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White Paper

Meat: the Future
Time for a Protein Portfolio to Meet Tomorrow's Demand

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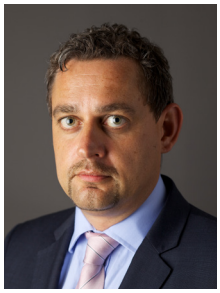
Foreword



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The provision of universally accessible, affordable, safe and sustainable protein in line with the UN Sustainable Development Goals ("21st-century protein") is a pressing issue that cuts across systemic challenges, such as consumption, the environment, food security, health and trade issues. It also offers a great opportunity to harness innovations in technology and science that the World Economic Forum has termed the Fourth Industrial Revolution.

This short introductory paper has been produced for the World Economic Forum Annual Meeting 2018 in Davos-Klosters to stimulate and promote discussion on this topic, in particular through a session entitled, Tasting the Future of Food, on Tuesday 23 January, 12.30-13.45.

Reflections from discussions at Davos will help inform further iterations of this paper further. This will then be used to support a more structured dialogue series planned for 2018 entitled, Meat: the Future.

The Meat: the Future dialogue will identify and engage leading economic policy, environment and food security experts, business leaders, civil society, investors and technology innovators from around the world in a series of workshops, conference calls and digitally curated discussions to explore the future of meat and other options for providing universally accessible, affordable, safe and sustainable protein, in line with meeting the ambitions set forward by the 2030 Agenda for Sustainable Development. Ideas and recommendations emerging from the dialogue will be captured in draft papers to be discussed in June 2018 at the World Economic Forum Annual Meeting of the New Champions in Tianjin, China; and in September 2018 at the World Economic Forum Sustainable Development Impact Summit alongside the UN General Assembly in New York. A final paper with recommendations will be published after the World Economic Forum Annual Meeting 2019.

The objective of this dialogue is to help accelerate the agenda for change – and to stimulate new ideas and collaborations. It will focus on the potential to positively disrupt our current systems for global meat production and wider protein delivery through new forms of public-private cooperation. In doing so, this initiative seeks to accelerate a market that can deliver 21st-century protein.

A selection of leading research institutes from around the world will be invited to offer their analyses and economic impact studies during 2018 and submit ideas into this discourse. The aim is to help stimulate discussion and provide a holistic view for the final paper and its recommendations.

The Meat: the Future dialogue will be hosted by the World Economic Forum System Initiative for the Future of Environment and Natural Resource Security in collaboration with the Future of Food Security and Agriculture System Initiative. It will invite and draw on expertise and partners from these System Initiatives. Reflecting the interrelated nature of the topic, the dialogue will also invite and draw on expertise and partners from the Future of Consumption and Global Trade and Investment System Initiatives, as requested or sought.

The World Economic Forum's Environment and Natural Resource Security Initiative is grateful to journalist, writer and broadcaster Nick Easen for his lead authorship of this paper, supported by Lisa Sweet of the World Economic Forum, as well as to Climate Works Foundation for its wider support to the Meat: the Future dialogue. Other World Economic Forum representatives working on this activity include Gaia Felber and Victoria Lee at the Forum Center for the Fourth Industrial Revolution in San Francisco, and Callie Stinson, Project Lead for the Water Initiatives. They are supported by Dominic Waughray, Head of Public-Private Partnership, and Sean de Cleene, Head of the Food System Initiative.

The World Economic Forum would also like to thank Patrick Brown, Chief Executive Officer and Founder of Impossible Foods, for kindly supporting the lunch discussion at the Annual Meeting 2018 in Davos, as well as for engaging in the dialogue.

The Meat: the Future dialogue also forms part of the Fourth Industrial Revolution for the Earth project, hosted by the World Economic Forum System Initiative for Environment and Natural Resource Security, with support from the MAVA Foundation.

Fourth Industrial Revolution for the Earth enables the world's leading environmental experts and technology innovators – drawn from across governments, international organizations, civil society, business, research, science and start-up communities – to form unique partnerships that identify, co-design and test new policy innovations and technology applications for improving the world's environment and natural resource security. The project will help shape a new agenda for how companies, governments and international institutions better understand – and manage – nature and our natural resources, making use of the latest science and technology for the benefit of all in society. The Fourth Industrial Revolution for the Earth initiative is in collaboration with PwC as official project advisor and Stanford University Woods Institute for the Environment as knowledge partner. It also works closely with leading issue experts and industry innovators from around the world, convened through the World Economic Forum's System Initiative and Global Future Council on Environment and Natural Resource Security.

