CHAPTER 1
Microbes: the Drivers of a New Agricultural Revolution?

The year is 2019. Covid-19 has not yet shaken confidence in globalization, and Ukraine—a major global supplier of grain and fertilizer—is not yet in the grip of war. Climate change is high on the political agenda: tens of thousands of young people are skipping school on Thursdays to protest in Stockholm and Brussels. In France, the "yellow vest" protests sow chaos and destruction, while in the Netherlands, public frustration is erupting into farmers' protests against the nitrogen policy.

In this tense but otherwise relatively stable context, scientists turn their attention to an American report titled *Rethinking Food and Agriculture 2020–2030,* subtitled *The Second Domestication of Plants and Animals, the Disruption of the Cow, and the Collapse of Industrial Livestock Farming.*

The end of intensive livestock farming, as it has been known for the past half-century, gets predicted with clockwork regularity in debates and on the opinion pages. But this report was different. What shocked the readers was not the technology described, but the speed at which that technology could become affordable. By 2030, it claimed, producing milk proteins in steel vats using microbes would be five times cheaper than producing them from cows. These low-cost microbial proteins would flood the American food chain as an alternative to cow's milk, triggering ripple effects far beyond the United States.

It is now almost 2030, and the predicted economic tipping point has not yet arrived. Even so, the report set a great deal in motion in Europe as well as in the US. The question is no longer *if* the turning point will come but *when*, and how the affected sectors will adapt.

What Are Proteins?

Proteins are essential building blocks of the human body. On average, however, most Westerners consume more protein than they need. We get proteins from animal products, but also from bread, pasta, potatoes, legumes and more. For our health, the source of protein matters as much as the total amount we eat. According to the Flemish Institute for Healthy Living, our intake should be roughly half animal-based and half plant-based.

Yet the "EI-MEET" protein monitor of the Flemish Government's Department of the Environment shows that, in 2023, the average Flemish diet still derived 58.7% of protein from animal sources and 41.3% from plant or mixed sources. Strikingly little—just 6.9%—came from so-called "high-quality" plant proteins such as legumes, nuts, Quorn and other meat or dairy alternatives. We dive deeper into alternative proteins in a later chapter.

Fermentation

In Ghent, a company called Those Vegan Cowboys is already doing what the American report predicted: they make soft cheeses in a lab without a trace of animal protein. These cheeses are indistinguishable from classic Camembert or mozzarella in taste, texture, and mouthfeel. Just a few kilometers down the road, Biotalys is leading a revolution in crop protection. Their innovation: camelid antibodies for plants to fight fungal infections, a potentially powerful alternative to chemical fungicides.

What do these neighbors have in common? They use no milk, no camels, and no synthetic chemical building blocks. Instead, they grow microbes in small bioreactors. These microorganisms are yeasts, bacteria, fungi, or microalgae—invisible to the naked eye, but essential to all life and all processes on Earth. The unique talent they all share? The ability to convert one molecule into another, which changes the properties of the environment where they live. Add lactic acid bacteria and salt to meat, and it ferments into salami. Add starter culture and rennet to milk, and it curdles into cheese. Add yeast to grape juice, and it loses its sweetness and transforms into wine.

The name of this transformational process? Fermentation. We have used it for centuries to preserve food. You can imagine that scientists have always been fascinated by fermentation. In their attempts to understand it, they have slowly uncovered a vast potential. Now we know that microbes and fermentation are behind the miracle that happens in a cow's rumen, the first of its four stomachs. As the cow eats grass and chews its cud, microbes in the rumen ferment the grass, creating milk proteins our bodies can absorb. Behold the magic of fermentation!

The logical next question is whether this fermentation process can happen outside of the cow. Can microbes in a lab directly produce nutrients that humans need? The answer is yes, and that is the game changer. With the precision fermentation technology used by Biotalys and Those Vegan Cowboys, it is now possible to produce virtually any protein, as well as most fats, flavorings, vitamins and pigments. Just put the right microbe in a controlled environment, then add water, energy and a suitable nutrient medium. Of course, the reality is more complex—we'll get into the details shortly—but the first products of this revolution are already on the market, and they're here to stay. One example is EverSweet from Avansya, a joint venture between food giant Cargill and ingredient manufacturer DSM-Firmenich. EverSweet is as sweet as stevia but without the bitter aftertaste. Available on the B2B market in Europe since 2024, it is about to transform the candy and beverage aisles.

Cultured Meat?

The new wave of fermentation technology may remind you of meat grown in a lab, but there is a key difference. Cultured (cell-based) meat starts from existing animal cells, which then multiply until they form muscle tissue. In contrast, microbial production uses no animal cells at all. Here, microbes are programmed to produce cells that take over the function of animal cells—taste, texture, color, nutrients—in the finished product.

