AgriTech

The future of protein - filling the need for meat, dairy and animal 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

As of September 2020, Bryan Garnier & Co's Equity Research is becoming more thematic-focused. This note specifically addresses and illustrates the following themes:

Alternative proteins – the trend towards meat, dairy and feed substitutes.

Sustainable farming – fueling demand for more sustainable protein production methods.

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The future of protein

Introduction

With rising income levels and a multiplying global population, food demand is increasing. By 2050, there will be a 70 per cent increase in the global demand for protein. Fortunately, agriculture will continue to improve the efficiency with which it is able to produce larger quantities of protein.

- Conventional meat production will largely be able to fulfil demand by implementing best practices on a global scale, improving the genetics of the livestock, and employing the use of precision feeding. Insects and microalgae could play a crucial role in supporting these productivity improvements as they offer a sustainable feed additive and a source of protein and fat for all farmed and aqua cultured animals. This will allow for the insect industry to reach a potential size of between 7.3m tonnes (USD13.1bn) and 14.9m tonnes (USD20.9bn) by 2035.
- Another part of the demand is likely to be filled by plant-based analogues, based on their healthier and more sustainable proposition, while cost and taste should equal those of the conventional meat and dairy industry. We expect the industry of plant-based protein alternatives for human consumption to increase to USD70bn in 2025 from USD23bn in 2020. By 2050 we expect the size of this industry to be USD325bn.
- Further down the timeline, cultured meat will make inroads into human food when it can overcome the technical hurdle of scaling up production and associated costs.

EXECUTIVE SUMMARY

The agricultural industry is facing a medley of challenges. These can broadly be split into two categories: supply and demand. On the demand side, there are two factors at work. First, the global population is predicted to grow by 25% from 7.8bn in 2020 to 9.7bn in 2050. Second, income growth in low- and middle-income countries is expected to engender a change in dietary composition towards a higher consumption of protein (meat, poultry, fish and dairy) in what are currently cereal-dominated diets.

Clearly, this will require shifts in output and place added pressure on natural resources. We predict that the production of animal protein will need to increase by about 30% in the next 10 years and by about 70% in the next 30 years in order to meet this changing global demand. In short, there is a growing global population and changing dietary demands within this global population.

On the supply side, resources are limited; land that can be used for agriculture is nearing capacity and expanding of the arable area (1.8bn ha) into the pasture area (3.0bn ha) is unlikely or at best only marginal. Livestock farming has a significant environmental impact through land degradation, biodiversity loss, water stress and pollution, and climate change. Our analysis shows that livestock uses resources inefficiently; globally, meat and dairy provide just 18% of calories and 37% of protein and yet it uses 76% of total agricultural land and produces 65% of agriculture's greenhouse gas emissions. Most of these emissions (40%) occur through enteric fermentation (burps) and the rest (25%) is 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 liters of water. Pork is less intensive and chicken even less. To produce pork meat, 5.3kg of grains and 5,500 liters of water are necessary. For chicken that is 2.6kg and 3,600 liters.

In order to close the demand/supply gap and avoid it widening, agriculture has to produce more food - and better quality food - at affordable prices. All this must happen while, simultaneously, pushing for sustainability (i.e. not compromising the ability for current or future generations to meet their needs) and the need to protect the environment. It has, therefore, become imperative that agriculture finds innovative methods to increase productivity, while also enhancing the efficiency of supply chains. Initially, innovation tended to focus on the biotech sector and genetics. While this still continues to be an important driver, the past decade has seen the agricultural industry adopting a variety of technologies, bundled under the umbrella of AgriTech. In short, AgriTech aims to increase yield, efficiency, and profitability. Worldwide, advanced technologies such as IoT, AI, machine learning, drones, blockchain, 3D printing, robotic work, autonomous vehicles and more are being leveraged to achieve maximum productivity and output with minimum input. Plant-based analogues, insects and cultured meat are promising alternatives that can be used as protein sources in the future.

However, our view is that the conventional meat industry will largely be able to cater for the growing demand through increased productivity. There is still a huge 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.). In developing markets there is a significant catch-up to the level of production per animal in developed countries. Meat production per animal in Asia and Africa is about half of where it is in North America (and dairy production is only a fraction of developed country levels). Even without assuming that efficiency levels in developing countries would converge with those in developed countries, we expect productivity to lead to a 20% increase in protein production. This means that 30% of the increased need for proteins over the next 30 years can be supplied by the existing meat and dairy industry.

In developed countries, production per animal is likely to be supported by increases in the use of animal genetics, allowing for a better feed conversion ratio and the use of by-products, 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. Our view is that insect protein and microalgae could play an important role in animal feed and increase animal productivity. Not only is demand for feed increasing generally but, in particular, demand for additives and precision feed. Importantly, insects could play a crucial role in transforming by-products (manure, waste) of the food chain as feed (currently almost 10 per cent of the food made available to consumers is lost through waste). Insect meal/oil for compound animal feed products are fulfilling the same functionalities as fishmeal/oil. They are considered an exceptional source of protein and fat for all farmed and aqua cultured animals. Animal health and growth improves with the inclusion of insect and fish meal/oil. We expect that insect products will take a large share of the increased need for high quality protein in feed. Currently the insect industry is geared towards providing high quality proteins in pet food and replacing fishmeal/oil in aquaculture. However, as prices decline, we expect insect meal to enter into piglets and poultry markets assuming that additional trials and economic analyses prove that the nutritional benefits of insects are at least equal to those of fishmeal. That would point towards a potential for the insect industry of between 7.3m tonnes (USD13.1bn) and 14.9m tonnes (USD20.9bn) in the next 10 to 20 years. Protix from the Netherlands, Agronutris, InnovaFeed and Ÿnsect from France, Bühler Group in Switzerland, and Aspire from the US are among the companies that should benefit from the growth in the insect industry.

Although edible insects can replace traditional meat as a good protein source from the perspective of nutritional value, it is still uncertain if consumers will accept this source ahead of traditional meat. Hence, we have only included insects as an ingredient that can be used in other food products (e.g., protein bars, flour,…). Also, although cultured meat is the only method to produce actual animal muscle-based traditional meat, we are not predicting that it makes large inroads in human food in the next 20 years. Indeed, not only has a prototype that is ready for commercialization not been developed yet, but also technical difficulties, especially in scaling up production and reducing costs, remain. Nevertheless, cultured meat alternatives could one day become a part of human food and the opportunity is extremely large. In our forecasts we assume that from 2040 to 2050, cultured meat grows to 7% from 2% share in the total protein market. Companies that are spearheading the cultured meat developments are MeaTech 3D, Future Meat and Aleph Farms from Israel, Mosa Meat and Meatable from the Netherlands, Memphis Meats (USA), and Eat Just (USA).

In the short to medium term, we expect much more from the plant-based meat and dairy analogues. Today, milk alternatives are already reaching a 14% share of the milk market in the US and because of their premium positioning and margin are making nearly half of the profits of the US milk market. However, that premium positioning has been a function of the lower calory proposition of the plant-based milk alternatives. Other dairy and meat plant-based analogues do not have that same additional functionality to offer. Instead, they want to offer a product that is similar in taste and cost to the conventional product. Our view is that as the industry is scaling up, they will be able to offer that and with the additional positioning of being more sustainable have a winning proposition. We expect the industry of plant-based protein alternatives for human consumption to increase to USD70bn in 2025 from USD23bn in 2020. By 2050 we expect the size of this industry to be USD325bn. Developments in the plant-based alternative protein market are led by the US firms Beyond Meat and Impossible Foods on meat-alternatives and by JUST, WhiteWave (Danone), Nestle, Oatly on dairy alternatives.

Résumé

L'industrie agricole est confrontée à un ensemble de défis. Du côté de la demande, la population mondiale devrait augmenter de 25 % pour atteindre 9,7 milliards d'habitants en 2050, contre 7,8 milliards en 2020. En outre, la croissance des revenus dans les pays à revenu faible et intermédiaire devrait accélérer la transition alimentaire vers une consommation plus élevée de viande, de volaille, de poisson et de produits laitiers (demande accrue de protéines), de fruits et de légumes (consommateurs plus soucieux de leur santé), par rapport à celle de céréales, ce qui nécessite des changements dans la production et accroît la pression sur les ressources naturelles. Nous prévoyons que la production alimentaire de protéines animales devra augmenter d'environ 30 % dans les 10 prochaines années et d'environ 70 % dans les 30 prochaines années. Du côté de l'offre, les ressources sont limitées : les terres pouvant être utilisées pour l'agriculture sont proches de leur capacité et l'expansion de la zone arable (1,8 milliard d'hectares) vers la zone de pâturage (3,0 milliards d'hectares) est peu probable ou, au mieux, marginale. L'élevage a un impact environnemental important en raison de la dégradation des sols, de la perte de biodiversité, du stress hydrique et de la pollution de l'eau, ainsi que du changement climatique. Notre analyse montre que l'élevage utilise les ressources de manière inefficace, étant donné qu'au niveau mondial, la viande et les produits laitiers ne fournissent que 18 % des calories et 37 % des protéines, qu'il utilise la grande majorité - 76 % - des terres agricoles et qu'il produit 65 % des émissions de gaz à effet de serre de l'agriculture, principalement (40 %) par la fermentation entérique (rots) et le reste (25 %) par le fumier. Le fait que la production de viande soit très inefficace pour produire des aliments et des protéines est particulièrement vrai pour la viande rouge. La production d'un kilogramme de bœuf nécessite 10 kilogrammes de céréales - pour nourrir l'animal - et environ 17 000 litres d'eau. La viande de porc est moins intensive et le poulet encore moins. Pour produire de la viande de porc, 5,3 kg de céréales et 5 500 litres d'eau sont nécessaires. Pour le poulet, ce sont 2,6 kg et 3 600 litres.

Pour combler l'écart entre l'offre et la demande et éviter qu'il ne s'accentue, l'agriculture doit produire des aliments plus nombreux et de meilleure qualité à des prix abordables, tout en étant durable (c'est-à-dire sans compromettre la capacité des générations actuelles ou futures à répondre à leurs besoins) et en protégeant l'environnement. Il est donc devenu impératif que l'agriculture trouve des méthodes innovantes pour accroître la productivité, tout en améliorant l'efficacité des chaînes d'approvisionnement. Au départ, l'innovation tendait à se concentrer sur le secteur de la biotechnologie et de la génétique. Et cela continue d'être un moteur important. En plus de cela, au cours de la dernière décennie, l'industrie agricole a adopté une variété de technologies, regroupées sous l'égide d'AgriTech, pour augmenter le rendement, l'efficacité et la rentabilité. Dans le monde entier, des technologies avancées telles que l'IdO, l'IA, l'apprentissage automatique, les drones, la blockchain, l'impression 3D, le travail robotisé, les véhicules autonomes et bien d'autres encore sont mises à profit pour obtenir une productivité et un rendement maximum avec un minimum d'intrants. Les analogues végétaux, les insectes et la viande cultivée sont des alternatives prometteuses qui peuvent être utilisées comme sources de protéines à l'avenir.

Cependant, nous pensons que l'industrie de la viande conventionnelle sera en mesure de répondre dans une large mesure à la demande croissante grâce à une productivité accrue. Il existe encore un énorme potentiel d'amélioration de l'efficacité par la mise en œuvre des meilleures pratiques à l'échelle mondiale (prise en compte de la saisonnalité, supplémentation, fertilisation des pâturages, IA, augmentation des aliments pour animaux, amélioration génétique, alimentation de précision, etc.) Sur les marchés en développement, on observe un rattrapage important du niveau de production par animal dans les pays développés. La production de viande par animal en Asie et en Afrique représente environ la moitié de celle de l'Amérique du Nord (et la production laitière ne représente qu'une fraction des niveaux des pays développés). Même sans supposer que les niveaux d'efficacité des pays en développement convergent vers ceux des pays développés, nous pensons que la productivité entraînera une augmentation de 20 % de la production de protéines, ce qui signifie que 30 % des besoins accrus en protéines au cours des 30 prochaines années seront couverts par l'industrie laitière et carnée existante. Dans les pays développés, la production par animal devrait être soutenue par l'augmentation de la génétique, ce qui permettra d'améliorer le ratio de conversion des aliments et l'utilisation des sous-

produits. Nous pensons que les protéines d'insectes et les microalgues pourraient jouer un rôle important dans l'alimentation animale et accroître la productivité des animaux : non seulement la demande d'aliments pour animaux augmente en général, mais aussi, en particulier, la demande d'additifs et d'aliments de précision. Il est important de noter que les insectes pourraient jouer un rôle crucial dans la transformation des sous-produits (fumier, déchets) de la chaîne alimentaire en aliments pour animaux (actuellement, près de 10 % des aliments mis à la disposition des consommateurs sont perdus à cause des déchets). La farine et l'huile d'insecte pour les produits d'alimentation animale composés remplissent les mêmes fonctions que la farine et l'huile de poisson. Elles sont considérées comme une source exceptionnelle de protéines et de graisses pour tous les animaux d'élevage et d'aquaculture. La santé et la croissance des animaux s'améliorent avec l'inclusion de farine et d'huile d'insectes et de poisson. Nous prévoyons que les produits à base d'insectes représenteront une part importante du besoin accru de protéines de haute qualité dans les aliments pour animaux. Actuellement, l'industrie des insectes vise à fournir des protéines de haute qualité dans les aliments pour animaux de compagnie et à remplacer les farines et huiles de poisson dans l'aquaculture. Cependant, à mesure que les prix baissent, nous nous attendons à ce que la farine d'insectes fasse son entrée sur les marchés des porcelets et de la volaille, à condition que des essais supplémentaires ainsi que des analyses économiques prouvent que les avantages nutritionnels des insectes sont au moins égaux à ceux de la farine de poisson. Cela laisse entrevoir un potentiel pour l'industrie des insectes compris entre 7,3 millions de tonnes (13,1 milliards de dollars) et 14,9 millions de tonnes (20,9 milliards de dollars) dans les 10 à 20 prochaines années. Protix des Pays-Bas, Agronutris, InnovaFeed et Ÿnsect de France, Bühler Group de Suisse, Aspire des États-Unis sont parmi les entreprises qui devraient bénéficier de la croissance de l'industrie des insectes.

À court et moyen terme, nous attendons beaucoup plus des analogues de la viande et des produits laitiers d'origine végétale. Aujourd'hui déjà, les substituts du lait atteignent une part de 14 % du marché du lait aux États-Unis et, en raison de leur positionnement haut de gamme et de leur marge, ils réalisent près de la moitié des bénéfices du marché américain du lait. Cependant, ce positionnement haut de gamme est fonction de la proposition calorique plus faible des substituts du lait à base de plantes. Les autres produits laitiers et carnés analogues à base de plantes n'ont pas la même fonctionnalité supplémentaire à offrir. Ils veulent plutôt offrir un produit similaire en termes de goût et de coût au produit conventionnel. Nous pensons qu'avec la montée en puissance de l'industrie, ils seront en mesure d'offrir cela et, avec le positionnement supplémentaire d'être plus durable, ils auront une proposition gagnante. Nous prévoyons que l'industrie des alternatives protéiques d'origine végétale pour la consommation humaine passera de 23 milliards de dollars en 2020 à 70 milliards de dollars en 2025. En 2050, la taille de cette industrie devrait atteindre 325 milliards de dollars. Les développements sur le marché des protéines alternatives d'origine végétale sont menés par les entreprises américaines Beyond Meat et Impossible Foods sur les alternatives à la viande et par JUST, WhiteWave (Danone), Nestlé, Oatly sur les alternatives laitières.

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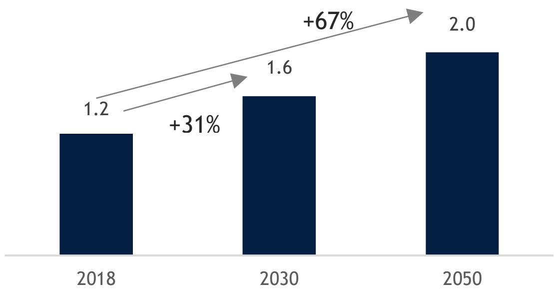
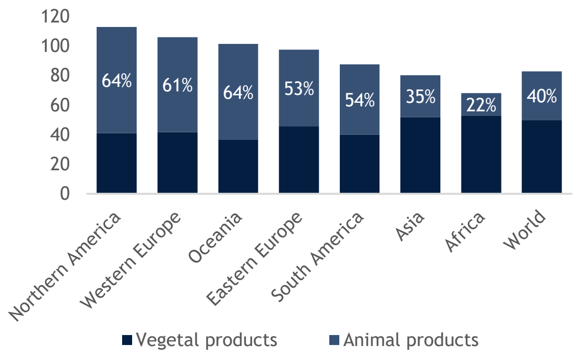
Fig. 1: Global demand for animal food supply (bn tonnes/year)



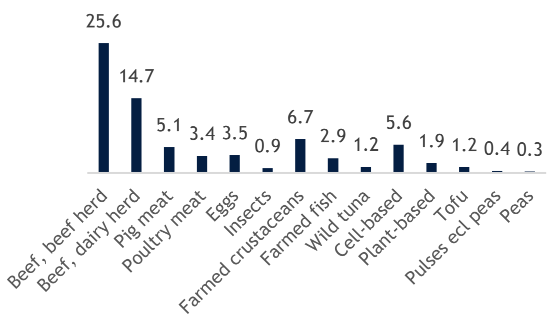
Source: Bryan, Garnier & Cie est

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



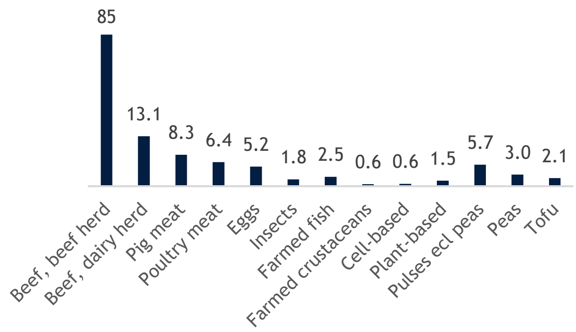
Source: FAOSTAT

Fig. 3: GHG footprints per 100 g protein in kgCO2e/100g protein



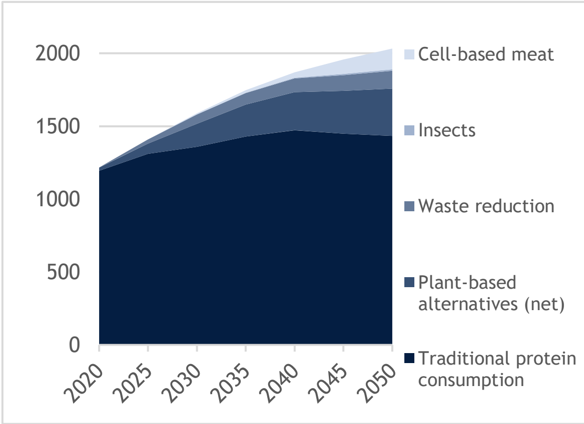
Source: Frontiers

Fig. 4: Land use per 100 g protein in m2 year/100 g protein



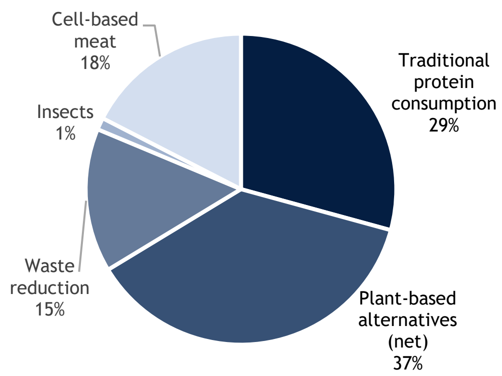
Source: Frontiers

Fig. 5: Global protein consumption (billion kg)



Source: Bryan, Garnier & Cie

Fig. 6: Source for additional protein production (2020 to 2050)



Source: Bryan, Garnier & Cie

Section 01

The growing demand for food and proteins

The growing demand for food and proteins

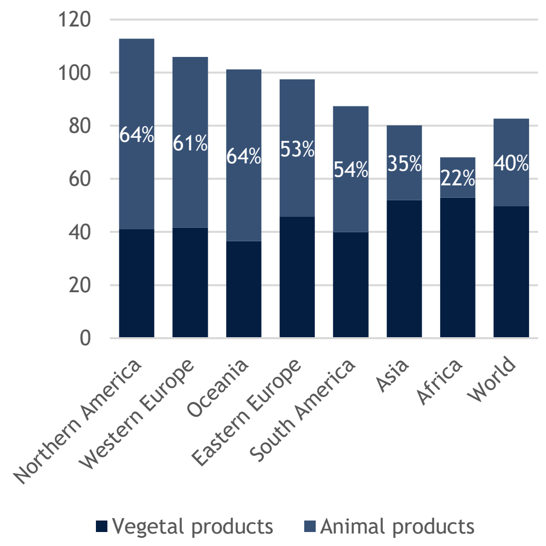
Global food demand has tripled over the past 50 years driven by population growth and increased per capita consumption due to rising living standards.

Over the last 50 years, global food demand approximately tripled. This rapid growth was caused on the one hand by the more than doubling of world population from about 3.7 billion to nearly 7.8 billion people and on the other hand increased per-capita consumption due to rising living standards. Over the next 30 years, further population growth along with rising incomes in developing countries (causing dietary changes such as eating more protein and meat) will increase global food demand further.

The underlying assumption is that as the global population adopts western consumption patterns a 58% rise in agricultural output will be needed over the next 30 years. Within this assumption the type of food commodities that is consumed (i.e., meat) is more important than the quantity of per-capita consumption in determining the agricultural land requirement, largely due to the impact of animal products and in particular ruminant species. Exploration of the average diets in the North American and Asian (which are two distinctive diets) provides a framework for understanding land use impacts arising from different food consumption habits. Hypothetically, if the world were to adopt the average Asian diet, only a 17% increase in agricultural output would be needed to satisfy 2050 demand, while global consumption of the average North American diet would necessitate a 94% increase in output.

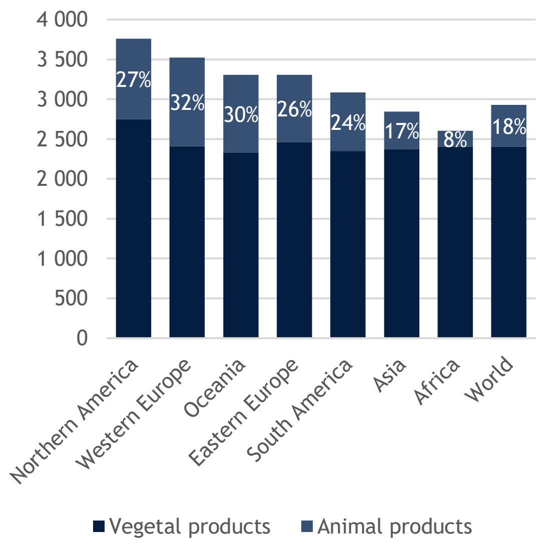
Furthermore, consumers want their food to be traceable to validate and authenticate food origin and ensure that it has been grown right. Some consumers demand sustainability and consume only organically grown food to reduce ecological footprint from their end but putting additional pressures on global natural resources.

