnes by 2030. In our scenario where insect meal is a viable alternative, we do not expect the fish meal&oil industry to grow much beyond its current size, given over fishing, but instead look for insect meal & oil to capture the increased demand for higher valued feed protein sources. Indeed already over the past 25 years, the inclusion of fish meal in fish feed for marine fish has dropped to 12% from 50% and for farmed salmon to 12% from 45% (Olson et al.) as the growth in fish demand has increased prices for fish meal and the industry has been replacing fish meal with soybean protein concentrate. We believe that in future, insect meal could be a high valued protein source to fish meal and to a certain extend soybean meal.

And even a low penetration in human food could add another 1.5m to 3.0m tonnes (but at significantly higher prices).

Furthermore there is an additional market for insects in human food. Although there is a significant aversion to eating insects by Western consumers, insects have historically contributed to the diets and cultural practices of humans and is, according to the FAO, consumed by about 2bn people on a regular basis (additional comment: …but mostly for snacking). We calculate that in countries like China and Thailand, insects take up about 0.3% of protein consumption and that in Latin American countries the ratio is somewhat lower at 0.03% as consumption patterns have been heavily influenced by western diets. Nevertheless, the addition of insects as an ingredient (e.g. in snacks/protein bars for athletes or in flour that than can be used for bread, pizza, pasta etc) is likely to contribute to a more wide spread acceptance. In our base case we expect insect proteins to take up 0.5% of protein demand for human food and in our best case 1.0%. That would add 1.5m tonnes and 3.0m tonnes respectively bringing the total market demand for insect proteins in the next 20 to 30 years, to a range of 7.3m tonnes to 14.9m tonnes and USD13.1bn to USD20.9bn. Given the price differential between feed and food proteins we expect that around 35% of the market would be food applications, with feed applications accounting for 65%.

Fig. 34: Potential size of the insect meal & oil market

				Base Case		Best Case	
	Market size (m tonne)	% protein	Protein market (m tonne)	Insect meal/ oil share	Size (m tonne)	Insect meal/ oil share	Size (m tonne)
Layer	158	15%	23.7	5%	1.2	10%	2.4
Broiler	307	15%	46.1	5%	2.3	10%	4.6
Pig	261	15%	39.1	2.5%	1.0	5%	2.0
Beef	115	10%	11.5	0%	0.0	0%	0.0
Dairy	130	10%	13.0	0%	0.0	0%	0.0
Aquaculture	41	30%	12.3	5%	0.6	10%	1.2
Pet	28	25%	6.9	10%	0.7	25%	1.7
Equine	8	15%	1.2	0%	0.0	0%	0.0
Other	79	15%	11.8	0%	0.0	0%	0.0
Total feed (m tonne)	1127		165.6		5.8		11.9
Total food (m tonne)	1200	25%	300.0	0.5%	1.5	1.0%	3.0
			465.6	1.6%	7.3	3.2%	14.9
Feed (USD m)					8,628		13,374
Average feed price (USD/tonne)					1,494		1,124
Food (USD m)					4,500		7,500
Average foot price (USD/tonne)					3,000		2,500
Total market size (USD m)					13,128		20,874
Average price (USD/tonne)					1,805		1,402

Source: Bryan, Garnier & Cie

BRYAN, GARNIER & CO

Section 03

Conversations with Key Opinion Leaders

Conversations with Key Opinion Leaders

Clement Tiret, CFO Innovafeed

Where in the alternative protein market can I place Innovafeed?

Innovafeed is a biotech company that produces natural and sustainable ingredients for animal feed and plant nutrition from insect rearing. We first demonstrate the efficiency of our products before partnering with suppliers and customers to create value for all. For example in an extensive trial with Skretting, Innovafeed demonstrated increased feed efficiency in trout by up to 14% and improved organoleptic quality (deeper color, increased juiciness) through replacing up to 100% of the fishmeal with its insect meal. Using the improved quality of the end product, Auchan launched the insect-fed trout in its outlets, reinforcing B2C marketing on sustainability.

Where are you now in your development?

At Innovafeed we are looking to take a sizeable share of that market with existing plans for developing several plants that can each produce 15,000 tonnes of protein, 5,000 tonnes of oil and 50,000 tonnes of fertilizer.

Producing insect proteins is a capital intensive industry, but over the medium term Innovafeed could move towards a licensing model for part of the production process. Currently Innovafeed is operating two plants and a third one is being build. The company has its pilot site, inaugurated in October 2017, in Gouzeaucourt in the north of France, within the largest European deposit of agricultural and agri-food by-products. At our Nesle plant, that opened in November 2020, we are working with Tereos (starch manufacturer) that conveys wheat ethanol residues (bran and stillage) with a direct pipe, and Kogeban (biomass plant) to valorize its waste energy. The plant is set to reach 70,000 tonnes in capacity (15,000 insect proteins, 5,000 tonnes insect oil and 50,000 tonne fertilizer) Building on the experience acquired in France Innovafeed will replicate, through its partnership with Archer-Daniels-Midland, this industrial symbiosis model in the United States on the Decatur (Illinois) site – the largest corn processing site in the world. ADM Decatur's corn-based co-products will be locally recycled to feed insects through connected infrastructure between the two sites. We are currently building our US team to be in a position to start construction as soon as possible.

To further support the growth of the company, Innovafeed is already identifying large and promising feedstock deposits throughout Europe, North America and South East Asia.

What are the main markets that you are targeting for your insect products?

Our main focus is aquaculture and in that market both salmon and shrimp are a commercial priority with salmon currently being somewhat further in the adoption of insect meal as feed. Pet is our second focus but with somewhat more effort and traction from our side than a year ago because in this market it is already possible to sell volumes at interesting price points. However even today the aqua feed market is already potentially much larger than the pet market. The only limiting factor is to produce enough protein at the right cost. Today the pet market can absorb some volumes, but it's rather focused on niche applications. So that market will be saturated earlier than the aquafeed market.

I have heard figures that in pet food, insect meal sells at around USD3,500/tonne and in the aquaculture market around USD2,000/ton.

This is a fair estimate, insect meal in the pet food industry sells at a 70% to 80% premium to the aquaculture market.

How is the pig and poultry market developing for you? Is that still further away?

Already today we are selling in that market but it is with different products. Our insect meal goes mainly to the aquaculture and pet food markets. In aquaculture we are replacing fish meal and in pet food, the by-products from the meat industry. Frass, the manure from our insects, is used as a fertilizer. Our insect oil addresses the monogastric market, that is poultry and swine. In that monogastric market there is less potential for our insect protein because there it would compete with soybean meal and that is not a very well-priced product. But our oil is competitive with some of the vegetal oils that are used in the market, like copra oil. Next there are two kinds of upside. There is product upside with 1) developing new products in food, sport food, specialty proteins with more functionality, proteins for cosmetics, B2C versions of our fertilizers Next there is also model upside leveraging its proprietary technology for other applications (e.g. insect rearing for biocontrol, vertical farming of plant species like mushrooms, etc.).