Introduction

The provision of safe and affordable protein is critical to human nutrition.

Protein, including sources from meat, provides essential micronutrients such as vitamin A, vitamin B12, calcium, iron and zinc. International nutritional guidelines suggest a goal of 80g-90g of protein per person per day, with perhaps 50g per day coming from red meat. The growth of protein and red meat in the human diet over the last generation has delivered innumerable health and life benefits.

In 1960, about 45 million tonnes of meat (beef, pork and chicken) was produced globally[1]. Within a generation, human economic activity has urbanized, the journey out of poverty has materialized for many and the middle classes have mushroomed at an unprecedented rate. In the process, and in line with rising affluence, the demand for meat has exploded.

Global meat production today stands at 263 million tonnes and is expected to nearly double again to 445 million tonnes by 2050[2]. This represents about a factor-of-ten rise from 1960 to 2050. Over the same period, the global population is expected to triple – from roughly 3 to 9 billion people.

Despite such growth, the benefits of this expansion in meat production have not been universally distributed or realized. Today, many people still suffer from not having enough meat; at the same time, other parts of the global population are over-consuming. This dichotomy is illustrated by a tenfold difference in meat consumption around the world between those who eat too little and those who eat too much, extremes that significantly increase the risk factor for debilitating and economically costly non-communicable diseases among both groups.

In addition, the way we currently deliver protein – with a strong partiality towards red meat – is creating significant unintended consequences on our wider public health, agriculture and food systems, as well as on the environment.

In the public health arena, the World Health Organization is concerned that the spread of microbial resistance due to the overuse of antibiotics is reaching "*dangerously high levels ... with a growing list of infections … becoming harder, and sometimes impossible, to treat as antibiotics become less effective*."[3] The livestock industry is a significant contributor to this concern, as about half of all antibiotics use currently occurs, not to tackle human or animal disease, but in the livestock industry for growth promotion and disease prevention in healthy animals.

Turning to agriculture, in 2016, for the first time ever about a third of all the grain produced in the global food system was fed to livestock – enough grain to feed about 4 billion people for a year. While inequivalent in terms of nutrients (the UN Food and Agriculture Organization, FAO, has determined that 86% of livestock feed is not suitable for human consumption[4]), the feed-to-food conversion of grains to meat raises key questions on the efficacy of a protein delivery system geared predominantly towards meat from livestock. Additionally – with the FAO Statistical Database reporting that cereals such as maize and wheat account for about half of all feed ingredients[5] – the consolidated nature of today's feedstock practices place increased risk on the resilience of the food system, as well as greatly contributes to reduced biodiversity.

Finally, there are also significant environmental consequences from today's global meat production, as recent research sponsored by the Climate and Land Use Alliance shows[6]. According to the FAO, livestock generates just under 15% of the total CO_2 equivalent greenhouse gas emissions a year, with beef cattle alone contributing about 6% of the global total[7] – an equivalent of about three times that of the aviation sector[8]. Researchers also calculate that it can take about 15,000 litres of water to produce a kilo of beef[9] – a challenge exacerbated when key livestock production regions such as the south-west United States and south-west Brazil are facing increasing frequencies of drought and subsequent water stress. Additionally, meat production is a major driver of deforestation, habitat and biodiversity loss, through conversion of natural landscapes to pasture lands and to agriculture for feed production.

Beyond production issues, there is also a demand-side challenge facing the future of meat. Looking forward to 2050, projected demand for meat and protein is set to double from today's numbers, reflecting both a growing population and, more importantly, an increase in middle class aspiration for protein – by 2050, 66 % of the world's population is expected to be urban. What will the future generations demand from their meat and protein products? These preferences are likely to be shaped in line with current millennial trends for better health and provenance dimensions related to food.