Fig. 7: Sources of protein supply (g/capita/day)



Source: FAOSTAT

Fig. 8: Sources of food supply (kcal/capita/day)



Source: FAOSTAT

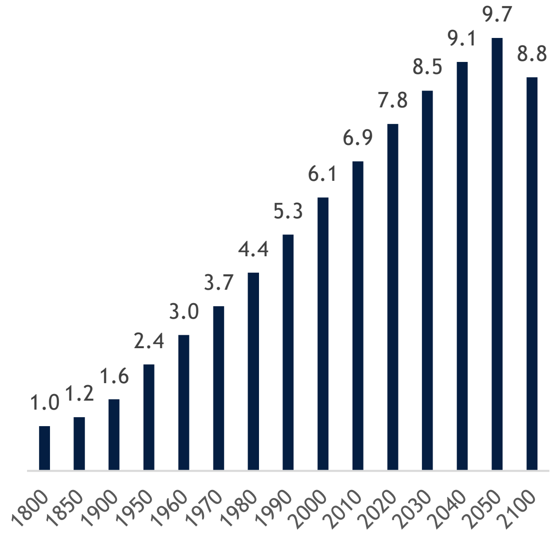
Population growth of 25% by 2050 and declining afterwards

Global population to rise by 25% to 9.7bn by 2050 from 7.8bn in 2020

Over the last century, the global population has quadrupled. In 1900, there were 1.6 billion people in the world. Today, 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%). However, after 2050, most experts expect a stabilization and then a decline in population, although there is disagreement about how fast and to where the number of people could shrink.

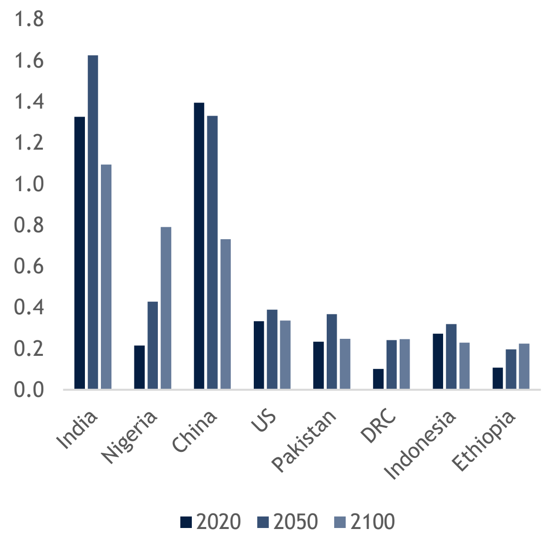
The medical journal The Lancet published research by the University of Washington suggesting that world population will peak in 2064 at around 9.7 billion people and fall to 8.8 billion by 2100. In their base scenario, researchers assumed growing access to education and contraception for women would catapult Indian and Chinese fertility below replacement levels, leading to population levels of just 1.1 billion and 731 million people in India and China in 2100, respectively. The researchers did not see the same factors at play in most African nations, where population growth would continue to 2100 and beyond, according to the model. This would make Nigeria the second-largest nation ahead of China by 2094.

Fig. 9: World population



Source: World Bank, The Lancet

Fig. 10: Population in the most populous countries



Source: World Bank, The Lancet

Income growth adds another 9% to total food demand by 2050

Next to population growth, rising income in developing countries is expected to increase both the food demand per head as well as demand for proteins. Food demand is mostly expressed in kcal per capita per day, comprising both food intake and non-eaten household food waste. According to the latest data from FAOSTAT, the average 2018 world food supply measured 2,927 kcal/capita/day. Estimates for 2050 range from 3,070 to 3,250 (Alexandratos and Bruinsma 2012: 3,070; Bodirsky et al. 2015: 3,177; Kruse 2010: 3,250). Using the calculations from Bodirsky, the global average kcal intake is expected to increase by 9% by 2050.

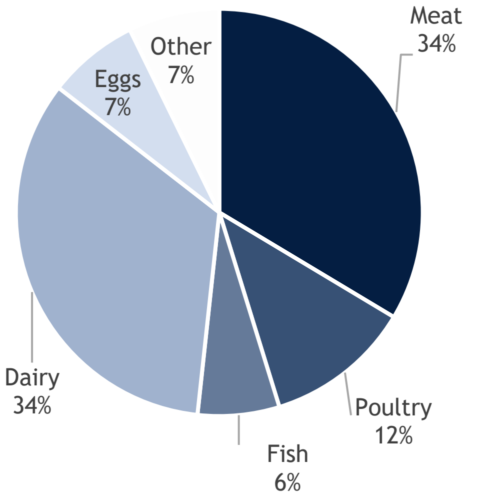
Demand for animal-based products to rise 67% by 2050

Income growth also increases the amount of animal-based products like meat, milk, eggs and fish that are being consumed. In the last six decades, the global population-weighted average share of animal-based products rose from 15.4% in 1960 to 17.9% in 2020 mainly attributed to rising consumption of animal-based products in developing and emerging economies, while in developed countries this share stagnated or even decreased in the last decades. Bodirsky et al. (Potsdam Institute for Climate Impact Research, Global Food Demand Scenarios for the 21st Century) expects that the share of animal-based products will rise to 22.1% in 2050 (from 17.9% in 2018) and that the kcal derived from animals would increase to 702 by 2050 from 525 in 2018 (+34%).

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

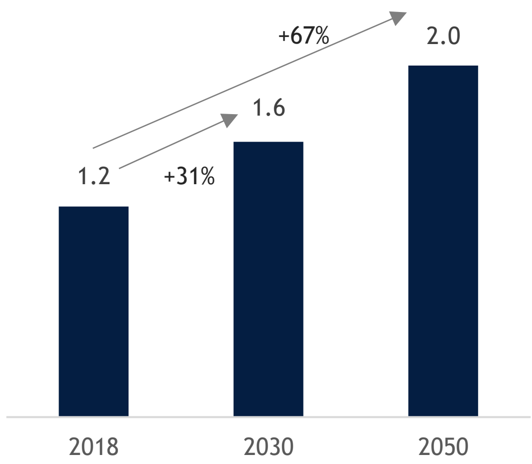
Combining these findings with the expected evolution of the global population, we calculate that in the next ten years (by 2030), demand for animal proteins will increase by 31% and in the next 30 years (by 2050) by 67%.

Fig. 11: Composition of animal food supply (kcal/capita/day)



Source: FAOSTAT

Fig. 12: Global demand for animal food supply (bn tonnes/year)



Source: Bryan, Garnier & Cie est

Section 02

Key supply concerns of conventional protein production

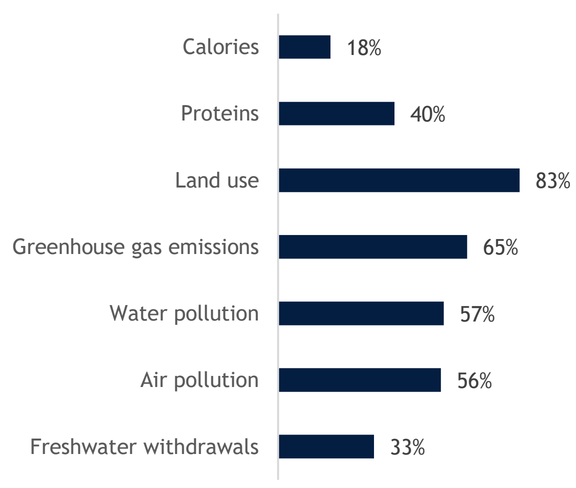
Key supply concerns of conventional protein production

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.

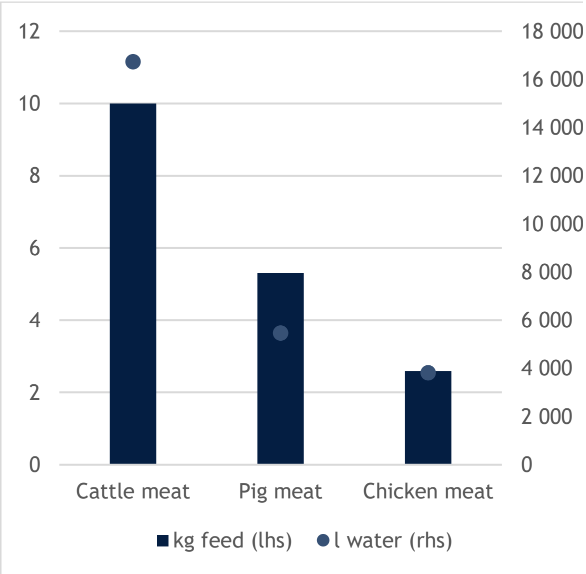
Since food, water and land are scarce in many parts of the world, livestock is an inefficient use of resources. Our analysis shows that while globally, meat and dairy provide just 18% of calories and 37% of protein, it uses the vast majority – 76% - of agricultural land, and produces 65% of agriculture's 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.

Fig. 13: Contribution of farmed animal products



Source: Bryan, Garnier & Cie, Poore and Nemecek

Fig. 14: Feed and water input to produce one kilogram of different animal products



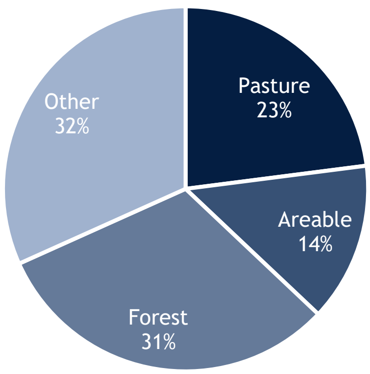
Source: Bryan, Garnier & Cie

Disproportionate amount of land use for livestock

Livestock produces 18% of world calories, 37% of world proteins and uses 76% of all agricultural land.

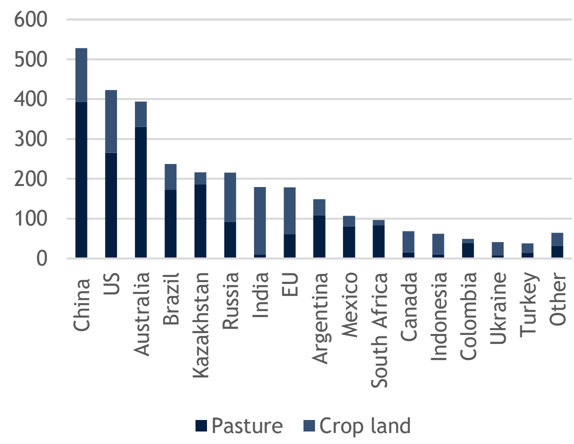
28% of all land is currently used for livestock farming. Livestock is the world's largest user of land resources with pasture and arable land dedicated to the production of feed representing 76% of the total agricultural land. And by contrast livestock only produces 18% of world calories and 37% of world protein supply. Based on OECD and FAO data, we estimate that 37% of the world land mass is used for agriculture (4.8bn ha) and that 62% of that is for livestock and 38% for crops. From the 38% used for crops, just over half (55%) of the crop calories are actually eaten directly by people. Another 36% is used for animal feed and the remaining 9% goes toward biofuels and other industrial uses. So, in total livestock uses about 76% of agricultural land.

Fig. 15: Global land use, 2018e



Source: FAO, OECD, Bryan, Garnier & Co

Fig. 16: Livestock and crop land in selected countries (m ha)



Source: OECD

Feed and water sourcing

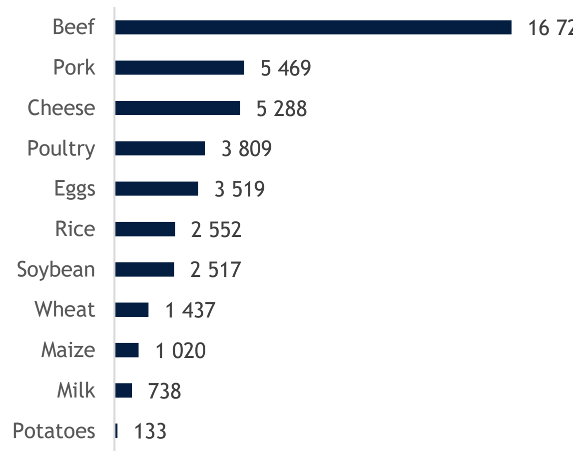
Beef and pork are an unproductive use of water

The production of beef requires nearly 17,000 litres of water per kilogram and 5,500 litres for a kilogram of pork.

Different studies have been done to quantify the water use of agricultural products. We have averaged the result of a number of them and related to the amount of calories and proteins produced. The production of beef requires nearly 17,000 litres of water per kilogram and 5,500 litres for a kilogram of pork.

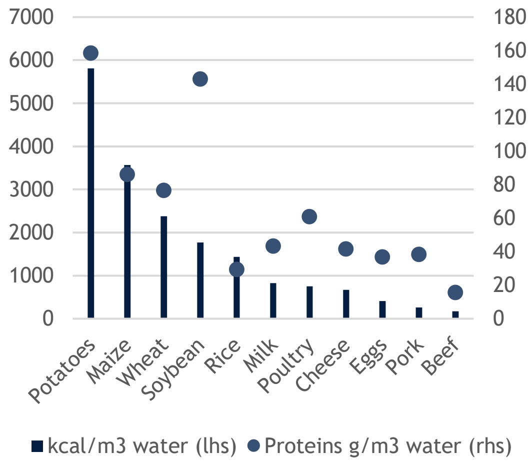
Beef stands out for its unproductive water use, producing one of the lowest calories (172kcal) and proteins (16g) for a cubic meter of water. And pork is the second lowest on calories (261kcal) and third lowest on proteins (38) per cubic meter of water. By contrast vegetal crops are more productive. 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. 17: Virtual water content of a few selected products in m3 /tonne.



Source: Average from estimates by different authors

Fig. 18: Virtual water use to produce calories and proteins for different agricultural products



Source: Estimates by different authors, Bryan, Garnier & Cie

Cattle and lamb require 4x more feed than chicken

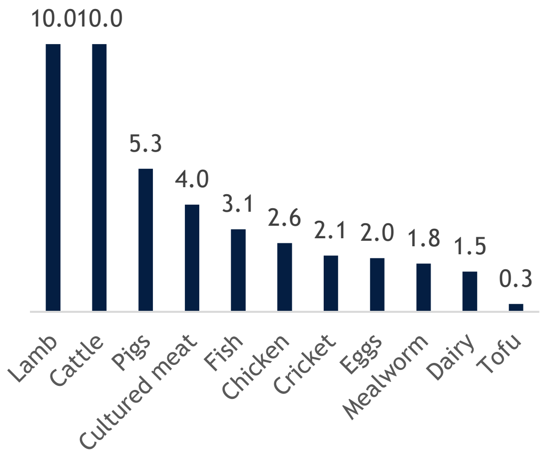
The feed conversion rate is a ratio or rate measuring of the efficiency with which the bodies of livestock convert animal feed into the desired output. For dairy cows, for example, the output is milk, whereas in animals raised for meat (such as beef cows, pigs, chickens, and fish) the output is the flesh, that is, the body mass gained by the animal, represented either in the final mass of the animal or the mass of the dressed output. FCR is the mass of the input divided by the output (thus mass of feed per mass of milk or meat). To complete the picture only the edible portion of a carcass is taken into account. Animals that have a low FCR are considered efficient users of feed.

Carcass wight FCR is 10x for beef, 5.3x for pigs, 2.6x for chicken and below 2.0x for insects.

For beef cattle a FCR of 6x is typical and with an average carcass yield of 60%, the typical carcass weight, the FCR drops to 10x meaning that it takes 10kg of dry matter weight of feed to produce 1 kg of beef. The carcass weight FCR for pigs is 5.3x and for chicken 2.6x.

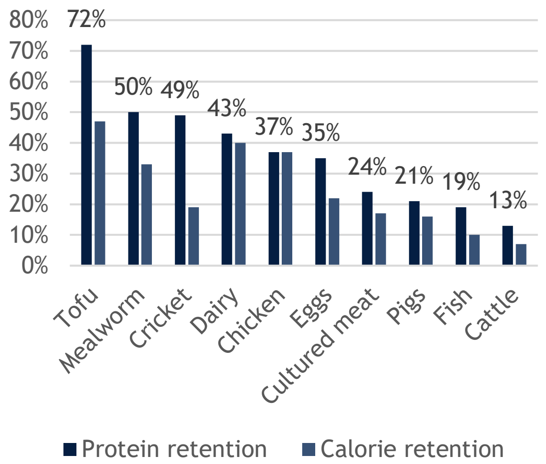
In terms of conversion efficiency (how much proteins and calories are retained from the proteins and calories in the feed), cattle and fish (which requires high protein feed) are far less efficient than chicken. Crickets and mealworms are in the same range as chicken with a FCR of respectively 2.1 and 1.8. Interestingly, some calculate that cultured meat does not seem to offer benefits over poultry meat or eggs but given the early stage of development, significant efficiency gains should still occur.

Fig. 19: Feed efficiency ratio/Feed conversion ratio



Source: Heinrichs and Ishler, PennState Extension, 2016; Alexander et al., science direct, 2017

Fig. 20: Protein and calorie feed conversion efficiency

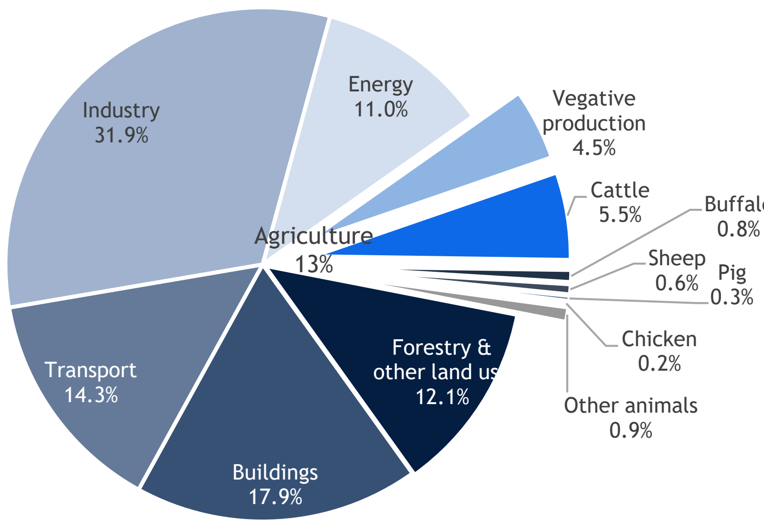


Source: Heinrichs and Ishler, PennState Extension, 2016; Alexander et al., science direct, 2017; Bryan, Garnier & Cie

Greenhouse gasses emissions from the agricultural industry

The third supply concern of the conventional protein production is how it contributes to climate change. One of the key issues is the greenhouse emission from livestock. Agriculture, forestry and other land use (AFOLU) is the second largest source of greenhouse gases (25% of world emissions or circa 10 to 12 GTCO2eq/yr.) mainly from deforestation and agricultural emissions from livestock, soil and nutrient management.

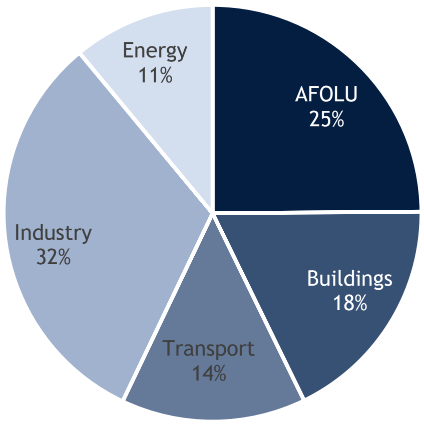
Fig. 21: World greenhouse gas emissions



Source: Fifth Assessment Report of the Intergovernmental Panel on Climate Change, FAO, Bryan, Garnier & Cie source

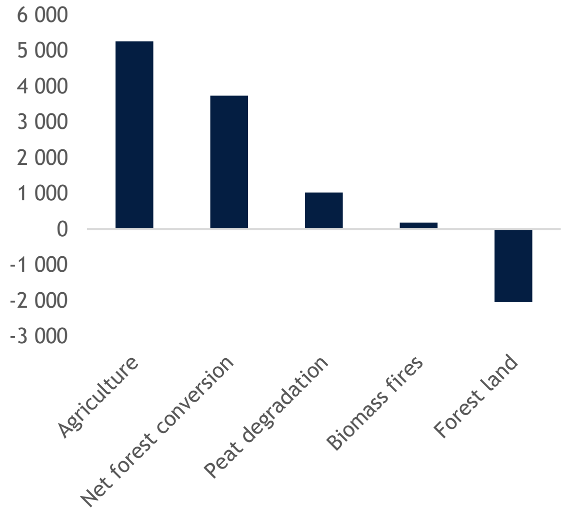
According to the FAO, within AFOLU, the largest emission source is agriculture (50%), followed by net forest conversion (38%), peat degradation (i.e., cultivation of organic soils and peat fires) (11%) and biomass fires (1%). Forest (forest management and afforestation) contributed 100% of FOLU removals by sink, and represented a 20% offset of total AFOLU emissions by source.

Fig. 22: Greenhouse Gas Emissions by economic sector



Source: Fifth Assessment Report of the Intergovernmental Panel on Climate Change

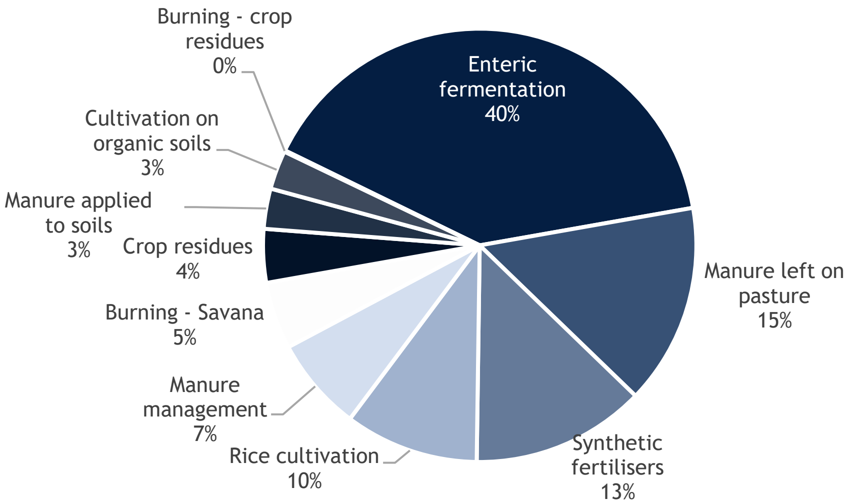
Fig. 23: AFOLU emissions in 2010 (Mt CO2 eq)



Source: Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks, FAO

Emissions from enteric fermentation were the greatest contributor to agricultural emissions (40%), followed by manure left on pasture (16%), synthetic fertilizers (13%), rice cultivation (10%), manure management (7%) and burning of savanna (5%). Greenhouse gas emissions from enteric fermentation consist of methane, CH4, produced in digestive systems of ruminants and to a lesser extent of non-ruminants. Emissions of enteric fermentation were dominated by cattle, contributing 74% of all enteric fermentation (55% non-dairy cattle; 19% dairy cattle), followed by buffaloes (11%), sheep (7%) and goats (5%). Emissions of manure management were dominated by cattle, responsible for half of the total (31% non-dairy cattle; 19% dairy cattle), followed by swine (34%) and buffaloes (9%)

Fig. 24: Agriculture emissions by sub-sector, 2011

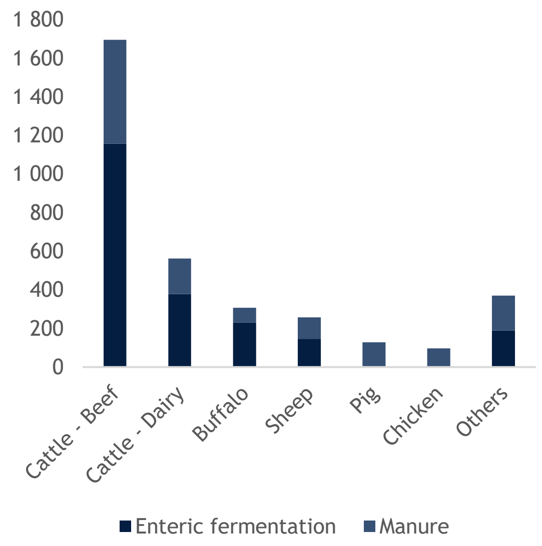


Source: Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks, FAO

66% of agriculture GHG emissions comes from livestock and cattle.