Fish meal prices have been around USD1,500 per tonne but have recently jumped to USD1,650 per tonne. Is that the prices you are competing with? So you charge a premium?

We price our product in a way that allows us to remain competitive with high quality fishmeal, which trades at prices that are consistent with the numbers you mention. However we are able to charge a premium to reflect the additional performance we are creating for our customers (zootechnical performance and environmental performance).

So why are customers wanting to move to insect meal?

It depends on the market segment. For pet food it is a sustainability angle and the functional properties of the product in particular the hypoallergenic pets because insect proteins do not create any allergies, while the by-products of the meat industry can create allergies. In the aquafeed market it is first an enabler of the growth in that sector. Today the growth of aquaculture is capped by the availability of fish meal. And because aquaculture is growing fast it needs to find alternative sources of feed. Plant based proteins is not enough and they need to include a certain amount of animal protein in the diet of fish and shrimps. So the only alternative today to fill that gap is to use insect meal. So that's the first driver of customer adoption. A second driver is the full value proposition of our product as a replacement for fish meal. A first part here is that insect meal has positive effects on the growth rate and on the health of the animals fed. And the other part is that it improves the footprint of aquaculture. Today 80% of the carbon footprint of salmon is driven by feedstock and if salmon producers want to position salmon as the animal protein with the lowest CO_2 footprint they need to lower it by 50%. A kg of salmon produces 6 to 7kg of CO_2 compared to chicken which is at 4kg.

When I hear you, you seem more advanced than others in the aqua culture area?

We have been focusing from the beginning on aqua feed and that has consequences on many of the choices we've made. It has consequences on how we define our production model. So there was the choice to go larger scale and to build our factories on an industrial symbiosis model optimizing our cost base with automation, feedstock and energy in order to achieve a lower cost. And that has also driven our commercial strategy: we have today the largest contracts in the industry in the aqua feed with the main players. And now the challenge is for us to scale production to meet our customers' demand.

Where do you see the insect protein market in ten years?

Based on the pace at which we are ramping up, deploy technology and also if we see what our competitors are doing, we are convinced that in 10 years from now, the insect meal industry will be above one million tonnes of protein per year. Fishmeal is currently at just over 7m tonnes and could rise to 10m in 2025, so we would still remain smaller than fish meal but be a very credible alternative and with a clear path to fast growth. Our guess is that between 15 and 20 years, the industry can really expand and potentially bypass the fish meal production.

Would it be a game changer if you could use other feedstock for your insects eg. waste?

The waste is a very interesting topic. It is very promising in the long term. Bear in mind that not all insects can recycle waste eg. the mealworm cannot be fed on organic waste streams, BSF can. Although there is some great longer term upside, it is extremely difficult to build an industry with a consistent quality product if your main input has a high level of variability. Regulatory wise in Europe, pre-consumer waste (industrial and supermarket waste) can go in the human food chain but post-consumer waste cannot. The aquaculture market that we are targeting need large volumes with a consistent quality. And the quality of the larvae depends from their feed. The one player who tried to produce at scale was Agriprotein, the South African company, which, unfortunately, went bankrupt. There were probably different reasons for that but adding the complexity of variability of feedstock to producing at scale was probably one of the reasons.

So we are starting with large volumes of stable feedstock, meaning agricultural byproducts. And once we have a production system which is extremely reliable, then we take it to the next level of complexity adding to that system the waste processing.

Has the invasion of Ukraine had any impact on your business?

I guess it reinforces the need for local sources of protein. Insect products are local sources and reduce the need to import from Russia or elsewhere. It is particularly true for fertilizer that is imported from both Russia and Ukraine and where frass, insect manure, is an organic alternative. So we see increased interest and prices. Most fertilizers are linked with gas prices and as a consequences the market prices of frass has doubled.

If you look back in five years' time, what would you define as having been successful?

The company was created with the ambition to have a strong and positive impact for society. It's an impact driven organization. And the way to maximize our impact is to sell as much protein as we can, because every tonne of fish meal that we replace is less fish caught and less CO_2 produced. So success would be a fully scaled up business with multiple commercial scale plants in operation in the geographies that we want to address, which are EU, North America and South East Asia. The projects have been identified and now it is about turning them on to make sure that they produce what they are designed to produce. Additionally we would like to have created an attractive technology platform for other players to license and to speed up the development of the industry. If we can partner with other players to speed up the development of the industry. And then another key objectives is to extract as much value as we can from our insects. There are still a lot of products in development that could increase the value we can extract, for instance in human food applications.

Mehdi Berrada, Co-Founder Agronutris

Agronutris has been experimenting with both the black soldier fly and mealworms. In the end you choose to focus on the black soldier fly.

Black soldier fly and mealworm are at this stage of the industry the two species that are mostly considered for mass production. Choosing between the two depends on the market that one wants to address. We selected the black soldier fly for the feed market because from an economical point of view it is more efficient to produce: it has a shorter life cycle, (14 days vs 70 to 100 days for mealworm), there is a higher feedstock flexibility, it has a more efficient feed conversion ratio and is cheaper to produce for an equivalent quality.

So from our analysis it will be more efficient to produce BSF at scale given that for B2B (customers are fish farms, pet food producers, etc…) the cost sensitivity will be high. It does not mean that when the industry will be more sophisticated and that it starts to address different functionalities that each insect could find an area with high value added. But at this stage of maturity of the industry the question is which insect can deliver the best business model to address the protein challenge.

It seems to be easier to compete with insect meal in the pet food industry than in aquaculture. Why would that be the case?

The petfood and aquafeed industry are quite different. The pet food market is a growing industry and they really need proteins. They need sustainable solutions. They need innovation in the premium area with new ingredients. And the value chain is quite simple. Our pet food clients have brands and are in direct relationship with the end consumers and they are quite profitable. If you put it all together: there is room for innovation that has value for the end consumer, which simplifies things. In aquaculture the agenda is clear. Everyone wants to reduce the carbon footprint of the feed, mainly because the feed is the main contributor to their carbon footprints. All have the agenda to reduce soil and marine resources. But the value chain of aquaculture is quite complex: you have a long value chain with feed manufacturers, farmers, transformers, and a lot of private label products. So building innovation that has value for the end consumer and that is priced at premium, is much more complex. We are very confident for the future, given the convergence of interest between our solution and the agenda of all these aquaculture companies, but as an industry. The right answer is more challenging. And also we are not yet price competitive with fish and soybean meal. We will get economies of scale and have prices for insect feed below those two, but it is a journey that we have to make with our clients.

So access to waste is key to bring cost down dramatically and start competing?

It could be a game changer, but we shouldn't rely on that too much. First of all the starting point is amazing because we have already today a carbon footprint that is half of the one of fishmeal and three times lower than soya and even five to ten times lower than the pigs and poultry and 30 times than beef. So we have a solution that is very, very competitive. And I think in the next 10 years thanks to economies of scale, thanks to improvement of genetics and nutrition and thanks to access to waste, you can divide our carbon footprint but four to five times. So it gives you a feel to what extent insects are answering the agenda of carbon footprint reduction.