On examining both the impact of expanding supply and the nature of changing demand in the current "future of meat" equation, therefore, is taking a business-as-usual approach for delivering tomorrow's growing desire for protein, largely focused on producing more red meat in the manner in which we do so today, really a credible strategy? Is it even possible?

Building on the zeitgeist of strengthening trust in the integrity of our systems to deliver long-run economic health and prosperity, the nations of the world collectively agreed to the Sustainable Development Goals (SDGs) and the Paris Climate Agreement in 2015. These global goals include a range of health, food security and environmental and biodiversity targets to be met by 2030. The time is right to ask, what role can the meat and protein provision sector play in helping to deliver on these targets, while also rising to the growing demand challenge?

Furthermore, how might a concerted focus on technological innovation and new collaborations (involving researchers, business leaders, investors, governments, farmers, consumers and civil society) help both the livestock and protein provision sector, and the future nature of demand, adapt to the challenge ahead? Can programmes of public-private cooperation identify the key practical areas to focus on to help the sector meet and exceed the SDGs and Paris Climate Agreement targets *and* help build new market opportunities around meat and other protein options for a growing consumer base, with potentially different needs and changing tastes?

If so, what kind of structured effort is needed to build new platforms of collaboration to design and deliver a range of trusted "protein possibilities" – universally accessible, safe, affordable and sustainable – (collectively, perhaps a "*21st-century protein*" portfolio), and to shift demand in critical ways, in ways that can both meet future forecasts and deliver on the relevant SDG and Paris Climate Agreement targets.

Meat: Today

In 2017, the world was projected to produce a record 263 million tonnes of beef, pork and chicken meat. Overall, livestock is one of the fastest growing sectors of the agricultural economy[10]. Consumers spend between $750 billion[11] and $1 trillion[12] on meat every year, with net growth in spend unlikely to slow down[13].

For many people, animal products are the most desirable way to access nutrient-rich and tasty protein. Meat – in particular, red meat – is commonly perceived as the core of protein delivery as it is nutritious: it packs much more of a protein, micronutrient and amino acid punch per kilo than plants. Often, consuming red meat is also a sign of affluence – from its traditional scarcity among hunter-gatherers to its relative costliness for the world's emerging middle classes. For others, whether at a tailgate BBQ in Australia or the United States, or around the table for a family lunch in Argentina, the consumption of meat also has important cultural connotations.

Globally, however, 815 million people are still malnourished[14]. Although today's global average of meat consumption is about 100g per day, *consumption per capita* is unevenly distributed, with approximately a tenfold variation between high-consuming and low-consuming populations. People living in higher-income countries consume significantly more meat – on average, 200g-250g or more per person per day. (To put these numbers into context, one quarter pound is 113g of meat.) This also creates unwelcome health problems: overconsumption of meat contributes to growing rates of obesity and leads to higher risk for non-communicable diseases (NCDs) such as cancer and type 2 diabetes – the kinds of lifestyle diseases the health SDG is seeking to reduce by one third. Indeed, research suggests that switching these diets to rely less on meat could save up to 8 million lives annually by 2050, as well as saving healthcare systems billions of dollars[15].

It seems there could be win-wins for the health SDG if food systems can get the balance of affordable protein delivery and desired demand figured out; meeting the need for increased amounts of 21st-century protein across Africa and Asia where malnutrition is high, especially over the coming decades as the population increases and urbanizes; and rebalancing the portfolio elsewhere, in particular across industrialized economies where NCDs continue to rise.

For the agriculture sector over the last generation, to meet the rapid increase in demand for meat due to the "great acceleration" of human economic activity and urbanization, there has been an unprecedented *intensification* of the global livestock industry. This global meat delivery model, which took root in the late 20th century shaped by the know-how and scientific understanding at the time, has proved successful in delivering more meat to more consumers since the 1960s. Livestock intensification, however – while increasing productivity both in livestock farming and in feed-crop agriculture and reducing pressure on land-use conversion[16] – has also come with unintended consequences for our health, food and environmental systems.

Today, there are about 1.5 billion cattle on the planet (one cow for every five humans), 1.2 billion pigs and 1 billion sheep. Increasingly they are kept in so-called Concentrated Animal Feeding Operations (CAFOs)[17], which have historically provided benefits of lowering both production costs and land requirements for livestock production. According to a 2016 report by the Farm Animal Investment Risk and Return Initiative (FAIRR), approximately 70% of livestock globally is produced in such intensive, factory-style farms[18].