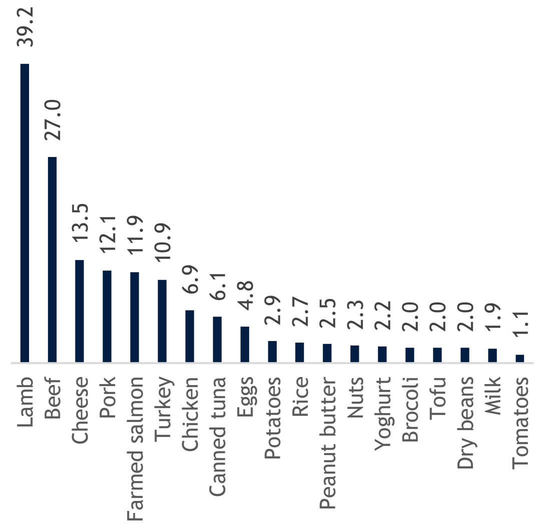
Of the total GHG emissions, about 25% came from AFOLU of which 13% came from agriculture. Of the agriculture GHG emissions 65% comes from livestock and cattle (non-diary, dairy) contributes 66% (50% non-dairy cattle; 16% dairy cattle), followed by buffalo (9%), and sheep (8%). To produce a kg of cattle meat, about 27 kg CO2eq is being emitted, compared to only 12.1 for pig meat, 11.9 for salmon, and 6.9 for chicken meat.

Fig. 25: Total GHG emissions from different breeds (Mt CO2 eq)



Source: Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks, FAO

Fig. 26: Full lifecycle GHG from common proteins and vegetables (Kg CO2 eq/kg consumed)



Source: Environmental working group

Climate change affects agricultural productivity

There is a growing academic school of thought that climate change-driven water scarcity, rising global temperatures, and extreme weather will have long-term effects on local crop yields. However, exact assessments of the impact has not been done (source: Intergovernmental Panel on Climate Change). And indeed the impact on global crop yields is a complex matter: some regions and crops are likely to suffer and others to benefit. Nevertheless some research institutions (eg. The Conversation) suggest a net global decline in caloric yield of as high as 1% p.a.:

- Many major agricultural regions, especially those close to the Equator could suffer. For example, the Brazilian state of Mato Grosso, one of the most important agricultural regions worldwide, may face an 18% to 23% reduction in soy and corn output by 2050, due to climate change. The Midwestern U.S. and Eastern Australia — two other globally important regions — may also see a substantial decline in agricultural output due to extreme heat. Yet some places are expected to benefit from climate change. Countries stretching over northern latitudes — mainly China, Canada, and Russia — are forecasted to experience longer and warmer growing seasons in certain areas. Russia, which is already a major grain exporter, has huge untapped production potential because of large crop yield gaps (the difference between current and potential yields under current conditions) and widespread abandoned farmland (more than 40 million hectares, an area larger than Germany) following the dissolution of the Soviet Union, in 1991. The country arguably has the most agricultural opportunity in the world, but institutional reform and significant investments in agriculture and rural infrastructure will be needed to realize it.

- Where climate change might impact some crops negatively others are likely to benefit. Yields of sorghum, which many in the developing world use as a food grain, have increased by 0.7% yearly in sub-Saharan Africa and 0.9% yearly in western, southern and southeastern Asia due to climate shifts since the 1970s.

- In Europe and the US, agricultural output is expect to increase slightly despite a projected small decline in agricultural land. Their implied improvement of yield is mainly because of the reduced demand for pig and beef meat allowing for a decline in pasture and a increased use of agricultural land for human food (mainly protein rich crops such as soybean, common bean, pea, chickpea, lentil) and less for animal feed.

- Furthermore, the impact will also depend on the degree of global warming.

Section 03

Demand/supply imbalance – adding it all up

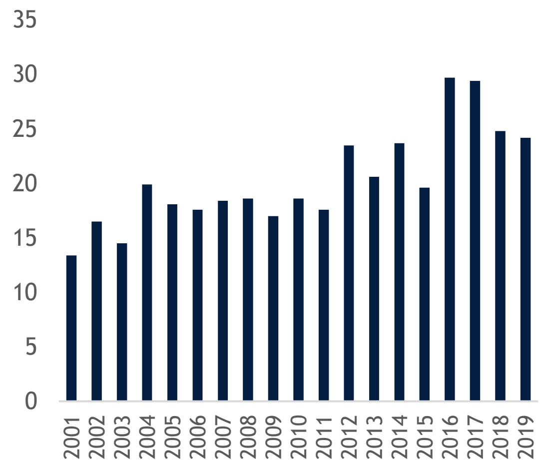
Demand/supply imbalance – adding it all up

Population growth and a surge in demand for animal proteins demands in the next 30 years, a 58% increase in agricultural output

By 2050, the growth in population to 9.7bn (+25% vs 7.8bn in 2020), increased demand for food to 3,177 kcal/capital/day (+9% vs 2,927 in 2020), and a surge in the share of animal proteins to 22.1% of calories (vs 17.9% in 2020) calls for a 58% increase in agricultural output. That should be matched with an increase in land available for agricultural production and/or agricultural yield. However, given the scarcity of agricultural land, it is unlikely that supply will be able to match demand: currently 4.8bn ha are used for agriculture of which 1.8bn for vegetal production and 3.0bn for animal production. If the scenario is an increase in demand for animal products, then expanding of the arable area into the pasture area is unlikely or at best only marginally. Indeed, according to FAO data for the period 1980-1998, only 74m ha of arable land was added (+0.26% p.a.) and in the period 1998-2015, only 36m ha was added (+0.13% p.a.).

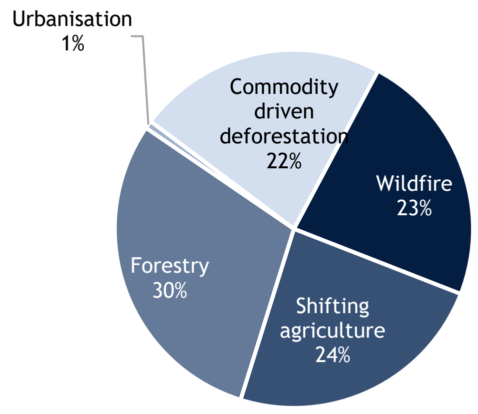
That also fits with the trend details for 2019 from Global Forest Watch, that reveal that only 24% of the tree cover loss was from shifting towards agriculture. Extrapolating this over the last 20 years would indicate that only 0.1bn of ha was added to the agricultural land use.

Fig. 27: Global annual tree cover loss (m ha), 2001-2019



Source: Global Forest Watch

Fig. 28: 2019 global tree cover loss by dominant driver



Source: Global Forest Watch

In terms of productivity gains, the environmental impact of agricultural production on land and water degradation, biodiversity loss, deforestation, greenhouse gasses, climate change, is unlikely to be beneficial for agricultural productivity. As a consequence agricultural technology need to find novel ways to increase food and protein supply.

AgriTech solutions

A 58% increase of agriculture output is unlikely to be supported by additional agricultural land, necessitating productivity growth of at least 50%.

Growing caloric and protein demand driven by population and income growth coupled with a decline in caloric yield, will require according to our calculations an increased agricultural output of 58% over the next 30 years. It is unlikely that any of that increase will come from additional agricultural land, necessitating productivity growth of at least 50% to fulfill the caloric and protein demand. At the same time, consumers and governments are asking that agriculture is more sustainable and protects the environment.

Although agricultural investments and technological innovations are boosting productivity, growth of yields has slowed. Food losses and waste claim a significant proportion of agricultural output, and reducing them would lessen the need for production increases. However, the needed acceleration in productivity growth is hampered by the degradation of natural resources, the loss of biodiversity, and the spread of transboundary pests and diseases of plants and animals, some of which are becoming resistant to antimicrobials.

AgriTech is offering innovative solutions to increase productivity and enhance supply chain efficiency.

It has therefore become imperative that agriculture is finding innovative methods to increase productivity, while also enhancing the efficiency of supply chains. Until the beginning of 2010, innovation tended to focus on the biotech sector and plant genetics. Since then the agricultural industry has been adopting a variety of technologies, bundled under the umbrella of AgriTech, to increase yield, efficiency, and profitability. Worldwide, advanced technologies such as IoT, AI, machine learning, drones, blockchain, 3D printing, robotic work, autonomous vehicles and more are being leveraged to achieve maximum productivity and output with minimum input.

Fig. 29: Trends in AgriTech

Technologies that "produce differently using new techniques"	Technologies that bring food production to consumers while increasing efficiencies in the food chain	Technology and applications that cross industries
Hydroponics	Vertical/urban farming	Drone technology
Algae feedstock	Genetic modification	The internet of things
Bioplastics	Cultured meats/artificial proteins	Data analytics
Desert agriculture	3D printing.	Precision agriculture
Seawater farming		Nanotechnology
Insects		AI
Biotech		Digital platforms
Food waste		Social networks
		Blockchain

Source: World Government Summit

Numerous AgriTech initiatives look to support sustainable food supply. Yamaha in Japan, DJI in China and the US/Swiss Parrot Group/senseFly are developing drone technology to help to boost yields and optimize inputs for food production; Gamaya in Switzerland have invested in imaging and AI; iFarm of Finland has had success developing technologies for automated management of vertical farming ; IBM develops techniques for using blockchain and AI in farming while genome editing by companies like Bayer and KWS of Germany, are expected to make a big contribution in reducing food waste, once a regulatory framework is adopted. In the area of freshness extension products the US firm Apeel Sciences is leading the way followed by Agrofresh (US), Decco (US/India) and start-ups like AgroSustain of Switzerland and PolyNatural of

Chile, which are developing entirely biological freshness extension solutions. Biological crop protection that can support the trend for organic, residue-free food and also for sustainable farming is increasingly captured by the major crop protection companies like, Bayer/Syngenta, BASF next to independent AgBiome, Biotalys, Marrone Bio Innovations, Koppert Biological Systems, Valent Biosystems and Novozymes.

Others are focusing on diminishing the ecological impact of traditional meat production. Genetics companies like Genus are looking to create breeds that grow faster to maturity, that have a better FCR or that don't need anti-biotics. Companies like Blue Ocean Barns on Hawaii's Big Island is among a handful of companies in the world that cultivate a red algae called Asparagopsis taxiformis found to be the best type for reducing methane in cows' burps (adding just a small amount of seaweed to cattle feed can reduce the output of methane in their burps by 82%, according to a UC Davis study). However, the seaweed in question is not common enough, so Blue Ocean grows it on land in tall tanks. In France, Inalve, has developed a technology which can cultivate microalgae in a biofilm using only water, sunlight, CO2 and minerals. This process significantly increases productivity, resulting in a more efficient use of resources. The patented process results in a highly concentrated biomass that has unique physical and nutritional properties. Once harvested, the microalgae (Inalve choose to work with Tetraselmis suecica) are transformed into ingredients for nutrition and health.

In this white paper we are focusing on developments in the field of alternative proteins.

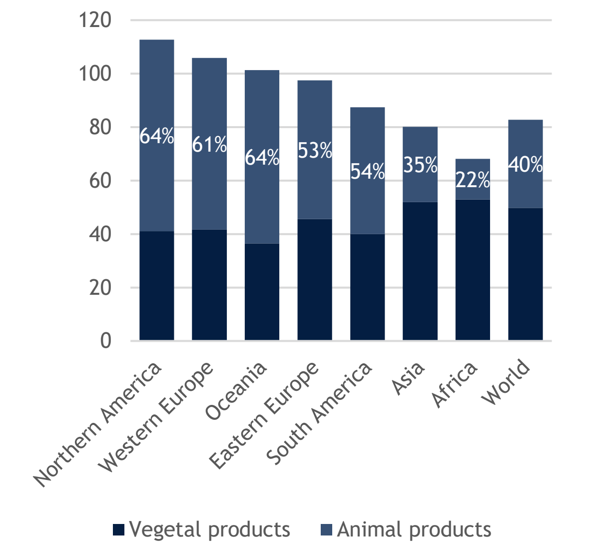
In this white paper we are focusing on the field of alternative proteins. The interest in this field has two origins: on the one hand increased wealth in developing countries leads to a higher protein lifestyle. However, complete protein commodities are becoming increasingly scarce as the environmental impact in terms of land use, water consumption and carbon emissions, is unsustainable and alternative sources are required. On the other hand, in developed countries there is growing consumer interest in alternative-protein sources, due in part to health and environmental concerns as well as animal welfare. The developments in the alternative protein technology are led by the US firms Beyond Meat and Impossible Foods, the Dutch firm Mosa Meat and the Israeli/Belgian firm MeaTech 3D/Peace of Meat. In China, that has surpassed the US in its consumption of plant-based meat local players like Zhenmeat and Hong Kong based Green Monday Holdings are well positioned to cater for the local eating habits. Meanwhile, Protix from the Netherlands is developing techniques to grow insects using plant waste which will then be turned into sustainable proteins. Also InnovaFeed from France is producing natural and sustainable ingredients for animal feed and plant nutrition from insect rearing. The French company, Ÿnsect, is breeding and transforming insects for inclusion in animal, human and plant nutrition and have also developed an insect-based fertilizer. Agronutris is a French biotech company specialized in rearing and transforming insects into proteins for animal nutrition.

Alternative proteins in focus

Given the scarcity of agricultural land it is unlikely that that supply will be able to match a 67% increase in demand for proteins.

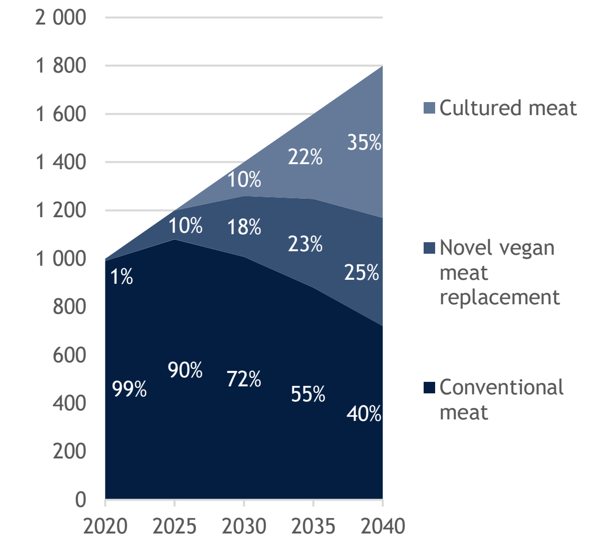
Although on average 40% of world protein supply is from animal products, the numbers vary greatly by region in function of the average living standards. In North America, Western Europe and Australia, over 60% of protein supply comes from animal products compared to only 35% in Asia and 22% in Africa. As income growth increases the amount of animal-based products the expectation is that 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, we calculate that in the next 30 years, demand for animal production will increase by 67%, which should not only increase demand for pasture but also demand for animal feed grown on arable land. Given the scarcity of agricultural land, it is unlikely that supply will be able to match demand.

Fig. 30: Sources of protein supply (g/capita/day)



Source: FAOSTAT

Fig. 31: Global meat consumption (USDbn)



Source: AT Kearney

Alternative protein products range from reconfigurations of the typical plant-based legumes to using edible insects and introducing novel products such as lab-grown meat or single-cell proteins from algae, yeasts, or fungi.

Hence manufacturing alternatives to animal-based food products are a growing part of the Food and AgriTech space. An alternative protein industry focused on producing alternatives to animal meat, milk, and eggs, has emerged. Alternative proteins products range from reconfigurations of the typical plant-based legumes into meat substitutes, like Beyond Meat and Impossible Burger, to using edible insects and introducing novel products such as lab-grown meat or single-cell proteins from algae, yeasts, or fungi. Compared to meat counterparts, alternative proteins' projected positive impacts on climate and animal welfare and potential health benefits have excited interest in the sector. Next to companies producing alternatives to animal meat, milk, and eggs, there are also companies manufacturing leather without animals (Modern Meadow) and coffee without beans (Atomo).

There are two main ways to manufacturing meat, milk and egg alternatives: 1) using animal cells to culture a biological replica of the product without the animal in a process called cellular agriculture, and 2) processing plant proteins to mimic the feeling and taste of the animal product. Other companies are growing algae and insects as a more sustainable source of protein for both human and animal consumption. In general the segmentation of the alternative protein industry is by protein source and level of processing: fortified or otherwise modified plant-base (including fungi and algae), insect-based, and lab-grown meat or by application: direct consumption, animal feed, and supplements.

Some, like AT Kearney predict that by 2040, up to 60% of the meat industry could consist of meat products made from alternative proteins.

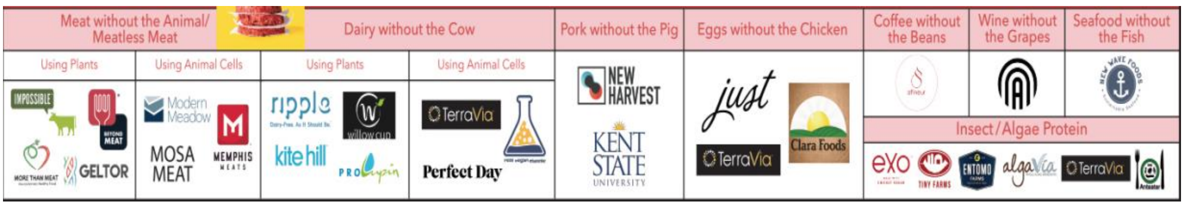
In the coming decades, as new products and production techniques are being developed, traditional protein farming will be disrupted. AT Kearney predicts that by 2040, up to 60% of the meat industry could consist of meat products made from alternative proteins (USD1,080bn), with cultivated meat comprising 35% (USD630bn) and plant-based meat reaching 25% (USD450bn). Based on the firm's analysis, around 30% of the global meat supply will be provided by these new approaches (meat cultivation and substitution) within the next 10 years, reaching a total market size of USD400bn. The firm forecasts that vegan meat replacements will show a strong growth until 2030, while cultured meat (with an annual growth rate of 41 percent) per year will outgrow them between 2025 and 2040, due to technological advancements and consumer preferences.

Fig. 32: The alternative protein landscape

Cultured		Plant-based	
Single cell proteins		**Proteins**	
Calysta	US	Oatly	SWE
Solar Foods	FIN	Hari&Co	FR
Deep Branch Technology	UK	Prolupin	GER
		Meatless Farms	UK
Air Protein		Heura	SP
Ledgendairy	GER	Valorex	FR
ReMilk	ISR		
Multi-species (meat, seafood, dairy)		**Multi-species (meat, seafood, dairy)**	
Oatly	SWE	BeyondMeat	US
Hari&Co	FR	Impossible Foods	US
Prolupin	GER	Vivera	NL
Meatless Farms	UK	MeatTech 3D	ISR/BE
Heura	SP	Ripple	US
Valorex	FR	Oatley	SWE
Mosa Meat	NL		
Perfect Day	US		
Micro-algae		**Insect-based**	
Inalve	FR	Protix	NL
Microphyt	FR	Ynsect	FR
Olmix	FR	Innovafeed	FR
Fermentalg	FR	Agronutris	FR
Damhert	BE	Nextprotein	FR / TUN
		Enterra	CAN
		Aspire Food Group	USA
Fungi-based		**Ingredients, flavors, colors, casings, equipment**	
The Protein Brewery	NL	Seattle food tech	US
Natures fynd (Danone	US	Myco Technology	US
Quorn (Monde Nissin)	PH	Lallemand	BE
		Aker Biomarine	NOR
		Geltor	US

Source: Bryan, Garnier & Cie

Fig. 33: Alternatives to conventional agriculture products



Source https://newprotein.org/

The Bryan, Garnier & Cie outlook

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

An important driver for the size of the alternative protein industry is first of all how the incumbent protein industry will be able to cater for the growing demand through increased productivity. 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 knowledge and technology are driving productivity gains and we believe here is still a huge 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). Our view is that there is still significant upside for production per animal driven by increases in 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. 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

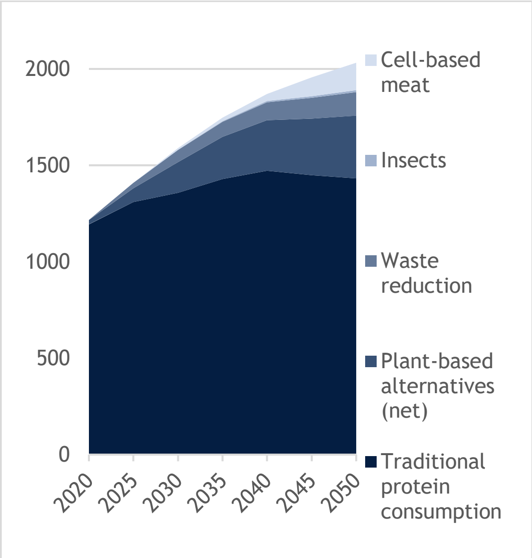
Additionally we expect a decline in food waste and loss or use as feed stock, to provide 15% of the increased need for proteins. Currently almost 20 per cent of the food made available to consumers is lost through over-eating or waste, a study from scientists at the University of Edinburgh suggests. The world population consumes around 10 per cent more food than it needs, while almost nine per cent is thrown away or left to spoil, researchers say. 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 increases and productivity (29%) and the use of food waste (15%), the remaining 56% of increased demand for proteins could 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, are 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) and replacement of fish and soy meal. Most of the insect protein producers are positioning themselves as ingredient providers for the animal feed industries. They tend to expect that over time only a small part of their revenues could come from human food.