So we are answering the question on reducing the external costs that is not priced today, but everyone knows that it exists. Second thing is that the price differential between fishmeal and insect meal is that big as a starting point before we are scaling up as an industry. And to close the gap there are three levers that has been used in all the other animal rearing areas that has been industrialized: nutrition, genetics and also rearing conditions like the climate, the humidity, the density, etc . And you have on top of that economies of scale. So before looking at waste to further lower our cost base, there is a lot we can achieve. I am very optimistic that we can beat fishmeal and even soybean meal prices in the coming years. Being able to use waste will definitively be a game changer but it depends on an external event, i.e. legislation.

So what is the level of price differential today? It seems a closely kept secret.

The prices have evolved a lot and all depends on the volume and length of the contract. On the most competitive contracts, I would say the price is 50% above fishmeal and that can go up to two times the price for much lower volumes. Most of the contracts today are around USD3,000 to USD3,500 because most of the contracts are not volumes where you can be very competitive.

If you would get a significant contract, would you be able to deliver the volumes?

Yes and no. For the moment we are in the scaling up phase and that will allow us to deliver significant volumes. Our current pilot plant is for R&D and not to serve customers. Our new factory will be producing 5,000 tons p.a. and that compares to a fishmeal industry of 6m tons. So, obviously, this is the challenge. The bigger our factory, the higher will be our volumes and our efficiency and competitiveness.

Do you expect one day that the insect industry could be as large as the fishmeal industry?

To be honest I can see it will be much larger in the medium term. Insect meal is not impacting bio diversity, it has a lower carbon footprint and, in the coming years, it will be more price competitive than fishmeal. When we achieve the price point of fishmeal, we are opening a huge market and if we touch the pricing point of soybean meal, it will be another game changer. And it will happen.

The salmon industry have improved its efficiency by 40% in the first ten years. And the salmon industry did that while reducing the part of fishmeal in their feed to something like 20%. So they improved efficiency while at the same time reducing heavily the nutritional profile of the feed. So we are starting with a profile that is already better, we have lifecycles that are very quick compared to salmon (two months versus 2.5 years). So we can learn very quickly with the black soldier fly.

So what is the latest update on Agronutris? When will you have your first commercial harvest?

In September of last year we raised 100m euro to finance the first industrial scale factory in Rethel and fund the creation of a larger second site. Normally by the end of this year we will create a reproducer population and in April next year we should ramp-up to producing insect for harvest in the second quarter.

Mohammed Ashour, Co-Founder and CEO of Aspire Food Group

Most of the companies I speak about the insect industry are involved with the BSF. You on the other hand are very much into crickets

We all understand the thesis for insects as a more environmental and sustainable protein source. Furthermore, around the world there are changes in consumer demands and perceptions that are converging with these issues. Increasingly consumers are more aware of their environmental impact and concerned about the sustainability, they are increasingly more demanding a clean label, but at the same time they also want to enjoy great optionality and don't want to scarify on taste and so on.

We are entering a world with greater expectation from the consumer but it is also being met with greater technology and advancements in food science including the production of protein that allow you to meet those really high expectations and demand. That is where the insect protein category is positioned to be successful because fundamentally when you think about a lot of the protein sources (livestock) the major limitation is the animal itself. They are a bioreactor that is converting feedstock in protein biomass. It is not rocket science. If you can identify the animal that has the best conversion efficiency, you are going to land on a production system of protein that uses the least of other feedstock which means that you safe money because it is less expensive to feed the animal and it is also better for the environment because you are using less land, water, energy, etc.

When we looked at insects more broadly, we firstly wanted to identify the insect that has a high appeal for people. The reason is that it are people that are making the decision to buy food for themselves but also for their pets. Their dog or cat might eat indiscriminatory any insect in the wild but if an insect carries a negative stigma for whatever reason or if for any particular reason they find a particular insect gross, they are unlikely to buy that for their pet even if the pet is perfectly happy to eat it. For us at the Aspire Food Group, it was important to get in the psychology of the consumer making those purchasing decisions from the very beginning.

The second aspect is that we wanted an insect where there was already a significant domestic production of that insect. We did not want to reinvent the wheel, we saw many different insects that are being bred in captivity and we found that crickets was the most universal farmed insect in the cottage industry from Kenya, to Latin America to most of Asia and North America , albeit it for pet food and reptile feed. It checked the box that there is already decades of farming it, with most of the issues in farming it being resolved and that it is a species that exists everywhere in the world. So if we think about global scale and setting up global production systems everywhere around the world, it is very convenient to source that organism locally as opposed to importing invasive insects in another country.

How does your industrial set up look like?

We followed a bid the tesla business model where you not just want to build a company but also the infrastructure to support an industry. If our goal is to make crickets affordable to a single mother with three children in a rural community in Ghana, our cost has to be so low that we still are able to make a margin to be profitable . That means we will need massive economies of scale which will take years to achieve. Our dream is to serve a mass market but we are not there yet so we start with this high end model, premiumise the product and as we gain more scale and efficiencies and our costs come down and consumer excitement increases we will effectively capture that market as we continue to grow. Our focus has been predominantly been on pet food as well as the performance market in human food as well as frass in the plant nutrition market. So we have not been focusing on agricultural feed and other livestock markets even though we are actually cost competitive with a number of the BSF producers. A lot of people are assuming that cricket farming is more expensive and more tiresome but in fact we have developed a methodology that we can farm crickets in a fully enclosed system (and we are the only company in the world to do this) in a hyper dense environment. That allows us not to intervene, open or touch the bins for the entire 4 week cycle of production. For a lot of companies that produce worms or larvae, the challenge is that the feedstock is also the substrate in which they live. So the problem is that they excrete their waste in the same substrate . So at some point the ratio of food to frass is high enough that it is no longer an efficient conversion and that is why a lot of these operations, in the mid cycle, will swap over substrate for fresh feed. That is a costly step as it involves capex and working capital. So we have achieved a cost structure, assuming that we purchase our feed (opposite to the assumption that we source our feed for free – that is going to be quickly arbitraged). A modular platform for production of insects that is suitable to crickets but that can be applicable to other species of insects. Our focus today is the petfood and the performance market in human food as well as frass. Cricket frass has the highest NPK value of the different frass that is produced by mealworms as well as by BSF. In a nutshell the main differentiator for cricket is that:

1. They have a lot of benefits of the other insects without some of the challenging production handicaps at scale

2. They are more desired in the premium end markets which we think we have to play initially.

How far are you now with the construction of your factory?

Our first facility here in London, Ontario will be able to produce about 12,000 tonnes of crickets as well as 12000 tons of frass annually. We have completed construction and are now in the process of commissioning. So we are completing the installation of the equipment and we expect our first production to be next month. So we had we had a few delays, obviously, because of the covid. But for the most part, things have moved along better than probably most companies that were impacted with the construction timelines. So yeah, we're excited to get our first harvest in about a month's time from now. Our expectation is that within the next 7 years we will be operating 8 facilities globally. Future facilities will each produce approximately 30,000 tonnes each of cricket and frass.

How large will that first harvest be and how many harvests can you do p.a.?