Investors Are Enthusiastic

According to a study commissioned by Avansya, the carbon footprint of its EverSweet sweetener is 81% smaller than that of sugar. Its production would use 97% less water and 96% less land. This was only one study, but it illustrates why both scientists and investors are excited about this technology. It takes little land, few raw materials and far less time and water than traditional livestock farming or manufacturing, while emitting fewer greenhouse gases. Some of the biggest problems we face in food production—shortages of raw materials, nitrogen emissions, climate change and soil depletion—could be addressed, at least in part, by fermentation technology.

Full life cycle analyses (LCAs) are still needed for each molecule produced, but the production process shows clear potential for being highly efficient, cost-effective and scalable. Combine that with Europe's mandatory sustainability reporting (CSRD) for large companies and lenders, and you can see why investors are interested. Biotalys raised nearly €53 million in 2021 to develop its antibodies. Paleo, a Belgian start-up that uses yeast to produce the protein that gives meat its signature color and flavor, secured €12 million in 2023. The Biotope incubator of the Ghent-based biotechnology institute VIB has recently seen a steady stream of entrepreneurs seeking funding for their microbial innovations.

Venture capitalists are not the only ones making these moves; established names from traditional industries are stepping in as well. We already mentioned Cargill, which was built on global grain trading, and DSM-Firmenich, known for plastics, fragrances and flavorings. But Those Vegan Cowboys say that even conventional dairy and food companies are showing interest. "Food companies are facing increased uncertainty in supplies of raw materials and they are exploring ways to address that," says CEO Hille van der Kaa. "Others want to expand their range with plant-based alternatives." The chocolate sector is showing similar curiosity, with rising interest in cell-based cocoa as an alternative to costly cocoa beans.

Precision or Biomass Fermentation

Back to our cow. The microbes in its rumen produce a remarkably complex milk protein. In contrast, the microbes in your sourdough starter do nothing more than multiply on their own. Differences in complexity and end product can also be found in modern fermentation technology.

In single-cell or biomass fermentation, microbes are grown under controlled conditions, and the entire resulting paste or slurry is used as a protein-rich raw material. Quorn has been made this way for years. The process used by Those Vegan Cowboys and Paleo—precision fermentation—is far more complex. Here, microbes are programmed to produce a specific protein, fat or antibody with specific properties using gene-transfer technology. Lots of time, money and research are being invested into this step of the process. Thousands of microorganisms and millions of their strains first need screening, and then targeted genetic modifications are carried out to ensure they yield exactly the desired molecule. At the end of the process, only that specific molecule is harvested. The rest of the brew, including the biomass of the programmed microbe, is left over as a potentially usable by-product.

More Than Protein

Precision fermentation is far more complex and costly than biomass fermentation, but it attracts the most investment because the target molecules are far more rare, and far more valuable, than a protein-rich paste. Pioneering companies are racing each other to discover the one molecule so rare that the market will pay a premium for it. The initial hype centered on proteins, but investors now expect to see the first commercial breakthroughs elsewhere, in more scarce components required for food or feed ingredients, or for chemicals, pharmaceuticals and cosmetics. These could be substances we currently import from other regions, like amino acids or palm oil; compounds we produce synthetically, such as vitamins; plant-derived extracts like stevia; or substances that plants can hardly produce, such as certain pigments or camelid antibodies.

"Today, it costs three times as much to produce one ton of protein from fermented potato peels as it does to import one ton of soy from South America. Even swapping just 5% of soybean oil with an alternative—whether plant-based or microbial—would already triple production costs. Imported soy is simply too cheap to replace on cost grounds alone," says Annatachja De Grande, ILVO researcher and feed specialist. She recognizes the lack of appetite for microbial protein in the feed sector, but amino acids and fats from microbial sources are another story. "Feed producers are heavily dependent on imports from the U.S., South America and China for amino acids. The sudden price spikes and shortages of recent years have shown just how vulnerable those imports make livestock farming. We are self-sufficient in fats for feed, but microbial fats could improve the quality of animal products. It's possible to tailor the fatty acid profile in meat or eggs to meet the needs of specific consumer groups. Retailers and pet food producers are especially interested—margins in dog and cat food are higher than in livestock feed. Who knows? The first breakthrough might just happen there."

Flanders at the Forefront

Perhaps surprisingly, the tiny region of Flanders has become a global hotspot for fermentation technology research. Companies from across the world bring their microbes to the Flemish Bio Base Europe Pilot Plant for help in scaling up production. Knowledge centers Ghent University, KU Leuven and VIB lead the way in screening, designing and programming microbes to produce exactly what industry needs. Flanders also hosts the founders and members of the unique platform called The ProteInn Club, which concentrates high-level expertise in real-world applications ranging from food, feed and pet food to chemicals and cosmetics.