The increase in CAFOs has, in turn, led to a complex industry for animal feed. In the United States, for example, 50% of all grain produced in 2016 was for livestock feed[19]. Worldwide, the UN Food and Agriculture Organization (FAO) estimates that 30% (763 million tonnes) of the 2.62 billion tonnes of grain produced in 2016 was used for animal feed[20], while other studies put the estimate at about 1 billion tonnes (or about 40%) of all the grain grown globally by mankind[21].

As well as reshaping systems for global grain production, the increase in livestock intensification has also meant a rise in the use of antibiotics. In 2011 it was reported by the FAO that about half of the world's antibiotic production was used in livestock[22]. This rises to 70% in the United States, according to a 2016 study by the US Food and Drug Administration (FDA)[23]. In addition to the treatment of disease when animals were found sick (therapeutic usage), antibiotics were introduced into the protein production systems for healthy animals to support disease prevention and growth promotion. The overuse of antibiotics for non-therapeutic use is becoming a grave concern to the World Health Organization (WHO) and many national policy-makers due to the rise in antimicrobial resistance.

The WHO states that: "Antibiotic resistance is rising to dangerously high levels in all parts of the world. New resistance mechanisms are emerging and spreading globally, threatening our ability to treat common infectious diseases … Without urgent action, we are heading for a post-antibiotic era, in which common infections and minor injuries can once again kill." [24]

The WHO estimates that about 700,000 people die each year from antibiotic-resistant infections and it is predicted that, without addressing the challenge, this number could rise to 10 million by 2050[25].

As a result, the WHO is recommending that farmers and the food industry stop using antibiotics for non-therapeutic use. Several companies have already taken a lead in this regard, but the problem of over-using antibiotics in intensive livestock farming and accelerating the threat of widespread antibiotic resistance remains. Without further action this risk will simply grow as the demand for meat increases.

Meat: Tomorrow

As we look to meet a doubling in demand by 2050 in line with global health, food security and environmental targets, it becomes increasingly clear that the world's increasingly intensive industrial protein production practices will need to adapt. Addressing these "legacy" issues today will influence how tomorrow's demand is met. The impact of expanded meat production on our food systems and on our environment are two critical areas.

The Food Systems Factor

The unintended consequences arising from simply expanding today's legacy meat and protein delivery system are worth considering with respect to our wider food systems. Set within the wider food security targets of the SDGs, the intensification business model may not be as efficient for the next generation as it has been for the last.

Recall that estimates suggest between 760 million and 1 billion tonnes of the global grain harvest are currently used as feed for livestock. Under a business-as-usual scenario, a doubling in meat production would likely mean even more grain being grown for animal feed. Yet, 1 billion tonnes of grain – while lacking nutrient diversity – are, from a calorific perspective, estimated to be enough to feed 3.5[26] to 4[27] billion people. This means a projected population of just over 9 billion people by 2040[28] would require a global grain yield of up to 2.3 billion tonnes, which is actually slightly less than the global grain harvest today. Consequently, if an *alternative* feed for tomorrow's livestock could be found – or if tomorrow's human demand for meat and protein could be met in a variety of *other* ways than only through grain-fed livestock production – then the world could feed the caloric requirement of the global population by 2040 with broadly the same amount of grain we grow today[29]. Alternatively, we could wait and face a much more difficult set of trade-offs in terms of the global grain harvest, if an expansion in livestock for meat production continues under business-as-usual conditions.

Furthermore, efficiencies in the feed systems for animal protein delivery have encouraged high concentrations of a *limited number* of feedstock crops. In the US alone, 98%[30] of the soy and 36% of corn produced feeds animals. China also allocates more than three quarters of its maize to animals. Globally, 85% of soy production is used in the same way[31]. The consolidated nature of today's feedstock practices places risk on the system – resilience is limited and biodiversity is lost. A risk to extensive crop loss from future disease blight – both for animals and for people - is being amplified by the concentration in growth of just a few feedstock crop types.

The Environment Factor

The second bucket of unintended consequence arising from today's legacy meat and protein delivery system relates to the environment.