We expect to do about 13 harvests a year and look to produce about 1,000 tonnes per month of wet matter crickets. And 1 tonne of wet matter can produce 0.3 tonne of dry matter crickets and about 1 tonne of dry frass (over time that should come down to 0.8 tonne of frass as we improve in feeding).

So that is a very similar output to BSF. Nevertheless you believe that you can be more efficient and achieve higher margins than with BSF?

That is correct. Ultimately, the simple answer is that crickets experienced one biological change in their life. They're basically born baby crickets and they grow to become grown-up versions of the same cricket. BSF fly larvae are effectively a worm or a larvae and then a fly. So there's two different life cycles that you have to manage, which have their own individual and very different breeding systems, husbandry systems, production systems, feeding and watering kind of regiments. So that adds a layer of complexity to the process and introduces a separate stream of workflow, as opposed to where we're able to take advantage of the economies of scale of all the insects going through the same exact lifecycle for every stage.

On the selling/marketing side of the equation, do you have already contracts lined up with pet food producers or is it still exploring what their appetite might be?

No, we've already committed 60% of the production of the facility already on take or pay contract. So we already have commitments for about 60% of the facility's output. And then we have some soft commitments for another 25%. So we are optimistic but of course, it's going to be a busy few months. And we have to make sure we get our specs and everything is produced as expected. But we do have some strong commitments already in place.

Can we speak a little more about your end-markets. You look more to focus on the pet food market rather than the aquaculture market.

Yes, actually, we're very focused on the pet food market at this stage. We think that there's a lot of room to grow that market opportunity and that there is enough potential there to satisfy our production capacity for a number of years to come. So we've never really been focused on aquaculture feed. You know what's interesting is if you look at all the different companies that are farming different insects, the reason each company farms the insects that they do is because of the markets they initially focused on. So all the black soldier fly companies were initially were focused on aquaculture and so they needed to pick an insect that can opportunistically consume basically any source of feed, ideally where you can get the feedstock for free and where you can produce a protein that can be consumed by aquaculture. So that makes a lot of sense for black soldier fly larvae right? Now obviously if you're going to sell black soldier fly larvae to pet food, that value proposition is not very attractive to the consumer. The consumer wants to know that their pet food is very high quality and that the feed that is being given to the animal or the livestock is a high quality feed. Using pre-consumer post-consumer waste to feed black soldier fly is exciting from a sustainability perspective. But for a lot of consumers, it's not really great to know that you are feeding your pet fly that was fed on waste streams. So a lot of the black shoulder fly larva companies that are trying to penetrate the pet food market now have to purchase a high quality feed to give the black soldier fly larvae which sort of defeats the purpose a little bit of that value proposition.

From our perspective we picked crickets because we wanted a human food insect that has an established history of human consumption. So from our perspective, I don't think a cricket is the ideal insect for aquaculture feed. That's not to say that you can't use waste streams to feed crickets, but I view that as a completely different business model.

All the black soldier fly larvae companies are effectively three businesses into one: they have a feed processing business, then they have a breeding business and then they have an actual rearing business. From our perspective, that's not really the business model. We found that involves a lot more complexity and also requires is more supply chain restrictions because you have to locate your business near a waste provider, you have to get locked into these long term waste offtake contracts and that creates a lot of dynamics in the business model in the sense of restraint for scalability and growth. So from our perspective, we wanted an insect for which you can use an off the shelf feed and grow that insect and still have a strong enough unit economics to build a meaningful business around it. And that's why I'd say our focus for the foreseeable future is going to be pet food, not so much aquaculture or livestock feed.

So you feed your crickets with any normal compound chicken feed?

Correct.

Are crickets than the most sustainable way to use that chicken feed. Why not use the chicken feed to feed pets directly?

So the issue with chicken feed is that it doesn't involve animal meat. So most pet food has to involve meat. Dogs and cats both require the consumption of meat. So if you're using a largely plant based feedstock, that's not really something that can feed pets in a reliable fashion. And so that's a big part of it. Of course, it wouldn't be better from a sustainability perspective to use waste as a feedstock. There's no debate about that. The challenge that creates some supply chain tension. So I would prefer to trade off losing a little bit of sustainability points for the durability of the business model and the knowledge that we can build this business virtually anywhere in the world because we're not having to co-locate with a very specific feedstock supplier. So that was the choice that we that we made as a business.

If you look back five years from now, what would you have liked to create?

I think that we would have to have validated the very thesis of why we started Aspire in first place. We started Aspire as a response to a challenge to build a business that can, on the one hand, be highly beneficial from a sustainability and environmental perspective. It was also meant to address global hunger, while at the same time, be highly profitable. So if five years from now we are a very profitable company, but our sustainability scores are not much better than whatever it is we're displacing than I don't think we will have succeeded. If five years from now we're very, very amazing on sustainability and impact, but we're still depending on investors, subsidies or grants than we haven't succeeded. But if we accomplish the dual goals of demonstrating the social and environmental benefits in a real way, while being profitable, to me, that is success. So that means I don't need to have 10 facilities five years from now, I just need to have a business that is delivering real metrics on sustainability and impact while being highly profitable.

Would it still be in business that looks at pet foods, or would you already have shifted more towards human foods?

My expectation is that trends in human food will continue to pick up over the next five years. But in the best case scenario it would be 50/50. Like 50% of our production is going to human food and 50% is going to pet food. In other words, that we would see a very significant increase in human demand relative to the rate of increase of pet food demand? But more practically speaking, I imagined that the demand in pet food will continue to be overwhelmingly very large. So it'll be very interesting to see what that looks like. But objectively, five years from now, the demand in human food will be, in my view exponentially larger. than it is today. Whether it's going to be the same amount in absolute terms, as the demand for pet food or a fraction of it will remain to be seen.

Who are your competitors in the pet food market?

I view our competitors as companies who produce insects at scale and who are trying to take a share of the pet food market. So for me if it's an insect protein company that is focused exclusively on aquaculture feed, I don't view that as competition because it's not the same product, but it's not the same market. But if it's either the same product, so if it's a cricket farming business, or if it's the same market, pet food, then it's obviously potentially a competitor. In that case, I would say there's probably about five companies that I would consider meaningful competitors that are looking to obtain a share of the pet food market. Some of them are black soldier fly larva companies, some of which are mealworm companies, but as far as crickets, we're really the only ones to my knowledge in the world that are operated at this scale. For mealworms, I would say Ynsect was the only one in the world operating at scale. For black soldier fly larvae, I'd say there's probably three companies that are operating in a very large scale. You have Protix in the Netherlands. Enterra out of Western Canada and EnviroFlight from Ohio and then perhaps you could throw into the mix InnovaFeed.

Mohamed Gastli, CEO nextProtein

Where does the insect industry stand today and how do you see its development?

Today, the most advanced players around the world – including nextProtein – have proven they could farm insects at industrial scale. In other words, they have proven they could develop a technology from scratch to enable insects to thrive on organic waste and breed them in a fully controlled environment.

