ISSN 2372-6504

FOOD PHREAKING

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What is In Vitro Meat?

Preface

Food Phreaking is a publication of experiments, exploits and explorations of the human food system. It aims to connect foodies who care about sustainability with the scientists and hackers who care about open culture. Food Phreaking is where food, technology, and open culture meet.

We are very excited about this issue, as it gathers the ideas and opinions of a number of scientists and other experts around the topic of in vitro meat. The authors in this publication range from being in vitro meat's developers and most vocal supporters, to some adamant opposers. Collectively, these essays present a diversity of perspectives, and illustrate the challenge of pinning down an emerging technology.

Introduction

So, what is in vitro meat? The basic idea is to encourage muscle cells to grow into a foodstuff and produce meat in a way totally unlike how it is done on farms. Although not currently possible, some scientists are researching how to create a cultured meat that can be produced in factories, expanding small quantities of muscle tissue into much bigger amounts.

But the question 'what is in vitro meat' is so much broader than that. *What could in vitro meat be? How could it be made? How could it fit into our daily lives?* In this publication, a range of experts offer their answer to the question: What is in vitro meat? Some of them are biologists who have been working to make in vitro meat, others are social scientists analysing how it might fit into society. We also have the executive director of the leading in vitro meat support charity (New Harvest), and an artist working with food and science. Some of our authors are strong supporters of the technology, others are very critical, while the rest fall somewhere in between.

Some of our contributors are working on in vitro meat because of a project called EPINET: an EU-funded research project that integrates different ways of assessing the good and the bad of new technologies. In vitro meat was used as a case study, and in 2013 EPINET hosted a meeting in Utrecht bringing together a wide range of experts to discuss in vitro meat. Most of the essays in this publication are written by people who attended.

Today, in vitro meat (also called cultured meat: more on that later) remains an early stage technology. A relatively small number of laboratories around the world work on producing small quantities of food, barely enough to fill a petri dish. The task of perfecting the techniques and then upscaling the process is yet to be achieved. The most famous example to date is the cultured burger made by Mark Post's lab in 2013, designed as a prototype or proof of concept. Post also kicks off this collection of essays on page 10, where he writes about the barriers to scaling up the process. Although in vitro meat is not currently a commercial reality, we believe we need a wide ranging debate about it from the outset, and we see this book as a step towards that. Enjoy!

Timeline

1927
"The Future of Biology" in *Possible Worlds and Other Essays* by JBS Haldane
"We can now kill an animal and produce a fluid from inorganic constituents that will keep its heart or liver alive for a day or more... We could cut our beefsteak from a tissue culture of muscle with no nervous system to make it waste food in doing work, and a supply of hormones to make it grow as fast as that of an embryo calf."

1931
"Fifty Years Hence" by Winston Churchill
"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."

1952
The Space Merchants
This novel written by Frederick Pohl and Cyril Kornbluth depicts a dystopian future where the protagonist falls from success and leads a harsh subsistence life farming "vat-grown meat".

JULY 1, 1971
Russell Ross Publishes "Growth of Smooth Muscle in Culture and Formation of Elastic Fibers"
This paper describes growing a smooth muscle from immature guinea pig aorta with tissue culture.

1996
Tissue Culture & Art Project
The first time tissue culture is grown with the intention of eating it. Artists Oron Catts and Ionat Zurr set up a lab in a gallery and create the first tissue cultured 'steak' using frog cells. The artists title it 'disembodied cuisine' and it is served to an audience.

1997
Growing Fish & Meat for NASA
Bioengineer Dr Morris Benjaminson researches growing fish muscle as space food for NASA.

1998
Patent Filed: "Method for Producing Tissue Engineered Meat for Consumption"
John F. Vein files and later secures a patent (US 6,835,390 B1) in which he proposes a process of producing meat products by culturing muscle cells, fat cells and/or cartilage cells together.

1999
Patent Filed: "Industrial Scale Production of Meat From In Vitro Cell Cultures"
Dermatologist Wiete Westerhof from the University of Amsterdam, medical doctor Willem van Eelen, and businessman Willem van Kooten file for a world-wide patent on a process to produce in vitro meat.

JULY 23, 2004
New Harvest is Founded as a Charity
This organisation is the most active and vocal promoter of the development of in vitro meat technologies. They are instrumental in framing in vitro meat as a sustainable alternative to current meat production.

MAY 1, 2005
The Dutch In Vitro Meat Project Begins
The Dutch government funds a research project for the development of in vitro meat, subdivided into 3 areas: scientists in Amsterdam study the culture medium, scientists at the University of Utrecht study the proliferation of muscle cells, and scientists at the Eindhoven University of Technology study the development of bioreactors.

JULY 1, 2007

The In Vitro Meat Consortium is Established

"An international alliance of environmentally concerned scientists striving to facilitate the establishment of a large-scale process industry for the production of muscle tissue for human consumption through concerted R&D efforts and attraction of funding to fuel these efforts."

2008

PETA Announces $1 Million Prize for the First In Vitro Meat Chicken Nugget

People for the Ethical Treatment of Animals (PETA) announce they will award the prize to the first laboratory to use chicken cells to create commercially viable "test tube meat".

APRIL 2008

The First International In Vitro Meat Symposium

The symposium was held in Ås, Norway, hosted by the Norwegian University of Life Sciences (UMB) and the Norwegian Food Research Institute (Matforsk).

JUNE 10, 2009

Vladimir Mironov Introduces the Field of Biofabrication

Biofabrication can be defined as the production of complex living and non-living biological products from raw materials such as living cells, molecules, extracellular matrices, and biomaterials.

2011

Mark Post Receives Funding for In Vitro Meat Burger

Mark Post announces that he has secured funding from an anonymous donor to make an in vitro burger.

2011

Modern Meadow is Founded

The first commercial venture focussed on developing in vitro meat and in vitro leather was founded in Fall 2011 based on technology developed at the University of Missouri in Columbia, MO.

JANUARY 15, 2013

New Harvest Hires its First Full-Time Employee

The charity New Harvest gained enough financial support to hire a full-time employee. Isha Datar is appointed as its director.

AUGUST 5, 2013

In Vitro Hamburger Tasting Press Conference

Google co-founder Sergey Brin is revealed as the anonymous funder of Mark Post's research, and they stage a press conference where an in vitro hamburger is presented and tasted.

JUNE 18, 2014

Modern Meadow Receives $10 Million

Modern Meadow raises $10 million from Horizons Ventures in order to 3D print meat and leather products.

JANUARY–DECEMBER, 2015

Israeli In Vitro Meat Chicken Project

The Modern Agriculture Foundation funds a one year study to be conducted from Tel Aviv University. The research will focus on the feasibility of cultured chicken meat production.

OCTOBER 18-20, 2015

International Symposium on Cultured Meat

"We strive to create an inspiring but also critical atmosphere discussing tissue engineering for food, in particular cultured meat."

In vitro meat is...

In vitro meat is...

In vitro meat is
an emerging technology

Professor Mark Post heads the laboratory in Maastricht that produced the world's first beef burger grown from cells in a laboratory in 2013. This was a significant milestone for the field and received worldwide media attention. He is currently studying and developing in vitro meat to improve quality and functionality, in order to make it into a consumer product. In this section, Mark highlights the link between stem cell science used in medicine and in food. He shows how producing minced meat is a different challenge to producing a steak. He identifies four key challenges to in vitro meat production and the type of team needed to address them.

In vitro meat (IVM) is medical stem cell and tissue engineering technology to produce consumable meat in a potentially, yet to be proven, resource efficient way. Meat is a mixture of skeletal muscle, fat tissue and supportive tissues such as connective tissue. Stem cells of each of these tissues can be harvested from animals and multiplied to such an extent that a small sample can be multiplied into industrial quantities of meat, thus vastly reducing the number of animals that need to be raised, fed and slaughtered to satisfy consumer demand.

By starving the stem cells they differentiate, maturing into skeletal muscle cells that then merge into primitive fibers. When placed into a specified gel around a central column, the primitive muscle fibers self-assemble and self-anchor into a multicellular muscle fiber that allows gradual and spontaneous development of tension through muscle contraction. Although very elegant, this method limits the attainable size of muscle fibers to that of ground meat. To produce a full thickness piece of meat more advanced and technically much more complex methods are needed. These methods are being developed for medical purposes, but are not yet sufficiently robust.

For ground beef, feasibility was shown as a proof of concept hamburger, but clearly, the product as well as its production process needs to improve before

delivering on the promise of environmental, food security and ethical benefits.

Four categories of boundary conditions have been defined for the success of IVM:

First, the production process needs to be resource efficient, so that less nutrients, or feedstock in general, is required to produce 1kg of meat than with livestock production. This is easier to achieve for beef than for other meats, simply because cattle are very inefficient in converting vegetable proteins into edible animal proteins. When resource efficiency can be improved, cost-effectiveness can be achieved as well, as more than 80% of the manufacturing costs were modeled to materials, i.e. feed. Although there is great potential, it is currently unknown if this efficiency can be realized.

