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CHAPTER TWO

Culturing Meat For The Future: Anti-Death Versus Anti-Life

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Humans can no longer afford to eat meat on a large scale. Livestock production imposes a vast burden on global resources and it is one that the expanding world population can no longer sustain. Yet imagine if we were able to culture such food in factories: we might then be able to manufacture virtually limitless supplies at a greatly reduced cost and a lessened environmental load. In 1976 I calculated that: "We could provide more than enough food for the world's population from an area the size of an industrial estate." The culture of living cells, I said, would allow us to provide proteinaceous foodstuffs for a large global population from an area the size of a city.[1] The complex could be sited in the freezing wastes of the Arctic so that metabolic temperatures could be simply controlled (there was no thought that the warming effect might pose a problem, when writing one-third of a century ago).

There is now an upsurge of interest in the possibilities of meat produced from cultured cells *in vitro*. What should we call it? How does it fit into a broad social context? Can it work? Does it matter? Will it solve our current demand for food? What will be the environmental consequences? Would people accept it – and how diverse are public attitudes to the consumption of meat?

Although the idea of cultured meat seems novel, it is not new. In 1932 Winston Churchill wrote: "Fifty years hence we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing by growing these parts separately under a suitable medium." [2] His words now seem prescient, though the idea was not Churchill's own. Two years earlier, the writer and Conservative politician Frederick Edwin Smith, 1st Earl of Birkenhead, had predicted: "It will no longer be necessary to go to the extravagant length of rearing a bullock in order to eat its steak. From one 'parent' steak of choice tenderness it will be possible to grow as large and as juicy a steak as can be desired".[3] Since the idea was proposed so long ago, we might have expected the principles of meat production in culture to be well established seventy years later. Not so. The whole topic was widely ignored and it is only now receiving attention. A group named New Harvest was set up in 2004 by Jason Matheny and is the first non-profit organization to advance the vision of cultured meat.[4]

Rearing livestock for meat production contributes more greenhouse gases to the atmosphere than the entire transportation network of the world (18%). Producing meat currently consumes 8% of all freshwater and involves 30% of the ice-free land surface of the earth. With curious symmetry, the land area unsuitable for grazing or cultivation is also 30% while the land covered by forest is 31%.[5]

The West is greedy. American sources calculate that the amount of food and grains that supply the average world inhabitant is 1,353 pounds *per capita* annually[5]. In China it is only 1,028 lb whereas in the United States the figure reaches 3,265 lb, an unsustainable level of consumption.[6] Meat also threatens global biodiversity. More species have been threatened, or entirely exterminated, by livestock rearing than through any other cause.[7] More than a quarter of

all rain-forest land in Central America has been converted to cattle rearing since 1960[8] and 70% of former tropical rain-forest in Costa Rica and in Panama has been stripped and converted to cattle-raising pasture. Brazil calculates that almost 40% of its land has been cleared for raising beef.[9]

Eating meat to excess can itself pose a health hazard, though attitudes to livestock are curiously related to cultural norms. In the USA, eating steak is considered manly. In China there has long been a belief that the suffering of an animal as it is prepared for the table can be positively correlated with the benefits it brings to the consumer, and traditional standards of animal rearing and husbandry are very different from those expected in the West. Yet, even in supposedly humanitarian societies, animals are customarily reared under inhumane and intensive conditions. For all their reputation in the Western world as 'animal lovers', the British still produce eggs in battery farms where several hens can be confined within a cage with a floor measuring no more than 45 x 50 cm (approximately that of a microwave oven). The hen's wingspan is about 75 cm, so severe constraints are put upon these birds. They have become little more than living egg-laying production units; a hen in its wild state lays about 20 eggs per year, whereas those bred for intensive production can produce 300 per year, almost one every day. This sits in contrast with the strong pressure towards meat avoidance. Vegetarians and vegans are voluble and visible, and people have turned in increasing numbers towards this way of life.[10] The numbers are hard accurately to determine, but in Australia, 3.7% of people are vegetarian and in the USA the population claiming to 'never eat meat' rose from 4.5% in 2000 to 6.7% in 2008.[11]