Looking ahead, insect farmers will seek to multiply the number of production facilities around the world to turn insects into a mainstream source of protein on par with conventional ones such as fishmeal or soya. To achieve this and disrupt the projected 265m tonnes soja and fish meal markets, millions of tonnes of insect meal will need to be produced.

How do you see the feed market responding to this new industry? What are their concerns? How do they see the benefit?

The insect farming industry emerged for several reasons: as a solution to food waste but also to address another global challenge : the protein gap. By 2050, we will need to feed an additional 2 billion people. As things stand, our current food systems are simply unable to address that increase and, naturally, the nutrition industry has been searching for new sources of proteins. It is in that context that our industry emerged : as a solution that would address the protein gap but that would also put our food systems back on a more sustainable track.

How international is this insect feed market? Why not produce insects in Asia, where regulations on the use of waste are more relaxed, costs are lower, and ship the product to the European markets?

Today, insect protein production is essentially concentrated in Europe and China/South East Asia. Due to high transportation costs and mostly uncoordinated regulatory frameworks from one country to the next, insect feed markets are for now mostly regional. For example, a company farming insects in Vietnam may produce in line with domestic standards but will not be able to sell in the EU either because the countries do not have compatible regulations/trade recognition or simply because transportation costs will make the transaction prohibitively expensive. The only notable exception is the North American market which is served by other regions due to the lack of significant local production.

Where does your company stand in the insect industry?

nextProtein is one of the most advanced players worldwide. It has already developed its first industrial scale facility and is in the process of fine tuning its technological blocks before replicating its model around the world. More importantly, the company has developed a strong brand by pioneering a new business model. 7 years ago, when most of the industry's development was taking place in France and the Netherlands, nextProtein decided to make a different bet.

Although headquartered in France, the company decided to develop itself in places that had limited access to waste management solutions and focus on low grade feedstock that would otherwise end up in landfills. In other words, nextProtein found a way to make circularity and cost efficiency work hand in hand. The underlying assumption being that by reducing cost faster than the competition, the company would benefit from a first mover advantage in the commodity-driven aquafeed industry.

Let's look at some financials for your business?

nextProtein has finalized its facility with an installed capacity of 400 tonnes annually of insect meal. Next year, the company will reach an installed capacity of 2500 tonnes. Profitability will be reached when the production scale up is finished in the 2500 tonnes factory. nextProtein’s business model was designed to reach profitability at a relatively low scale to make its facilities relevant not in just a few places around the world.

How is your solution different from your competitors? How competitive is your pricing vs competitors but also other protein sources?

nextProtein’s heavy focus on cost efficiency allows the company to always adopt a lower pricing point compared to its competitors while remaining on par in terms of safety and quality. The company’s objective for the short term is to become price competitive compared to fishmeal so as to enter the commodity market.

In 5 years’ time - what would be for you the criterium to judge if you were successful?

In 5 years time, nextProtein will:

- farm insects on three continents
- become a waste management solution to a wide array of stakeholders :farmers, food processors, supermarkets, hotels as well as municipalities
- offer its products in most animal nutrition industries not only as more sustainable options but also as price competitive ones

Marc Bolard, Co-Founder Nasekomo

Let's kick off with a very broad question on where the insect industry sits today and what are its opportunities to develop further?

For me, we are only at the beginning of the insect industry for bioconversion and this new industry is still working to understand where it should be positioned and what is the best approach to grow. But its starts with a real need from the agricultural sector for new quality protein ingredients, not to replace existing fishmeal or soybean meal, but to fill an already existing and further widening gap. Furthermore, the end-consumers are increasingly questioning food and feed producers about their products sustainability, their efforts to reach carbon neutrality, encourage biodiversity etc. It is playing an increasing part in their decision making when consuming and insect products are one of the leading solutions to improve our food sustainability.

At Nasekomo, we are focusing on the bioconversion by the BSF (Black Soldier Fly) to address the protein needs of the animal feed and pet food markets and, with our frass, on plant fertilization.

How competitive is frass in the fertilizer market?

Frass is classified as an organic fertilizer. Already before the Russian invasion there was stress on supplies of organic fertilizer because of current changes in rules on the use of pig and poultry manure in organic fertilization that are becoming stricter. The Russian invasion added additional tensions on the supply chains. Furthermore, there is initial scientific evidence that frass as an organic, locally produced, non-fossil fuel-based fertilizer, has functional advantages over conventional fertilizer. Along with other nutrients, frass contains chitin, and that component seems to impact positively the soil microbiology and improves the immune system of plants. The combination of being innovative, organic, and offering functional benefits does allow for frass to be properly valued on the market.

I understand that using waste to rear insects is particularly interesting because it plays into the idea of a "circular food production system" — one in which waste products can be reinvested into the system so that more food and less waste is produced.

It is true that insect can play a key role in the circular food production systems through feeding them with products that otherwise are wasted. However, it is not exactly the positioning that Nasekomo has chosen. In the early stage of our development, we were working with unsold fruit and vegetables from supermarkets. However, when we started discussions with potential clients, they were alarmed because of this feed source for which traceability is difficult to guarantee along with other requirements such as non-GMO certification, potential contaminations and so on. We understood very quickly that we would not be able to answer in a convincing way these critical questions. Since then, we have developed a comprehensive checklist of all the necessary requirements expected for a potential ingredient to enter our insect diet and most waste stream do not qualify yet. Our focus is more on agro-industrial by-products for now that do not have satisfactory downstream processing.

And together with our clients, we are finding out more about our products, their compositions, functionalities, their uses, and impacts on the final consumers. Our industry is young, and we do not have all the answers yet. For example, we all speak about insect protein meal, but the truth is that there is a huge variability behind this product category. Insects are not fed with the same diets across producers, but they are very flexible animals, and their composition will change because of their feed or the ways they are produced and processed. It is most likely that this variability will impact differently the animals or plants that consume insect-based ingredients. This means we need to work for better definitions of our product portfolios and towards a higher degree of standardization of our product range.

For the moment insects are more in a premium, high value feed market. And if we want to be in that market segment, we need to be premium all the way along the value chain and that means we cannot really be associated with waste for now. In the head of the consumer, you cannot produce a premium product with waste, so if we want to produce premium food (e.g. salmon), we need to use premium insects and they need to be fed with premium ingredients. Producing locally is also strategic for insects as a source of protein meal and oil, when other main supplies, soybean meal and fish meal are imported from far away outside Europe.

What is Nasekomo's place and vision in the insect industry?

For the moment we are producing protein products and frass but we are in a transition towards becoming an industry enabler and solution provider. So, it will not be about producing protein meal ourselves but to build partnerships with insect bio converters and to give them the solutions to develop their bioconversion and to address together the needs of the key accounts in the animal feed industry.

We are building a new factory that will be a research and development center but also a showroom for our technology and all the solutions and services that we can bring to the industry. We want to develop partnerships with agricultural producers that are willing to enter the insect bioconversion market and we bring them all the tools they need:

1. The first solution we bring to our partners is the biology. We are already producing and selling young larvae and some of them have been genetically improved to be more efficient in the bioconversion industry thanks to our joint-venture FlyGenetics with Grimaud Groupe.