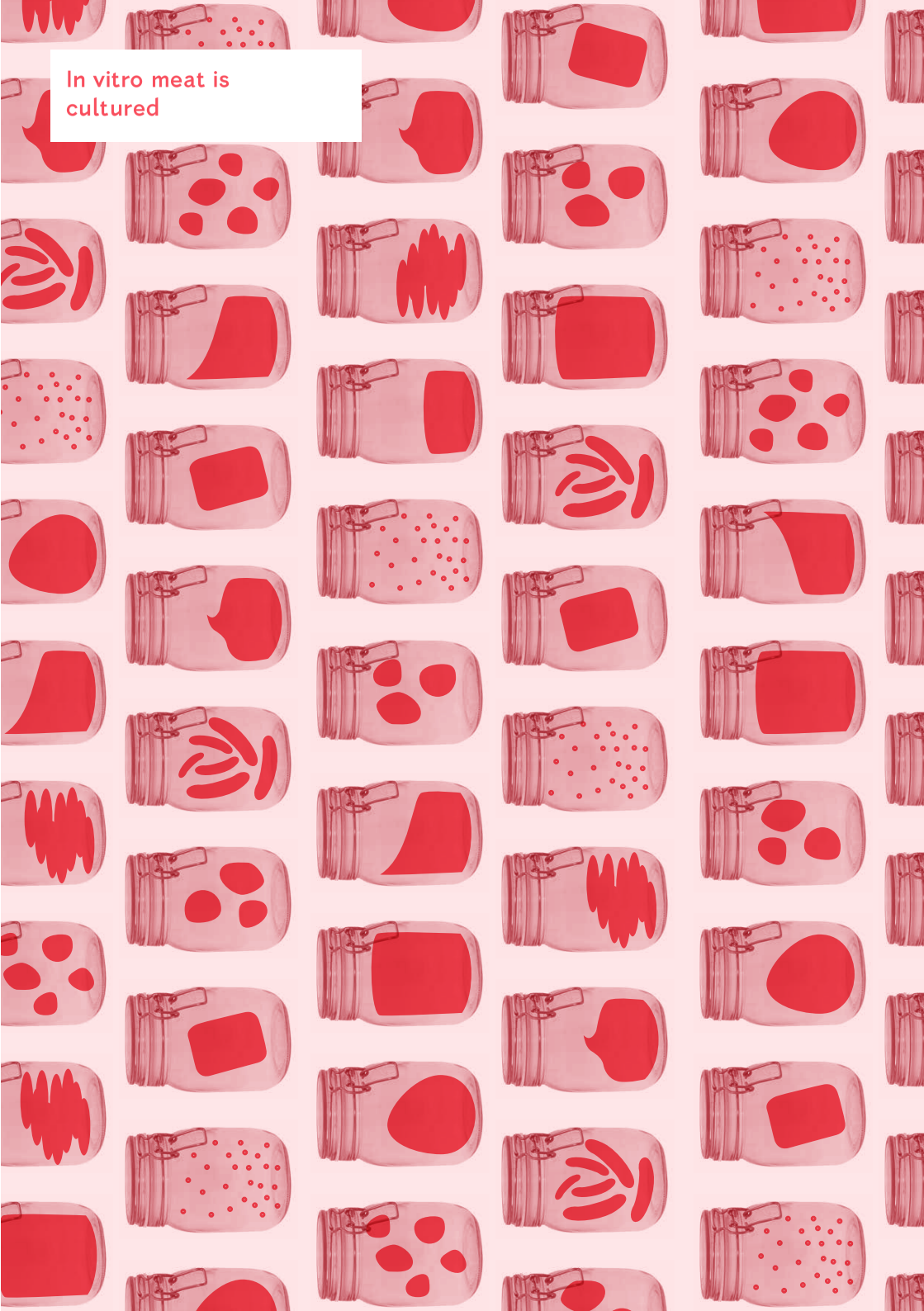
Second, the production process has to be sustainable sensu stricto, specifically by eliminating animal-derived materials such as serum and collagen hydrogel that would inevitably become limiting factors. There are good reasons to believe that IVM can be produced entirely without the use of animal derived products, other than the stem cells.

Third, cultured meat needs to be a much better mimic than vegetable protein substitutes in order to compete with livestock meat, in terms of all sensory qualities, but most importantly texture (mouth feel), taste and visual resemblance. The first hamburger came reasonably close in terms of texture, but lacked for instance fat tissue. Like muscle, fat tissue can be tissue engineered as well and is indeed being pursued for this purpose.

Finally, IVM needs to take over a substantial portion of the meat market in order to impact food security, the environment and animal welfare. Scaled and commercialised production, regulatory safety approval, distribution and marketing all need to be aligned to enable the success of IVM as a consumer product.

Given the nature and extent of these conditions, only a truly multidisciplinary team of biotechnologists, process technologists, psychologists, philosophers, MBAs, designers and retailers can establish the integrated knowledge and skills to produce a product that realistically replaces the long-lasting, highly cherished, staple food that meat is.

In vitro meat is cultured



Isha Datar is Executive Director of New Harvest, a charity dedicated to advancing research and development of animal products made without animals, working with industry and academia to support this goal. For over a decade, New Harvest has been the leading group supporting and promoting in vitro meat production, and now also focuses on other technologies like plant based proteins and cell cultured milk. In this section, Isha explains her preference for the term cultured meat over in vitro meat, and who she imagines could be the cultured meat eaters of tomorrow.

The community of in vitro meat proponents don't call it in vitro meat. We call it cultured meat.

In the scientific sense, cultured meat is a more accurate term. This meat will always be produced in cell culture in controlled conditions, not necessarily in glass, as in vitro implies. In vitro also generally refers to exploratory studies and experiments that take place in the laboratory; once cultured meat reaches marketability, its production will take place in dedicated equipment and facilities beyond laboratory scale. Cultured meat is also the term used most often in the literature by laboratory researchers focused on its development. While other terms could be suitable– ex vivo meat, for example–there are other reasons why "cultured" is a fitting word.

"Cultured" is a term we're familiar with in the food context. Civilization has been culturing foods for centuries through fermentation with a variety of living cultures: bacterial cultures, as used in yogurt, sour cream, cheeses and pickled vegetables; yeast cultures, as used in beer, bread and wine; bacterial and yeast co-cultures as used in kefir, kombucha, ginger beer and sourdough; and fungal cultures as used in cheeses, tempeh, miso, and soy sauce. These living organisms transform foods to have longer shelf lives, new flavour landscapes, and novel textures.

Cultured meat is a step further than fermentation in two ways. The first is that the culture is of mammalian

cells–a cell type which has not been applied to food before, independent of a whole animal. The second is that this type of culture is not transforming a food substrate like in fermentation. Instead, the culture itself becomes the food. Cultured meat pushes the definition of a cultured food but can also be seen as a logical next step in the application of cell biology to food. Whether it is a revolution or an evolution of cultured foods, cultured meat is certainly worth exploring, especially as it promises to benefit society and the environment.

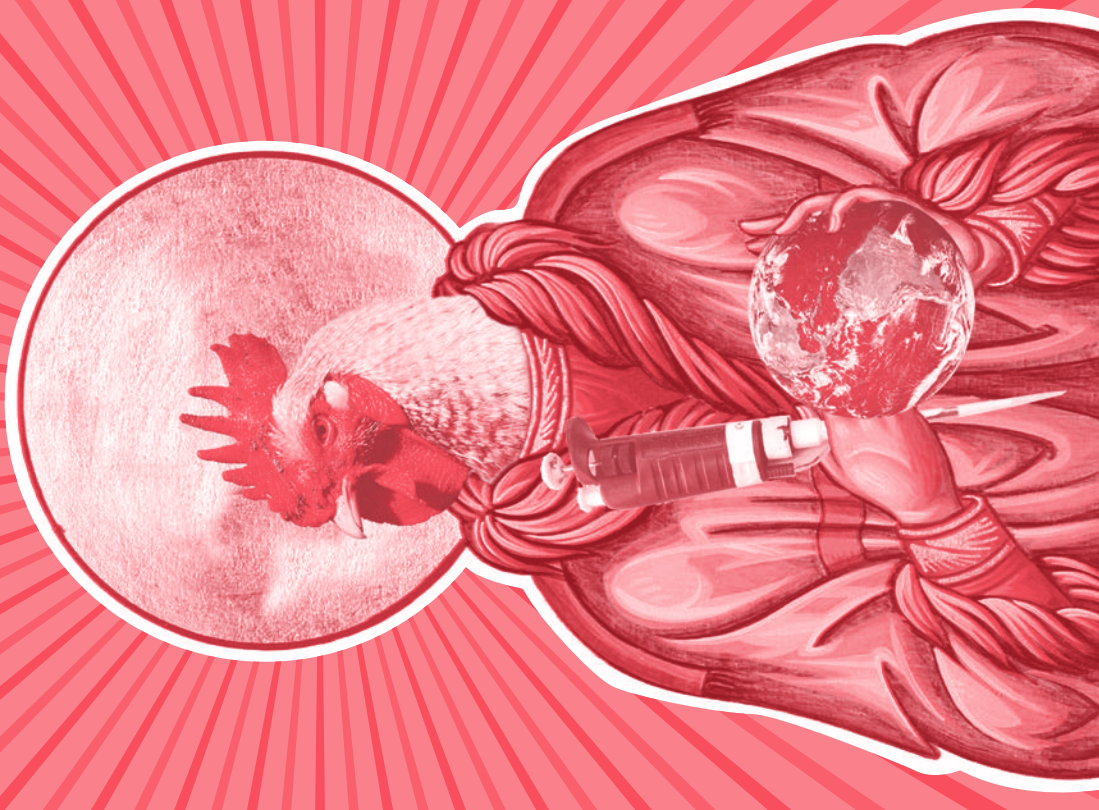
In the non-scientific sense of the word, this meat is "cultured" because it is environmentally considerate, sanitary, healthy, and humane. Many would argue that cultured meat would be the only ethical meat. By convenient coincidence, "cultured" implies that this meat and the people who consume it are enlightened, civilized, and of discerning tastes.