Definitions of vegetarianism are hard to establish. Plenty of 'vegetarians' admit that they eat fish without demur; a good number of consumers include white chicken meat in their diet, while still claiming to espouse a vegetarian

ethic. It seems perverse to designate fish and fowl as ‘vegetables’. The *vegan* diet is an extreme vegetarian lifestyle which precludes all animal products. This has a clear basis in reason, and it includes all dairy products (such as butter and milk) along with eggs, and even honey. I was once approached by an acquaintance who had been ostracized by her vegan friends because she was breast-feeding her newborn son. They argued that, since breast-milk was of animal origin, it was unprincipled to feed it to a baby. I suggested that the ideological opposition of a vegan standpoint to an omnivorous diet was founded on cruelty to animals, or the wanton exploitation of livestock. Dairy milk is obtained from cattle whose newborn calves are removed while the cow is lactating, the continuous milking maintaining the supply of milk for the farmer. Since the woman was donating her milk voluntarily and naturally to her baby there was no exploitation of any other animal. This seemed to mollify my acquaintance, and indeed most vegans concur that breast-milk for babies is natural and acceptable.

Some people believe it wrong to harm plants. These are *fruitarians* (or *fructarians*) and they consume only raw fruiting structures (e.g. pineapple, mango, apple, berries, tomato, cucumber, olives, nuts and, confusingly, sprouted seeds) while avoiding all cut plants. Many individuals regard themselves as fruitarians if 75% of their food conforms to the principle. Although vegetarians should avoid animal-based foods, many of them still consume dairy products and many more eat eggs. The *lacto-vegetarian* diet is defined as including dairy products but excludes eggs, while *ovo-vegetarianism* sanctifies the consumption of eggs (but not dairy products) and the *lacto-ovo vegetarian* diet includes both eggs and dairy products. Quite where fish and chicken come into the picture remains far from clear.

This becomes particularly interesting when we bring cultured meat into the frame. In the production of meat

foodstuffs in this category, there is no animal suffering; there is no exploitation, no slaughter, merely the growth of cells in a fermentation vat. Even a vegan could, in that case, in principle consume cultured meat.

I can imagine your response: the objection would remain based, not on any supposed inhumanity towards livestock, but founded instead on the fundamentally unnatural production methods involved and the human-made nature of the product. Yet we already are selling technologically-produced meat-like foods and these wholly unnatural products have become popular among vegetarian and vegan groups. They are made either from cultured fungus hyphae or vegetable protein extracted from plants like soya that can be processed and textured to imitate meat.

As long ago as 1955, it was anticipated that there would be a global famine due to a shortage of protein-rich foods within the following few decades. Investigation began to find meat substitutes, and plans were soon hatched by the National Aeronautics and Space Administration (NASA) to produce food of this sort for prolonged journeys through space. One experimental product intended for public consumption was developed in Britain in the 1960s under the acronym CESP (standing, if I remember correctly, for Courtaulds' Extruded Structured Protein).

At about this time the British firm of Rank Hovis McDougall (RHM) began to investigate whether waste starch from cereal manufacture could be processed by microorganisms to produce edible proteins. Large-scale investigations of possible fungal products were soon under way, and it was experiments by RHM with the mold *Fusarium venenatum* that proved to be most promising. This species of ascomycete fungus was first isolated in a wheat field in 1967 and it has since been extensively investigated.[12]

After a decade of exhaustive testing, RHM was first authorized to produce foods made from *Fusarium venenatum* protein in 1980. Five years later the first retail products appeared in the shops, and they have since become the most successful meat substitute developed in the West. The production company was named Marlow Foods Ltd, after the town of Marlow, Buckinghamshire, where RHM's headquarters were situated, and production began as a joint venture between RHM and Imperial Chemical Industries (ICI) who provided a fermenter that had been left unused from their abandoned single-cell animal feed research.