2. Secondly, we also develop a proprietary industrial scale technology for the entire bioconversion process which I think is completely different from the currently available solutions.

3. Thirdly we want the insect bioconversion industry to be data driven and so we bring all the digitalization technologies to our operations and add a digital connection part that is operated in real time.

4. Last thing we do is to organize the network of bioconversion partners, so that these partners cooperate together to address the needs of the global market. Our understanding is that one operator will not be able to address the needs of the key accounts who tend to order fish meal and soybean meal by boatloads. No insect bioconversion unit alone will be able to fill a boat, so we need a "swarm" of insect farms that operate together and deliver.

In what sense is your technology different from what currently exists?

Most of the industry grows insects inside boxes that are moved in a warehouse type construction. We grow insects in beds that are 80 meters long, 2.5 meters wide and 30 cm high and we stack vertically up to 12 of them on top of each other. We call this solution an "Airbnb" (Automated insect rearing beds and bots) because it includes all the robotic, automation, ventilation, and monitoring solutions to operate the bioconversion process and "accommodate" our highly efficient insects. It is a massive structure for a solution specifically designed for insect bioconversion that allows extreme scalability. One Airbnb can process without any human intervention about 20,000 tons of feed for insects per year (producing 5000 tons of insects per year). So, you do not need many Airbnb's to build an industrial scale farm.

And that is particularly important to us. We develop not only a scalable model but also a complete approach for geometric growth of our industry to have a real impact. We want to push this ambition by enabling a partnership model where we can grow in each region and at the same time networks of connected insect farms in synergies with partners willing to enter the insect bioconversion industry. Our technology is geometric with its ability to scale and to operate, our digitalization services are geometric (all insect farms will benefit from the centralized processing of data) and of course our animal population grows geometrically both in head counts and in total biomass (you need billions of insects to power those bioconversion units). (BSF females average around 500 offspring's).

In five years' time, what would be the criterium to judge if you were successful?

I will be successful if I am able to deliver insect-based products and services to our industry key accounts, through my network of insect bio conversion partners. It means that Nasekomo will have developed the biology, the technology, the digital solutions, and a partners' network that works together to deliver and have a significant positive impact on our world.

Antoine Hubert, CEO Ynsect

Where does the insect protein industry sits in the alternative protein industry?

The world will need 70% more food and proteins by 2050, so it is inevitable that all the proteins that can be produced will be needed, whether it is from insects or any other source. However, it will need to be a clean and healthy protein product which raises questions if in the long run the ultra-processed ingredients such as those in plant based products will still be interesting. They are not contributing to the health of consumers because of the processes and chemicals involved in the manufacturing of these products. In general insect companies pitch their products as protein and sustainability, telling that insect are a protein like chicken, beef, fish, but that they are more sustainable as they take waste from other industries and are transforming it. At Ÿnsect, we believe that is not enough. Just producing insect proteins as an alternative is not enough, it has to have more functional and health properties to command a premium price position. Otherwise it will be an alternative to soy protein which is a commodity.

Why did Ÿnsect choose to develop a mealworm business?

Not only is the protein count higher in mealworms (72% protein) than other main farmed insect including black soldier fly (between 40% and 55%) but mealworm also has the lowest ash count (less than 3%) compared to other lesser insects such as black soldier fly which has generally above 10% ash. However, it's not enough as mentioned earlier: it has additional properties for aquaculture, petfood, human food and human health. In aquaculture, a 34% increase in yield for rainbow trout was observed, a 40% mortality reduction on shrimp; a 25% increase in yield for rapeseed; a 25% mortality reduction for seabass; and a reduction in skin disease for dogs among others. In mice, adding insect meal reduced cholesterol by 60%. As a result mealworm proteins have not only a much better protein count and a much lower ash count but also have properties that would allow for more markets and a premium positioning in those markets.

In April last year, you acquired Protifarm. What are the drivers behind this deal and what kind of synergies do you expect?

We did this acquisition because they were the largest mealworm producer after us. Even though it is another type of mealworm – the lesser meal worm, while we are producing the yellow mealworm, we find there are a lot of technology synergies. However, the first reason to acquire them was that they are the largest European producer in the food segment, delivering all start-ups in this field with their products. There is also a strong link between human food and pet food in terms of standards, hygiene, best practices, so being good in human food can have a positive impact on our position in the pet food market. The second reason was that they had also an interesting extraction technology that can be also relevant for the production of animal feed products. And thirdly also in the farm they had some other methods that were complementary to what we were doing and that increases the overall performance of the yellow mealworm production. Fourth it is a different species and with that we found some different compounds that also later on could be valued differently in the market. So that were the reasons. In the global IP portfolio size we and Protix are the leaders and Protifarm and Aspire are the next largest IP owners. So we combined two larger players.

In the near future, could you imagine to produce both the lesser meal worm and the yellow meal worm on the same site?

It is not going to happen on our next site in Amiens (regulatory wise we cannot yet produce animal and human food on the same site) but in the future that could happen. As we have increased our knowledge of both the lesser mealworm and the yellow mealworm, we have now developed a new design of co-generation that is supper efficient and that would allow to have both insects on the same farm.

What is now your combined capacity?

We don't communicate on precise capacity except for that Amiens will be about 100,000 tonnes of ingredients and this is about 1/3 proteins and 2/3 of frass.

Where are you with the Amiens plant?

By the end of this year, we expect to start producing insect proteins for the animal feed industry. We are currently commissioning the plant. And most of the production of the plant is sold out for the next two/three years for a total of USD150m of contracted revenues.

Is there more M&A on the horizon?

We are considering other M&A. We are looking to opportunities in the mealworm segment. There are a dozen or so mealworm producers, that are significantly smaller than we are but could add interesting segments or geographies. We already bought the US-based Jord Producers, which was a smaller yellow mealworm farm that is selling live mealworms globally for the backyard chicken feed market, which is than another segment that we were able to enter. As the company is based in the US we then also entered a new geography. But next to other mealworm producers, we are also looking to other species. In the future it is likely that we will be farming also other species next to the mealworms.

How are you differentiating yourself from competitors?

Compared to other mealworm producers we are able to deliver significant volumes with consistency, proven track-record and have a large range of products. Next, there is all the IP which is a big barrier. Furthermore we continue to invest in science and are continuously developing new claims, properties. Compared to other insects, we have this premium positioning because of the research that we are funding. For our products, we have proven the nutritional benefits on animals and plants.

What drives customers to your solutions and why do they want to pa a premium?

In the beginning the industry participants thought that the main selling point was the sustainability angle, but afterwards found that is not enough to sell its products at a premium. We sell now products with higher functionality, performance, quality and backed by science often developed together with the customers themselves.

How did the invasion of Ukraine changed your business?

So far there is no large impact because our company is still relatively small. But there is an impact on capex because of the rising prices of concrete, energy and materials. On the operational level, raw materials and energy costs are increasing. Because of the impact on natural gas prices, we are now doing efforts to be less reliable on that energy source, either through biogas or full process electrification. And for raw materials, it is important to note that we have a broad range of feedstock for our insects. Actually we have more than 300 different feed sources that we can combine and switch from one to another, and still get the same consistent output. It has been one of our main investment over the past 10 years to be flexible enough, to have enough diversity in the recipes and are able to change the recipes according to the economic context, the local availability, the local price.