This definition of the word "cultured" is also used to describe diamonds which share several similarities with cultured meat. Cultured diamonds are made by creating a controlled environment that emulates and optimizes the diamond-forming conditions found in the earth's crust. They are molecularly identical to mined diamonds and differ only in how they were created. Cultured diamonds do not contribute to conflict in unstable nations and they do not drastically alter landscapes like diamond mines, even ethical ones, do. These socially-conscious and environmentally-friendly diamonds also happen to be more affordable.

Analogous to cultured diamond production, cultured meat is made by creating a controlled environment that resembles the in vivo conditions inside a farmed animal. The meat is identical to farmed-animal meat on the plate and under the microscope–only differing in how it was created. In avoiding unsanitary, resource intensive and polluting animal farming, this meat will be more safe, sustainable and affordable than the current status quo.

Of course, affordability won't be achieved immediately, but this only contributes to the second definition of "cultured". As cultured meat enters society, through a series of iterations of declining cost per gram, those to first sample food's newest cell culture will be sustainability-focused, ethically-minded, forward-thinking food lovers. They will be cultured meat eaters.

In vitro meat is
a promise



Dr Neil Stephens is a sociologist who has been studying the social shaping of in vitro meat, tracking the field since 2009. He has been interviewing and observing key people involved and attending key meetings, exploring the motivations and challenges of the field. In this section Neil describes some of the benefits that in vitro meat promises to deliver, and shows the relationship between what in vitro meat is said to do and what it is said to be.

Exploring the promises of what in vitro meat (IVM) can do is an interesting business. Some of the earliest laboratory experiments were conducted around the millennium by a NASA funded group who were interested in producing a meat source that could be carried, grown, and eaten during long term space travel. Interstellar food was their single driving ambition. Today, however, not one of the leading laboratories lists space exploration in their vision for IVM.

Instead, the most widely circulated promises for what IVM can do include addressing environmental issues like climate change, improving animal welfare, making healthier meat, and making money. I want to show that each of these promises contains a particular vision for what IVM is. My interest is not in being pro or anti IVM, instead I want to write a history of the present, recording what happens in a sociologically interesting way. A study of promise is one of the ways I do this.

Different people, and different interest groups, give different accounts of how IVM should be understood. The ways people understand what IVM is can be related to what they believe (or don't believe) IVM can do. These accounts of what IVM can do are almost always based upon what IVM could do in the future, once a set of social and technical barriers faced today are overcome. That's why it is a promise – because it cannot be done at the moment. Of course, overcoming these barriers is also part of the promise.

So, what are the options for what IVM could be? Potentially there are as many options as there are people to think about it. Some more salient examples to get us started include 'meat', 'a meat-like alternative', 'meat that is better than traditional meat', or 'not food at all'. Beyond these broad categories there is more subtle definitional work going on as people try to position IVM as a particular type of thing that does particular types of things.

Let's start with the promise of addressing environmental issues, as this is the most visible argument for IVM made today, as highlighted in the now famous cooking and consumption of the cultured beef burger made in Mark Post's Maastricht laboratory. The vision is that the lower land, energy and water usage, combined with lower greenhouse gas emissions, make IVM more sustainable than traditional meat. However, Mark Post is clear in his account, for him IVM is meat. It is the same thing as meat today, only more sustainable. He argues that if it is not meat, if it is a meat alternative, it will fail in its task of addressing environmental issues because it then falls into the same category as tofu, or textured vegetable protein, or any of the other existing meat alternatives that great numbers of people do not eat. For Post, to address environmental issues IVM must be meat, because meat alternatives exist now, but not enough people eat them. Impacting the environment means impacting the daily diets of a great number of people.

Another prominent promise today is improved animal welfare. This is based on the 'meat without murder', or the 'meat with much less murder' argument. Again, the meatness here is clear, as we already have tofu without murder. The issue then becomes the wellbeing of the animals from which the original cells are taken, and the wellbeing of other animals whose tissues are used in IVM production. The question becomes whether this is meat for vegetarians and vegans, suggesting ethically equal to current meat-free diets, or whether this is meat for meat eaters, suggesting ethically better than current meat-based diets. In this instance defining what IVM is also involves defining who it does animal welfare for.

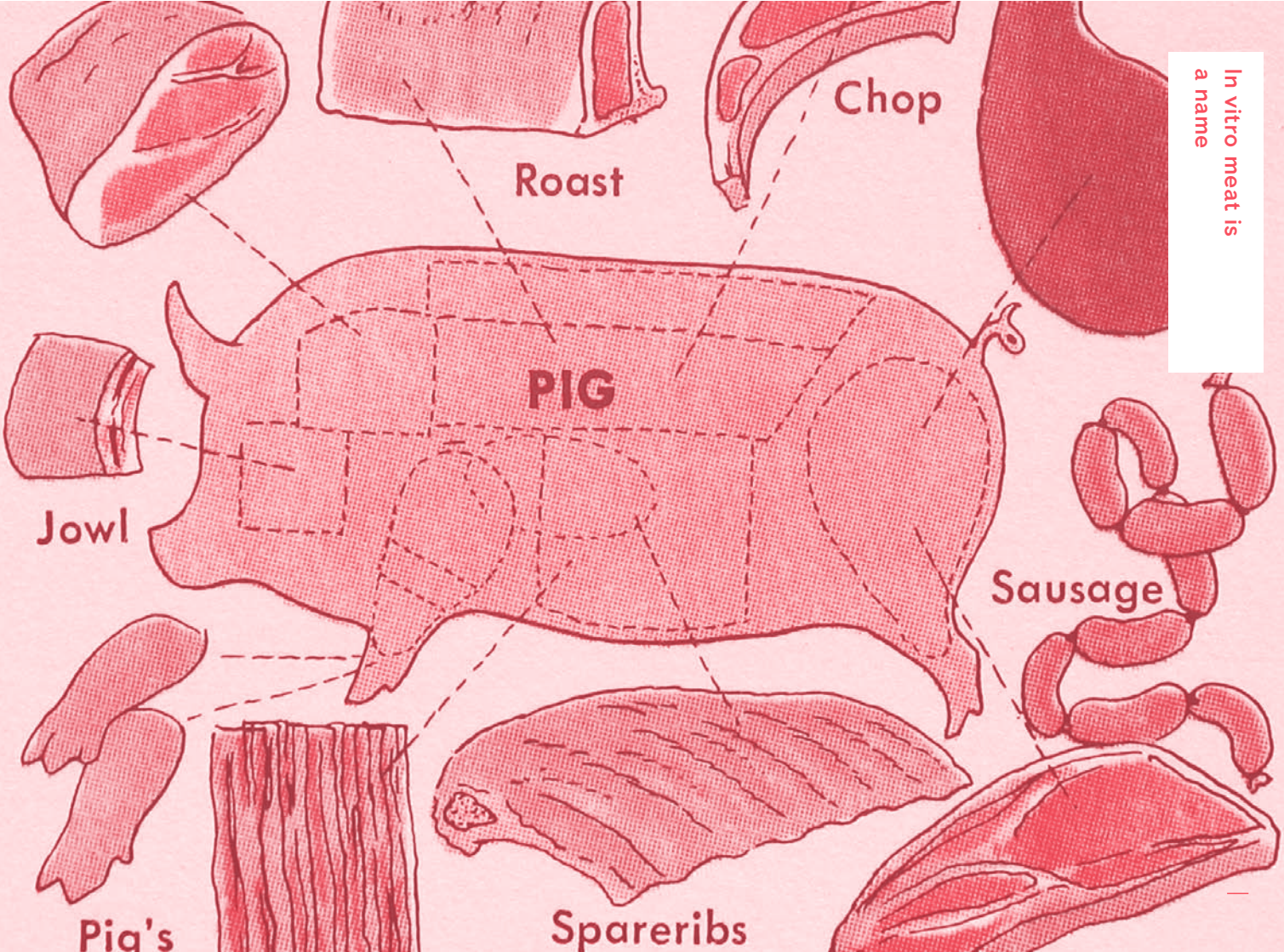
The health argument positions IVM as meat like we have today, but better. It is meat free from animal borne disease and antibiotic build up. It could also be meat that has added nutritional or taste benefits engineered in. It is a promise of making something better than what we have. So, again, the promise asserts a vision for what IVM is, based on what it can do. It is healthier meat, it is meat+.

To deliver on the promise of making money, IVM needs to be marketable. The assertion is that it is

a product, so doing equals selling. Of course, to sell as food it needs to be recognised as food, and since the market for meat is much bigger than the market for meat alternatives, the pressure here is to make it meat: either meat that is cheaper to produce, or meat that is more attractive to consumers (and perhaps bringing with it a higher price point).

Of course, my account here reflects the work I have done, interviewing people who support IVM. Others produce a counter argument: that IVM is unnatural, unpalatable, unwanted. From this perspective it can be easier to say IVM is not food at all.

Like many new technologies, different people have different opinions. The point I am keen to make is that when people make promises for what IVM can do they also assert what it is. Whether these promises can be delivered upon, and what IVM will generally understood to be in the future, remains an open question. I for one look forward to seeing what happens next.