Total emissions from global livestock are about 7.1 billion tonnes of CO_2-equivalent each year, representing 14.5% of all anthropogenic greenhouse gas (GHG) emissions, according to the FAO[32]. Beef cattle contribute 41% of this total, or 6% of the global total of CO_2-equivalent emissions a year[33]. This is about three times that of the global aviation sector[34].

Meat production is a major driver of both deforestation and habitat loss – either for direct conversion to pasture or through conversion to agriculture for feed production. The Union of Concerned Scientists have found that converting forest to pasture for beef cattle, largely in Latin America, is responsible for destroying 2.7 million hectares of tropical forest each year[35]. In the Amazon basin, for example, cattle ranching has historically driven about 75% of forest clearing[36]. This makes livestock the single largest driver of *habitat loss*, which is especially important in biodiversity hot-spots like the Amazon. Many scientists argue that, as a result of such agricultural expansion mainly for livestock, Earth is currently losing its biodiversity at mass extinction rates[37].

Despite increasing recognition of this challenge, beef and soy supply chains are the worst performing of the forest risk commodity supply chains in terms of insuring environmental integrity. These supply chains are lagging behind palm oil and timber/pulp in terms of both commitment to deforestation-free sourcing and their implementation[38]. In Brazil, for example, the world's largest beef exporter and second-largest beef producer after the United States, nearly all beef production is currently pasture-based rather than intensively farmed[39]. While avoiding some of the earlier pitfalls, this has historically created great pressure on forest lands as they are cleared for ranching. Moratoria on clearing virgin forest land to grow soy for livestock – or to convert to ranching land – have helped to slow deforestation rates but they also put pressure on Brazil's livestock sector to meet growing demands for beef at home and abroad. Intensification offers a key solution, but only if undertaken in a more sustainable manner.

For the international community, it is increasingly recognized that the targets of the Paris Agreement on Climate Change cannot be met without reductions in GHG emissions and elimination of biodiversity loss from food and land-use systems, including meat production[40]. This means the sector will have to respond. Innovation is required.

Without a change to business-as-usual, current approaches to farming meat in the EU, US, Brazil or other regions (whether intensive grain-fed or via grass-fed ranching) will be challenged to deliver on both priorities simultaneously – to meet growing demands for affordable beef and protein and to do so in a way that does not increase GHG contributions or drive deforestation and habitat loss[41].

Meat production is also a thirsty business. It takes about 15,000 litres of water to produce a kilo of beef, compared to 1,600 litres to grow a kilo of wheat[42]. This is a material challenge when key livestock production regions, such as the south-west United States and south-west Brazil, and regions dependent on livestock production for exports, such as Australia and India, are facing changing weather patterns, resulting in increasing frequencies of drought and related water stress[43]. State and provincial governments face a stark choice: either they allocate scarce water away from agriculture and towards higher-value urban, energy or industrial uses, or they charge farmers much more for the water. When facing a future of increased water scarcity and dry weather spells neither option is easy for the livestock sector, nor will either necessarily resolve the problem.

In the broader protein delivery lens, it is also worth noting the environmental impact of fish. In 2013, fish accounted for about 17% of the global population's intake of animal protein and 6.7% of all protein consumed. However, based on the FAO's analysis of assessed commercial (marine) fish stocks, 31.4% of fish stocks were estimated as fished at unsustainable levels[44].

Given this backdrop, it is pertinent to ask how our current global system of protein delivery might best be re-engineered to not only minimize its environmental impact but also to be more resilient – and not worsen – environmental conditions in the future.

The Human Choice Factor

Protein will continue to be in demand, and this demand will grow as the global population increases and – more importantly – as people become more affluent, aspirational and urbanized. The nutritional value of protein is long-standing and well recognized, it is not saddled with any of the debate that surrounds other dietary components such as sugar and certain fats. However, the key is getting the correct balance of protein consumption right on an individual basis.

We see signs of changes in consumer-driven demand already happening. In many western markets and in China, there are rising levels of consumer concern about food – and not only from a safety perspective. Consumers, especially millennials, are increasingly asking: What is in my food? How was it made? Where does it come from?[45] These concerns may also be reflected in recent consumption patterns and help explain why, in certain economies, consumption of red meat is decreasing. For instance, beef consumption in the US has dropped by nearly one-fifth from 2005 to 2014[46]. A survey linked to this data found that 25% of consumers ate less meat due to health concerns[47].