The name chosen for the product was Quorn, after a village of that name in Leicestershire, England. The village of Quorn did not always have that name; it was originally known as Quorndon but in 1889, as the postal service began to expand, it was often confused by delivery staff with the nearby village of Quarndon, so the postal authorities applied to have the name shortened in the interests of clarity.

When meals made with the Quorn protein were introduced as a meat substitute in the staff canteen of RHM, they proved to be popular, but the product went through a number of iterations before it was generally marketed. The supermarkets all refused to sell the product until Lord Sainsbury agreed to market it through the Sainsbury's chain of food stores, and production increased greatly from 1994. Over the next few years it was progressively marketed across Western Europe, and introduced to the United States in 2002.

It is important to note a crucial change of emphasis as the global food supply increased faster than the population. This was particularly evident in China, and it challenged the eighteenth-century Malthusian dogma that humans were always doomed to starvation as population growth outstripped food supply. Half a century ago the world was short of food. In 1960 the index of food production per head

of population was 85. It rose to reach 90 by 1970. In 1990 it was standardized at 100 and by 2000 it was as high as 105.[14] The world-wide view, that we have experienced famines due to a global food shortage, is wrong. The world's population has not been experiencing a shortfall of food production so much as a lack of distribution and political goodwill. During the widely publicized Ethiopian famine of 1984, for example, their central government was still exporting grain and devoting almost half of the Gross National Product to military expenditure. They were fighting insurgency by groups like the Tigrayan People's Liberation Front and food supplies were not permitted to enter the breakaway territory of Eritrea where the population was starving. The well-intentioned Live Aid fundraising event distributed money that served to prolong the civil war, and added to human suffering. Food shortage was not the cause of the famine; the root cause was political intransigence and, as always, it was the population that suffered the horrendous consequences.

Food supplies increased until they exceeded demand. This was, in reality, a success story for global agriculture and a watershed for the modern world. It went on to give rise to such absurdities as the grain and butter mountains. During the 1990s the European authorities introduced the 'set-aside' scheme which obliged farmers to stop food production and return 10% of their land to a fallow state. The proportion of starving people in the world, however, remained disturbingly high. For all the meticulously planned high-efficiency farming, there was little sign of a similar effort to distribute the products to victims of famine around the world.

With food so abundant, there was little pressure for the production of meat substitutes as an alternative source of food. The need for a product like Quorn had been superseded by events, and the business model became obsolete. It was resolved to market it as a health-food instead. Although cultured fungus protein seems very state-of-the-art, there are

several ancient precedents for this approach to making artificial foods. *Tempeh* is a traditional meat substitute produced in time-honored fashion in Indonesia by fermenting cooked soya beans with the common pin-mold *Rhizopus*. The fungal threads bind the bean protein together into a tasty mass that contains all the essential amino acids and is thus an excellent vegan food.

A similar protein-rich food (traditionally made in Japan from soya) is the bean curd *tofu*. It originated in China as *doufo* and is made by coagulating curds of protein from soya milk. It has the look of a soft cheese. Tofu is increasingly popular in the West as it is rich in nutriments and can lower blood levels of low-density lipids (popularly known as 'bad cholesterol') by 30%.

In South-East Asia, there have been such artificial meat substitutes for at least 2,000 years. The success of a novel product like Quorn has been remarkable for – although it is so very popular with health-food fanatics – it is fundamentally science-based and is an entirely unnatural form of food. Once the fungus mass has been extracted from the fermentation vat it is textured to feel, in the mouth, similar to meat; it is also artificially flavored so that it can be used in meals as a substitute for beef, pork, chicken or lamb. How curious it is that this high-tech product can become so popular with those who espouse 'natural' foods; and how anomalous that, instead of being marketed solely as a vegetarian product, its appeal to vegetarians is founded on the fact that it looks, tastes, smells, and feels like meat.