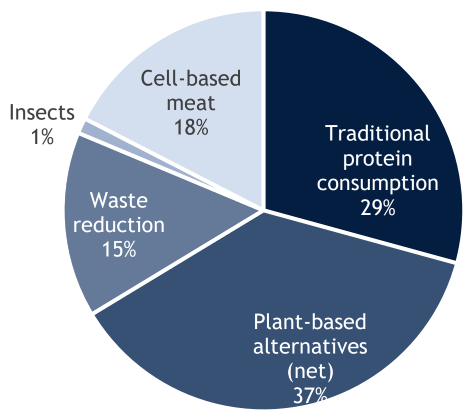
Cultured meat technologies is still facing significant barriers to commercializing: lowering costs and improving taste. Careful attention to texture and judicious supplementing with other ingredients could address taste concerns. And in order to accomplish cost-competitiveness, innovation is needed in 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. 34: Global protein consumption (billion kg)



Source: Bryan, Garnier & Cie

Fig. 35: Source for additional protein production (2020 to 2050)



Source: Bryan, Garnier & Cie

Section 04

Plant-based proteins

Plant-based proteins

The plant-based category is the largest source of alternative proteins today. Plant-based drinks have been a staple in many cultures all over the world. The most popular drinks made from beans are coffee and cocoa, but also almond, coconut and soya milks have a long history. Coconut milk that is made from grated coconut meat has been a main ingredients in South and Southeast Asia, Africa, the Caribbean and Southern America for centuries. The first written mentions of almond milk are from the 13th century (Egypt) and of soya milk from the 14th century (China). During the Middle Ages, almond milk was widely used in Europe during fast-days (Lent and Fridays) as a replacement for dairy milk. Also plant-based meat substitutes tofu (made from soy milk curd) originated in China more than 2000 years ago and tempeh (made from fermented soy beans) was first made on Java hundreds of years ago.

Product range

The market for plant-based proteins is led by plant-based milk that gained popularity in the early 2000s due to a mix of product innovation and a strategic change in merchandising.

The market for plant-based proteins is led by plant-based milk that gained popularity in the early 2000s due to a mix of product innovation and a strategic change in merchandising (selling it alongside cow's milk in the refrigerated dairy case, as opposed to in a segregated store section). The environmental impact of different plant-based alternatives is sigfnicantly lower than cow's milk. The global warming potential for cow's milk — measured as kilogram of carbon dioxide equivalent per liter of milk (FPCM - fat and protein corrected milk) — varies between 0.8 in New Zealand to 1.08 in France, 1.5 in Germany and over 2 in Africa. Compare this to the global warming potential of plant-based milks, which, on average, is just 0.42 for almond and coconut milk and 0.75 for soy milk. Dairy also requires more land than any of the plant-based alternatives. Every liter of cow's milk uses 8.9 square meter per year, compared to 0.8 for oat, 0.7 for soy, 0.5 for almond and 0.3 for rice milk. Water use is similarly higher for cow's milk: 628 liter of water for every liter of dairy, compared to 371 for almond, 270 for rice, 48 for oat and 28 for soy milk.

Soy milk is still the number one ingredient for milk alternatives globally, accounting for circa 55%. Soy milk is rich in vitamins, potassium, and protein and has lower calorie content than cow's milk. The product is facing strong competition from other non-dairy liquids, especially almond milk. In North America and in Europe, almond milk, which is thicker and creamier than other plant-based products, has become more popular than soy milk. Almond milk is low in calories as compared to cow's milk. Rice milk is also increasingly popular especially for manufacturing snacks and baking goods. Rice milk is the least allergic dairy substitute and has witnessed high demand from consumers with milk and nut allergies. But in North America, oat milk is growing fast and has now become the second most popular plant-based milk after almond milk.

The global plant-based milk market is highly competitive in nature with major players including The WhiteWave Food Company (owned by Danone), Nestle, Unilever, Blue Diamond Growers, Archer Daniels Midland, Hain Celestial, Eden Foods, Freedom Foods, Pearl (Kikkoman), Pacific Foods (Campbell), Oatly, and others

Fig. 36: The market of plant based milk alternatives highly competitive

Source nestandglow

The second generation plant-based products, that are made to mimic meat as closely as possible, have been interesting consumers.

The market for plant-based alternatives for meat was until recently small and relatively stagnant, as the market had largely been limited to vegans and vegetarians. But the second generation plant-based products, that are made to mimic meat as closely as possible, draw in additional consumer interest. Indeed in a survey last year done by The NPD Group 89% of consumers of plant-based meat were meat eaters.

This approach to producing plant-based meat began in 2012 with the launch of Beyond Meat's chicken strips, and it really took off with the 2016 launch of the Impossible Burger and the Beyond Burger, both of which have succeeded in mainstream fast-food outlets. Since then global food companies and protein producers, such as Tyson, JBS, Pepsico, KraftHeinz and Nestlé, have entered the sector complementing a flurry of startup activity. For instance Wicked Healthy is marketing Good Catch plant-based tuna (a blend of chickpeas, lentils, soy, fava beans, navy beans, algae and seaweed); and the UK company THIS is scaling up production of its bacon and chicken analogues — mainly from pea and soy protein. Vivera in the Netherlands have produced plant products with a similar bite and mouthfeel to that of ribs and steak.

With the growth of the consumer interest, different food retail and foodservice outlets have been stocking plant-based alternatives

Fig. 37: Impossible Whopper

Source Burger King:

Fig. 38: McPlant

Source: McDonald's

Egg replacer ingredients have long been the subject of supplier innovation, largely driven by unstable egg prices. Now, the drive toward plant-based diets gives manufacturers an additional reason to consider alternatives – as well as an additional marketing platform. Egg replacers have become more acceptable to consumers as companies have started supplying vegan alternatives for home consumption, such as JUST Egg in the United States. Social media has also raised the profile of simple ingredients like aquafaba, the liquid drained from canned chickpeas, which has similar foaming properties to egg whites. Industrial egg alternatives are often plant-based, and include various starches, proteins, fibers and hydrocolloids – companies often use a combination of these to achieve a certain result in finished products.

Fig. 39: Just plant-based scramble egg

Source Just:

Fig. 40: Oggs aquafaba as alternative for eggs in baking and cooking

Source: Oggs

Production process

Plant-based milks are made by grinding a bean or nut, then adding water, flavors, vitamins and minerals. The nutrients and amount of sugar in plant-based milk varies considerably based on how it was produced and what has been added. Plant milks are also used to make "ice cream", plant cream, vegan cheese, and "yogurt", such as soy yogurt.

Plant-based meat alternatives provide the same amount of proteins compared to meat.

Plant-based meat alternatives can be manufactured using protein extracted from plants. The most basic products like tofu and tempeh have been around for hundreds of years. However, those products have been more geared towards vegans and vegetarians and have not been fully accepted as a meat alternative as they did not have the same protein content, flavor and texture of traditional meat. Indeed, an important reason for meat consumption is nutrition and in general, plant protein is limited in nutritional value because of the lack of several essential amino acids such as lysine, methionine, and/or cysteine, and has low bioavailability. Hence it has been important to manufacture plant-based meat alternatives that meet the nutrient specifications of traditional meat. In the current market, several products are successful as plant-based meat alternatives and seem to provide sufficient amount of proteins as compared to meat alternatives.

Fig. 41: Beyond and Impossible burger compared with a beef burger per 100g

Per 100g	Beyond burger	Impossible burger	Sainsbury's British Beef Burgers, Taste the Difference	Carrefour Steak haché burger du chef 15% de MG Bio SOCOPA	Lean ground beef
Ingredients					
Energy (kcal)	257	212	250	207	230
Fat (g)	19	12	17	15	12
of which saturated (g)	4	7	8	6	5
Proteins (g)	18	17	22	16	28
Sodium (mg)	398	327	970	750	87

Source: Bryan, Garnier & Co

Despite the good nutritional value and continuous development of plant-based meat alternatives, their palatability remains a critical obstacle for consumer acceptability. For improving the texture and flavor of plant-based meat alternatives, different ingredients are added during the manufacturing process. Regarding texture, different techniques such as spinning, thermoplastic extrusion, and steam texturization have also been applied for the structural organization of plant protein. Among these, extrusion is the most frequently used technique, as it is an economical method and can manufacture different shapes and sizes of meat analogues. The process is based on a screw system within a barrel by means of which plant proteins are compressed, heated to be restructured into a striated, layered, and cross-linked mass, ultimately leading to the production of texturized vegetable protein (TVP). Research suggested that utilizing wheat gluten and soybean protein as TVP ingredients could impart an appearance, texture, taste, and nutritional value similar to that of traditional meat. In addition, proteins produced from starch by-products using fungi (a.k.a. mycoprotein) have structures and diameters similar to those of muscle fibers of meat with almost a similar texture. Furthermore, flavor enhancers and coloring agents are added to replicate meat.

Interestingly, when compared with natural beef, plant-based meat alternatives have comparable energy value, total fats, saturated fats, and Na and Fe contents, perhaps because of the addition of excess fat and/or oil (e.g., coconut oil and cocoa butter) for mimicking animal fat, coloring agents, and spices to the meat analogues during the processing of plant proteins. However, there is far less salt in the plant-based burger than in the prepared burgers in supermarkets.

Both the Beyond burger and the Impossible burger are made from similar ingredients, the exception being the main protein source. Beyond Meat uses pea protein instead of soy protein, and there's no soy leghemoglobin, which is Impossible's key ingredient that makes the burger "bleed." Beyond Burger's red color comes from beet extract, rather than heme from the leghemoglobin like in the Impossible patty.

Fig. 42: Ingredients Beyond and Impossible burger

Beyond burger: Water, Pea Protein Isolate, Expeller-Pressed Canola Oil, Refined Coconut Oil, Contains 2% or less of the following: Cellulose from Bamboo, Methylcellulose, Potato Starch, Natural Flavor, Maltodextrin, Yeast Extract, Salt, Sunflower Oil, Vegetable Glycerin, Dried Yeast, Gum Arabic, Citrus Extract (to protect quality), Ascorbic Acid (to maintain color), Beet Juice Extract (for color), Acetic Acid, Succinic Acid, Modified Food Starch, Annatto (for color)
Impossible burger: Water, Soy Protein Concentrate, Coconut Oil, Sunflower Oil, Natural Flavors, 2% or less of: Potato Protein, Methylcellulose, Yeast Extract, Cultured Dextrose, Food Starch Modified, Soy Leghemoglobin, Salt, Soy Protein Isolate, Mixed Tocopherols (Vitamin E), Zinc Gluconate, Thiamine Hydrochloride (Vitamin B1), Sodium Ascorbate Vitamin C), Niacin, Pyridoxine Hydrochloride (Vitamin B6), Riboflavin (Vitamin B2), Vitamin B12

source Bryan, Garnier & Co

Environmental impact

Greenhouse Gas Emissions

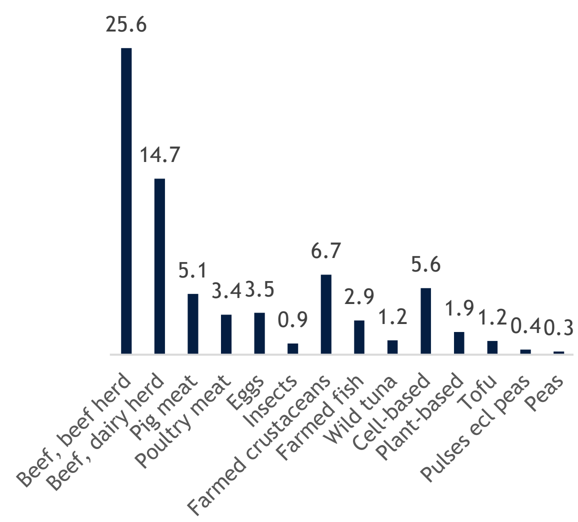
GHG emissions, land-use and water use from plant-based meat alternatives are considerably smaller than animal proteins.

Based on a review of Frontiers the median GHG footprint of plant-based substitutes was 34, 43, 63, 72, 87, and 93% smaller than those of farmed fish, poultry meat, pig meat, farmed crustaceans, beef from dairy herds, and beef from beef herds, respectively, per 100 grams protein. Among the animal foods considered only wild tuna and insects were less GHG-intensive than plant-based substitutes. Plant-based substitutes were 1.6, 4.6, and 7.0 times more GHG-intensive than the less-processed plant proteins in this review, i.e., tofu, pulses (excluding peas), and peas, respectively.

Land use

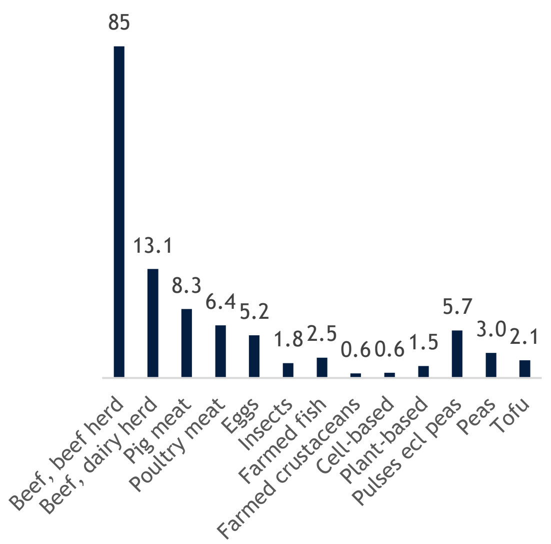
The median land use footprint of plant-based substitutes was 41, 77, 82, 89, and 98% smaller than that of farmed fish, poultry meat, pig meat, beef from dairy herds, and beef from beef herds, respectively, per 100 grams protein. Thus replacing a share of farmed meat in the diet with plant-based substitutes could theoretically free up cropland to feed more people or provide other ecological services such as reforestation for carbon sequestration or the preservation of pasture-based livestock production systems that provide biodiversity benefits in certain landscapes. The median land use footprint of plant-based substitutes was 32, 52, and 75% smaller than that of tofu, peas and other pulses, respectively. These comparisons are skewed, however, by the fact that the values for less-processed plant proteins reflect global averages that include data from low-yielding countries (Poore and Nemecek, 2018), whereas the figures for plant-based substitutes likely assumed ingredients were sourced from more efficient production systems in industrialized countries.

Fig. 43: GHG footprints per 100 g protein in kgCO2e/100g protein



Source: Frontiers

Fig. 44: Land use per 100 g protein in m2 year/100 g protein



Source: Frontiers

Water use

Based on Frontiers review of the available literature, per 100 grams protein, the median blue water footprint of plant-based substitutes was 21 and 42% smaller than those of pulses and soy; 76, 77, and 89% smaller than those of farmed poultry meat, bovine meat, and pig meat; and two orders of magnitude smaller than those of aquatic animals raised in ponds, e.g., farmed shrimp and tilapia. The values for pulses and soy were likely larger than those of plant-based substitutes in part because the former reflect global averages that include data from low-yielding countries, whereas the figures for plant-based substitutes likely assumed ingredients were sourced from more efficient production systems in industrialized countries. By contrast, the median blue water footprint of cultured meat was larger than those of all other foods considered in the Frontiers review except for those of farmed pig meat and pond-raised aquatic animals. Eutrophication and pesticide use

Many popular plant-based substitutes are derived from legumes, which in addition to their food value, are noted for their ability to improve soil fertility through fixing atmospheric nitrogen into a form that is usable by plants. Hence incorporating legumes into crop rotations can diversify farmers' production systems and sources of income and reduce their dependency on synthetic nitrogen fertilizer. However as with fertilized fields, nitrogen can leach from legume-based cropping systems into surface or ground water, which can contribute to eutrophication. One study found that conventional pork production resulted in six times greater eutrophication potential and required 3.4 times more fertilizer per unit of protein compared to a pea-based plant-based substitute (Zhu and van Ierland, 2004). The same study found also that conventional pork production involved 1.6 times more pesticide use per unit of protein compared to the production of a pea-based plant-based substitute.

Biodiversity and ecosystem function

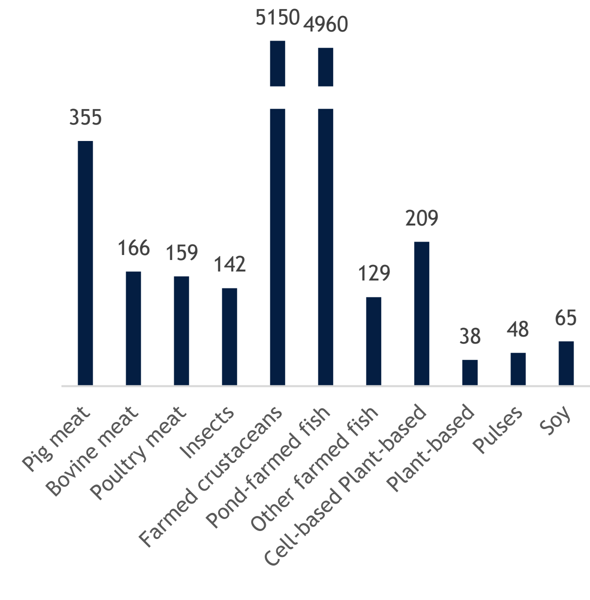
Declining biodiversity of agricultural systems is also a concern for long-term food security and resilience, threatened in part by monoculture production systems and genetic uniformity in crop varieties and livestock breeds in conventional livestock production. To the extent to which meat alternatives integrate ingredients other than soybeans and wheat (which are among the most produced crops worldwide, for both human foods and livestock feed), such as peas and lupins from which several plant-based substitutes are now derived, this could help diversify diets and foster agrobiodiversity. Furthermore producing legumes—the primary protein ingredient in most plant-based substitutes—can improve soil biodiversity and above-ground vegetative and invertebrate biodiversity, although the extent depends on management practices including tilling, chemical pest control, and fertilizer inputs (Williams et al., 2014).

Many plant-based substitutes include coconut or palm oil among their ingredients. Both of these plant-based lipids are grown in tropical regions rich in biodiversity, which is threatened by deforestation and anthropogenic forest disturbance (Barlow et al., 2016). However, these concerns attributed to plant-based substitutes would also need to be evaluated in light of existing deforestation for pasture and feed crop production associated with conventional meat production (Goldstein et al., 2017).

Animal welfare implications

Meat alternatives, if widely adopted as a replacement for farmed meat, may greatly reduce dependence on livestock to be raised and slaughtered for meat production. In contrast, while most plant-based substitutes in theory do not contain animal products, the use of coconut oil in many plant-based substitutes raises animal welfare concerns. Many large coconut plantations in Thailand rely on monkeys, either stolen from the wild or bred on farm to harvest the coconuts. While there are some coconut oil producers that are "monkey free," the continued employment of these animals in chained working conditions raises ethical dilemmas for the continued expansion of the coconut industry without specific standards on this issue.

Fig. 45: Blue water footprint in litres blue water/100g protein



Source: Frontiers

Fig. 46: Monkey picks coconuts in Thailand

Source: NPR

Barriers to overcome and other considerations

Replicating texture, flavor and aroma of meat

An important reason for the increased acceptance of plant protein is their low cost and fibrous texture. However it is a major challenging task to develop the umami flavor (associated with meat) and the fibrous three dimensional structure from these plant proteins while maintaining their nutritional properties so as to provide these alternative meat products the same meaty texture.

Genetic manipulation: Texturized wheat gluten is commercially available in several forms differing in size, shape, density, color, and texture. The popularity of texturized wheat gluten is rapidly increasing due to abundant production of wheat throughout the globe. The researchers are trying to develop wheat varieties that have a minimum amount of gluten while maintaining its technological properties. Genetic engineering can enhance the quality of plant based food products through the silencing of genes.

New manufacturing techniques: The new generation of plant-based meat is inspired by the biochemical composition and three-dimensional structure of meat and these qualities are replicated using non-animal ingredients and novel manufacturing techniques such as Couette (shear) cell technology and 3-D printing, next to the existing extrusion technology. A deeper understanding of protein texturization has enabled restructured meat products to progress from crumbles (used in patties) to shreds and chunks that are ideal for pulled, shredded, and diced meat applications.

Plant-based meat alternatives are well underway to mimic the full meat experience.

While plant-based meat taste and texture have been key drivers of consumer adoption, food innovators are designing products to mimic the full meat experience—from appearance at point of purchase to aroma upon cooking to protein content when consumed. Several products on the market today, such as Beyond Sausage and the Impossible Burger, have demonstrated that this approach can create the flavor, texture, and overall experience of eating meat with a high degree of consumer satisfaction.

The strategies to replicate the complex structure of animal products are :

- 3D printing: Startups like Redefine Meat and Novameat use machines to print plant-based ingredients, such as pea protein, into fibrous strands meant to replicate the complex texture of animal muscle. They could also use the same 3D printing tech with cultured animal cells, though they haven't branched into that space yet. Currently 3D printing is not yet cost competitive.
- Mycelium: It is cheaper to create meat-like texture is through mycelium, or mushroom roots made through fermentation. Atlast Foods grows mycelium scaffolding on which companies can either place cultured animal cells or plants, and Prime Roots and Emergy Foods are developing their own meat alternatives based off of the fungi.
- Gelatin: Harvard scientists have successfully grown cow and rabbit cells on a scaffold made from gelatin. When it comes to texture, gelatin has two advantages. In addition to providing a flexible physical support on which the cells can easily grow, gelatin, which is protein, melts when cooked, which could help cultured mimic the tender texture of steak. The same technique, developed for cultured meat could also be applied to plant-based alternatives.

Fig. 47: Meati mycelium steak

Source: Meati Foods

Fig. 48: Heppi ribs

Source: Ojah

Consumer's barriers

Perceived barriers to adopting a plant-based diet may be particularly strong among people who are male, live in rural areas, have low educational attainment, lack any vegetarian family members or friends, eat meat frequently, and exhibit emotional attachments to meat.

With a reported 89% of consumers of plant-based meat alternatives, being meat-eaters, producers have been looking to replicate the meat pallet as close as possible.

Furthermore, with a reported 89% of consumers of plant-based meat alternatives, being meat-eaters, producers have been looking to replicate the meat pallet as close as possible. Indeed an important driving force for meat consumers to choose for a plant-based alternative is to benefit from a vegetable enriched diet (without giving up the taste, texture and protein levels of traditional meat). However, with health being an important driver, consumers are also asking more questions about the product's formulation. This puts forth yet another challenge for these products. Ensuring a cleaner label product, free from artificial preservatives, artificial flavors and artificial colors is now a consumer-imperative. Further, consumers scrutinize labels on nutrition content such as salt content.

At the same time, plant-based meat consumers do not want to sacrifice the high levels of protein they traditionally get with meat. In a survey from the Kerry Group, roughly 40 percent of consumers surveyed selected "high protein" as the most important attribute when choosing a plant-based meat alternative. Beans/legumes (62 percent) were the most-preferred source of protein, followed by nuts (55 percent) and mushrooms (48 percent).