Alternatives to meat do exist, and consumer – especially millennial – attitudes in some industrialized markets seem to be shifting towards them[48]. However, despite having been available for at least three decades, plant-based meat alternatives have yet to make a significant impact on any consumer market[49], according to the *Financial Times*. Taste and culture play an important role, but perhaps growth is also held back by understandably cautious policy-makers, given long-held attitudes to novelty and safety surrounding new food options.

In certain societies regulation is set to play a significant role in human choice and behaviour. In China, for instance, among a series of policies aimed at improving public health and reducing GHG emissions in the future, one is focused on cutting meat consumption by half, to 75g a day[50].

How the demand grows in other markets – Africa and other regions of Asia – and evolves in other large meat-consuming markets – the US, the EU and Brazil – remains to be seen. However, given the challenges that lie ahead to meet tomorrow's demand, this may also be the time to ask how some emerging trends within the human factor of consumption can be further harnessed to shape a more sustainable future for the consumption of protein and meat.

Meat: the Future?

The science fiction writer William Gibson once famously said: *"The future is already here – it's just not evenly distributed."*[51]

Indeed, there is no silver bullet or single solution that will lead to 21st-century protein delivery – universally accessible, affordable, safe and sustainable – for a population of 9 billion. Instead, we need to work simultaneously on a number of pathways if we are going to be successful in finding ways to feed people and still have a healthy planet.

The future offers plenty of innovation potential and the technological advancements of the Fourth Industrial Revolution present significant enablers to make these innovations a reality.

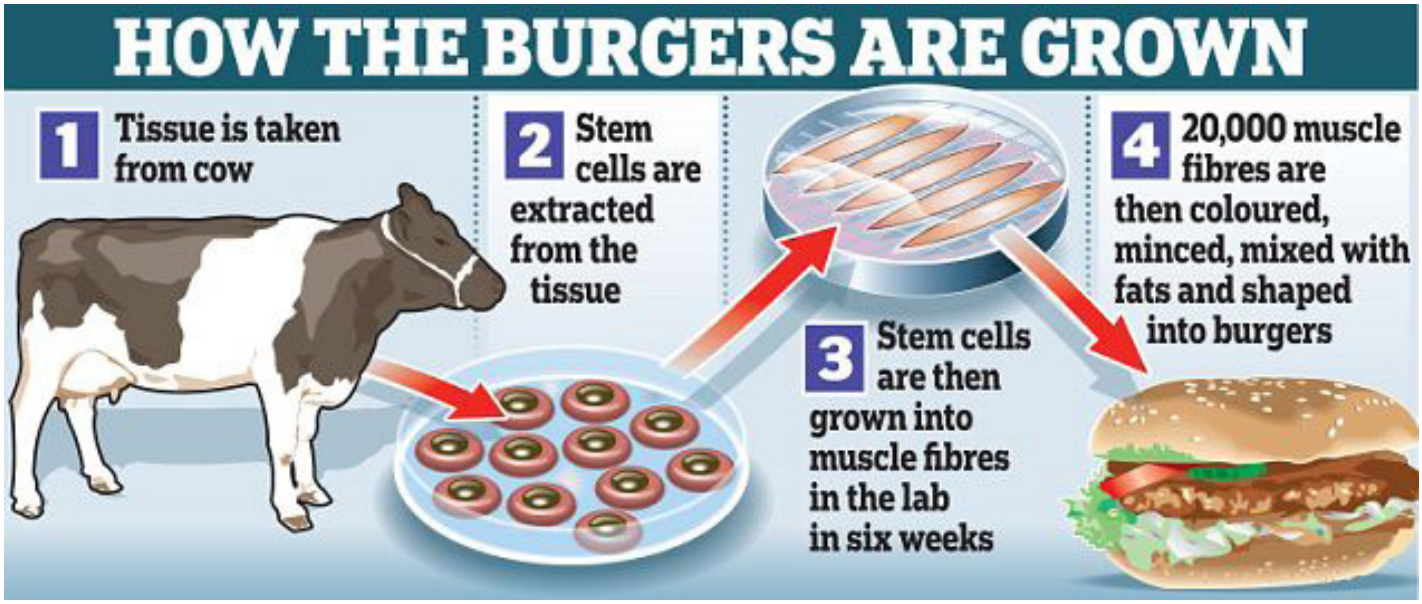
We are already seeing significant innovations, from alternative proteins and synthetic meats to advancements in production systems – including feed – to behavioural changes including diet diversification and the reduction of food waste. Taken as a "portfolio" of solutions (see Figure 1), alongside existing animal protein options, whether grain-fed or grass-fed, beef, chicken, or fish, this could offer an effective approach in making more 21st-century protein possibilities available for a larger part of the world, in ways that can be adapted to different markets, needs, consumer preferences and price-points. The net result of which, as the global protein market grows, should mean relatively less reliance on red meat alone.