These issues are of concern to the scientists working on the development of cultured meat, for we have to consider the trend towards vegetarianism and reflect both on why these views are held, and where they originate. Some vegetarians adhere to their diet for the simple and unarguable reason that they do not like meat: its taste and texture are

unappetizing to them and even repugnant. The obsession with the production of a food that isn't meat (but looks, feels, smells and tastes exactly like it) will never bring in these consumers. Other vegetarians claim that theirs is the only natural diet for the human species. This cannot be supported. Wherever we look at mammals and their diet, we find evidence to the contrary.[15] First, our dentition is distinct. Carnivores have a large carnassial tooth whereas herbivores have none; in humans a conspicuous canine tooth is present, but is only slightly enlarged. Carnivores have a closed root to the tooth – there is no open pulp cavity in the mature teeth – whereas in all herbivores the apical foramen (the opening at the root) is large. In humans it is small. Our dentition clearly represents a half-way house between carnivores and herbivores. We have the teeth of an omnivore.

The internal anatomy provides further evidence. The appendix in herbivores is very large; in carnivores it is entirely absent. Humans have a small appendix; the half-way condition of an omnivore. Herbivores bear their eyes on the sides of the head (where they can maintain a wide lookout) while carnivores have eyes on the front of the face (to maximise binocular vision for hunting prey). In our species, the eyes are at the front, as in carnivores.

On this basis, there is unarguable evidence that humans are intended to include meat in the diet. Although our eyes point forward, as they do in carnivores, the other evidence shows that we are not intended to consume an exclusively carnivorous diet. Clearly, humans are omnivores by nature. In terms of human biology there is no case for vegetarianism.

What of that ancient religious view, namely that we should never kill any form of animal? It is difficult to reconcile this with our modern knowledge of living organisms. You cannot close your teeth without killing

countless millions of living beings, or stand on the ground without crushing large populations of minute and sentient organisms. There has long been faith in reincarnation, in which a human might return as, say, a dog or an eagle. With our modern understanding of life, we would have to accept that we might equally be reincarnated as *Paramecium*, or even *E. coli*. Religions tend to sit uneasily with our modern scientific understanding, and this is a prime example of incongruity.

It is a broader sensitivity to reverence for life and animal welfare that underpins many vegetarians and this is hard to challenge. I am not raising the question of animal rights. It is often said that rights connote responsibility, and in any event no gazelle claims an 'animal rights' argument against a predatory lion with a family to feed, any more than a vegetarian will resist swatting a wasp that threatens their child. Cruelty and destruction underpin life in the real world, and we cannot envision a form of existence in which it does not. There are religious pamphlets showing – literally – the lamb lying down with the lion, and a web search reveals an extensive iconography of such idealized coexistence. This can work only if we condemn all carnivorous creatures to a painful death through starvation, followed by widespread destruction by famine of the catastrophically expanding populations of herbivores that would result.

Unrealistic prognostications of this sort have bedevilled persons of faith for centuries. The founder of scholasticism, and thus a pioneer of academia was Anselm of Canterbury who affirmed the nature of absolute truth in his tract of 1086 entitled *De Veritate*. For St Anselm, absolute truth is rooted in a belief in God as the ultimate foundation of all thoughts and realities. Whether or not any individual is persuaded of the role of God, the essential concept of an absolute truth can help us dismiss such naïve nonsense as a

world model entirely devoid of biological competition and cruelty.

Can we use this to sanitize our attitude to animals? Since animals so often inflict unspeakable cruelty on each other, in the natural course of events, it might seem perfectly sensible to accept human indifference to the welfare of animals. Part of the Cartesian philosophy was that, no matter how it may appear, animals are incapable of suffering. Descartes was a proponent of the view that all creatures are automata – mere machines that are unable to experience suffering or feel pain.[16] Current investigations lead me to a very different conclusion. All animals have their own sensitivities and their own forms of language and emotion; it is just that we have been unwilling to investigate them. They are sentient fellow-travelers, not emotionless subjects.[17]

Humans have a higher awareness. We cannot inflict cruelty insouciantly or without moral awareness of what we do, and it is for this reason that we can argue for the revelation of our human nature through our relationships with the non-human living world. Cruelty to animals can be interpreted as indicating potentially inhuman attitudes to other people. Societies still exist in which animals are treated indifferently, with little amelioration of their suffering. Western societies have embodied such attitudes for countless generations and some examples – the celebrated Spanish bullfight, for example – remain with us to the present day.