Food Safety

Most plant-based substitutes contain at least one major food allergen among their ingredients, with wheat and soy being the most common. Individuals allergic to peanuts and soy may also experience reactions to pea and lupin protein and there is also a risk of allergic and gastrointestinal reactions to mycoprotein-based plant-based substitutes (e.g., Quorn). Individuals with intolerances to certain food additives and gums must also be careful given their prevalence in plant-based substitutes.

Carrageenan, for example, is a structural ingredient derived from seaweed that is commonly used in plant-based substitutes and other processed foods for purposes of thickening, gelling, or stabilizing. The safety of carrageenan has long been debated, with attention being focused on its potential to elicit gastrointestinal inflammation, alterations to intestinal microflora, and other related outcomes such as irritable bowel syndrome and colon cancer. Additionally, because carrageenan is grown in seawater, it has the potential to accumulate significant concentrations of heavy metals.

Some concerns have also been raised about the safety of new additives present in some plant-based substitutes, such as soy leghemoglobin used in Impossible Foods products.

Regulations

Proponents of limiting the use of dairy and meat terms argue that they are necessary to protect consumers. Moreover, proponents argue that descriptors such as “veggie burger” and “plant-based” create a misleading impression that a “veggie burger” is healthier than its meat counterpart. Opponents, however, argue that no one believes that a product labeled “vegan sausage” is made from real meat, and that the use of a term like “sausage” is necessary for consumers to understand the intended use and flavor profile that a plant-based product is designed to mimic.

EU law bans the use of dairy terms like “milk,” “cheese”, “yoghurt” or “butter” for vegan products that don’t come from animal milk. It also bans phrases like “yogurt-style vegan snack” and “similar to cheese.” However, EU law does not prohibits the use of meat-related names for plant-based meat substitutes such as “veggie burgers”, “vegan sausages”, “tofu steaks,” etc. EU member states have the power to issue their own food labelling laws to prevent consumers from being misled. France passed a legislation to ban the use of meat nomenclature for vegetarian and vegan substitutes.

The U.S. Food and Drug Administration (FDA) is tasked with regulating plant-based meat alternatives but does not currently have any specific regulations concerning the labeling of plant-based meat alternatives, beyond its general prohibition against false or misleading representations. However, nearly 30 states have proposed legislation aimed at limiting the ability of plant-based protein producers to label their goods with terms associated with animal meat, such as sausage, burger, and bacon. For example, Arkansas and Louisiana enacted legislation that expressly prohibits plant-based meat alternatives from using terms like “burger” or “sausage” on their labels. However, if the FDA were to set a definition for the word “meat” or for related products, which it has not done yet, state regulations setting different standards would be preempted. This occurred in the related debate over the use of terms like “almond milk” for plant-based dairy alternatives. There, appellate courts have held that state regulations prohibiting dairy alternatives from using words like “milk” to describe their products are preempted by the Federal Food, Drug, & Cosmetic Act because they go beyond the FDA’s requirements. While the FDA regulations would not allow an almond milk manufacturer to label its product simply as “milk” under its standard of identity, appellate courts have held that they may use the word “milk” in conjunction with a descriptor like “soy” that indicates it is plant-based.

Economics of the plant-based alternatives

The development of a good number of plant-based milk alternatives (eg. WhiteWave, Ripple, Califa) gives a good idea about the type of margin an returns that can be achieve with plant-based alternatives compared to the original food. In 2015, WhiteWave’s operating margins were 9.7% on EUR3.9bn of revenues compared to Danone’s 12.7% margin on EUR22.7bn of revenues (meanwhile with synergies the combined group is margin 15.2% operating margin). From our discussions with WhiteWave we understand that operating margins are currently around 20% but mainly because of the premium position of plant-based milk that offers a lower calories alternative to milk. The same is not true for the other plant-based dairy or plant-based meat alternatives.

At maturity, Beyond Meat is looking for mid-teens EBITDA margins with its products priced at or below conventional meat.

In the conventional meat industry, operating margins are 4%, 5% and 8% for the pure meat packers Ter Beke, JBS and Tyson Foods respectively. Companies that have operations closer to packaged food like Hormel Foods and ConAgra, have operating margins of respectively 13% and 18%. Analysts are expecting operating margins for Beyond Meat in 2022 of 6%, but the company is still developing. Beyond Meat founder and CEO Ethan Brown is looking for mid-teens EBITDA margins once the company is maturing (implying an operating profit margin of 13%) which also assumes that its products are priced at or below conventional meat.

Fig. 49: Expected operating margin and ROCE of quoted meat processers (2022)

	Operating profit	Revenues	Op. margin	ROCE
Tyson Foods	3447	44894	8%	11%
JBS	15432	291765	5%	15%
ConAgra	1991	10808	18%	9%
Hormel Foods	1259	10059	13%	14%
Beyond Meat	55	902	6%	6%
Ter Beke	32	811	4%	

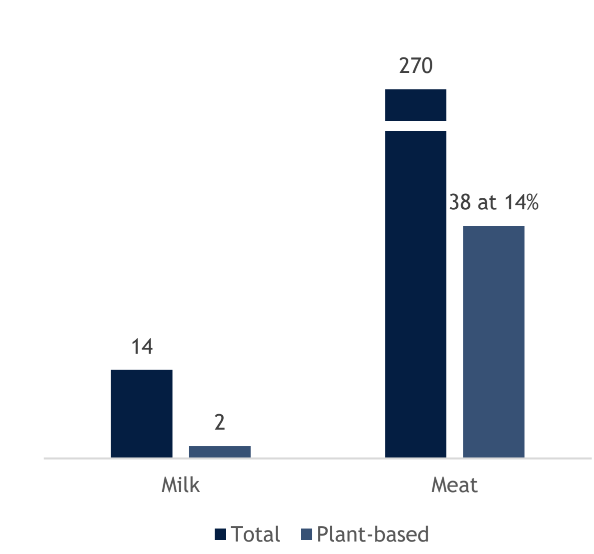
Source: Refinitiv

Outlook for plant-based alternatives

The plant-based products market is estimated to reach USD100.5bn by 2030 growing at a CAGR of 12% from USD32.7bn in 2020.

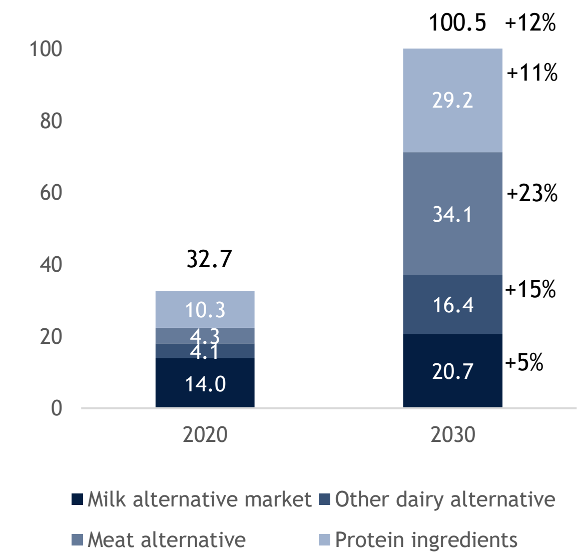
Global plant-based milk sales reached an estimated USD14bn in 2020 while global plant-based meat sales hit an estimated USD4.3 billion in 2020. We are expecting plant-based milk sales to reach USD20.7bn by 2030 (CAGR 5%) and plant-based meat alternatives USD34.1bn (CAGR 22%). Furthermore, the global plant-based protein market is estimated at USD10.6bn in 2020 and is likely to reach USD29.2bn by 2030, growing at a CAGR of 11% during the forecast period. Overall, the plant-based products market is estimated to reach USD100.5bn by 2030 growing at a CAGR of 12% from USD32.7bn in 2020.

Fig. 50: US plant-based milk (2019) and plant-based meat potential in USDbn



Source: Beyond Meat

Fig. 51: Global plant-based products market (USDbn)



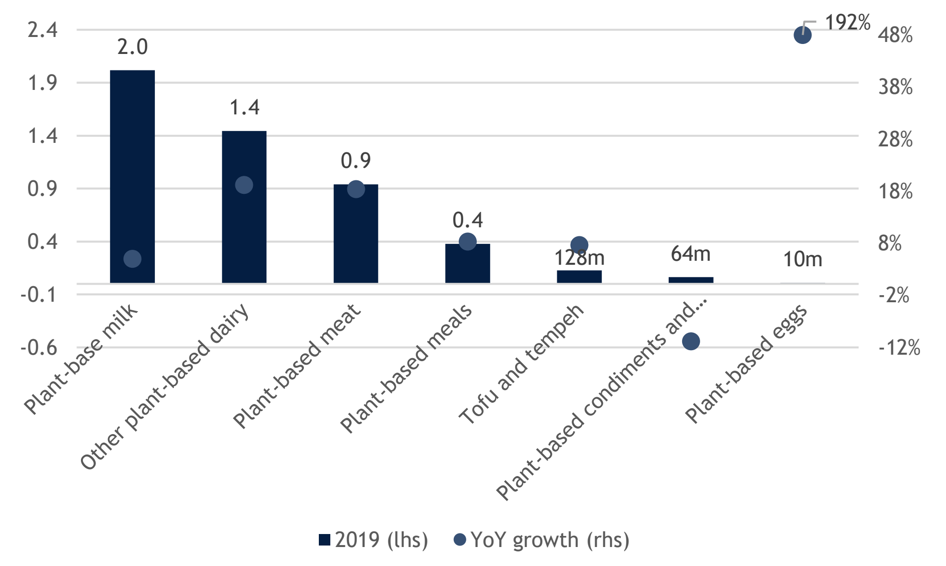
Source: Marketsandmarkets, Fortune Business Insights, Bryan Garnier & Cie estimates

Already today in the US plant-based milk alternatives have a 14% share of the total retail milk market and we expect plant-based meat alternatives to trend in the same directions.

The expected strong and prolonged growth in the plant-based meat alternatives market is based upon the current penetration of plant-based milk alternatives. Indeed in 2019, US retail sales of plant-based milk reached USD2bn, which equates to 14% of the total US retail milk market. Furthermore, according to Gallup, 41% of the US adults have tried plant-based milk (which has grown consistently from 18% in 2010). Within the different age brackets, younger adults are more likely to purchase plant-based milk. In the same survey 47% of respondents 18-29 and 50% of those 30-49 said they have consumed plant-based milk. That share falls to 38% among adults aged 50-64 and 26% of those over the age of 65.

Plant-based meat alternatives market is by far not so developed. It has only a 1% market share but is backed by a 14% household penetration). If the plant-based meat retail and foodservice categories were to reach a market share comparable to that of retail plant-based milk, plant-based meat's share would reach more than USD37.8bn of the USD270bn US meat market.

Fig. 52: Total US plant-based food dollar sales and growth by category, 2019

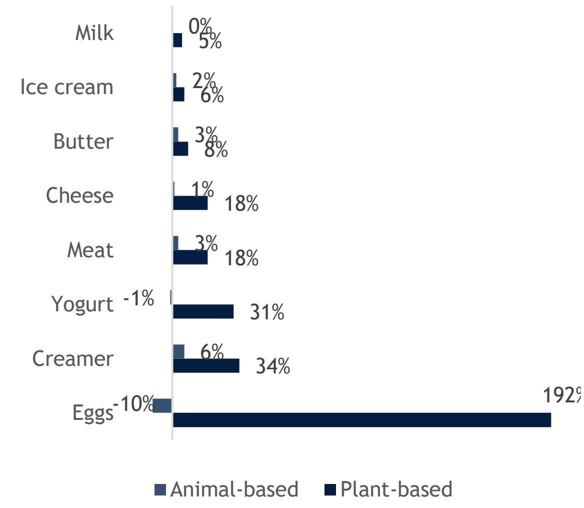


source SPINSscan

Across key categories, dollar sales of plant-based foods is growing significantly, while dollar sales of conventional animal foods are declining or growing only modestly. Over 2019, dollars sales of conventional milk were flat, while dollar sales of conventional yogurt and conventional eggs decreased by 1% and 10%, respectively. By contrast plant-based milk grew 5% and plant-based yogurt and eggs grew 31% and 192%. In total, plant-based US food sales grew in 2019 by 11% to USD4.98bn while US retail food sales grew by just 2% during the same period. Also retail dollar sales of plant-based meat, the second-largest category behind plant-based milk has started growing strongly. Nevertheless, in 2019, plant-based meat was still only 1% of the total US meat category compared to 14% for plant-based milk. But in the Natural channel (channel with at least 50% of sales from natural and organic products), plant-based meat already holds a 8% share of all meat sales (plant-based milk holds a 41% share of all milk sales in this channel). This is important because the Natural channel is where trends first emerge before disseminating into conventional stores.

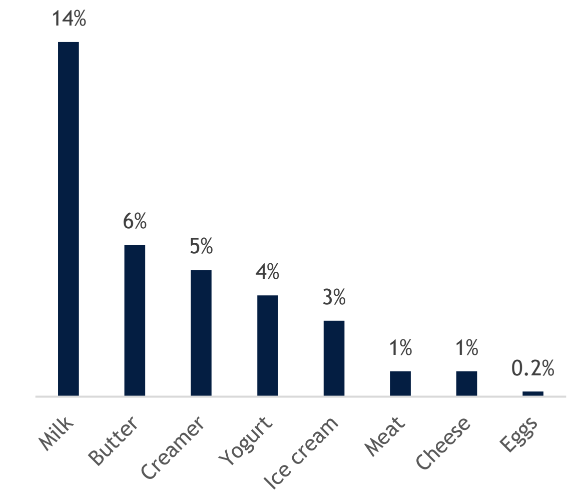
Across the different markets, plant-based alternatives are especially supported by the rising number of vegans and vegetarians. In Germany , for example, last year a Skopos Study found that the number of vegans had doubled over the past four years to 3.2% in July 2020 from 1.6% in 2016. On top of that about 4.4% of declared themselves vegetarian. In 2020, the country's Federal Statistics Office said the total value of meat products in Germany was valued at EUR39.3bn, a 4% decrease from 2019. However, plant-based meat alternatives skyrocketed 39 percent in 2020, compared to the year before to EUR374.9m from EUR272.8m but accounted for only 1% of the total meat and meat alternatives market.

Fig. 53: Growth in plant-based and animal-based products, US 2019



Source: SPINSscan

Fig. 54: Plant-based dollar share of total category in the US, 2019



Source: SPINSscan

Section 05

Cultured meat products

Cultured meat products

Cultured meat is genuine animal meat grown from cells in bioreactors rather than using animals.

One of the most interesting AgriTech developments is cultured meat. Cultured meat (often referred to as clean meat or cultured meat) is genuine animal meat that can replicate the sensory and nutritional profile of conventionally produced meat because it's comprised of the same cell types and arranged in the same three-dimensional structure as animal tissue. By growing meat from cells instead of from a whole animal, it becomes possible to create high-quality cuts of meat using fewer resources and with less environmental impact.

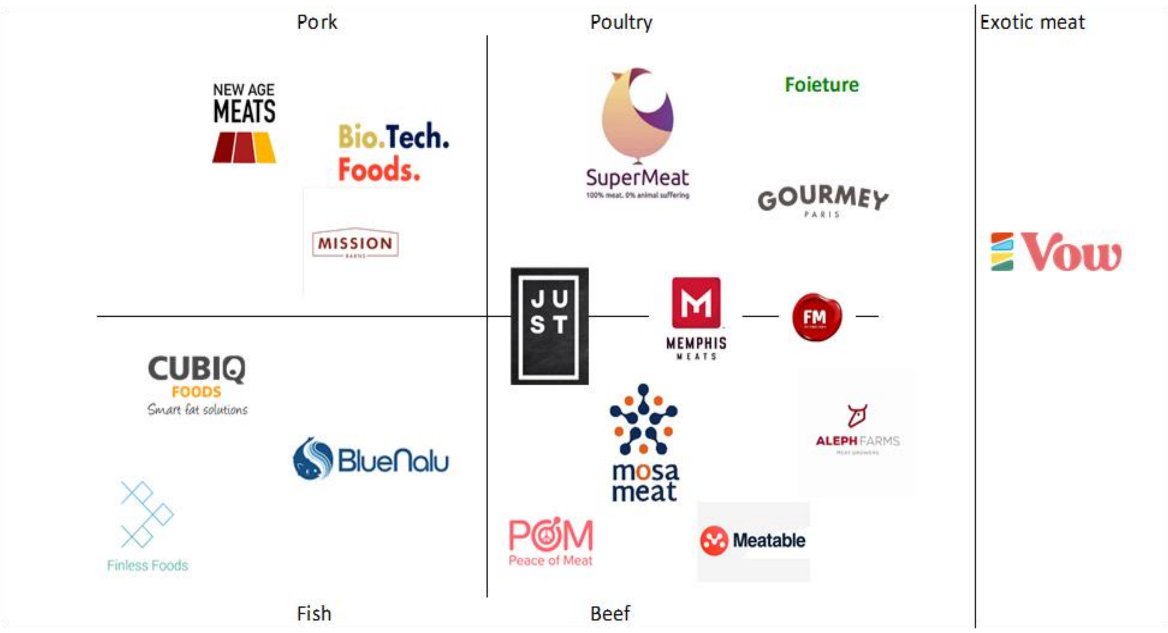
Product range

In 2013, Mark Post, a professor at Maastricht University, was the first to showcase a proof-of-concept for cultured meat by creating the first burger patty grown directly from cells. Since then, several cultured meat prototypes including chicken, duck, steak, pork sausage, and fish cakes have gained media attention among them Mosa Meat (co-founded by Mark Post) and Meatable from the Netherlands, Peace of Meat and the Foieture Project from Belgium, CUBIQ Foods and Bio.Tech.Foods from Spain, Gourmey (France), Memphis Meats (USA), SuperMeat (USA), Eat Just (USA), Finless Foods (USA), Future Meat and Aleph Farms from Israel.

Proof of concept was only showcased in 2013 and currently there are no cultivated meat products on the market.

If the goal of cultivated meat production is to significantly reduce the levels of meat consumption from industrial animal agriculture and in turn reduce the associated negative impacts, then large quantities of meat will need to be produced affordably and efficiently. Currently, there are no cultivated meat products on the market, although several cultivated meat products have been taste-tested, including duck, chicken, salmon, yellowtail, shrimp, pork sausage, foie gras, fish maw, fat, beef meatballs, beef hamburgers, and beef steak strips, amongst others. Some companies have announced that they expect to start selling products this or next year.

Fig. 55: focus of cultured meat companies



Source Bryan, Garnier & Cie

Production process

Stem cells, the building blocks of muscle and other organs, are collected from animal tissue to begin the process of creating the cultured meat. There are several different possibilities for the starting stem cell population, delineated by their potency, or ability to differentiate into a diversity of cell types. For instance, embryonic stem cells have the ability to differentiate into cells of all three developmental germ layers (i.e. ectoderm, mesoderm, and endoderm), while adult stem cell populations found throughout our body are typically more specialized and limited to creating cells of the same germ layer or organ type.

Fig. 56: Cell Line Choices

Cell Type	Cell Types Created	Difficulty to Obtain	Proliferative Capacity	Origin
Embryonic Stem Cell (ESC)	All	Highly difficult	Immortal	Derived from early embryonic, just a few days post-fertilization
Induced Pluripotent Stem Cell (iPSC)	All	Difficulty to Obtain	Immortal	Cellular reprogramming that maintain properties of embryonic stem cells
Mesenchymal Stem Cell (MSC)	Bone, Muscle, Fat, Connective tissue	Moderate	Limited (10-40 doublings)	Adult stem cells mostly originating from a bone marrow
Myosatellite Cell	Muscle (some potential for fat & bone?)	Moderate	Limited (10-40 doublings)	Stem cell from adult skeletal muscle tissue
Fibroblast	Connective tissue, muscle, fat	Easy	Limited (10-40 doublings	The principal active cell of connective tissue.

Source: Elliot Swartz

Stem cells are placed in a growth medium to proliferate and are subsequently transferred to a new environment and triggered to differentiate into a mature cell type.

The process of cultivated meat production following cell line selection starts with proliferation whereby stem cells are placed in a growth medium (amino acids and carbohydrates) to divide repeatedly generating a large number of cells. Next, those cells are transferred to a new environment and triggered to differentiate into a mature cell type via changes in scaffolding, medium composition, or both. Once enough muscle fibers have grown, the result is a meat that resembles ground beef.

Currently, the main challenge from a technological perspective is scaling up production and making it affordable for mass markets. Bioreactors with volumes up to or beyond several thousands of litres, are needed to produce meat at scale.

Environmental impact still needs further assessment

It's too soon to assess the environmental impact of producing cultured meat, but it could reduce the environmental costs of meat production as resources would be needed only to generate and sustain cultured cells, not an entire organism from birth. Compared to conventional beef, lab-grown beef requires “at the farm” 45% less energy, 95% less land, 95% less water and produces 80% fewer greenhouse gas emissions for 100% same nutritional value. However, its growth media require also substantial inputs leading to the argument that currently lab-grown meat has no ecological benefits over conventional meat. Since cultured meat is grown in a clean facility, it does reduces the risk of contamination by harmful pathogens and eliminates the need for antibiotics, thereby reducing the serious public health threats posed by foodborne illness and antibiotic resistance. Next there is also an ethical dimension of eliminating much of the treatment of animals raised for food.

Barriers to overcome and other considerations

Still a lot of work need to be done to lower cost and to improve taste and texture.

The two largest barriers to commercializing cultivated meat are 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.

Whereas the current cost price of culture meat cannot compete with traditional meat, technological advances should make that the cost to produce cultured meat should continue to decrease and it could become even cheaper than conventional meat. One of the reasons is that producers will expand to bioreactors of 20,000 litres or larger to be able to produce batches of 4,000 to 5,000 kg. The other reason is that the cost of the culture medium in which the cells grow will reduce - one of the largest cost items for growing cells in the bioreactor is the culture medium that is made up of amino acids, sugars and salts.

The first lab-made hamburger was created in 2013, and it costed about USD280,000 to produce given that cellular agriculture was a novel and costly technology. However that costs is expected to drop to USD10 by 2021, according to Dutch food technology company Mosa Meat and Spain-based Biotech Foods. The average cost of producing a kilogram of cultured meat was about USD110 in 2020, down from USD800 cited in 2018 by Israeli biotech company Future Meat Technologies. Memphis Meat claims that it would be able to produce a burger for approx. USD600 and hope to be down to USD5 within a few years. Future Meat currently seems to be able to produce a burger for USD90 and believe it can lower the cost to USD1 by the end of this year. Future Meat is advancing well to cut the costs of the culture medium through recycling that medium and its production process is also avoiding the use of serums, which are made from animal blood.

Ground meat products like chicken nuggets, sausages and ground beef are likely to reach cost-competitiveness with conventional meat first. More complex cuts of meat that require more complex production methods should take longer to become cost-competitive. But even before, cultured meat/fat could be blended with plant-based meats to lower costs and to add texture to the plant-based meat. The Israeli company MeatTech 3D acquired Belgium-based Peace of Meat exactly for that purpose.