As the technology evolves, so has the ability to mimic the traditional taste and feel of meat with plants – lowering the trade-off barrier consumers often feel is at stake. California-based Impossible Foods, for instance, is producing a "burger" made from wheat and soy that tastes like meat by adding a heme molecule found in the root of certain plants. Impossible Foods says its burger patty uses 95% less land, a quarter of the water and produces an eighth of the greenhouse emissions compared to a regular meat burger. It has taken five years for the Founder and CEO Patrick Brown and his team to engineer a vegetable-based burger that mimics cow flesh[52], and they are looking at impossible steaks and impossible eggs next. Beyond Meat and many other companies are also at work innovating around plant-based alternatives.

Companies and innovators are also racing to develop "cultured" meat. These are meat products grown from starter cells taken from live animals. This novel protein source could be produced in urban "breweries", requiring just 2% of the land that the global livestock industry uses today. This would relieve 25% of the pressure on global agricultural water demands by 2030, and produce just 4% of the GHG emissions of today's global industrialized cattle herd, according to Professor Marc Van der Post of Maastricht University, a leading innovator in the cultured meat field and Chief Scientific Officer of MosaMeat[53]. With a much lower land and resource footprint and no need for antibiotics, this meat could also be healthier for people and the planet. This is potentially a huge prize for the meat and protein production sector to help deliver on the SDGs and

Figure 1: Illustrative Portfolio of Solutions

Alternatives	Advances in current production systems	Consumer behaviour change
Meat replacements (e.g. plant burger) Cultured/Lab-grown Fish oil and Omega-3 alternative sources Insects Single-cell sources Traditional plant-based alternatives (chickpea, mung bean, etc.)	Sustainable and new feedstocks Sustainable intensification Utilization of food and industry waste streams New breeds of cattle	Diversification within per capita diet Right-sizing of diet (shift towards protein equity per capita) Reduction of food waste



Source: MosaMeat[54]

Paris Climate Agreement, in terms of relieving pressure on the global environment, while also delivering accessible meat protein for the world's urban population. It also offers an opportunity for jobs and entrepreneurialism, given the localized supply chain and distributed nature of the "brewery" model and the associated services it will require.[55]

Scaling up the production of single-celled and alternative sources also has a lot of potential, since it is high in protein and also uses less land than other protein options[56]. TerraVia in the US, for example, is producing a synthetic alga, which contains 63% protein and has a high digestibility of 88%. It is being used in snacks, baking products and beverages[57]. Spirulina, of course, has long caught the imagination as a protein alternative[58] and is predicted to show significant growth in the years ahead. One of the oldest such single-celled commercial products is Quorn, which is made from a mushroom-like fungi called mycoprotein[59]. This British company, having been a rather niche producer for many years, reported a 19% rise in sales in the first half of 2017 and, with changing consumer tastes, it aims to become a "billion-dollar brand" within 10 years[60]. MycoTechnology in the US has also recently raised $35 million to take mushroom protein to the mass market, converting pea and rice protein into Shiitake mycelium[61].