Next there has been also an increased price for our products. Prices for insect proteins, insect oils and frass have gone up significantly.

In five years from now, which achievement would you consider a success?

We will be running a few factories in the world (Europe, North America, Asia) of the size of the one in Amiens, producing insect ingredients for animals, pets and humans. We have already an improved design and we are working on new locations. In five years or so, we could hope that the applications in human food will start to be meaningful, but so far in our Business Plan we have been prudent as we foresee to be only a small part of our revenue by 2027.

Kees Aarts, Co-Founder and CEO of Protix

Kees, you've written 'The Footprintarian'. Was the idea behind founding Protix to make the world a better place?

Yes, that is very much Protix' aim. My book, 'The Footprintarian', encourages people to limit their ecological footprint to a minimum with their everyday choices for food and feed. At Protix we believe that every individual can contribute to a more sustainable future by asking the footprint question with each product they buy or consume. We believe that this attitude will have massive impact on our food system – more than confessing to a single solution such as skipping certain products from their diet such as other -arians.

As a company we want to make a positive contribution to the planet, restore the balance of nature, and promote greater biodiversity. The role Protix plays in this is to provide ingredients with an incredibly low footprint for food and feed applications. Our ingredients use minimal energy, water and land, as proven in work we have done with the Deutsches Institut für Lebensmitteltechnik and ETH Zurich. Consider this: We can produce a phenomenal 10,000 tonnes of protein per hectare annually based with our insects whereas soy is produced at a rate of three tonnes per hectare and even the best algae farm produces only 100 tonnes per hectare. To change the food system, we need to deliver a quality product and a reliable output which is exactly what Protix does.

We have achieved these game-changing figures by extensively researching and investing in our technology, the biology, our operations and our customers. The black soldier fly (hermetia illucens) is a key player in bringing our vision to life: their larvae provide us with a unique source of protein and other nutrients for food and feed. We are unique in having complete control of the production cycle and harnessing the power of insects – nature's greatest upcyclers – on such a large scale and in a very high-tech environment. Using our insect ingredients, i.e. proteins and fats, in feed and food dramatically reduces the footprint of our entire food system in a natural way.

The question is whether the masses want to eat insects?

That's exactly right! An insect is a very high-quality package of proteins and other raw nutrients. All birds, reptiles and fish, and most mammals eat them when they are young, have to grow quickly, and build up their immune system. Insects are already standard fare in many countries and it may take time for other cultures to adapt. But it was just the same with raw shrimp or sushi in the beginning. It takes some time as people need to understand the value and get used to the idea.

What are the key segments Protix wants to be involved in?

We see Protix as an ingredient partner for manufacturers mainly in pet food, livestock, aqua and fertilizer as well as human food. Insects are a solution with huge potential. Ultimately, everyone is looking for novel ingredients with a low footprint and we are uniquely positioned to respond to that demand.

Our strategy has always been to listen carefully to our customers and add value with high-quality ingredients. We believe that insects will create a new platform of applications and there will be high value niches in feed, pet food ingredients and human nutrition across different products and applications. The next wave of research will uncover many different opportunities, some of them unexpected.

We are the only producer that can deliver on the scale that we do, and we were the first to serve the pet food industry. As such, we can rightly claim to be pioneers, and we see far greater potential as we broaden our horizons and our capacity. It is important that we maintain our focus on adding value where we can, and the solutions that are economically interesting!

What could ultimately be the size of the insect industry?

We know that there is massive potential in the market, and we expect certain segments to expand more quickly than others. Several industries are interesting, including pet food, livestock (which gained EU approval last September), aqua and fertilizer. We are also excited about the possibilities in terms of human food, although this is in its infancy compared with other parts of the market. We are gearing up to significantly increase production as we are confident there are huge opportunities we have not yet begun to tap. As far as we are concerned the potential and size are endless.

More companies are moving into the pet food market. How do you see that competition playing out? Will it lead to lower prices in that segment?

It is great to see that the pet food sector is turning more and more towards insect-based ingredients. It is after all a natural and sustainable alternative, with health benefits for the pets too. Our strategy is to work together with our customers to deliver added value for which pet owners are willing to pay more. We look closely at the needs of the end users and support pet food manufacturers with the development of more sustainable products with health benefits based on our black solder flies.

We see that pet owners are extending their own environmentally-conscious behavior to their pets, so natural and green pet foods are in increasing demand. At this stage the added value of insect-based nutrition is high. At Protix we will continue to invest in (scientific) research to develop future high value.

Where are you now in production capacity and plans for the coming two years?

We run our plant at full capacity and keep investing to make our plant even more efficient. Over the last years we invested further in our black soldier fly breeding program and have been able to yield a higher output. We now have a 20+% improved production and are clearly leading the way in this respect.

Protix is standing on the threshold of scaling up production and creating exciting growth for all parties involved. The next big milestone as part of this roll-out plan is to open new large-scale plants in the coming years.

Do you have any numbers on your business in 2021 and 2022 that you would like to share?

We currently have 15,000 square meters running at full capacity in Bergen op Zoom, The Netherlands. Though it is the largest plant in the world with 15,000 square meters, it cannot satisfy increasing customer demand. As mentioned we work very closely with our customers and as part of that, are excellently positioned to gauge demand, hence our confidence to expand across additional sites in the near future. We foresee that demand for insect ingredients in feed markets will be higher than the industry capacity which is estimated at ca. 500,000 tons in 2030.

How is your solution different from your competitors?

We are active in different segments with different propositions, with our customer base spanning pet food, livestock, aqua, and also moving into food. Moreover we also deliver ingredients for fertilizer markets. Overall, we focus on creating added value for our customers by collaborating closely with them and continuously improving our ingredients.

All our ingredients are based on the black soldier fly, a superior insect allowing many compelling claims in the areas of sustainability, health and animal welfare. We ultimately selected the black soldier fly because of the fact that its larvae contain more nutrients than the larvae of other insects. This is due to the fact that the matured insect doesn't eat and has to live off these accumulated reserves. A second reason for favouring the black soldier fly is its short lifecycle which allows large-scale production and more reliable supply compared to other insects. Finally the fact that the black soldier fly eats waste and is in turn eaten by many animal species, creates unparalleled potential in the area of sustainability, health and naturalness claims for our customers.

Our company has grown thus far in close collaboration with our customers. We work together on scientific claims and ongoing research. We are very strong in developing knowledge, for example in PPPs such as INSECTFEED and are also committed to sharing knowledge across and beyond the industry. We have a very firm and well-founded belief in and passion for bringing the food and feed system back into harmony with nature, both sustainably and ethically. It is our palpable enthusiasm for what we do that makes working with Protix such rewarding fun.

In 5 years', time, how will you look back and judge your success?