Roast
Chop
PIG
Jowl
Sausage
Pig's
Spareribs

Cathrine Kramer is an artist, curator, and co-founder of the Center for Genomic Gastronomy. Among other things, she creates artworks and events about the future of protein and meat consumption. With Oron Catts, the Center for Genomic Gastronomy has produced ArtMeatFlesh: a public cooking show where artists and scientists face-off in the kitchen, confronting lab grown meat, future food cults, and a secret ingredient. Here Cathrine discusses some of the terms that have been used to describe in vitro meat, specifically questioning what it means for meat to be cultured.

The practice of culturing muscle tissue in a laboratory environment for human consumption has had many names over the years—from synthetic meat to in vitro meat (IVM), cultured meat and test-tube meat—with each name evoking a very different image of the concept it seeks to represent. Names can play a very important role in the support, public acceptance and the development of new technologies and concepts. The public might expect the naming of scientific phenomena to be precise, neutral and dispassionate, but that is not the way naming happens. New language is often tied up in old metaphors and driven by partisan beliefs.

'Cultured meat' is the preferred term of the nonprofit New Harvest, one of the most vocal promoters of the technology. New Harvest has been instrumental in shaping the way the media reports on 'cultured meat', creating sophisticated online promotional videos, soliciting and advising press, and creating a support network for advocates of the concept. Their voice is the loudest and most persistent, and for that reason, if we are still talking about IVM at all in five years time, it may be 'cultured meat' we are discussing.

The term 'cultured meat' comes from the term 'tissue culture', which is the growth of tissues or cells in vitro. In vitro means 'in glass' in Latin, and refers to the site where cells are grown outside of their biological context. However, despite scientists acknowledging the differences between these terms, the term

‘cultured’ has been very cleverly applied, possibly to garner public support or to make it more accessible. It is at the same time meaningful and meaningless. One could argue that all meat derived from farm animals is cultured, in that human culture has intentionally and heritably altered them through domestication and selective breeding.

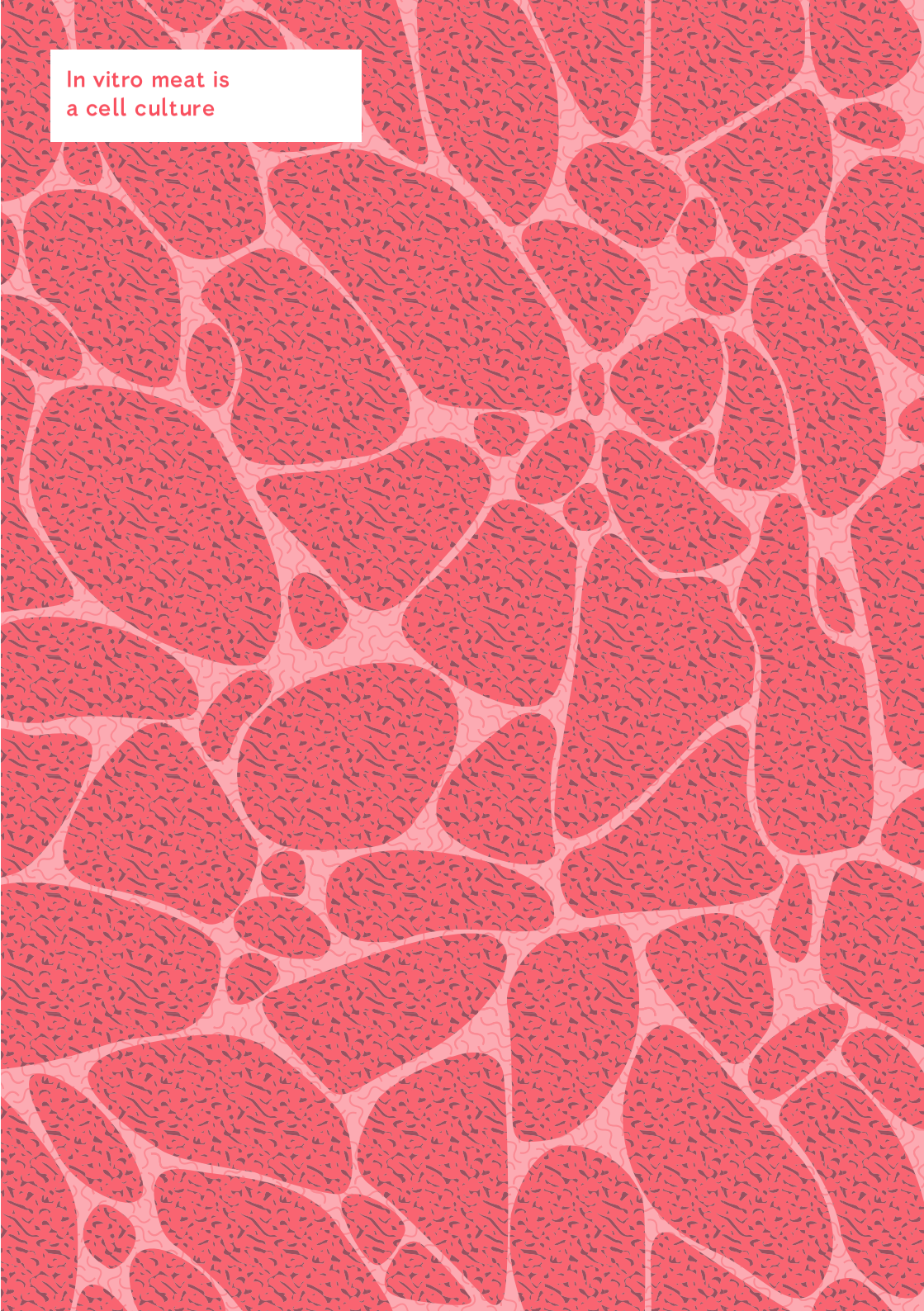
The term ‘cultured’ can mean different things to different people, including evoking sophistication and tradition. A promotional video on the New Harvest website cleverly uses this dual meaning of the term cultured to help soften the mental image that is produced when thinking about muscle tissue grown in a lab.

The term in vitro has different poetic baggage, and in its precision it is potentially less valuable for propaganda or marketing. It comes from Latin, which one could argue makes it less accessible to the general public. It doesn’t evoke the same negative connotations as ‘test-tube meat’ might, and it has been the most widely used term within academic writings about the concept. However, debating the difference between ‘cultured’ and ‘in vitro’ is essentially discussing the use of a prefix, when it is the use of the word ‘meat’ that we should really be interrogating.

How should we define meat? What are the boundaries that the definition of meat sits within? The flesh of an animal? Are muscle tissue and fat cells grown separately and processed together really meat? When the concept of culturing ‘meat’ in vitro is discussed, the meat is talked about as a homogenous thing. When people say they love meat and can’t give it up, are they talking about a steak cooked medium rare so the blood runs out when you cut it? Or is it anonymous pieces of chicken floating in a green curry? Or is it the hodgepodge of processed animal products blended together to make cheap sausages? Perhaps if more specificity was used when addressing issues of meat production and consumption, and people’s desires and tastes, more specific solutions could be devised to address those issues. Taste matters. IVM will never produce a steak. If the practice becomes more widely adopted and technically successful, it will produce a range of processed meat products with manufactured texture and flavour.

The more productive discussion is not about cultured meat, but rather, it is about food culture. E.B. Tylor, a founder of cultural anthropology, proposed that culture is “that complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by man as a member of society.” Culture is constantly evolving and adapting to environmental and societal shifts. Perhaps instead of re-designing our meat, it is time to re-define the meaning of meat consumption.

In vitro meat is
a cell culture



Dr Bernard Roelen and the team he works with specialise in understanding how cells grow (through cell division). They have a focus on cells from farm animals, and cells from embryos. They are one of the few groups in the world who have done some laboratory work aimed at growing meat. Here Bernard tells us more about the biology of cell growth, as he discusses in vitro meat as a cell culture.

All organs and tissues, including the muscle tissue of farm animal species that are consumed as meat, is composed of structural units called cells. Cells have the capacity to multiply by division and at each cell division the blueprint of the animal stored as DNA is being carbon copied so that the information is not lost. Cell division and DNA replication is a complex process and most cells can only divide a handful of times.

In our bodies the cells receive nutrients and oxygen from the blood via an intricate vascular system. Scientists have been trying to culture cells outside the body in dishes (in vitro, literally in glass), and indeed succeeded in doing so decades ago. However, because of the absence of a circulating blood system in a dish, in vitro culture of cells is only possible when cells are cultured as a very thin single cell layer. The nutrients and oxygen needed for the cells to stay alive are provided by a liquid culture medium and reaches the cells via what we call diffusion. When the cell layer becomes too thick, diffusion is insufficient and the cells die. The liquid medium we use is relatively simple and mostly contains water, salts, amino acids and sugars. Importantly the cells and the medium need to be kept sterile, since bacteria and fungi also thrive well in the medium and we want to avoid that.