Trends in the Western world are moving away from these ancient orthodoxies. In Britain, dog-fights were popular diversions for centuries, and the Cruelty to Animals Act 1835 was the first legislation in the world to make them illegal. Dog-fights persist in many countries where they are no longer lawful, including India and Afghanistan – and even in Britain. Prosecutions for dog-fighting still take place in Britain, where fox-hunting and hare-coursing have

recently been outlawed. In other places (such as Russia, Japan, South Africa and Latin America) dog-fights are still openly staged and remain a popular form of entertainment.

The intensive rearing of pigs and poultry has become an integral part of Western agriculture, and it is a fact that the public turn their backs on the realities of animal rearing and the slaughtering process. People recoil in disgust when presented with the facts and figures on battery hens, yet often eagerly purchase the eggs from a supermarket. They may dislike any sight of animal slaughter, yet relish the idea of a steak, served rare, for dinner.

Cattle became elevated to a major art form when, in 1999, the city of Chicago introduced them as a type of urban sculpture. This was the famous Cow Parade, in which life-size fiberglass cows were decorated by noted artists.[18] Some were emblazoned with pastoral scenes, bizarre clothing, or covered with flags and flowers. Others indulged in trades or professions: there was a taxi cow, and even a cow surfing.

One of them was decorated in a lifelike manner by film-maker David Lynch to portray a cow in the process of being rendered for human food. Its head was missing, and a large gash had opened the animal from the backbone to show the viscera. This sculpture was entitled 'Eat My Fear'.[19] Within days of being added to the parade, this single sculpture had disappeared. Some spectators were so upset at the image of a cow depicted as being processed for food that it was removed from display. It was banished to a warehouse and covered with tarpaulins. Was this because of squeamishness on the part of the American authorities? Possibly so – though it must be true that most readers of these words, while relishing the prospect of a fine meat meal, would recoil from personally having to butcher a live animal.

The concepts of farm animals reared intensively, and battery-raised poultry so distorted that their legs break under the weight of their abnormally large bodies, are eminently justifiable reasons to turn away from eating the products of the farming enterprise that capitalizes on such procedures. Slaughter, and the bloody nature of the butchering process, may deter many other people from wishing to consume the meat that results. People who use humanitarian arguments to support adherence to a vegetarian or vegan ethic are acting entirely rationally. We may not follow their beliefs, but there is the essence of an 'absolute truth' in all this.

Considered thus, the prospects for cultured meat seem both timely and promising. Those who will not eat animal-derived foodstuffs for reasons purely of aesthetics may not concur, but vegetarians and vegans can have no objection in principle to consuming foods of this sort. The main underlying problem might be envisaged to be a tendency for traditional consumers to avoid anything based so soundly on the technology of cultured cell protein – but the experience with Quorn belies this line of objection. Quorn is based on highly refined technology and offers to the consumer a food that none of them can obtain in the natural course of events. It is entirely unnatural. The industrial culture of meat is a similar process, though in this case we are providing (admittedly in novel form) types of food that have been eaten as long as humans have existed.

One form of artificial foodstuffs that has been heartily rejected by Europeans, though espoused by American consumers, is genetically modified (GM) crops. Questions of public safety are given as the reason. There have already been doubts raised over the safety of Quorn[13], and I have pointed out that we do have a huge population of experimental subjects on whom these novel GM foods are already being mass-tested.[20] These are Americans, a diverse group of people who are known to be litigious; the moment

any adverse reaction appears, we can be sure of visible repercussions. None has arisen, just as we would expect.