We are pioneers in the insect industry, and currently the only party able to offer large-scale commercial production. Our aim for the future is to maintain our world-class position, which we are well on track to achieve with our new planned new facilities. The biggest challenge we, and the industry as we whole, face over the next five is to scale up together with our customer and partners such as the Wageningen University, and grow the insect sector as a whole. There is huge potential which we have started to unlock, but there is lots more to do to make feed and food more sustainable, healthier, and more animal friendly. We also want to stick to our principles of a circular cycle and locally sourced. When in five years more products contain our insect ingredients, and we have widened and deepened the knowledge of insect ingredients among research institutes, the market and the general public, we can claim success.

Bernd Pütz, Technischer Vertrieb Reinartz

What is your company's involvement in the insect industry?

There are several industries, applications or solutions where you can find REINARTZ presses. We have a company history of almost 170 years, worked and manufactured as an extended workbench for the neighboring oil mills. About 110 years ago we started to build and manufacturer our own oil presses and focused on cold pressing which is different from what the big oil mills are doing. They are more focused on the hot pressing, which is oil extraction by solvents producing very bright colored, odorless cheap sunflower and rapeseed oils. Our cold pressed oils are higher value because of their flavor, odor and a higher nutritional value. Those oils are used in the cold kitchen for salads, etc. In the countries where those cold kitchen, those cold pressed oils, are preferred you will find installations from REINARTZ. We have installations around the world although there are spots where we are not or hardly to find like the US, South American and African market. Concerning insects we are involved since about eight years when we started with some trial pressing here in our pilot plant. And we have seen that dried insect larvae behave very similar to oil seeds and that we are able, with our equipment, to cold press and separate in solids, the protein rich insect meal, and the liquid, the oil. We also learned that every insect species may behave a little bit different. It is same like with oil seeds. There is a difference if you process sunflower, rapeseed or any other seed or nut.

So with that long back ground in the insect industry, how have you see the industry evolving?

That is a very good question. Over the years, we have tested and tried different insects like mealworm, lesser mealworm, BSF larvae, crickets or others like silk worm pupae. But in the last two years we have seen a remarkable growth in the revenue for REINARTZ from the insect industry. And we are continuing to see demand for our cold pressing equipment, for dry processing, for feasibility studies, for basic project planning and our engineering service. In total, we have now a reference base of about 40 projects and the insect business is now approximately 10% of our revenue. And more is in the pipeline. We have 160+ active projects that we are looking at. Next to that we have also a strong growth in the cold pressing for the plant-based proteins and the increasing demand for plant based proteins for human consumption. This will also impact the insect proteins market, because not every animal can be fed by plant based proteins only. To maintain a well-balanced nutrition and to compensate the plant protein interests of others, insects are a sustainable alternative.

How competitive is the insect engineering market?

It is difficult to say but there are only a handful of companies around the world that are able to offer a complete engineering solution. I don't mean to boast but I think REINARTZ is one of the only companies worldwide that is able to offer the full service for a BSF plant. We have a lot of knowledge as well for mealworms but there we have still some shortcomings that we need to address. Next to the handful of companies that are able to offer engineering solutions, you will find local smaller companies which have already something but do not cover the whole process from insect technology, insect rearing, insect processing, insect products. On the other hand the technology now used for insects is already available and known since decades. It is not rocket science but one has to link the different stages.

In Europe we have stopped eating insect since centuries, but in other parts of the world – part of Asia, Latin America - it is still happening. For example in South Korea there is a long history in small insect farming. The same is also true in Mexico. Furthermore in many countries there are companies that are rearing insects for pest control on a relative large scale, e.g Koppert from the Netherlands or Katz in Germany. There are also insect farms that supply the world market for reptile feed.

In the business of oil mills, there are countless engineering companies out there and for that segment we mostly only supplied the cold pressing machines, the presses. With the insect business, the demand changed as the questions changed. There are entrepreneurs who had a plan to do something more sustainable, something more circular. But they got quickly stuck in an amount of unanswered questions. They wanted to do everything and that drove them close to failure. On the other hand those real big lighthouse insect projects. They are doing a lot of marketing for the insect industry. That is good, but I think that next to the bigger companies, there will also be a lot of smaller companies. For those smaller companies, as for the big ones, we are able to provide an answer and solution to those questions. You cannot be a specialist in genetics, in rearing, in processing and in marketing at the same time.

So what is the solutions that you are offering?

For BSF we can offer the complete solution from the substrate receiving and preparing, the larvae reproduction, rearing and processing. We are also collecting a lot of scientific knowledge. For example there is a big demand on how to achieve by nutrition, a better growth, higher efficiency or a special protein composition that can be used for a specific application. The latter is only a niche business to some, it is something for insect companies to improve profitability. With regard to profit and prices, we surveyed last year about 200 companies with a feedback of 40 companies and learned that the global price for BSF meal is still between 4,500 to 5,500 Euro per ton.

How does BSF meal competes with fish meal?

Farmers want to know from the feed mills how much feed do they need, what is the bioconversion and how much does it cost per ton. Not requested is every detail about nutritional value and digestibility and so on. That is something for the feed mills and they are a crucial relationship that the insect producers need to develop more. Feed companies and their clients have a sustainability agenda and the sourcing of feedstock is an important part of that. End-consumers are asking where their food is coming from, if it is being produced in a sustainable way, they are even willing to pay more for the product. But sometimes the feed producers are still hesitant as they believe that the regulation is not properly developed, that it is difficult and others. Insect producers should discuss more with those feed producers. It is true that companies like ADM or Cargill are already entering the insect market, but I cannot fully qualify their involvement because such large companies will always be interested in alternative sources. Generally, I think that all those big global players are already doing some insect project either with partners, or they are closely connected to an insect farm or insect project.

But actually missing is a proper comparison between fishmeal quality classes and BSF meal quality classes. The latter does not actually exist.

Finally, what is than the future of the insect industry? Should insect meal prices come down to fish meal prices to make it a significant business?

It depends on how efficient you are in producing and processing those insects. Every insect project is different because of the different local sources. In the EU we don't have the space to feed everybody and that is why they have created the farm to fork strategy. Insects is one answer to that.

Importantly not every story is already told. There is a lot more to come and this makes an optimistic view on the potential growth of the market. There are countless feed mills and countless decentralized oil mills vs. centralized oil mills, this is what we know from the last decades and they all are running their business successfully. This picture can be used for the insect industry as well, there will be some big players but there is room for countless smaller businesses as well.

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The highest possible rating, based on a very strong conviction in the mid/long-term outlook and strategic choices made by a company, and should therefore be reflected in the extent of upside in the associated target price. There is no reason to limit the number of CONVICTION BUY ratings, however they must also reflect some kind of preference in relative terms within a sector.

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Opinion recommending not to trade in a stock short-term, neither as a BUYER or a SELLER, due to a specific set of factors. This view is intended to be temporary. It may reflect different situations, but in particular those where a fair value shows no significant potential or where an upcoming binary event constitutes a high-risk that is difficult to quantify. Every subsequent published update on the stock will feature an introduction outlining the key reasons behind the opinion.

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