Harvard scientists have successfully grown cow and rabbit cells on a scaffold made from gelatin. When it comes to texture, gelatin has two advantages. In addition to providing a flexible physical support on which the cells can easily grow, gelatin, which is protein, melts when cooked, which could help cultured mimic the tender texture of steak.

Too early to look at what potential profitability could be

Cultured meat production is still in its infancy with no proven prototype production yet and significant scaling-up challenges on the horizon. Nevertheless, the industry is developing fast but at some point will need to start scaling up, which will bring risks. Also on raw material, there will be challenges ahead. Amino acids that are already used in animal feed are relatively cheap at USD1 per kg, but FGF – a protein required in some meat cells sells currently at USD800,000 per gram. Although initially products are likely to be sold at a premium to conventional meat, ultimo prices of cultured meat need to come down to those of conventional meat (i.e. USD6 per kg for a mince product), which might happen in 10 years' time.

If that happens and the cultured meat industry manages to grow meat similar to conventional meat, the market opportunity could be the full 1.2bn tonnes of the current conventional meat. Coupled with strong patent protection, large scale profitable companies should emerge.

Regulations

In the U.S., the Department of Agriculture (USDA) and the Food & Drug Administration (FDA) agreed to jointly oversee the production of in vitro meat, according to their regular competencies: the FDA will oversee the first stages regarding cell-culture technology including cell collection, cell banks and cell growth and differentiation, and the USDA the production and labelling of food products derived from the cells of livestock and poultry.

In Europe, cultured meat is covered by the Novel Food Regulation, which involves a pre-market approval process. For being authorized as a novel food, the producers of in vitro meat need to file an application. If the product is deemed safe after a scientific assessment by the European Food Safety Authority (EFSA), the Commission can enact a Regulation to authorize cultured meat. No application for the authorization of in vitro meat has been received so far. Therefore, cultured meat cannot yet be placed on the market, and any such meat would be seized by the authorities. This is what happened in December 2017, when tasting experiments of cultured meat made by Eat Just were organized in the Netherlands, and the Dutch Safety Authority sealed the products to prevent them from being consumed.

Some Asian jurisdictions, such as Hong Kong and Japan, also are developing pathways to market. However at the end of 2020, Singapore was the first to approve the marketing for human consumption of a cultured chicken product from Eat Just.

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Section 06

Insects as feed and food

Insects as feed and food

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.

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. Hence edible insects, such as black soldier fly, mealworms (Tenebrio molitor), lesser mealworms (Alphitobius diaperinus) as larvae, mostly marketed under the term buffalo worms, house cricket (Acheta domesticus) and the European migratory locust (Locusta migratoria), are 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.

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. For fish, poultry and pigs, insects are already natural feed. 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 or flour:

- Insect flour (e.g. cricket flour): Powdered crickets don’t have the same baking abilities like ordinary flour, but the high protein insect powder can be used in bread, pancakes, waffles, smoothies… Examples include the all-purpose flour from Cricket Flours (USA), and the cricket protein pancake mix from Bud’s Cricket Power (USA).

- Insect burger and insect minced meat: These are hamburger patties made from insect powder/ insect flour (mainly from mealworms or from house cricket) and other ingredients. One of the first was the “Bux Burger” from German Bug Foundation that originally was launched in 2014 in restaurants in Belgium and later launched in grocery stores in Germany. Because of costs, often insects are mixed with soy. One example is Sirkkis from Finnish company Entis. Another example is Dutch Protifarm (recently acquired by Ynsect) who have developed an ingredient called AdalbaPro that can be used by food producers to make their own meat replacement products.

- Insect fitness bars: Companies that are producing protein bars containing insect powder include in this field are Chapul (USA), Näak (Canada), Kriket (Belgium) and Sens food (Germany).

- Insect pasta, crackers en crispbread: Pasta made of wheat flour, fortified with insect flour (house crickets or mealworms). One of the earliest companies to market insect pasta was Thai/Italian company Bugsolutely. Belgian Little Foods offers Tomato and Smoky Crickers (cricket crackers).

- Insect bread: Bread baked with insect flour (mostly house crickets). Frazer from Finland launched its cricket bread (adding 70 ground crickets for proteins, minerals and vitamin B12) already in November 2017. In March 2019 Bakehuset from Norway, followed, creating a bread containing mealworms.

- Insect snacks: Crisps and small snacks made with insect powder and other ingredients. Classics are insects covered with chocolate (e.g. dark chocolate crickets from Don Bugito) or the lollipops with a whole insect in them (Hotlix from the US). Some companies make insects candy or cookies with ground up insect powder (e.g. macarons and cookies from French Minus farms).

- Food and drink companies such as the Australian brewery Bentspoke Brewing Co and the South-African startup Gourmet Grubb even introduced insect-based beer, a milk alternative and ice-cream (made from black soldier fly larvae). Other beers are Savu Sirkka - “Smoked Cricket” from a Finish craft brewer, Aardvark from Garage Projects (New Zealand), Madora Brown Ale, an ale made with South African Mopane worms from Drifter. Another is the Belgian Beetles Beer, spiced with beetles.

Fig. 57: A snapshot of insect-based food products

Source Misc.

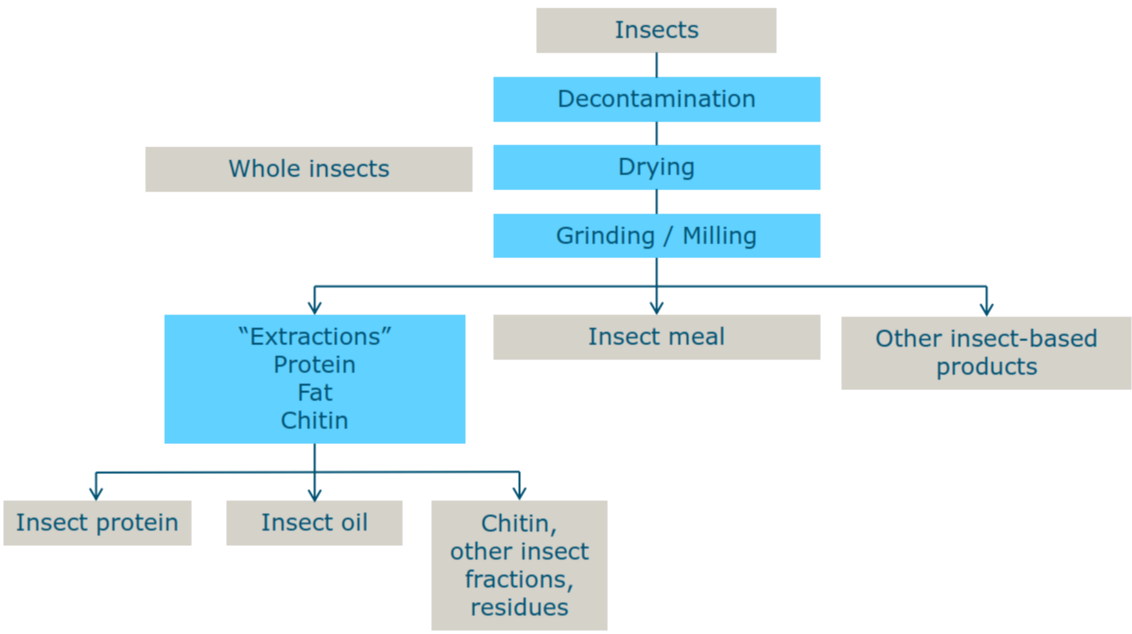
Production process

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 ℃ 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. 58: Elaborate insect processing



Source Wageningen University & Research

Environmental impact

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

Insects are a feed/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. In addition, 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 (Musca domestica L.) and the black soldier fly (Hermetia illucens L.) 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. 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.

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.

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.

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.

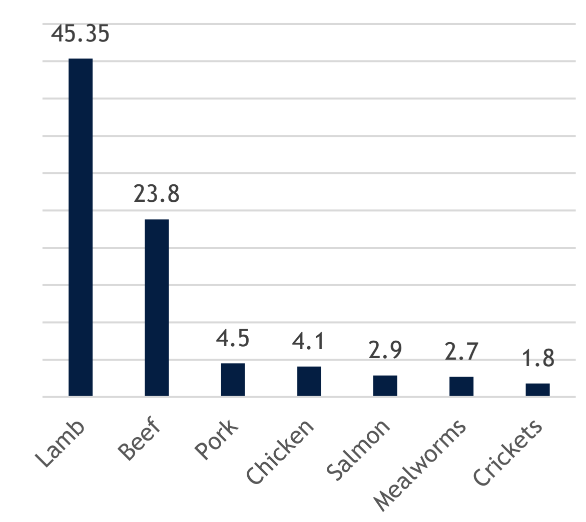
Fig. 59: Amount of land, feed and water needed to produce 1 kg of live animal weight

	% 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)

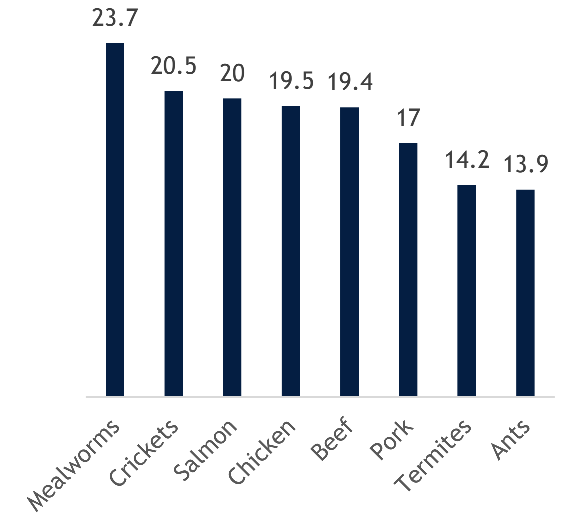
Greenhouse gasses: There is consensus that the biggest contributor to global climate change is greenhouse gas emissions, predominantly CO_2, nitrous oxide and methane, from fossil fuels and agricultural and industrial processes. The agricultural sector contributes the most to GHG emissions, with livestock 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. 60: CO2kg-eq emissions associated with producing one kg from different livestock



Source: Afton Halloran, University of Copenhagen, Denmark

Fig. 61: 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 thing that has often been talked about as a potential 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, the Diptera Fly is known to be able to convert agricultural manure into body mass and reduce the waste dry matter by 58%. For food waste the conversion is as high as 95%.

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.

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, the FAO authors 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).

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. 62: 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 is 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).

… and only 7 species of insects can be given to farmed fish and none to poultry and pigs.

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 and Field Cricket. However, the use of insect PAPs to feed poultry and pigs is still banned within the European Union, unlike in China, South Korea, Kenya, Uganda, and Canada (related to Hermetia illucens in poultry feeding).

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 authorised 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.

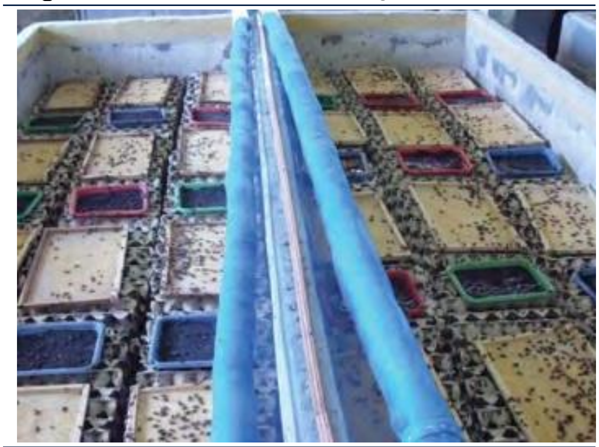
Southeast Asian countries have a tradition of entomophagy, but do not have regulations relating to the breeding, sale and export of insects. Thailand, the world's largest breeder of crickets, has released the guidelines for cricket farming (GAP – Good Agricultural Practice) in 2017. Also in China, insects 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 a replacement for fishmeal.

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. 63: Small scale cricket farming in Thailand



Source: FAO

Fig. 64: 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.

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.

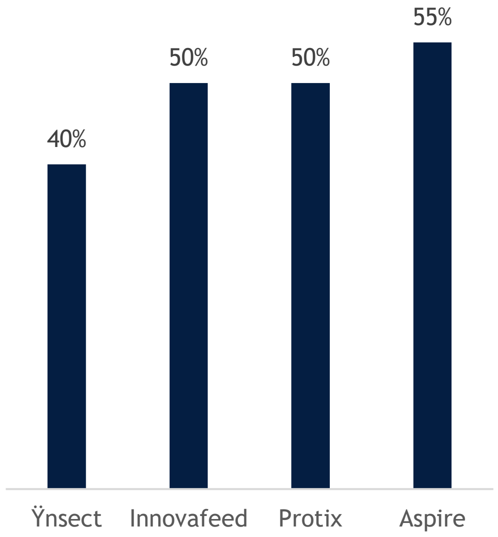
Other cost considerations are climate (In Western Europe and North America insects need heated conditions to optimize growth and hence controlled enviornments) and the type of species used. Species that will be mass produced need to have a high intrinsic rate of increase (short development cycle, high 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 fishmeal prices (USD1,500 per tonne).

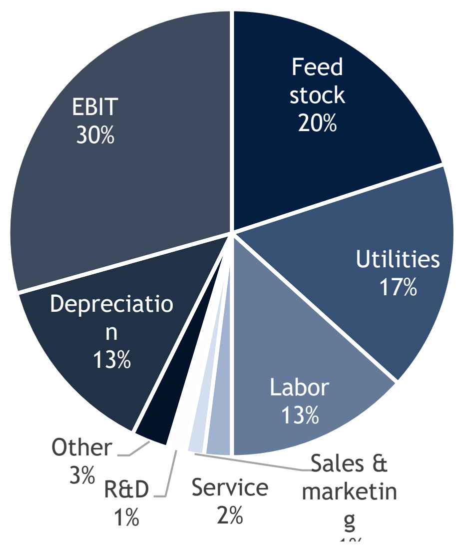
Most industrial insect companies are looking to achieve EBITDA margins between 40% and 55% assuming, depending of the species (BSF, mealworms, crickets), selling prices of insect meal/oil at USD2,000 to USD3,000 per tonne (price range also depends on market addressed and differs in aquaculture vs petfood 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. 65: Expected EBITDA margin different insect companies



Source: Bryan, Garnier & Cie

Fig. 66: Profit and Loss example of an insect compan



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. 67: Global feed of 6.0bn tonnes dry matter

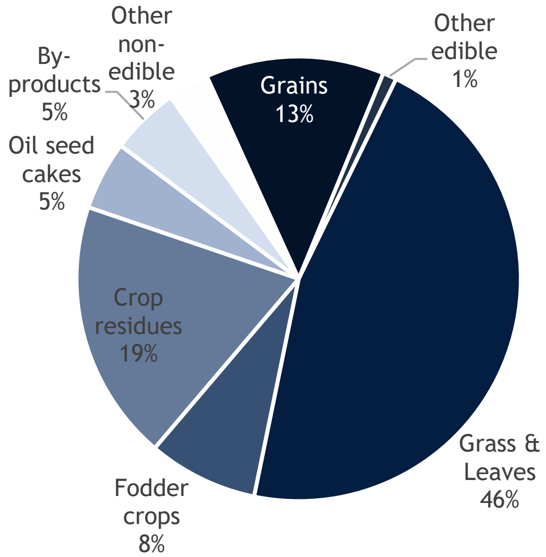
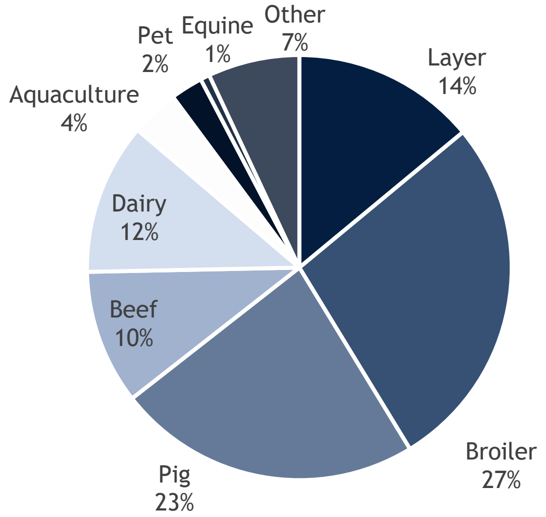


Fig. 68: Global compound feed of 1.1bn tonnes



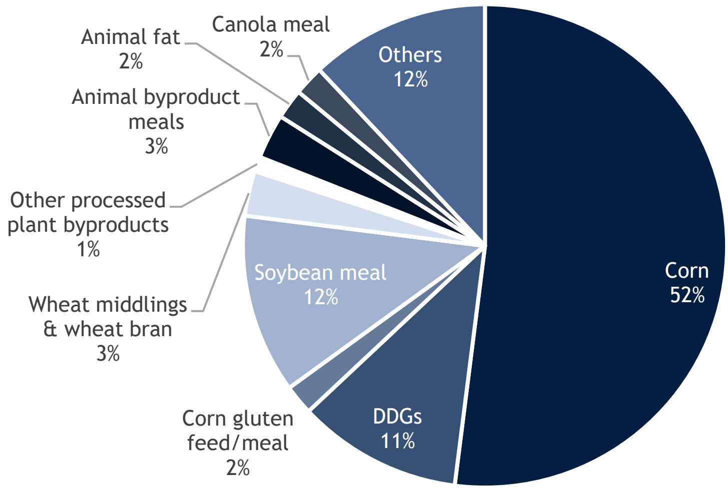
Fodder crops: grain and legume silage, fodder beets
Crop residues: straw and stover, sugar cane tops, banana stems
By-products: brans, corn gluten meal and feed, molasses, beetroot pulp and spent breweries, distilleries, biofuel grains
Other non-edible: second grade cereals, swill, fish meal, synthetic 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. 69: 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 prices of fishmeal and soymeal, are high and volatile. Moreover the increase in aquaculture is further driving demand. All this leads to a surging interest for edible insects in the aquafeed market. But also in the poultry and pig industry, demand for high-quality protein is rising, driving demand for fishmeal & oil and potentially that of edible insects and microalgea.

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

Indeed, edible insects (and microalgae) for animal feed products are fulfilling the same functionalities as fishmeal/oil. Fishmeal and fish oil are employed as high protein ingredients within the feeds 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 feeds. 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 chartecteristic is also likely to limit the prospects of the insectmeal & oil industry in general:

1) Insect meal & oil lacks standardisations: fishmeal 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 is due to 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 fishmeal at USD1,500/tonne, fish oil at USD2,000/tonne and soymeal 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 persisting 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), we expect insect meal prices to drop further. (And further increase the use including potentially replacing soymeal).
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.

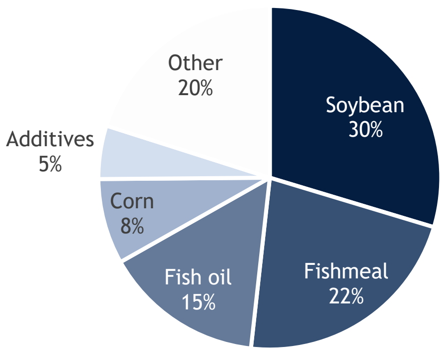
Currently the insect industry is geared towards providing high quality proteins in pet food and replacing fishmeal/oil in aquaculture, which are both very specific and high value added industries.

Currently the insect industry is geared towards providing high quality proteins in pet food and replacing fishmeal/oil in aquaculture, which are both very specific and high value added industries. In our base scenario we expect that insect meal could replace other protein sources by 5% for aquaculture and 10% in pet food. In that base scenario, the insect replacement industry for these two segments would be respectively 0.6m and 0.7m tonne (at USD2,500/tonne). In a best case scenario we estimate that in aquaculture 10% of proteins are replaced by insect 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.

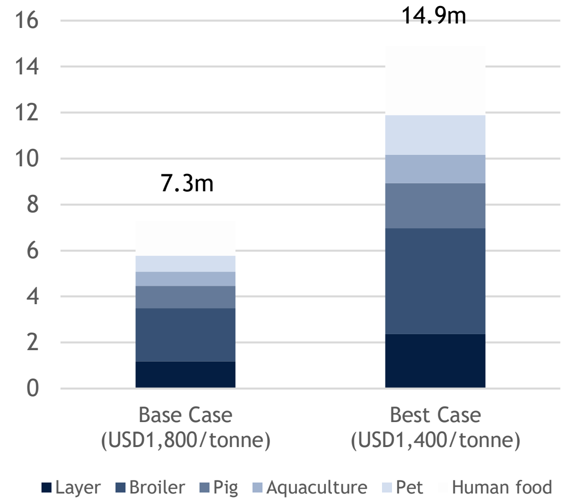
Next to the relatively highly priced aquaculture and pet market, we expect a more commoditized insect meal market (but still demanding prices of USD1,000 to USD1200 per tonne) to develop allowing for insect meal to enter into piglets and poultry markets assuming that additional trials as well as economic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

Fig. 70: Global aquafeed market (USD57bn) by ingredient, 2019



Source: Fortune Business Insights

Fig. 71: 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 of 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 fishmeal 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 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 soy 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 soymeal 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 fishmeal, sunflower meal, corn gluten meal or potato protein. Research showed that a full replacement of fishmeal 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 replacement of soybean and fish meal with locally derived insect protein sources 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. Given that yearly 1.4bn tonnes of food is wasted and a feed conversion rate of 2.0, the contribution of insects reared on feed waste could be 0.7bn tonnes. In the US alone, the 40m tonnes of food waste could be converted in 20m tonnes of insect feed. In the EU, around 90m tonnes of food is waste, allowing the production of 45m 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.

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 application and replacement by 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 7.1m 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 of insect meal replacement we do not expect the fish meal&oil industry to grow much beyond its current size of 7.1m tonnes, 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 replacing 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. 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 10 to 20 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. 72: Potential size of the insect meal & oil market

				Base Case		Best Case	
	Market size (m tonne)	% protein	Protein market (m tonne)	Replacement	Size (m tonne)	Replacement	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)					1494		1124
Food (USD m)					4,500		7,500
Average foot price (USD/tonne)					3000		2500
Total market size (USD m)					13,128		20,874
Average price (USD/tonne)					1805		1402

Source: Bryan, Garnier & Cie estimates

Section 07

Interviews

Interviews …

… with Guy Hefer, CFO at MeaTech 3D

How does MeaTech 3D position itself in the alternative protein market?

MeaTech 3D is developing cultured meat 3D bioprinting technology which can then be used by major food producers to manufacture hybrid and advanced cultivated meat and related products. From the on-set the company was designed to facilitate large scale production which is needed if 3D printing is going to replace slaughter houses. In-house capabilities include the technology, knowledge and experience in the application of tissue engineering practices for the production of fat and muscle as well as capabilities for 3D bioprinting a combination of living cells and the use of growth factors and other biological materials to produce cultured meat that mimics the characteristics of natural tissue.