The reaction in Europe against GM crops is all the more surprising since it was mostly in Europe that farm animals were first created. Although the techniques used to develop them were traditionally based on cross-breeding, most modern farm animals are already highly 'genetically modified' and have been selectively bred to produce desirable strains for at least 9,000 years.[21] Many of our domesticated animals are human-made species. Domestic pigs have more vertebrae than wild species, in order to maximize meat production, which was a remarkable innovation by our prehistoric ancestors.

The proponent of cultured meat thus faces a paradox. Reactions in Europe to GM crops suggest that there will be a wholesale rejection of anything so novel, even though most of our foods are already genetically modified, almost out of recognition. Yet, as we have seen, although Quorn is a profoundly artificial and human-made product, it has been warmly espoused by health-food fanatics – a fact which suggests that, for some meat substitutes, there is already an enthusiastic following. Cultured meat will need to be launched on the right wave, if it is safely to surf to a welcoming shore.

How would artificial meat be produced in culture? The first requirement is a food source for the growing cells, and cyanobacteria are a clear candidate. Cyanobacteria have a protein content in dry matter of 50-70% and can easily be grown in pond culture.[22] Other investigations have centered on the production of algal protein in photobioreactors.[23] We can assume that 50% of the cyanobacterial hydrolysate would be metabolized by the cultured cells, utilizing this as an energy source during growth, and further losses would be emitted as CO_2.[24]

The growth of animal cells in culture has now been studied for some years[25] and this poses no particular problem to the research scientist. Students of biology and nutritional science will have learnt that meat is muscle, and voluntary muscle is made up of striated muscle cells. Yet this is only part of the picture.[26] Striated muscle may be the main feature of the histology of meat, but pure cultures of striated muscle do not themselves make a steak. The meat we eat takes its appetizing taste, its desirability and its texture from the admixture of adipose cells and connective-tissue fibrocytes with the striated muscle fibers. The cooked fat confers most of the flavor, and this is what provides a crucial difference between muscle *cells* in culture, and cultured *meat*. There is also an argument that, to develop fully, cultured muscle tissues will need to be exercised, or stretched, as they grow.

Research is now showing some success. A pioneering patent published in the Netherlands in 1999 describes the production of cultured muscle cells in a three-dimensional structure, 'free of fat, tendon, bone and gristle'.[27] Healthy as this may seem (nobody wishes to find unexpected fragments of bone in a soft and succulent steak) it is an important fact that it is primarily the fat and connective tissue which convey to striated muscle its meaty texture and appetizing flavor. Many of the recent converts to healthy eating will already have experienced something similar. Rather than purchasing ready-made hamburgers, it has become popular to buy lean, red meat and make the burgers at home. Without the fat, they are not as appetizing. Lean meat makes a dry and hard burger; for a successful result the meat needs to be laced with fat (or 'well marbled' as the *cognoscenti* like to say). The promised fat-free pure culture of muscle fibers will not offer us beef-steak.

Striated muscle fibers are formed when maturing precursor cells fuse and lose their identity; thus, each fiber is

multinucleate and cannot itself proliferate. New muscle tissue arises only from the fusion of the precursor cells. The original Dutch process[27] envisages the production of a collagen matrix (the basis of connective tissue) with muscle cells that are artificially induced to divide. In 2001 a United States patent[28] set out an intention to produce cultured meat by growing colonies of muscle and adipose cells in an integrated manner that could imitate beef, chicken and fish products. That might yet prove to offer an answer.

In the following year, a paper for *Tissue Engineering* by Jason Matheny (who went on to found New Harvest)[4] and colleagues launched a discussion of the feasibility of laboratory-grown meat.[29] More recently, in 2008 the board of People for the Ethical Treatment of Animals (PETA) announced a $1m prize for the first company to release a food product that successfully brings cultured chicken meat to consumers in at least six states of the USA – by 2016.[30]

Governments are also becoming interested. In 2007 the Dutch government confirmed that they had invested €2m in cultured meat, with research taking place at the universities of Utrecht and Amsterdam; then in April 2008 the Food Research Institute of Norway set up a pioneering conference on cultured meat. In the United States of America there has been less evidence of support. The National New Biology Initiative announced by the National Academies of the USA in September 2009 promises much in fields such as genomics and applied GM technology, by bringing together physicists and engineers, computer scientists and chemists with the bioscience community. My personal belief is that we need a greater emphasis on whole cell biology, rather than more reductionism[31] and currently these American authorities do not propose to fund work on cultured meat.[32] Their new initiative clearly seeks to raise the international profile of American science, but is doing so by looking backwards (or sideways at best). It is to the far future that we

need to gaze, and the production of cultured meat is a clear candidate for high priority support.