Alternative feeds for livestock are also ripe with innovation. A number of innovations in the livestock diet have already been shown to significantly reduce GHG emissions (which are mostly methane). A team of researchers *at* James Cook University in Queensland, Australia, for example, have found in live trials with sheep that if their diet is made up of 2% seaweed, methane levels fall between 50% and 70%[62]. The Netherlands-based company Royal DSM has also produced a powdered feed additive through its Clean Cow project that can reduce methane emissions by 25% when fed to cattle[63]. It has also partnered with Evonik on a joint venture to create Omega-3 fatty acids from natural marine algae for animal nutrition[64].

To alleviate pressure on grain, maize and soy, Sylfeed is a project in France and the US looking at growing protein-rich micro-organisms using woody biomass, from byproducts of the lumber industry. Its protein meal SylPro is another alternative that could be used to feed animals[65]. Calysta is developing a sustainable animal feed based on synthetic bacteria fed on methane. Its factory in Memphis, Tennessee, will be the world's largest gas fermentation plant and will produce up to 200,000 tonnes of feed, called FeedKind. Operational by 2019, Calysta believes scale is important if it is to have any effect on global feed production. In time, it also hopes to use methane from landfill[66]. Other companies such as Protix and Ynsect (which, alongside Calysta, have raised over $100 million collectively from investors[67]) are also trying to make a difference in the $400 billion animal feed industry, as well as exploring the potential to derive commercial-scale protein solutions from insects.

It seems as if William Gibson could be right: the future of meat is here.

We are starting to see momentum. However, in to meet the 2030 targets for the SDGs and the Paris Agreement, we may not have the luxury of waiting for the markets to take their natural course. Today's options either exist in sporadic, early-stage developments and start-ups or have not yet been scaled up to become affordable, globally accepted, or mainstreamed possibilities for alternative meat and protein options.

Current industry watchers suggest large technology, IP sharing and regulatory hurdles mean it will take at least five years for cultured meat to arrive consistently in high-end restaurants and perhaps a decade to reach mass-market. It is also not yet clear exactly what scale of environmental benefits a mass-produced cultured meat sector could actually deliver[6869]. As with the technologies for renewable energy or electric vehicles, perhaps it might take the equivalent of a major economy such as Germany or China to help pump-prime the development of the global consumer market for new protein portfolios, as they did for solar energy a decade or so ago?

Affordability continues to play a major role in the uptake of alternatives, regulatory and technology hurdles notwithstanding. Five years ago, a cultured meat burger cost Van der Post and his team €250,000 to produce[70]. With support from New Harvest, a donor-funded, non-profit with a goal to support the research of cellular agriculture[71], Van der Post is now bringing down production costs rapidly and is approaching commercial viability. Memphis Meats is developing a similar process that seeks to produce beef, chicken and duck without the need to raise animals for slaughter[72]. Their cost is currently at about $4,000 per kilo[73]. As technologies improve and costs tumble, in time it is likely that these various cultured meat options will become cheaper than the least expensive conventionally produced cow, chicken or duck. Can additional multistakeholder collaborations further accelerate the pace of affordability?

A number of the major meat-producing companies already recognize the potential for these new markets, signalling that they are now in the sustainable protein business rather than the meat business alone. These champions will be key collaborators in any public-private effort as the sector transforms and new innovators are encouraged. International organizations in the food and agriculture sector, development finance agencies, philanthropic foundations, research and development agencies as well as civil society groups will also be vital stakeholders in this journey, as will governments and the general public.

Governments are also investing. As a key importer of beef, and a country that is unable to grow enough traditional meat to meet its domestic demand safely, sustainably and affordably, China recently signed a $300 million deal to buy laboratory-grown meat from three companies in Israel – Super-Meat, Future Meat Technologies, and Meat the Future[74].

With a concerted public-private effort, could we move into the future faster?

Such a big vision is not without precedent. The Consultative Group on International Agricultural Research (CGIAR) was created through unique collaboration between philanthropic foundations and governments in the early 1970s to fast-track new crop innovations to developing countries in response to the looming food crisis at that time. Looking ahead to 2030 and beyond, and given the pressing need to provide 21st-century protein to an urbanized world of 9 billion people, might a similar decade of global public-private collaborative effort on the future of meat and protein be worth considering for this generation?

Within the context of the current and future demand for – and production system of – our global meat and protein – these are the questions that the World Economic Forum dialogue, Meat: the Future, will seek to explore during 2018.

Endnotes

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