The ProteInn Club was founded in 2022 by ILVO, Bio Base Europe Pilot Plant, Ghent University and Capture, a research facility for the circular economy. The aim? To build a dynamic ecosystem for developing new value chains around fermentation technology in Flanders. Barely two years after its founding, the platform gathered some 200 professionals from across Europe to Merelbeke-Melle, a suburb of Ghent, to see lab- and pilot-scale innovations firsthand. The response was so strong that registrations had to close early due to the overwhelming demand for tours of the Bio Base Europe Pilot Plant and ILVO's pilot facilities. "Everyone is looking for the holy grail that will make their production more sustainable and circular," says relationship manager Stef Denayer. "Fermentation technology has that potential. What we're seeing today is just the tip of the iceberg."

The tip of that particular iceberg is quite impressive, however. Those Vegan Cowboys, Biotalys and Paleo are just a few of the Belgian start-ups that are quickly advancing in their development of microbial raw materials. The Scottish company Enough uses residual sugars supplied by Cargill to produce a fungal protein which is then used in Unilever's next-generation substitutes for meat and fish. Ghent-based Biolynx uses fungi to produce proteins for meat and cheese alternatives. They even use the same technology to make a UV filter for sunscreen. Avecom, a Ghent University spin-off, applies fermentation to convert food industry by-products into high-quality raw materials. In Jupille, Belgium, where Jupiler lager first flowed out of the vats, beer giant AB InBev is now brewing a range of protein-rich powders and sports drinks.

A new type of company is showing interest in The ProteInn Club, potentially transforming the entire fermentation sector: AI and robotics companies. The German firm VCG.AI, for example, develops models to automatically match technologies, raw materials and applications. Artificial intelligence can also accelerate screening of microbial strains and genetic modification. "The combination of AI—which can rapidly detect patterns in all kinds of data—with robots that automate lab work has the potential to cut weeks, months or even years from the extensive biotech development phase. That's where many fermentation pioneers are today," says Karen Verstraete, communications officer at The ProteInn Club.

Market Approval

Even with AI and robotics speeding things up, it may still take years before these innovations reach the market. In Europe, food ingredients from companies like Paleo and Those Vegan Cowboys fall under Novel Food legislation, which covers any ingredient not consumed in the EU before May 1997. Such ingredients can only be sold after European

Commission approval, based on a safety assessment by the European Food Safety Authority (EFSA). This process, which takes years to complete, is based on a thorough food safety assessment.

"This process is vital," explains Lieve Herman, an ILVO department head, researcher and expert scientist at EFSA. "Some microbes are known to produce toxic substances under certain conditions. The application must demonstrate an understanding of those risks and how they will be controlled. These safety assessments are so extensive because the risks vary with every strain, every application and every realistic dose that a person would consume."

Those Vegan Cowboys are currently seeking approval in both Europe and the United States, and expect to launch their vegan cheeses and vegan milk proteins within a few years. Biotalys' antibodies also face a thorough evaluation under legislation for new crop protection products. They expect a 10-year waiting period before their product could reach the market.

Economical and Circular

Microbes growing in steel bioreactors need remarkably few inputs to thrive: just some energy, water and a source of carbon and nitrogen. That source can be either glucose or, at least in theory, by-products such as potato processing waste, whey from cheese production, molasses from sugar factories or beer draff, a grain-based by-product. The only requirement is that they are available in large volumes and are not a critical link in an existing processing chain. In some cases, they need pre-treatment—heating, grinding, removing unwanted compounds—and not all microbes grow on all feedstocks. But it's still worth exploring the possibilities. "Food industry by-products often go into animal feed, which is already a good use for them, but in some cases, they can be upgraded through fermentation," says ILVO scientist Geert Van Royen. "If that can yield biomass and molecules that could replace fossil-based raw materials, for example, that would be a win-win for the companies and for society."

Food and Feed

As a founding member of The ProteInn Club, ILVO has invested heavily in expertise and pilot infrastructure. The first cornerstone was already in place: the Food Pilot has a unique combination of equipment and flexibility to produce virtually any food application on a pilot scale. Located on ILVO grounds in Merelbeke-Melle, Belgium, the Food Pilot is operated jointly by ILVO and Flanders' FOOD, the food industry cluster of the Flemish government. This collaborative arrangement ensures that all investments directly benefit the sector. Recent additions include a small fermenter for producing limited batches of microbial protein specifically for research trials and a new protein processing line to dry, purify and turn pastes and slurry into nuggets, vegan mayonnaise, snack bars and other products.