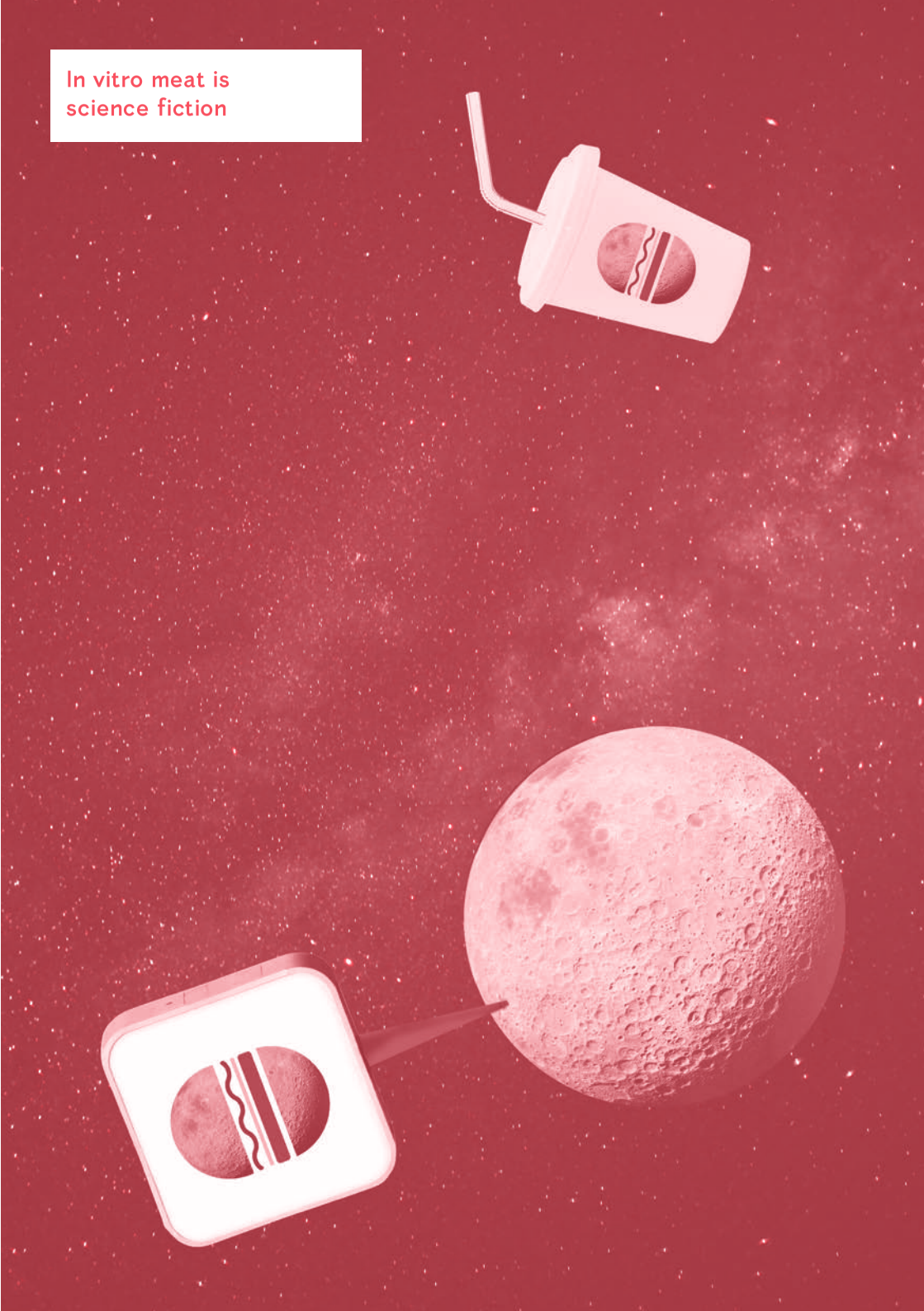
Most specialized cells do not have the capacity to divide. However, there are some cells that have

retained or regained this capacity to self-renew, and divide. These cells are called stem cells. Stem cells also have the capacity to differentiate to a specialized cell type. In general we can distinguish two types of stem cells: 1) embryonic stem cells, derived from early embryos and that can form all the specialized cells of the adult animal and 2) adult stem cells, that reside in many organs and tissue and that can only form a limited number of specialized cell types. For example, stem cells that reside in skeletal muscle can form skeletal muscle cells but cannot form nerve cells.

In vitro meat (IVM) relies heavily on in vitro cell culture. This involves generating skeletal muscle tissue from farm animal species cultured outside of the body. The idea is that stem cells are cultured first while they remain in their stem cell state and thus divide many times. A cell divides every 24 hours or so, meaning that if you start with 100 cells, after 14 days these have divided to over 1,600,000 cells. Starting with just a few cells, the technique could produce billions and billions of cells within several weeks. When enough cells are produced, a portion of the cells will be instructed, by using a different culture medium, to differentiate to skeletal muscle cells. These skeletal muscle cells can then be processed to an edible meat product: in vitro meat.

Therefore, IVM is a cell culture. This may sound 'unnatural', but in our current society, the production of many food items (e.g. beer and bread) is already industrialized. These items are produced in factories using processes very similar to those needed for IVM.

In vitro meat is science fiction



Professor Louis Lemkow is a social scientist studying, among other things, how in vitro meat is portrayed in science fiction. In this essay he notes that in vitro meat has been portrayed in science fiction in a wide range of ways, both positive and negative, before focusing upon one specific example: the dystopian vision of in vitro meat during the environmental and capitalist disaster found in Pohl and Kornbluth's 1952 novel 'The Space Merchants'.

In Vitro Meat (IVM) is as much part of the science fiction universe as spaceflight, extraterrestrial life, robots and artificial intelligence. Science fiction is replete with synthetic meat. In scenarios of the far future, IVM is grown in the laboratory-factories of mammoth sized starships, providing protein for human colonists that traverse light years to conquer new worlds. In the not so distant future, outposts on the Moon or Mars sustain their inhabitants through hydroponic farms and lab meat (as IVM is sometimes referred to in science fiction). Closer to home, in the dystopian imaginary of Earth's dismal future, we find foul tasting and poorly textured IVM providing a last-ditch solution to gross overpopulation, natural resource depletion and animal protein shortages, temporarily saving us from world hunger and malnutrition.

More optimistic narratives project IVM as a cheap solution to human protein requirements in a crowded world, where fortunately, technological fixes arise for every societal challenge. Today, hype often surrounds IVM; supporters of this technology insist that it is a key to our future wellbeing, and media outlets like the Guardian newspaper report that it is no longer a futuristic fantasy: "Is science fiction on the verge of becoming fact?...Two scientists on opposite sides of the world both claim to be on the verge of serving up the first lab-grown hamburger–and saving the planet

in the process. The new reality is so close, you can almost taste it."

This short text does not provide a comprehensive survey of IVM in science fiction, but instead focusses on a classic novel: *The Space Merchants* by Pohl and Kornbluth, published in 1952. This satirical dystopian book provides a critique of global capitalism, which nurtures and feeds on compliant consumers, manipulated by ruthless mega-corporations that know no bounds when achieving their objectives: accelerated consumption, growth, and above all, profits. One such company is even capable of enthusing consumers to sign up for colonising the utterly inhospitable planet Venus. This absurd project requires massive public funding, is detrimental to human collective interests, and would result in the depletion of resources, to the advantage of unscrupulous profiteering.

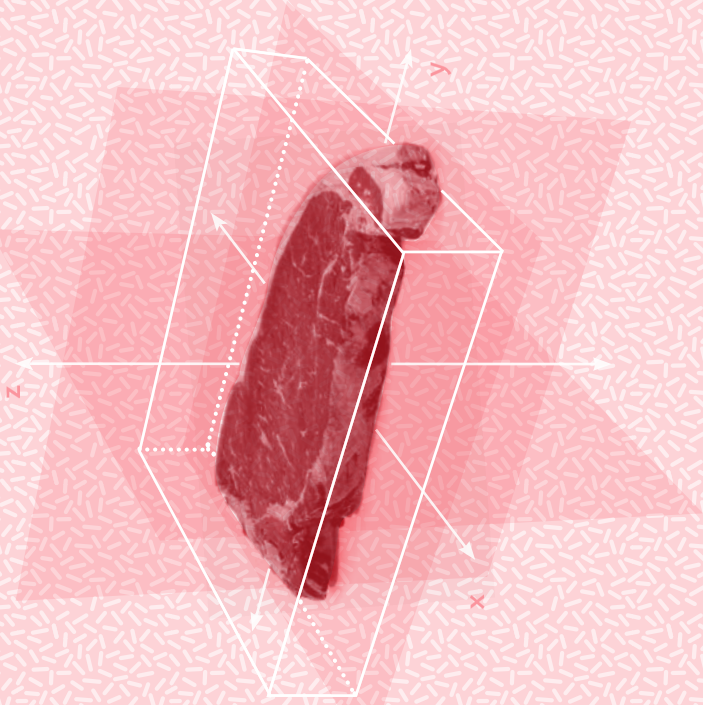
Its Corporate leader, Fowler Schocken, proudly announces the wonders of billing "megabucks" through Venus, and the good life he and his colleagues can lead as a result of such initiatives, boasting that he hadn't "tasted any protein but new (real) meat for years". One of the most lucrative activities of Schocken Associates is the marketing of factory grown IVM "cutlets" known by its commercial name as Chicken Little. This product was developed for and consumed by the masses. "Chicken Little grew and grew, as she had been for decades...she had started as a lump of heart tissue... As long as she got nutrient she grew."

Another profitable meat substitute that Schocken designed and marketed for mass consumption was called "soyaburgers" (the authors are the inventors of this term, as well as "R&D"). Not everyone is happy about this, especially the World Conservationist Association (WCA), contemptuously known as "comsies" by the ruling corporate elite who regarded them as "wild-eyed zealots who pretended modern civilization was in some way 'plundering' the planet. Preposterous stuff, Science is always a step ahead of the failure of natural resources".