Does the company has the know-how to be one of the leaders in the cultured meat market?

The CEO, Sharon Fima, was the founder and CTO of Nano Dimension (3D printed electronics) and Prof. Tal Dvir, adviser, is an expert in tissue engineering and his team was the first that successfully engineered and 3D print an entire heart (from a rat) replete with cells, blood vessels, ventricles and chambers. A good number of his students are also working in the company. On the commercial front, Chairman Steve Lavin is also Vice-chairman of the OSI Group, a global food supplier for foodservice and retail food brands including McDonalds, Starbucks, Pizza Hut, Kraft Heinz etc). OSI also co-manufacture with Impossible Foods, the Impossible Burger.

When will be the first products developed by MeaTech 3D be on the market?

In August 2020, MeaTech's scientists already succeeded in printing a single layer of tissue proving the team could successfully sort muscle and fat stem cells, produce the necessary cellular ink and combine the meat and fat cells in a way that causes them to coalesce into a single structure. By the end of 2021, the company want to be able to print with its prototype industrial printer a 100gram of structured tissue containing cultured muscle and fat. Subsidiary Peace of Meat is likely to be able to come with a commercial viable fat product by the end of 2022 enabling to create a hybrid plant/cultured product.

What could drive the cost price of cultured meat down?

The two main factors that need to be addressed to make cultured meat a cost effective alternative are the cost price of the growth medium and capex. With 3D bioprinting coming from the pharmaceutical industry, the quality and cost of the growth medium are pharma-grade. A more cost competitive food and beverage grade growth medium need to be developed and if the current price decline in growth medium accelerate to USD0.3 per liter in 2024/2025 compared to USD50 currently then cultured meat economics will make sense. In our view the main factor is the cost of the overall production process including the quality of the cell-line, the production yield per time and bioreactor volume as well as the cost of cell culturing medium. At this point we do not see the capex as main barrier. In terms of capex, a production line (3d printer and incubators) capable of printing about 5 tons of meat per annum (BG estimate) costs about USD10m. The other large investment is the bioreactor.

… with Alain Revah, Chief Marketing & Strategy Officer at Ÿnsect

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 another protein does not make a lot of sense unless by law production of beef or other foods with a conversation ratio of more than two is not permitted anymore. 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 much higher in mealworms (72% protein) than any other 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 15% 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.

At what prices does insect proteins sell?

That is a very touchy question. Because there is not enough supply in the market, current prices are not a reflection of prices for production at scale. Ÿnsect is selling its proteins from USD3,000 to USD10,000 per ton depending on the market for which the product is being used (aquaculture, pet food, human food & health). However, other insect companies are quoting the same prices although in many cases their products are inferior in terms of protein count (72% for mealworms), ash count (<3% for mealworms) and particular properties related to the growth, the survivability, gut health, nutritional benefits etc. If products are not able to claim these additional properties on performance, nutrition, health those insect proteins are more likely to become a commodity and have to compete with other proteins that are selling at USD 400/t to USD1,000 per ton. For most, if not all, that will be a level at which they cannot be profitable. If the business plan does not add up, there is an increased risk of bankruptcy (AgriProtein has fallen in receivership after having raised a total of USD130m and so have a few other black soldier fly companies). IP is a big differentiator and most insect companies have no patents. 50% of all insect patents are in the hands of Ÿnsect (300 patents) or Protix (30 patents).

So what about profitability at Ÿnsect?

Ÿnsect has been operating a demo plant of 1,000 ton capacity near Dôle over the past five years and is currently building a new one in Amiens of 100,000 ton capacity (expandable to 200,000 tons in 2023). That plant should be commissioned by the end of the year and will ramp up production in 2022. By then that plant is likely to produce 75% of all insect proteins globally. And once production is at level, Ÿnsect should be able to achieve EBITDA margins of 35% to 40%. So far Ÿnsect has raised USD425m of which USD372m in its latest round closed in October 2020.

… with Bastien Oggeri (Co-Founder), Clément Tiret (CFO) and Chloe Phan van Phi (Head of Sales and Marketing) from 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 insectmeal. Using the improved quality of the end product, Auchan launched the insect-fed trout in its outlets, reinforcing B2C marketing on sustainability.

What are the best potential applications for the InnovaFeed insect proteins?

InnovaFeed is currently active in three main markets. The first market is where insect meal is used to capture the increased demand for aquaculture feed as increased use of fishmeal would lead to further depleting fish stocks. And as such, it has been demonstrated that insect meal had a better performance (and even improve feed efficiency by up to 14%) than fishmeal or plant based alternatives. The second market is where insect meal is significantly boosting the performance of farms. That is the case for shrimps where insect meal improves feed efficiency by 28% and increases the survival rate by up to 15%. In a next phase InnovaFeed is expanding into improving the performance of pig and poultry farms. A third market for InnovaFeed products is the pet food market. In petfood, a bundled offer from insect oil and protein is to offer a distinctive environmental performance to end-customers combined with a better quality protein source (reduced ash content compared to chicken protein) and oil (lauric acid to improve health).

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.).

Why did you choose the black soldier fly to build an insect proteins business?

InnovaFeed has built technological knowledge around the black soldier fly which has a are a unique set of nutrients that can be used for aquafeed, pets and plant growing. We believe that the BSF is the most efficient for agricultural purposes and the right insect to allow for scaling up. Key for the financial performance is that we can use different kinds of byproducts to grow the larvae. InnovaFeed strategy is to collocate insect rearing units with feedstock deposits and develop an industrial symbiosis model to enable long-term logistics and energy synergies. Collocation will allow for a 20% EBITDA margin uplift with a key element being the possibility to feed the black soldier fly with wet products (slury) saving on drying the product

What is your view on the upside of the industry and your company's position?

We believe that the insect protein industry is high potential sector in alternative protein market and that by 2027, the industry would reach a capacity of 1m tonnes (compared to 1,000 tonnes in 2017). 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 tonne of protein, 5000 tonne of oil and 50 000 tonne 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 (1,000 tonne), inaugurated in October 2017, in Gouzeaucourt in the north of France, within the largest European deposit of agricultural and agri-food by-products. At its Nesle plant, that opened in November 2020, the company is 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.

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.

… with Nicolas Braun, Business Development at Buhler AG Insect Technology Group

How did Bühler got involved in the insect technology?

Bühler is a technology provider for food and feed industry. Ten years ago they got involved in the different alternative proteins industries including algae, plant based meat analogues and insects. And found that the insect industry is special as the current players are still expecting to do everything themselves from breeding, feeding, harvesting to processing (in the long run there will be specialization). From that involvement a separate business unit was founded in 2017 to facilitate the upscaling of insect production. Bühler's portfolio spans four key aspects in the production of insects: the feedmix preparation (intake, storage and mixing of different organic waste from other industry), the larvae rearing (automated crate logistics, larvae rearing under ideal growing conditions, harvesting), the larvae processing (transformation into high quality protein meal and lipids) as well as the rearing residue processing (transformation of frass into fertilizer) steps. So we are involved in the entire process with exception of the reproduction of the insects themselves or insect genetics.

How do you see the different alternative proteins sectors evolving?

It is hard to predict the future but it is not going to be a market where the winner takes all. In food there are the meat analogues with their products almost tasting as actual meat. But for plant based meat analogues, where prices are very much the same as for meat, that does not seem to be enough of an incentive to switch from meat to the analogues. All the alternative protein products need to fight against established meat industry players and that is a tough task. So they need to find niches where customers/consumers want to pay more for a sustainable product. That would allow to get better pricing, the market to grow and gradually become more competitive with established industries.

With insects for the feed industry it is the same. Prices of conventional sources can currently not be matched, so insects, despite already offering more sustainability, need to offer other functional benefits including advantages on productivity, health, mortality OR having a storyline on local area feed sustainability. And that is where the market is developing although there is still a debate on how effective insect feed is. In the end prices of insect meal will need to compete with fish meal as a commodity. But maybe it is not that insect meal prices need to come down but soy and fish meal prices need to increase (which has not happened over the past 10 years) to reflect the tense environmental balance. Insect meal prices internalize all costs which is not the case with soy and fish meal prices (soil erosion, nutrients, insecticides, over fishing).

So with all that how large do you estimate that the insect market could become?

At Bühler we are a little more prudent on the size of the market than other sources would suggest. We are estimating that in 2021 there will be 75,000 ton of insect proteins being produced globally and that could increase to 750,000 ton by 2030. In 2020, we estimate that the total market was about 25,000 ton but that does not do justice to the small producers in Asia. Current demand is sigfnicantly higher than production especially as some pet food producers like Purina are entering the market.

Black Soldier Flies or Mealworms?

Bühler has both technologies in house and believe that both species have their advantages in their respective fields of application. Generally, Bühler views mealworms to be better suited for the food industry, whereas BSF has advantages for the feed industry. The big difference is that mealworms need 30-45 days to develop while BSF larvae need 6-12 days and that BSF can be fed with wet waste. That will be reflected in the cost price of both and I believe that it will be difficult for mealworms to compete in the feed industry where price sensitivity is even larger than at the consumer level. Mealworms and black soldier flies have both an advantage over crickets and locusts–that are much more mobile insect species, which makes automation quite challenging and therefore a scale-up much more expensive.

What would you say is the minimum investment that is required in the industry?

To get an investment going it is important to take into account local factors that can change the cost of entry (feedstock, building, labor force). But for an industrial scale operation (>1'000t of BSF meal per year) the investment is likely in the range between EUR20 and 40m in Western Europe. Once the basic infrastructure is in place it costs far less to add additional capacity. As a consequence we see a tendency in the insect sector to go for bigger facilities moreover as automation is quite advanced and can exclude any manual labour except for supervision and cleaning tasks.

… with management at Beyond Meat

What is Beyond Meat's assessment on how big the plant-based meat industry can grow?

That is the million dollar question. The way we think about it internally is that the size of the market could be tremendous but it does depend on a couple of things to transpire over the next several years. The growth of the category and our brand leans on 3 pillars:

1) The first pillar is the taste and the sensory experience of the product. It is our goal to build meat from plants and to get to a point where these products are indistinguishable from animal proteins. We don't want the consumer to feel that he is making sacrifices from a taste and sensory experience when they are consuming our plant based meat products.

2) The second pillar is the nutritional profile of these products. We want to make it abundantly clear that there are certain benefits associated with consuming Beyond Meat products as opposed to their animal protein equivalents. However there have been questions – driven in part by the incumbent meat industry – if these plant-based products are indeed better for you, with the suggestion that these products are overly processed and contain excessive amounts of sodium. We think that a lot of that is just disinformation. We want to go out there and support with scientific data that our products are better for you. A small clinical trial was conducted by Stanford University where consumers during 16 weeks first 8 weeks consumed animal proteins and then the next 8 weeks Beyond Meat products. The findings that came out of that where that bad cholesterol levels where much lower in the same participants when they were consuming Beyond Meat products than when they were consuming animal proteins. We have a focus on the nutritional profile of our product and want to continue to educate the consumer on the health benefits of our products.

3) The third and last pillar is cost. Currently these products are priced with a healthy premium compared to animal proteins but we believe it is wrong to ask consumers to replace animal proteins with plant-based proteins and to pay a healthy premium for it. We want to take the cost consideration out of it. Long term we see no structural reasons why plant-based products cannot be at par or below animal protein as we are taking the biggest bottle neck in meat production out of the equation, which is the animal itself. You have to feed the animals, grow them, pay veterinary bills etc.. we are taking all that out and are building meat from its core components. So if we get taste/sensory right/ get the nutritional profile to a point where it is abundantly clear to consumer that it is better for you and we get the cost down at parity or below meat, then the market opportunity is tremendous. The global animal protein market is today approximately USD1.4 trillion in size. Anecdotally we have seen that in the US plant-based milks have achieved penetration levels of 15%. We believe that level of share, or greater is achievable if we can get those three things right (taste, nutritional profile, cost).

You don't make meat, but mince. Should we look only at that segment when assessing the opportunity?

Our core asset as a company is our understanding of plant based proteins and being able to take plant based proteins and build them into the architecture of animal based proteins. When you look at the building blocks of animal proteins there are 5 things: trace minerals, lipids, amino acids, water and vitamins. All of them are present in the plant kingdom. So for us it is about taking these directly from plants and building them in the architecture of meat and have things like fat distribution as closely mimicking as possible. So if the consumer bites into this plant based alternative his sensory experience ~~is~~ should ideally be entirely the same. It is easier to mimic the texture and appearance in the ground products (mince, burger, sausages). But we believe there is no reason why over time, Beyond Meat cannot produce a steak or chicken breast etc,.. that is a longer term opportunity. All of these things will be available over time. The smaller subset of ground -meat, depending on specific geographic regions, makes up roughly half of the USD1.4 trillion market. The vast majority of the rest will be whole muscle structure type product like a chicken breast, steak, where it becomes a little harder particular in products mimicking where there is visible fat in the consumer eye like bacon. But our R&D team has been very impressive on what prototypes they have been able to develop already.

Hybrid products with animal fats could give a quicker result?

It is a possibility. We are open to explore other avenues including cultured meat, however a big challenge for cultured meat is the steep cost curve required to make such products price competitive to the consumer. That particular portion of the industry has been dealing with the cost challenge for close to 2 decades now. I am not suggesting that plant based meat is already at levels at parity or below animal proteins. But we have a line of sight on how to get there in what we believe is a much shorter time period. That is why we believe the plant-based protein space is an attractive one. On the other side there is a growing body of research that is suggesting that certain things within animal proteins are not good for human health. On the flip side, the research that suggest there are benefits for plant-based proteins seems to be increasing. There is the question if there will be there a natural consumer preference towards plant-based products given the health considerations.

What is the line of sight to get the cost down to the one of animal proteins and how do we need the thing about your long term margins?

Across our entire platform of products (we innovate around 3 platforms, beef, pork and poultry), on average the selling price of our products is 2 to 3 times the price of animal proteins. There is still a long way to go. But we are closer to it in some platforms. In beef for instance we have a slightly more attractive cost profile relative to our pork and chicken products because the cost of beef is more expensive relatively to pork and chicken.

It is a philosophical question on what Beyond Meat is trying to achieve and how big are we trying to grow this category and our own brand. Do you need to go down the level of animal protein pricing, to enjoy a high level of success? We don't think so. We have generated strong growth over the past number of years despite the healthy premium compared to animal proteins. However we are a mission driven company and we do think that continuing to move more and more consumers away from animal proteins towards plant-based proteins has several benefits, not just to consumers from a health and nutrition benefit, but also for the planet. The animal protein industry (meat or dairy) has a significant environmental impact, eg deforestation is mainly driven by clearing land to be able to house more animals to feed the growing population. 80% of the world arable land is in some form or other (pasture, crops) occupied by the meat industry. We are a mission driven company and our goal is to expand this plant-based meat market to a level substantial enough to have a real impact, and one of the levers to do so is to bring the cost down.

Beyond Meat wants to bring down the cost for consumer to a level that is at or below the cost for animal proteins, however don't want to sacrifice margin to get there. We want to take our cost down so we can continue to run this target level of margin that we have been communicating before, i.e. mid 30% gross margin and a mid-teens EBITDA margin, while lowering our pricing to our customers.

… with Gregg Engles, former director at Danone and former Chairman & CEO at WhiteWave Foods

What are your observations looking at the current state of the industry?

The first observation I would make is that each alternative protein submarket is very different. The meat alternative market is about substituting plant-based protein for meat based protein. It is a direct substitution and the product developers in that space are trying to replicate the taste, the texture, and the savory characteristics of meat with a plant based alternative. That is how they are measured, that is how they are advertised. If you look at the burger chains that are offering an Impossible Burger, the advertisement is with customers and testimonials to the effect that they could not tell the difference between the plant-based burger and the meat burger. Quorn is very much the same thing, they are trying to recreate with plant-based proteins or alternative proteins, something that consumer like in the way it tastes. They might not like the source, the animal welfare aspect of it, but most people like a burger.

The dairy alternative space is a very different space. There, the product developers were attempting to create a product that was a substitute for milk and milk usage occasions: on cereal, as a beverage, as condiment in your coffee. They were trying to recreate the experience but with attributes that were very different to milk. We started out with soya based milk substitutes. Soy milks were very much like the meat example: we built products that had the nutritional profile of fat, protein, carbohydrates, that looked very much like milk. Although there were some taste difference, soy had a similar mouthfeel and experience to milk. But as the category evolved, we learned that people wanted to have the same usage occasion as milk, but they also wanted the product to be nutritionally different than milk. The biggest driver of that product differentiation in the beverage space was lower calories and lower sugar. So today by far the biggest component of the dairy alternative space are the nut milks -- almond milk, cashew milk, etc. Those milks have no proteins while dairy is a significant source of protein. The biggest selling SKUs in those product lines are the sugar free, unsweetened lines. Unsweetened almond milk has 30 calories in 240ml (milk has 210 calories for the same 240 ml). Consumers wanted something on their cereal that made it wet, had flavor but did not have all the calories, fat and proteins of milk. But the biggest difference was that there is no sugar in the plant-based alternative. The biggest users in dairy alternatives are woman, and the biggest driver we see for women is calorie avoidance. So very different from the meat example.

The plant-based milk alternatives category is much more mature than meat. Today there is a broad variety of products in the plant-based dairy alternative space: high protein, super protein fortified products; unsweetened low calorie products; products formulated to perform well in coffee. For example Oatly (oat milk) has a particular structure that causes it to be creamy in coffee and to froth and foam in a cappuccino. So Oatly is more about product performance and its mild taste as compared to the other dairy alternatives.

From milk-alternatives, we have now begun to branch out into other more value added forms of dairy alternatives: yogurts, desserts, ice-cream equivalents. Now we are trying to replace the exact usage occasion of dairy, but we are targeting people who are trying to avoid dairy for one reason or another. Lower calories is less important here, as these products are not always lower calorie, but they have less proteins than milk. So in this space, we are pursuing lifestyle adopters: people who are trying to be vegan or vegetarian or they have a particular need or desire to avoid lactose or dairy. So they are seeking out palatable, delicious alternatives to the products they love, but don't have dairy or lactose. What I am trying to say that it is a very complicate set of consumer needs that companies are addressing in these value added dairy categories today, but the one thing they have in common is that they are attacking the dairy usage occasion. We have not created new usage occasions, we are trying to source volume from this existing huge category of dairy.

Are meat alternative producers are targeting a similar 15% share that plant-based dairy has in the US?

Well, first of all, plant based dairy as a whole does not have a 15% share. That is true in milk alternatives, but not dairy as a whole. You have to look at the different categories separately, as what is driving consumers in these markets is different. Low calorie does not necessary apply to plant based yogurt and plant based ice-cream. Something else is driving switching to plant based, that so far has lead to a lower level of penetration. That is primarily because products in these categories are not low calorie, unlike the best performing sku's in milk substitutes. Higher levels of penetration in these categories will come down to companies building products that are preferred to dairy from a taste perspective, and are perceived to be healthier.

So, I do not believe that plant-based yogurt is going to go to 15% from 4%, just because milk is there. It might go there over time because companies in that space develop products that consumers prefer for health reasons or for taste, but they will need to be preferred for some reason. They need to be perceived as better for you. Dessert, cheese, eggs are even further away from the original milk dynamic. If you go into plant-based ice-creams it is hard to argue that any of these products is healthy. They are in general high in fat, high in sugar. So you have to give consumers another reason to switch from dairy. You are in the first instance seeking consumers that want to avoid animal protein. That can be for a number of different reasons: health reasons, ethical reasons, environmental reasons. I believe that is also driving the meat alternative industry.

Dynamics are different across the different spaces, they are both disruptive. Alternative meat producers believe that they will ultimately get to a product that is cost competitive with meat as they get to scale. That ultimately will be were their biggest market share opportunities arise. If they can create something that is an acceptable substitute to meat and cost competive and positioned as more sustainable, that is a big win proposition. We have never been able to get there in the dairy alternative space. Soy was the best possibility to get there but soy fell out of favor for health reasons. So soy will need to get rehabilitated to get there in the dairy alternative space. Or perhaps Oat can get there. But nuts are an expensive proposition.

How do the different plant-based milk companies compete with each other?

I think the best analogy for plant based milk competition is the wine industry – it would resonate with you more if you were an American wine drinker as opposed to a European one. In Europe, most great red wines other than the burgundies are blended wines. In Bordeaux you will have Cabernet Sauvignon, Merlot, Petit Verdot , Cabernet Franc and they are going to blend them to create a unique flavor and experience. In the US, Australia, other part of the world, the wine category is made up more of varietals, so the wines are all Merlot, Cabernet Sauvignon, all Syrah or all Chardonnay. They are not blended wines. The plant-based beverage industry has grown up along this varietal model. It was soy, it was almond, it was cashew, now it is oat and so the next disruptor moves to find a plant base, substrate, that has unique characteristics that they can market as a first mover in a mature category to the consumer. So Oatly is pounding on the benefits of oat as opposed to benefits of almond and cashew and are marketing varieties against one another. That is how competition is taking place in the space.

With Alpro we were lucky that we were able to observe what happened when almond attacked soy. And we could do it to ourselves in a way that was additive, not negative, in the positioning of the product. We built a fortress portfolio and we adopted at Alpro the model of a wonderful umbrella brand beneath which you could have multiple varietals. All that was much harder for the owners of the Almond Breeze brand. With such a name it is difficult to start competing when oat comes along. Silk was also a pretty good umbrella brand but it was so heavily identified with soy that we were on our backfoot when Almond Breeze entered the market. And now everybody is on the backfoot with Oatly, but the appeal of Oatly is limited by the varietal model, as have been soy and nuts. I believe that the holy grail of this business would be to move to the Bordeaux model and that would give you an incredible license to modify your formula over time, to deal with price variations among the various commodities and still deliver the same taste and nutrition profiles in your products. However, the industry is still growing so rapidly along the new varietals that the opportunity for that to happen has yet to emerge. I believe it will emerge, but it has yet to happen.

How did you see the competition with the conventional protein industry?

An interesting point is that most of these legacy categories are under attack. Let me take the example of milk. The milk industry has, overtime, over 100s of years, build up these moats around itself that are based on standards of identity. So for you to call a dairy product milk in the United States, the only thing you can do to modify its content is to remove some of the fat. So there is whole milk, semi-skimmed and skimmed milk. The industry wanted those definitions so nobody could compete with the basic fluid milk products by modifying the other components of milk: proteins, sugars, etc. That worked for 100 of years, but has become an incredible anchor against progress for the milk industry today. Under the Silk brand, we could go out and build products with different nutritional profiles targeting just modestly large segments of the population. We could build a 30 calorie product for woman who were calorie avoiders. We could build a 100 calorie product with sucrose and not lacrosse that tasted very sweet and was less than half the calories of milk. Kids liked it and moms loved it . We could go built a 10g of protein milk with no sugar added for people that were interested in performance and that were protein advocates, but wanted to avoid sugar. Milk can't do that under current standards of identity. Moving to plant-based, adopting the term milk but withouth the dairy standards of identity, allows plant based brands to pick-off little segments of the market in way milk struggles to defend. They cannot build the product to compete with plant based innovation and still call it milk because of the regulatory structure that exist. The same is true in Europe.