What should we call it? The generally accepted term is *in vitro* meat, though *ex vivo* has attracted some currency and my personal preference of *cultured meat* is useful in that it is a term that is meaningful to a wider public. All new scientific procedures need abbreviations, of course. Already we have *Single Cell Protein* (SCP), *Meat Protein Production System* (MPPS) and now the first acronym: *In Vitro Meat Production System* (IMPS).[33] Whether this will suffice, I doubt; the acronym has connotations of gremlins at work. There must be better alternative acronyms. What about *Meat Under Novel Culture Hierarchy*? One could call the emerging discipline *Science-based Technological Edible Alternative Cell Kinetics*, though this gives us an acronym that is already in use. There is a serious need to find a convenient term for this novel concept. I find 'cultured meat' to be a perfectly satisfactory term, though a marketing executive might well propose something better than that. A generally accepted term is a prerequisite for widespread discussion about a focus for new research.

This is an urgent matter. World hunger is set to increase. The growing population now imposes such demands upon limited supplies of freshwater that there may not be enough water to continue with conventional agriculture. The great city of Sydney, Australia was covered with wind-blown sand and earth on the day that I wrote these words, as a harbinger of the fate of farmlands as average global temperatures increase and water is depleted. Beef farming is now often unprofitable, and a report in September 2009 speaks of the 'near collapse' of the entire beef production sector in Ireland.[34]

Since the factories producing cultured meat (like those manufacturing Quorn) could be in urban areas,

cultured meat will be produced closer to consumers with consequent huge savings in greenhouse-gas emissions (GHG). These novel products will have a lengthy shelf-life and will not be in need of refrigeration, with further savings of GHG, and there would be substantial reductions in watercourse pollution with nitrates, which is currently a pressing problem. We will see a slow-down in the further destruction of the rain-forests, and a lowering of methane emissions. Methane, as a greenhouse gas, is more than 20 times as dangerous to the environment as CO_2 and pure methane gas is belched out by ruminating cattle every minute of the day, a fact partly mitigated by the observation that atmospheric methane has a half-life of less than nine years.

There are potential health benefits of cultured meat. Fats, as a crucial component of steak, can easily be controlled both quantitatively and qualitatively. We could arrange for optimum levels of omega-3 and omega-6 oils in the products, for instance, and regulate their ratios. The widely-reported outbreaks of *E. coli* O157 H7 would be no more than a memory, and spoliation would be far easier to control.

Against the concept are claims about its artificiality, which are valid objections to raise. The widespread acceptance of products like bean curd and Quorn substantiate my view that the public are not likely, *en masse*, automatically to reject cultured meat products. Objections about quality, health hazards and safety are not sustainable, since these are all matters that can be regulated and product quality can now be reasonably assured. Although there are questions being raised over GM foods, currently there are few proposals involving genetic modification in the culturing of tissues from existing breeds of animal.

One of the most far-reaching objections, I believe, is the unspoken effect on the countryside. Britain, like much of

Europe, is characterized by a traditionally rural landscape in which the contour of the vegetation and the look of the land are due to farming over centuries. It is the populations of grazing cattle and sheep that are responsible for maintaining these classical and much-loved landscapes. And herein lies the paradox of the death and anti-death argument. The development of cultured meat would reduce, and even eliminate, the need for animal slaughter in food production. Yet consider: these creatures exist only because of the demand for their meat. If there is no demand, there will be no animal husbandry and many traditional breeds would disappear. Thus, a movement that is clearly anti-death would also, curiously, become anti-life. Death is the only inevitability – it is one of Anselm's 'absolute truths' – and we cannot determine that an anti-death stance has validity. Humans can only influence the nature and timing of death, not its inevitability, and farmers aim to bring into life only animals that serve a purpose. Without that impetus, we could lose a great swathe of farm livestock and with it much of our agricultural history.[35] The management of our landscapes would be revolutionized, and the ancient rural countryside could be severely compromised.