I will not divulge plot outcomes, so there are no spoilers for those who wish to read this highly recommended novel. *The Space Merchants* was ahead of its time with regards to its critique of global capitalism, related environmental degradation and the marketing of IVM, but very much of its time with regards to gender stereotyping.

IVM is present in many science fiction scenarios; utopian, dystopian, catastrophic, futuristic, techno optimist and planet saving. This is one thing that the literary and film genre can provide; a multiplicity of narratives and possible outcomes related to the complex relationship between science and society, and in the case of IVM in *The Space Merchants*, generating much food for thought.

In vitro meat is
a techno fantasy



Mario Giampietro works on integrated assessment of issues to do with sustainability, meaning he combines social, economic, physical and biological variables in his analysis of new technologies (he calls this "Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism"). In this section he criticises the arguments used to support in vitro meat, with a focus on animal welfare, arguing that the issues are oversimplified and in vitro meat offers a misplaced technical fix to a complex problem.

Humans have been co-evolving with other species, and eating a few of them, for hundreds of thousands of years. Therefore, the idea that killing animals for eating them is unsustainable, unnatural or ethically wrong is difficult to understand. In life, different species exchange information by eating each other and by affecting each other's lives. The moral obligation to reduce as much as possible the suffering of sacrificed animals, both during their life and during their killing, has nothing to do with the idea that eating animals is unsustainable or ethically wrong.

It is not clear whether the high-tech production of in vitro meat (IVM) will represent a dramatic reduction of the economic costs and environmental impact of meat production. Life needed about 3.5 billion years to generate mammals capable to grow their tissues at the right rate and in the right way, defending them from viruses, yeasts, fungus, and parasites while co-evolving with the other species. It is very naive to expect that technology will be able to obtain the same result, producing healthy meat outside the natural process, in a decade or two.

It is not true that IVM will represent a major break-through in the techniques of food production and provide an alternative to the costly conversion of plants into meat. This technical breakthrough has already been made more than 2,000 years ago in China and it is called TOFU (also called bean curd),

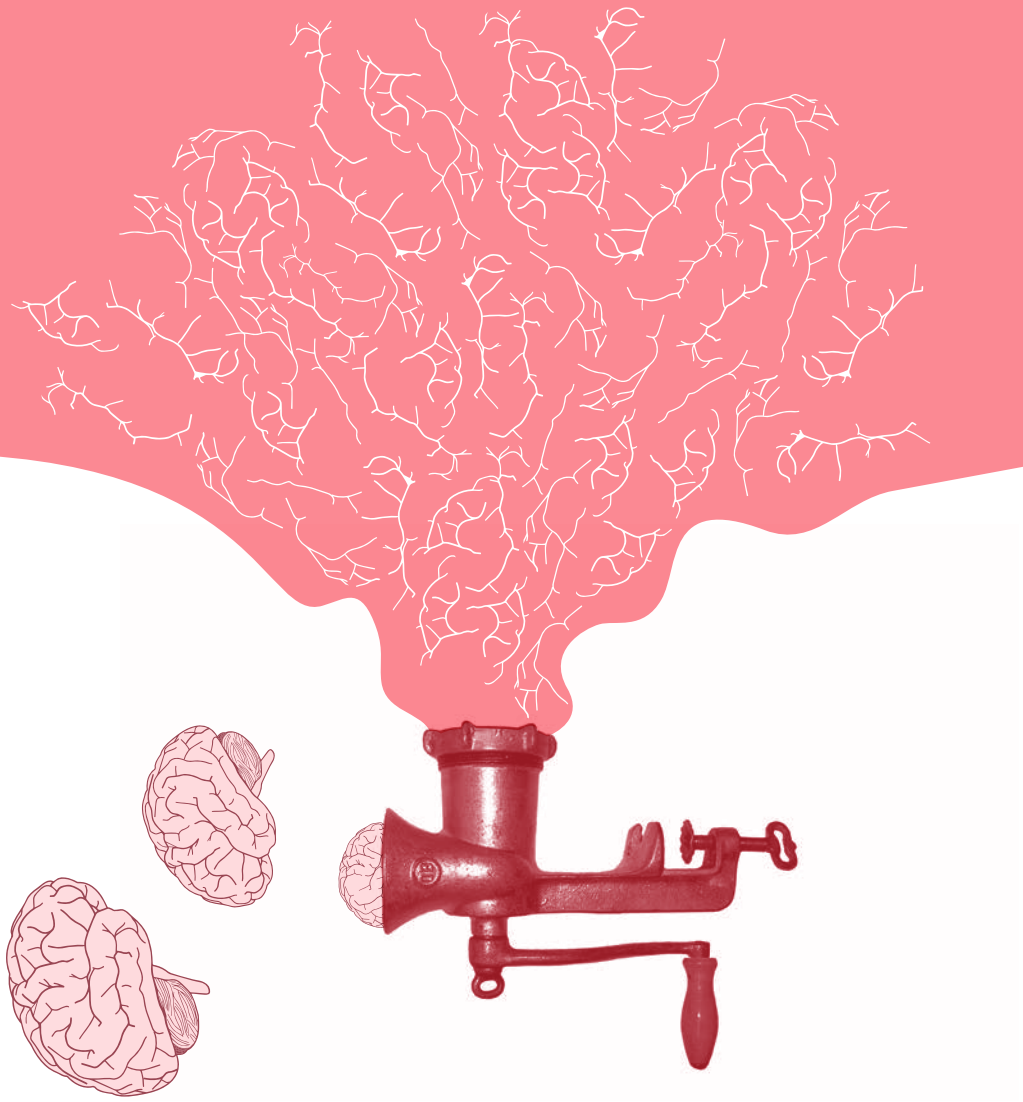
a coagulated soy milk. Tempeh, a similar product from Indonesia, is obtained by fermentation of soybean.

The big expectations surrounding IVM seem to represent a classic example of techno-fantasy generated by the Cartesian dream of prediction and control. Intoxicated by the technological successes of the 20th century some humans now seem to believe that by adopting reductionism they can solve all their problems. Troubles start with the identification of 'problems', including moral problems, obtained by looking at specific issues divorced from their context. In this way, the identification of a single problem (cruelty to animals) translates into the generation of a single solution (IVM) requiring the production of a silver bullet, better if produced in the market economy. This is not how life works and how sustainability is achieved.

The deep ecology view suggests that ecological systems function because the various energy forms within them (organisms) are killing each other in different ways (predator-prey, food chains, habitat competition) across different scales of activity (from microorganisms to whales). According to what is known in ecology, it is the continuous killing of existing energy forms that makes possible the birth of new energy forms, thereby enabling life and evolution on this planet. Even plants, fungi and bacteria (not only humans) kill each other using different strategies when competing for solar energy, soil and nutrients. Death and life are two sides of the same coin (Yin-Yang), they could not exist without each other.

Meat production from natural grazing is more benign to the environment than food production through high tech industrial agriculture. In fact, it keeps the density of human population low and results in reduced pressure on the environment, it requires very little work from humans, since animals produce themselves. In addition to proteins, animals provide fat and other valuable nutrients while keeping the productivity of pastures high. Natural grazing provides a livelihood to poor marginal communities and enhances biodiversity, instead of destroying habitat and polluting the environment. All these aspects are totally ignored by the reductionistic framing of the problem, that claims the issue of 'animal cruelty' would be solved if meat production was banned, or replaced by IVM.

In vitro meat is
a chance to rethink



Dr Clemens Driessen and Professor Cor van der Weele use philosophy to explore the different future worlds that in vitro meat might open up to us. They have watched the in vitro meat field develop, conducted focus groups with potential consumers to gauge their thoughts, and studied press reporting on the topic. Here they reflect upon how the idea of in vitro meat could change how we think about 'normal meat', and the ways we eat today.

Would you eat meat made from cells in a lab? This is the question that is 'posed' by the idea of in vitro meat (IVM). Implicitly this question seems restricted to individuals wondering about this new object and whether it is edible. Resulting in a kind of technology assessment as a matter of 'personal taste'. But in practice, conversations on IVM quickly turn from, "would I want to put that in my mouth?" or "is this 'yuck' or not?" to a much broader set of concerns and a more interesting moral dynamic.

For instance the media event around Mark Post's London hamburger revealed how, on second thought, the public response to the arrival of a tissue cultured piece of meat involved rethinking what is considered 'normal meat' and its production.

The Times: "How absurd is it to imagine all our meat one day being produced by a similar process? Not much more absurd than it is to imagine all our meat continuing to be produced as it is now… It is a compelling answer to a problem."

Daily Telegraph: "This should be a source of unalloyed joy for those of us, like me, who love a good chunk of meat but feel a nagging disquiet knowing that a conscious being had to be bred and then killed in order for me to eat it."

In the first quote, the strangeness of IVM is turned around, highlighting how present industrial meat

production can be considered problematic and absurd. The second quote directs attention to the author, him/herself as a consumer of meat. The editor of the Daily Telegraph confesses to be a deeply ambivalent or internally torn moral person. This moral person is aware of the realities of industrial meat production, but this burger–which ostensibly is not derived from a conscious being–brings home the fact that a normal one is.

IVM in this way generates, or helps explicate, a new outlook on a range of ethical concerns associated with contemporary meat production. This does not mean IVM has turned those who contemplate it into vegetarians. In a set of focus group meetings we organized to discuss IVM, we came across responses that were similar to those of the newspaper editors we quoted above. In view of the promise of IVM, a quite varied set of people showed they were acutely aware of serious problems regarding environmental sustainability and animal use. Even though they confessed to have only slightly or not at all changed their consumer behaviour, many did express hope that somehow the societal intake of 'normal meat' would change. Many worries about meat are not apparent when we just look at behaviour.