Lets speak about profitability. How profitable is the alternative milk space?

Dairy milk margins are not even close, in general, to plant based margins. The operating margin structure of plant based products are on average five times the operating margin structure of milk. For milk it is 3 to 4% and for the plant-based alternative it is 20%. So with 14% of the milk market in the US, the plant based industry makes us as much money as the balance of the category in dairy. And because of the margin structure, the plant-based alternatives have much more money to invest in marketing. The main driver for the higher margin is the higher price. A 35 year old woman is happy to pay an extra 75 cent a liter to avoid the calories. It is a lot cheaper than a gym membership. It is, after all, still an affordable product. Also it is easy to see what the benefits are, it is on the label: low calories, no sugar, high proteins etc… Taste just has to be acceptable, and in fact the taste of these new products is quite good.

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

How do you and the Aspire Food Group approach the insect opportunity?

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 were 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, ironically and paradoxilly, 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 petfood 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.

From the outset we saw the three market verticals:

1. The animal and livestock feed market. This is the market with the lowest possible stigma because who care if chicken and pigs are happily eating bugs. Also the farmer is comfortable with it. But it is also the most price sensitive market that typically deals with commodities.
2. The middle market is the pet food market where you have the more sophisticated discerning consumer that is discriminatory with what they want to feed their pet but they are more open minded feeding their pet with insects than eating insects themselves.
3. And then there is the human food market where you can capture the highest premium but also where you have the highest barrier for education (despite that according to the FAO there are many countries in the world where insects are eaten and the stigma does not exist). For North American and European consumers, eating insects is still gaining traction and is by no means mainstream.

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 extrate 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 does the insects category compares to plant-based and cultured protein alternatives?

We are going to this work with the same organsation that did the Beyond Meat life cycle analysis. Because crickets are not only a protein source but also a source of other micro nutrients like iron, calcium, b-vitamins, pre-biotic dietary fibers, etc. A pet food company that wants to prioritize a clean label, you will prefer the ingredient that gives you multiple functional benefits instead of sourcing a number of different ingredients.

With respect to a lot of the plant based protein companies the challenge is that you have to combine different plants that have different amino acid profiles because with the exception of soy, almost all plant-based protein are incomplete proteins. They lack at least one of the major amino acids that are required because our bodies cannot manufacture them. So for you to produce something like the Beyond Meat and the Impossible Burger you need to augment those deficiencies by combining different plant-based ingredients and you need to hyper process that product into the finished good that it ends up in. So if you facture in the environmental footprint, not just from the one plant that is the main one marketed but actually take into account the environmental impact of all the multitude of ingredients combined plus the processing etc, you would be making a mathematical case that ironically crickets which is an animal source, may be more environmental sustainable than some of these plant based alternatives. Having said that, I don't think it is wise for me to set out a campaign to steel away market share from Beyond Meat because the marginal difference that we are speaking about is tiny. It is still more attractive for all of us to try to carve away

share from the actual meat category. One of the exiting things for us from the human food side is that we are starting to develop meat analogues from cricket. That is a way for us to look at a direct one to one substitution of meat from the consumer plate. Today protein powder is interesting but it goes into a protein bar and most people don't get their protein from a protein bar. The more you can get to the center of the plate, the more you are actually delivering the impact and at the same time providing that use case that the consumer is looking to solve for.
With respect to cultured protein alternatives, we believe there are two significant barriers. There are much greater commercialization challenges that increase the risk profile of the potential success and cost-competitiveness of these products; there is also a significant consumer stigma about eating a "lab-made" burger and lots of consumer education to overcome this objection.

Insects are not able to deliver a full feed solution and are especially lacking fatty acids EPA and DHA. How do you go about to solve that?

We are in the process of conducting a 26 week trial where we are using cricket as the number one ingredient to produce a full feed diet for dogs and cats. We are not going to end up with a product that on the ingredient label has only crickets. There has to be other even binding agents to be able to make the product available in a pallet or kibble form. In the product that we are trailing we do use some other ingredients to augment those deficiencies like in the fat profile in particular. But our contention is that you will need to use a lot less ingredients to be able to develop a full deep formulation using crickets as your primary protein compared to the other existing protein sources and certainly compared to virtually all plant based proteins that are being positioned in the petfood market.

So it is not going to be a only cricket label. I don't think there is any single label out there for pet food as there need to be some processing and preservation. We expect it to be a cleaner, if not the cleanest label of animal pet food principally because the cricket offers other nutritional benefits that eliminate the need for some other ingredients that are typically added. Protein is usually about 30% of the petfood formula and we expect cricket to be 100% of that. So we believe that 30% of the dogfood could be substituted with crickets.

Can you produce cricket products in a cost effective way or do you need a premium pricing?

The global pet food market is split between conventional pet food market, the premium, natural and organic market and the veterinarian, specially diet petfood. The conventional petfood space is approximately USD60bn globally and then the other two segments are combined about USD30bn. So the overall global petfood market is USD90bn with 1/3 of it a market which we immediately can address and serve highly competitively. We would probably be the cost leader in that category and within a couple of years we expect to be very competitive – not to be the most competitive but in the 50th percentile in the USD60bn conventional petfood space.

Are hopping animals more difficult to breed?

No whatsoever because we have devised a methodology that is a closed lid system which means that it is not possible that the crickets can escape, because all the crickets exists in bins and those bins exist in an a meshwork architecture storage system. For harvest we retrieve those bins and removed the lid to harvest them after they have already been euthanized. As a result we have the only enclosed cricket production system effectively eliminating that disadvantage completely.
Our factory is completely automated. The interesting thing about crickets is that they interact more with their environment while worms move around in their substrate. With a camera you can better follow and do data analytics on crickets compared to mealworms as you can capture better the movement of the crickets. We collect datapoint son humidity, temperature, movement, chirping sound etc all of

which are important markers that help us optimize breeding and harvesting time frame. We partner with an AI company that is going to develop a neural network that is going take that data and correlate with things that we can further do to improve the environment. As a result of the rich data, crickets are an incredibly optimizable self-improving system of production if you are able to harness the right technologies. That turns the hopping aspect of the crickets from a disadvantage to a significant advantage. In addition crickets don't live in the own substrate so you don't have to intervene somewhere midcycle to swap out the feed for fresh feed.

For harvesting we use an automated proprietary continuously harvesting system were we can separate immediately the live crickets from any dead crickets and from the frass and then we bag and code all the different products. We take the crickets and freeze them and use a spray drying technology to process them into a protein powder.

We have already been doing selective breeding and we can also optimize deficiencies by particular feed. We have 19 patents that are issued or pending comprising of 176 unique inventions.

What does the future hold for the Aspire Food Group?

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. When fully operational we expect the facility to generate EBITDA margins greater than 50%. We expect that 70% of our revenue will come from petfood, 20% from frass and only 10% from human food. We already have offtake agreements for 60% of the production of this facility which is approx. 9,000 tonnes of committed contracted offtake. And we are in discussions and various stages of prototype developments and marketing with the largest petfood companies in the world.

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. By the end of 2028, we expect to be generating in aggregate just over 0.5bn dollar revenue and USD250m to USD300m of EBITDA. With petfood representing 70% of revenues, frass 25% and human food about 5%. We are not factoring in entering in the aquafeed or livestock feed markets which could be possible in two years from now when we feel we can be price competitive in those markets. But our interest is in focusing on the premium market and saturating those opportunities. Crickets have the unique advantage of doing so because we use organic feed and the feed is traceable. And because of the crickets positioning in the mind of the consumer we are able to leverage that premium angel a little bit more credibly with the end consumer.

All of that production that we expect to produce by the end of 2028 would still not be more than 1% of the opportunity set, so there is huge room for growth. Having said that I believe the petfood companies defined differences in the insects. So it is not as if they are creating one lump set category of insects and buy whatever is available BSF, cricket, mealworms. They are very much treating these as very separate and distinct insects with different functional benefits and production profiles .

… with Kees Aarts, Co-Founder and CEO of Protix

Kees the Footprintarian founding Protix to make the world a better place?

Indeed, I wrote a book called “The Footprintarian,”. A Footprintarian is consciously concerned with achieving prosperity or progress against the lowest possible pressure on the environment and surroundings. It is a new way of thinking and making choices in a positive way. Footprintarians are not only concerned with reducing their ecological footprint, but also make a positive contribution to a planet with more nature, more biodiversity and healthy climate conditions.

The development of this new term lies in the fact that many of the sustainability themes are currently very polarizing. That is partly due to the way in which we label behavior or give choices certain titles and names. A vegetarian, for example, is concerned with the environment and animal welfare and does so on the basis of positive beliefs. But when the person tries to explain what he or she is doing, it is often through a negative explanation; "I do not eat meat". That way, the chance that someone else will feel worse is very high, and this often makes the discussion negative and sometimes even aggressive. While both people often have positive motives; they just don't understand each other very well. It may even be that the meat eater is much more sustainable than the vegetarian because he or she no longer flies. In other words, the behavioral choices are not easy to frame.

That is why there is the Footprintarian as a new identity! It makes it much easier and more positive to explain why you have made certain choices, because the basis is the same for everyone. You live on earth and you have a Footprint. I as a consumer will like to fulfill all my needs (products, goods, experiences) at the lowest possible footprint. Then you do away with the emotional or source related arguments and replace it with arguments related to footprint.

So, every individual has a contribution to make, to make the future inspiring and motivating again. So, there’s one objective we all have, whether you’re a government and creating new legislation or at a company creating a new product or as a consumer buying something: You need to somehow source and fulfill your desires at the lowest possible footprint.

Applying it to foods. It doesn’t matter — it literally doesn’t matter how it looks like or how it’s made, as long as you like it, it’s tasty, and it’s produced at the lowest possible footprint. And in trying to achieve that, you have to overcome everything, anything. You just have to ask the question to companies, the government, to help you fulfill that need. And our contribution with Protix in that is that we have an ingredient that has the lowest footprint in terms of protein, unit of protein, in terms of energy, water and land. And we’ve proven that with the Deutsches Institut für Lebensmitteltechnik with ETH Zurich. We can produce over — and this is phenomenal — our production capacity is 6,000 tonnes of protein per hectare per year. And that number — I’ll put it in perspective. It’s three (tonnes per hectare) for soy, intensified soy. It’s 100 for the best algae farm. It’s about 400 to 500 for extremely well-developed fermentation-type approach or bacterial. And we have 6,000, and that is because our technology, the biology, the operations, everything is under control, and we manage it in a very high-tech environment. But that system — and it should then normalize that to the use (of) energy, water and land. And that protein meal just should find its way in every product imaginable, whether it’s a pet food, whether it’s a feed, whether it’s direct food — it doesn’t matter, because we need to reduce the footprint of our food system.

Where do you see insects in the alternative protein industry?

Protein is a nitrogen bound compound who’s structure is fixed by animals or plants. And now there is also the mechanical/chemical extraction processes that isolate some of the functionalities that are in some plants. Companies like Beyond Meat uses a mechanical/chemical extract recomposed with additives and flavors. But the source is the same: it is pulses.

So for me it is about what is the category. I would not structure it as meat, alternative proteins and lab grown. They are semi-overlapping. I would structure it differently. You have original sources that are land and water-bound and form there you have two types of outlets: conversion into animal proteins and conversion into structured proteins.

If you look at the technology routes: you have sources that are crop-based (seed, pulses, cereals, etc.) or water-based (wheat, algae, fish and mollusks). Some go directly into human consumption and some go indirectly into human consumption through a conversion mechanism (eg. feeding it into an animal). You have shortcuts when you mimic one of those indirect routes. If you take seeds and you go through an animal you have meat, if you take seeds and you go through a machine (e.g. a texturizer or extruder) you have also meat. That are the key layers and it is a radical view of looking at it because that is triggering the cost and investment routes. You have cost for production, cost for conversion and cost for recombination into products. Those resources also generate byproducts and Protix is tapping into a byproduct of that system and bring it back to an ingredient. That ingredient goes into all participants of the food system whether it is feed, it is human consumption or it is plant. So you got basically routes. Alternative proteins is for me about routing resources rather than if it is a faux meat or a real meat.

The question remains whether the masses want to eat insects?

Eating behavior always has a turnaround time. Just look at what people thought of raw shrimp or sushi in the beginning. And it is true that we are not used to eating insects here, but that is why they are also processed in butter or a meat substitute. There is a lot of work involved in making a vegetable burger with other proteins. There is little flavor to those proteins and no texture. With insects you can achieve a tasty meat substitute with very few extra additives.

It makes perfect sense in animal feed. In nature, a chicken also looks for insects. An insect is a very high-quality package of proteins and other raw materials. All birds, reptiles and fish, but also almost all mammals eat them when they are young, have to grow quickly and build up their immune system. Green is getting sexy, and so are insects.

What are the key segments in which Protix than want to be involved?

I see Protix as an ingredient producer with outlets mainly in agriculture, poultry, scrimp, petfood and human food – in that order. Any industry needs to be able to gain momentum through capturing high value niches. It has nothing to do with the fundamental nature of the addressable markets because if you are an ingredient player, the ingredients can go to any market. And if you are a mature player, you try to optimize your price/mix into market segmentation and finding the right customers. I am quite blue where this has to go. From an ingredient perspective it is all the same: all industries are looking for novel ingredients with a low footprint.

We were the first to move in pet food and others are now following, which flattering and annoying at the same time. The problem is that as they flock into that market, they cannot deliver as they are not producing in sufficient quantities. That dissolutions the industry.

There will be downstream processing into derivatives and there will be high value niches in feed additives, petfood ingredients and human nutrition with different products and applications. The next wave of research will uncover many different opportunities. It happened with pulses like lentils, beans, peas and chickpeas. Who-ever imagined that all of the sudden, these pulses would be the basis to create a whole range of meat analogues. It is interesting to see how many proteins and compounds there are in pulses. Insects will be a new platform of derivatives and applications. However, it is always a matter of mass balance. It starts with dry matter with water being useless and within the dry matter you have soluble and non-soluble compounds, chemical compounds, nitrogen and carbon based compounds, bio-active compounds.

Almost all these compounds are interesting but not all are economically interesting. But at a certain point you are at 0.01% of dry matter and that is the inverse of the cost. We produce a lot of flies, the flies have chitin (we produced already 30 tonnes of chitin per year, which can be sold for 30 to 60 euro's per kg) But compared to the mass-balance of the rest it is not interesting yet. It is hard not to fall in the trap to try to extract and sell everything.

Our revenues will likely be split 50-60% in mature markets in term of volumes and 60/70% in high value niches.

What could ultimately be the size of the insect industry?

One of the older assumptions was that insect meal could replace fishmeal for up to 40%. But we are already beyond that. We now say that we can fully replace fishmeal on a protein level. However, because of supply constraints insect meal is currently more perceived as an additive with special functionalities. Being practical, the industry currently targets sweet water fish and juvenile phases as you need less volume in these segments. But when production of insect meal picks up to several 100,000s of tonnes, insect meal will start replacing fish meal. As scale increases, the cost to produce insect meal will come down and insect meal will also be able to compete with fish meal on cost. The hardest part of our industry is that we work with byproducts of food waste. Insect companies will have a hard time, us included, if we promise too much as a raw material play. The owners of insect feedstock will be trying to claim whatever they can when our industry picks up in volumes. That could erode our margin and could be the downfall of the circular industry. We will need to solve that problem in the coming months.

… with Cédric Auriol and Mehdi Berrada co-founders of Agronutris

Why did Agronutris choose 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:

- The lifespan of the BSF is shorter (14 days vs 70 to 100 days for mealworm),
- There is higher feedstock flexibility for the BSF which is particularly important in terms of production cost and price competitiveness. When regulation allows, it will be possible to use biowaste as feed for the BSF, which will not be possible for mealworms.
- Another important aspect of production cost is the feed conversion ratio which for the BSF (0.8-2.6) is more efficient than for mealworm (2.0-6.4).
- In terms of protein-content, both BSF and mealworm have the same amino-acid profile but mealworm will have 10% more protein content (i.e 70% vs 60%). The additional protein content enough to justify the additional cost of raising mealworm.
- Also capex to produce the same amount of protein meal is lower in case of the BSF than for mealworm.

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.

Despite all that, you received from the European Commission the first and for the moment the only novel food approval for human consumption. Why mealworm and not BSF?

When we started our company in 2011, we were mainly focused on the human food sector. Because the acceptance of consumers for mealworm and cricket are higher than BSF, we choose initially to focus on mealworm. In human food consumption, price would be less important than acceptance. So, we started to collect data in 2011, drafted a dossier in 2015 and were able to apply for new novel food regulation in 2018. It took the European Food Safety Authority (EFSA) and the EC 3 years, but in the end we received the positive opinion from EFSA a few months ago and the approval from the EC this month. It gives us a five year exclusivity to market the mealworm as food in the European Union for products described in the novel food application. In our case it is products made from whole and visible insects (it can go to 100% insects). And it will also be for products with mealworm meal up to 10% of the product (energy bars, pasta, ready-to-eat meal, etc.). So for the moment everybody who wants to offer a mealworm product in the EU, needs to buy from us the ingredients. Other players could also come in the market in the coming 5 years, providing that they get they apply for novel food authorization and receive it, but for the moment there is no other positive opinion from EFSA.

Still as a company we decided to focus on BSF and will be scaling up in BSF to address the feed industry opportunity as a priority. For our position in the human food market we are looking at different solutions, eg subcontracting the mealworm production. Once the human food consumption would get some traction, we can than still decide to further invest in mealworm. For BSF we will also ask novel food status and although we see currently higher acceptance at consumers for mealworm and crickets, in the end it will be the market that will decide what it wants to consume.

In the beginning, the insect industry is a protein provider but over time it could become a solution provider with different types of insects having different profile. For producers, the synergies of adding other insects with different profile to their production are significant. Further down the road (20 to 30 years' time) one could see medical applications of insects to become more common. But at this stage there is no large difference between the different amino-acid profile of the different species (i.e. BSF and mealworm). Neither is there a difference in performance (for both the aqua and the pet market), although producers of the different types of insect are claiming otherwise. Most of the test show that on feed conversion ratio and weight gain of trout, seabass, salmon, insect meal is a good (and potentially even better) substitute for fishmeal. So for us at Agronutris we choose the BSF because if quality is the same across different species, as cost will become key for certain markets. That will be especially true for the aquaculture market. Although even in the aqua market farmers will want to increase the sustainability profile of their product (lowering fish in/fish out) so some premium for insect meal might be warranted. A promising areas is that insect meal improves the resistance of fish (and hence lowers the need for anti-biotics).

However, one has to be cautious not to see insect meal as a pure replacement of fishmeal in aquaculture. At least as important is the pet food market, where insect meal is an alternative low fat/high protein source that replaces other more traditional animal protein sources (lamb, beef, chicken etc.). Furthermore there is also the market for insects in human food and in cosmetics. So it is important to look at the industry much more than as a replacement for fishmeal.

Are selling prices than different across the different end-markets?

Given the still relative small scale of the industry, price is a sensitive question. As in any other industry, prices depend on volume and length of contract. And there is limited capacity in the insect market – the industry is looking for thousands of tonnes of production, not millions. The insect industry does not benefit from hundreds of years of research and economies of scale but do bring a product that is more sustainable, so that allows for a price premium. Also prices are higher in petfood than in aquaculture because it is a more premium end-product. Having said that, in the coming 10 years we will beat fishmeal prices as we will benefit from economies of scale, R&D and genetics improvements. On top of that, production costs will decline rapidly once the industry has access to biowaste (currently not allowed in Europe). So with prices at a certain moment dropping below fishmeal and products that offer better functionality, the market for insect products will be enormous.

But again, let me stress that the current pipeline is much bigger in petfood than in aqua and the petfood industry seems to be ready to pay the price for what it considers to be a novel ingredient that has a high value for the end consumer. For the moment, prices will be driven by the petfood market.

… with Christophe Vasseur CEO and co-founder Inalve

What is Inalve's raison d'etre?

The demand for ingredients rich in protein is exploding worldwide, especially in the field of animal feed. In thirty years, the consumption of fish has doubled. The growth in aquaculture has helped support this consumption. However, the industry is facing a scarcity and a rise in the price of the staple food, fishmeal. Microalgae are a great substitute for these flours. Besides proteins and amino-acids, microalgae are source of several valuable compounds with health benefits such as carbohydrates, polyunsaturated fatty acids, essential minerals, and vitamins which can increase the nutritional value of feed and food products upon incorporating. Inalve has a dual purpose: industrialize an innovative process for the production of microalgae and produce microalgae as functional ingredients for aquaculture and petfood.

What is specific about your production process?

As an oceanographer, I have always worked with microalgae and properties are well understood. They constitute the basis of aquatic food chains and have not only applications as food, feed, cosmetics, health products and fertilizers but as well as tools for wastewater treatment and biofuel production. However, it has always been the question if we can produce microalgae avoiding as much as possible chemical and physical processes of concentration to harness the whole quality of the algae. At Inalve we have developed a production method for marine microalgae in biofilm. By using biofilm, we do not loose the qualities of the product naturally excreted by algae and have yields that are double those of production in suspension (and at a much lower financial and environmental cost).

How does algae meal compares with other animal and plant-based alternatives?

Estimates on the number of different algae species differ, but current research suggests that there are about 320,500 diverse species of algae around the world and all have more or less the same complete amino-acid profile. We have chosen to work with the Tetraselmis suecica: they have a good quantity (up to 70% after concentration with our downstream process) and quality of protein that is very similar to fish meal. As such they have great nutritional benefits and are a one-for-one replacement for fish meal, with that difference that algae are a much more sustainable product than soy, fish or insect meal. Moreover, algae have different additional features (the 30% of the meal that is not protein) and the Tetraselmis ingredients contains powerful anti-oxidants and immunomodulators (immune boosters), these are sugar like molecules that have huge impact on the immune system of the animal that is fed on this algae meal replacing the fish meal.

Where are you in your journey with Inalve?

Inalve was created in 2016 with the mission to develop sustainable and functional ingredients based on marine microalgae with immunostimulant properties for aquaculture and pet food. We are not only a protein provider, but have also these products that improve the health of the animals. We have three products: FEAL protein (70% proteins and as nutritive as fishmeal), FEAL sanitas (with 35% polysaccharides which are powerful immunomodulators allowing to avoid the use of anti-biotics) and FEAL lipid (a natural source of polysaturated fatty acids and antioxidants with 65% lipids and 55% omega3). Currently there are 24 partners that are testing our products and we hope that by Q3, the first results are coming in. Our current pilot plant based in Nice produces 2 tonnes of algae and we employ 21 people. The next phase will be building (by 2022) a fully automated demo-plant of about 60 tonnes and to establish a fully commercial farm in 2023/2024 capable of producing about 1,300 tonnes p.a.. The next step will be developing production sites close to our customers.

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BUY

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NEUTRAL

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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CONVICTION SELL

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