Specialized ILVO labs analyze these new proteins. What is their chemical composition? Are they easily digestible? What are their functional properties, such as foaming or gelling capacity? "We also study the food safety of products made with new proteins as well as their shelf-life. We have a sensory lab for objective assessment of mouthfeel, taste and aromas. That combination of infrastructure and expertise makes us unique in Flanders and far beyond," says Geert Van Royen. He is part of a team exploring opportunities for new ingredients and processes. They collaborate with The ProteInn Club partners as well as agronomists, livestock experts and feed specialists at other ILVO sites. "We work from field to fork, and we mean that quite literally," Van Royen says. "In the field, my ILVO colleagues grow new protein-rich crops like chickpeas and faba beans (also known as fava beans, broad beans and field beans). In the Post Harvest Pilot—a recent addition at ILVO—we dry, sort and clean protein-rich seeds and other plant parts to prepare them for further processing. In the Food Pilot, we test their potential for human nutrition; in the ILVO Feed Pilot—another recent investment—we explore their use in animal feed. We do this for all kinds of new proteins and fats, whether they come from microbes, plants, insects, algae or by-products."

What Do Proteins Do in Food?

Proteins are complex molecules that play a key role in food quality. They are responsible for foaming in creams and drinks, they form gels in puddings and jams, and they bind ingredients in sauces and dressings. Depending on the molecular structure of the protein and the material it interacts with, it can add body, texture and stability to the final product. The way a protein is produced or isolated also influences how it behaves in food.

Life Cycle Analysis

Every piece of equipment in ILVO's three pilot processing plants–the Post Harvest Pilot, Food Pilot and Feed Pilot–is fitted with water and energy meters. This allows ILVO to assess not just the functionality of new proteins and fats, but also their environmental footprint. Unlike traditional animal products such as meat or dairy—where most of the environmental impact lies in the field, the barn, or in the bioreactor itself—microbial proteins shift that impact to later stages, such as purification, drying or texturing. "Life cycle analysis allows us to track environmental impact across the entire chain. In that way, we avoid shifting problems to other parts of the process or other parts of the world," explains Veerle Van linden, an environmental sustainability expert at ILVO.

Life Cycle Assessment (LCA)

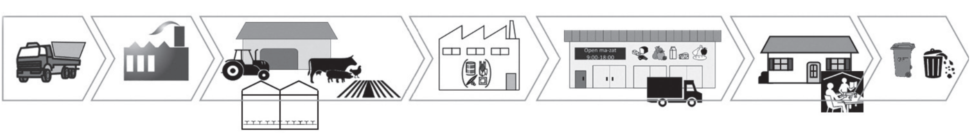

Figure 1: Life Cycle Assessment calculates the total environmental and climate impact of a product. It starts with raw material extraction and transport, and ends with consumer use and waste disposal. Per "link" in the chain, an LCA measures the amount of water, energy, land, metals, minerals and fossil resources used, as well as the emissions produced. This gives a good estimate of how the entire production process affects human health, the quality of our ecosystems and the depletion of non-renewable resources. © ILVO

This brings us back to the cow and the possible impact of fermentation technology on livestock farming. The 2019 U.S. report overlooked one important thing: cows do more than simply convert grass into milk and meat. Until recently, this was the main selling point of the dairy cow, also shared with goats and other ruminants. While ruminants may lose their monopoly on milk production, they still produce collagen, rennet, leather, hide glue, Botox, fat and manure. They help manage landscapes and keep our fields fertile, and they are the main reason for us to maintain valuable grasslands, which capture as much carbon from the air as forests and nature reserves do. Cows also process millions of tons of food industry by-products each year. At the opening of ILVO's Feed Pilot in June 2025, Katrien Deschepper, director of the Belgian mill Paniflower (part of La Lorraine Bakery Group), emphasized the importance of this valorization. "Every year, we sell 80,000 tons of by-products for processing into animal feed. That's an enormous amount and an important additional market for our company."

Growing one milk or meat protein in a steel vat cannot compare to the complex value chain of dairy production. The trumpeted "end of the cow" is not likely to happen. Still, livestock farming is vulnerable to market forces. Animal products and the raw materials required for animal farming are relatively cheap but highly volatile. Prices surge at the slightest shortage and collapse with oversupply. If it is indeed true that a surplus of cow-related products (milk proteins, collagen, fat, etc.) would occur due to competition from microbial proteins, this could indeed threaten the profitability of dairy farming.

"Protein is the ingredient at the economic cornerstone of dairy production. But fresh cow's milk contains only 3.3% protein. The rest is water (87.7%), lactose (4.9%), fat (3.4%), plus vitamins and minerals (0.7%)," wrote the American authors in the report quoted at the beginning of this chapter. That raises a few eyebrows, because large-scale microbial production of casein, the key milk protein, is looming on the horizon. Those Vegan Cowboys are already doing it at lab scale. The eventual market balance is hard to predict, but the effect of microbial protein will most certainly ripple through the pre- and post-farm supply chains.