IVM, while making us reflect on why we eat meat (or not), not only takes us to pluralisms hidden within our own individual minds, it may also expose differences between different meat cultures. Even though the reality of industrial farming looks more or less the same everywhere, and animals or their flesh are shipped across the globe as generic protein, the first responses to IVM may testify to quite different meanings of meat and its consumption in particular countries and (sub)cultures.

IVM is thereby not just a technological promise that may give hope to achieve a more sustainable 'protein transition' in the absence of widespread willingness to shift to a vegetarian or vegan diet. Even before IVM burgers hit the shelves as a consumer product, just to imagine eating it already allows us a second look at existing meat, at ourselves as moral subjects, and at the particular meat cultures we live in.

In vitro meat is incompatible with grain subsidies

This is Mario Giampietro's second contribution to this publication. As an expert on integrated assessment of food production systems and technologies, he is critical of the claim that in vitro meat could transform the global meat market. Here he summarizes research from previous papers to illustrate the the economic realities of global food production. He describes the ways in which existing grain subsidies, and the commercial interests that support them, mean livestock based meat production will remain for many years to come.

Meat production in developed countries is not driven by a growing demand for animal products, but rather by the need of keeping the demand for 'grain commodities' produced by the paradigm of industrial agriculture high. To explain this point, one has to consider that within market economies the agricultural sector is the economic sector with least competitiveness. It has the largest requirement of economic investment per worker; the lowest return on the economic investment; and the largest environmental impact per unit of added value produced.

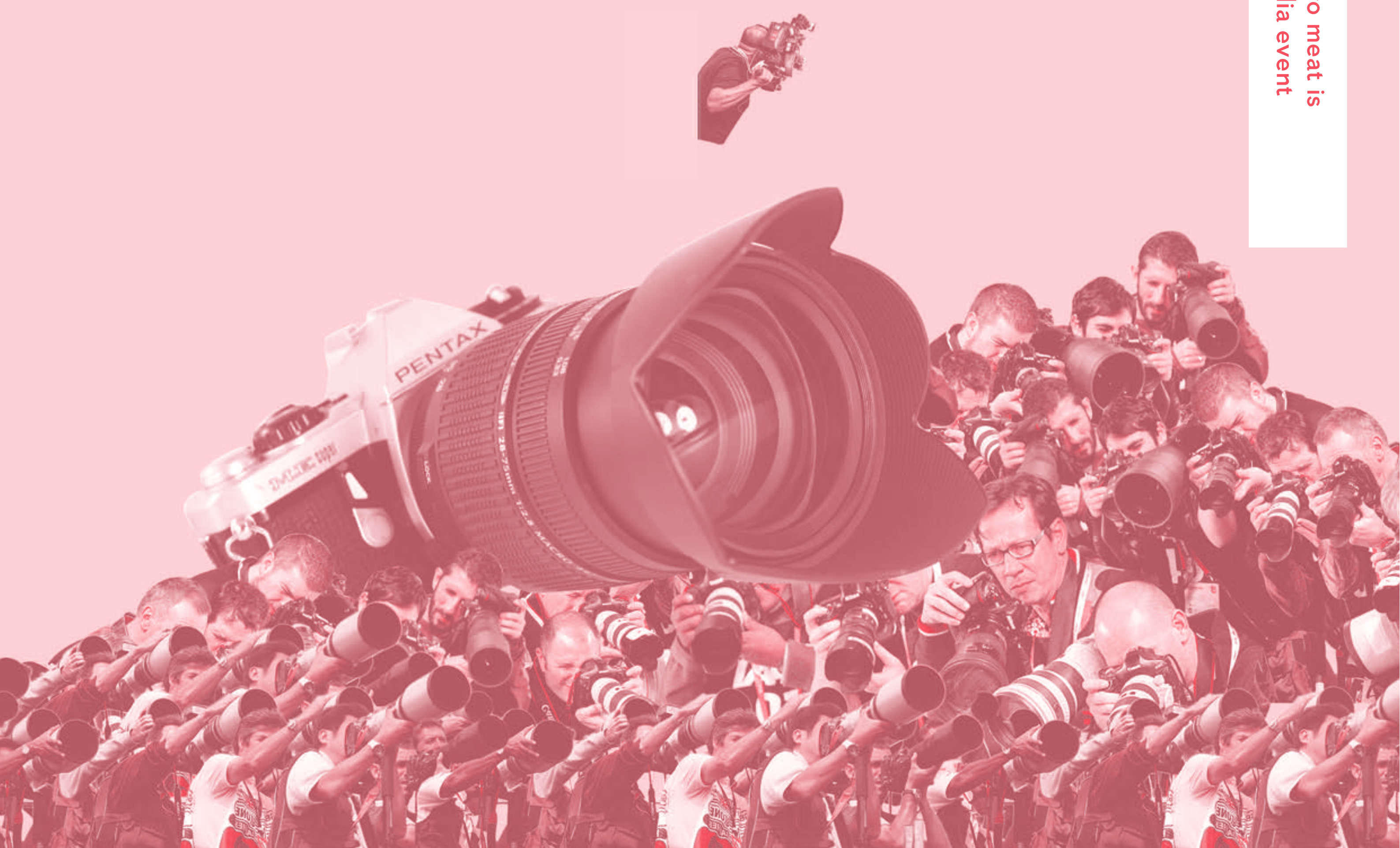
The reasons for this situation are biophysical: crops grow quite slowly and at low density when compared with the density of flows in the industrial sector. As a consequence the 'utilization factor' of technical capital in crop production is quite low (machinery is used in the order of hundreds of hours per year). For this reason, in order to have a high productivity of labor (e.g. 700 kg of corn per hour of labor in the USA) one has to dramatically boost the productivity of both land (e.g. 7,000 kg/ha/year in the USA) and labor (e.g. handling the required activities per hectare using only 10 hours of labor/ha/year in production of corn in the USA). This can only be obtained by producing monocultures of grain.

In contrast, technical capital is used daily in animal production (e.g. in feed-lots or milking parlors), adding

up to thousands of hours per year, and reaching the same level of utilization factor of capital as other economic sectors. This is possible because feed-lot meat production can concentrate the required input of biomass flows (by importing feed concentrates) and boost the pace and density of the animal products every day all year long (no longer relying on local pasture).

The vast majority of these flows is imported. In the Netherlands the production of animal products (meat and dairy) consumes an amount of biomass that requires 20 times more crops, than the country can grow on its cropland. Therefore, farming activities in developed countries have moved from crop production to animal production in recent decades. The economic viability of the agricultural producers in developed countries depends on the stabilization of a very high level of production and consumption of grain per capita. The demand of grain has to be internal to developed countries, because the grains produced in the EU and the USA would be too expensive for consumption by the poor in developing countries.

However, people in developed countries cannot consume more than 150-200 kg per capita/year directly in the diet. Therefore, boosting the consumption of meat translates into a boosting of indirect consumption of grain, keeping high the internal demand. This explains the generous subsidies to animal production and the continuous generation of surplus in this sector. The constant presence of surplus in butter production shows that the high level of butter production is not determined by consumer choices. The lock-in into this attractor is so strong that when the World Trade Organization started a discussion over a cut of the subsidies to the existing food commodity programs, the big lobbies behind industrial agriculture suggested to move to another method of double conversion – boost the consumption of grains by producing agro-biofuels!



In vitro meat is
a media event

Dr Kate O'Riordan, Dr Aristea Fotopoulou and Dr Neil Stephens are all social scientists who have been analysing the media profile of in vitro meat. In this section they focus on the press conference in which Mark Post's cultured burger was presented, cooked, and tasted, to explore how in vitro meat is being promoted and how its future uses are imagined.

The launch of the cultured beef burger in 2013, grown by Mark Post and funded by Google founder Sergey Brin, materialized in vitro meat (IVM) as a particular form and in doing so materialized a vision. The burger launch was a media event. It was a hybrid form combining multiple genres and production styles, and multiple meanings and functions. On the one hand it was a public experiment enrolling witnesses in the making of IVM as meat. On the other hand it was a promotional media event advertising the burger as a world saving technology. The event combined a promotional film made by a public relations company, a reality TV style cooking show with a live studio audience, and a social media presence.

The promotional film was created to give a positive view of IVM. It provided content which located the burger as a viable, world saving technology that could be used to address issues of over population, climate change and world hunger. The protagonists were powerful men from scientific and technological fields who made pronouncements on this message. Their commentary was edited together with a set of images connected to these, including epic imagery of the American west, food production and world history.

The reality style cookery show where the burger was cooked and tasted, was a hybrid form. It combined reality television, news, public experiment, cookery show and studio audience. It was structured by

news anchor Nina Hossain's commentary, and demonstrated that IVM could be cooked and was comparable to conventional meat products. The emphasis during the tasting was on texture, mouth feel and 'the bite'. This demonstration was not just to the effect that an edible substance had been created, but that something with appeal to meatiness, was viable.

The third component of the launch event was a social media presence combining website, Twitter hashtags and a Reddit thread. This element allowed the amplification of the event as live and extended its presence before and after the tasting of the burger. The quality of liveness is important in this instance. Staging the tasting of the burger as live is part of what made it experimental and invoked the witnessing of scientific experiment. The people tasting the burger were framed as unbiased professionals whose expertise would enable them to pronounce on the meatiness of the substance. The liveness of the event introduced the possibility of unpredictability and uncertainty. The studio audience enabled testimony to the witnessing of the live experiment and provided visual evidence that there was a public.