Although these are major issues that need sensible management policies, in my view we now have a pressing need for the new technology of cultured meat. It can produce a potentially healthier product, and at a lower financial and environmental cost. One line that I would advocate centers on stimulating stem cells to grow in actively differentiating communities that lead to the development of fully-formed and diverse tissues that, in a cohort, produce a naturally differentiated tissue. Harnessing biofabrication technology could allow us to assemble cell laminae into an appetizing and nutritious product. Biofabrication is a fast developing focus and even has a dedicated new journal.[36] If we could succeed in perfecting this technology, then GM gene-splicing could, in a future world, eventually permit us to

produce cultured forms of meat with the very best lipid spectrum that the consumer of the far future could desire.

Some pioneering progress has been made with three-dimensional tissue culture of muscle from the common goldfish *Carassius auratus* which has scored well with a taste panel.[37] Cell lines, like the creatures from which they originated, are mortal and will normally die out after a predetermined lifespan (the Hayflick limit). Yet occasional cell lines are known to be immortal. The familiar house-plant *Tradescantia zebrina* is reproduced vegetatively and does not exhibit senescence. Cultures of transformed HeLa cells, originally obtained from an American hospital patient named Henrietta Lacks who was suffering from cervical cancer, are widely used for tissue culture.[38] Mrs Lacks died on 4 October 1951 yet her cells exist in laboratories around the world, and take so well to culture that they are a frequent contaminant of other cell lines and have the longevity and virulence of a microbial culture. We know, then, that immortal cell types can emerge and it has been pointed out that a successful product can only be reliably produced either by (a) regularly replenishing the culture, (b) using an immortal cell line or (c) immortalizing an existing cell line.[39] Cells derived from an animal malignancy and amenable to culture would provide the best starting-point, as has been the case of the HeLa cell, though the aesthetic objections of the public would deter one from investigating the possibilities.

Embryonic animal stem cells are an obvious candidate, and progress has been made by culturing myoblasts on a scaffold of collagen. There have been experiments with adipose tissue-derived adult stem cells (ADSC), which are isolated from subcutaneous fat and can differentiate into cells including myoblasts, chondrocytes, adipocytes and even osteocytes.[40] Research is now even investigating ways of ‘exercising’ cultured muscle tissues, in imitation of what occurs in life, so that they become fibrous

and have a firmer texture in the mouth. But this approach may not be the most propitious way ahead.

The development of the existing meat substitutes has given us a good grounding in techniques that allow us at will to alter the texture of a proteinaceous product. The mass-production of cultured animal cells would allow the manufacturer to incorporate fibrous collagen, admixtures of striated muscle tissue and adipocytes (or fatty components derived from them) so that the meat product is made in the production plant through bioassembly, rather than growing like an explant. Full control over taste, texture, consistency and nutritive value could be assured.

There would be fewer technical problems than we might encounter with the sterile culture of complex tissues, and the technologies required are similar to those already in use. Bioassembly technology would allow us to produce meat substitutes from cultured components. 'Synthesized meat' would be the perfect product.

Has the time come? Will the public accept it? In a newspaper interview that was widely published around the world in 2005, I stated my belief that: "The widespread acceptance of meat substitutes such as Quorn, a cultured fungus, shows that the time for cultured tissue is near."[41] We are developing the technology to do it. We have the support of some European governments and many brilliant young investigators. With the concerted energies of research biologists we can crack this nut and savour what lies within.

The world will breathe easier when we succeed.

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