The mix of public relations, advertising, science communication and public engagement provided an address with multiple audience positions. It enabled multiple responses whilst invoking publics who would be enrolled in the promotion of IVM. Unruly publics emerged in both the studio audience and in social media. People in the audience resisted the position of witness and demanded to taste the meat. Online responses, whilst largely affirming, also brought in skepticism, criticism and cannibalism to the table. The publics of the event were largely promotional, the framing of IVM as viable (if cost were ignored) and world saving was carried through witness and discussion in the media of cultured beef.

It is important to register that promotional publics, and their inclusion early on in processes of innovation, is a feature of contemporary science and technology. Given these conditions it is crucial to take these features seriously. There is a tendency to minimize the role of advertising and public relations in the making of emerging technologies; to view these as superficial or cynical elements, or just symbolic or fictional. However, these elements are integral to the shaping of the possible and they require evaluation, as much as the technical specifications of the product. Under what conditions can elements of PR and marketing, found early on in innovation and research, be taken as constructive elements of public engagement and deliberation, and under what conditions might they be irresponsible conjecture?

In vitro meat is a policy issue

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This section provides a short overview of the conclusions from the EPINET research project on in vitro meat. These conclusions are posed as advice on in vitro meat for research policy-makers, such as officers in the European Commission and national funding agencies. However, research and innovation policy is politics in the true sense of the word: it is concerned with the complicated, creative and often difficult and controversial choices that will influence and direct the future of society, technology, nature and humanity. In this sense our conclusions are directed at all stakeholders: Industrialists, scientists, NGOs, citizens and civil society. The following is an excerpt from the final EPINET report to the European Commission.

1. *How is In vitro meat (IVM) conceived of and the research contextualised? Supporting pathways from laboratory cell-culturing into food development.*

Explanation/findings: We observe inconsistencies in the definition of IVM as an innovation object, and in the framing of its place and purpose in the world. It is unclear what this particular innovation is for. If it is a solution to something, then it is unclear what exactly the problem is. We observe arguments that seemingly justify the eventual IVM innovation, that it will target environmental problems linked to meat production and over consumption. However, these arguments find their way into contradictory narratives when they are presented, for example, in conjunction with ideas about new niche markets and in related developments that are likely to reinforce, not solve, current problems linked to overproduction. In other words, the low priority given to the IVM research field by public funding organisations and in innovation policy development is explained, in part at least, by 'unconvincing' sociotechnical imaginaries presented by the IVM research community and its supporters. Policy-makers will need to know what IVM is and the problems it is targeting before they can talk about developing an innovation policy.

Recommendation: An innovation policy regarding IVM research and development towards food production,

needs to reach clarity on the 'problem/solution' definitions and framing of IVM and of IVM research elements.

2. *How does IVM research attract attention and what kind of attention does it get?*

Explanation/findings: We observe that the IVM network has underestimated the importance of the fact that meat is not just 'animal muscle tissue' but an entity that attracts attention for a whole range of reasons other than possible ecological, ethical and industrial advantages. For example, we observed through focus group research that IVM is largely perceived as artificial and the artificiality of food products is typically seen in a negative light. This reaction indicates to us unease with IVM as a product or an ingredient in products that will be found in the marketplace in the future. However, as regards the media attention IVM has received, we observe mixed narratives of curiosity, awe and rejection, and also that so-called 'promotional publics' can be invoked by a big media event such as the cultured burger launch in 2013. The outcome of this media event suggests to us a way to think productively about the mix of public engagement with PR and advertising as integral to the making of technoscience (here IVM), while the dominant tendency is perhaps to dismiss PR and advertising as superficial and cynical, biased and irresponsible.

Policy consideration (general for innovation policy): To what extent should policy-makers take on board PR and marketing – occurring 'upstream' in research and innovation – as constructive elements of public engagement and deliberation?

3. *The social acceptance hurdles in transforming IVM technologies into food development, possibly large-scale industrial production*

Explanation/findings: We observe that the IVM network has underestimated the wide range of cultural and social meanings attached to meat, its production and consumption, leaving it an open question: What 'is' IVM? For example, they have been unprepared for the so-called 'yuck' factor and how to make sense of it. They have not been prepared for its persistence despite the work done to move beyond it, or to expect persistent social rejection on the basis of the artificiality of IVM, although, this is in accordance with past experiences of artificial food innovations. It is also of some concern how an impressive technical ability finds itself here in search of purpose, of social support, acceptance and justification. In that respect, IVM is like a toy in want of a convincing social argument. It remains a rather vague idea of a product, however, a product looking for a market which risks being open to all arguments (good or bad) in favour of IVM developments, i.e., if it is enough to justify monetary investment. Policy-makers will need to know if they

are looking at developing innovation policy or marketing strategies. […]

Recommendation: An innovation policy regarding IVM research and development towards food production, needs to reach clarity on the reasons for why IVM products are socially and culturally contentious, and on the extent to which marketing logics are allowed to dictate the justifications to move forward.

4. *The implementation hurdles in transforming IVM technologies into food development, possibly large-scale industrial production*

Explanation/findings: We observe that the IVM network has underestimated the structural and systemic challenges that would have to be met if IVM were to be scaled up to industrial level. In particular, the network has not appreciated the enormous challenge it would pose to attempt an integration of mass-scale IVM production into the existing agri-food system. In spite of some appealing arguments about reduced energy consumption, land use and climate gas emissions, IVM still risks being perceived as impracticable and unappealing from the point of view of production and marketing. However, should IVM products be allowed in principle, a host of policy and regulatory issues will need thorough consideration: Industrial, labour and market regulations (production planning, land use, employment issues, IPR issues, competition, etc.); Production oversight (hygiene standards, nutrition standards, donor categories, wellbeing of cell donors, etc.); Consumer protection (categorising, labelling, product safety, warnings/ endorsements, etc.). With all that taken together, the question still remains if we want IVM products in the world.

Policy consideration (general for innovation policy): Which technology assessment methodologies can come together to adequately clarify what is at stake in deeply uncertain early stage technologies and to identify how to constructively move them forward? With respect to IVM specifically: We recommend bringing together a range of technology assessment methodologies who, in coming together, can map and adequately characterise the challenges of integrating IVM into the agri-food system.

Conclusion

Professor Roger Strand is a philosopher interested in the moments when uncertainties arise as emerging sciences engage society. He also led the EPINET project that resulted in the production of this publication. In this section he summarises the findings from the EPINET project to describe policy challenges related to what in vitro meat is, how it is promoted, how it might be accepted, and moving it to large scale production.

The collection of essays in this publication is an outcome of EPINET, an EU-funded research project designed to promote integration of different methods to assess social (non-economic) impacts of new and emerging technologies. When discussing and assessing new and partly non-existing technologies, many aspects may be brought to the table: ethics, risks, uncertainties, sustainability, media and public perception, power, law, fiction, industrial upscaling, to mention but a few. Each of these aspects may be studied by their own research traditions that perhaps struggle to communicate with the other perspectives. There may be differences in methods and assumed knowledge, but also in values, presuppositions, interests and commitments. In EPINET we have tried to overcome such differences by working together with a range of experts on selected case studies: smart electric grids, wearable biosensors, robotics and in vitro meat (IVM).

From the time of designing the EPINET project in late 2010 we have been fascinated by the science, fiction, art and culture of IVM. The story of IVM is full of intriguing contrasts. On one hand, IVM has been present in science fiction and popular culture for a long time, and it is being written about in newspapers and magazines around the world. On the other hand, actual IVM research is sparse, down to twenty or so active researchers, depending on how we count.

Along another dimension, IVM is one of the rare cases of a future biotechnology that receives endorsement and praise by ethicists and environmental proponents for its promise to substitute cruel and ecologically taxing practices such as livestock production. Still, the general public and public policy-makers have received these promises with a mixture of disgust and indifference, at least in the sense that public funding for IVM has been almost non-existent.

In November 2013 we organized an interdisciplinary workshop in Utrecht. The choice of venue was not random. Most of the science and indeed ethics on IVM so far has taken place in the Netherlands. We invited IVM scientists, ethicists, environmental scientists, social scientists, an artist, an engineer, an IVM fundraiser, and a research policy-maker. An astonishing 100% of the invitees participated.

This publication is an outcome of the 2013 workshop and our later reflections on the topic. Our main conclusion is easily stated: The workshop revolved around the seemingly simple but actually very complex question: What is IVM?

Insufficient communication between experts and lay persons, between researchers and policy-makers, between science and industry, seemed to boil down to the lack of understanding between different visions of IVM that, by themselves are too thin and too partial. IVM is cell culture as well as popular culture. IVM is a basic science laboratory technology, but in order to reach the market, it has to be up-scaled and aligned with industrial agri-food systems. Such challenges are far from trivial and have bearing on what IVM is and what it might be.

Experts on tissue engineering have their own highly sophisticated understanding of what "meat" is from a biological and technical point of view, but this understanding is quite different from the cultural, anthropological and sociological understanding of what meat is, that is, what meat means to people and the role it plays in their lives. We believe that IVM proponents have underestimated this disconnect of knowledge.

What is In Vitro Meat? represents the multitude of legitimate understandings of IVM. Of course, we do not have the mandate to decide whether IVM research should be pursued, and in which direction. Rather, our mandate is to provide a richer understanding of IVM and point out that the question of public support should be seen together with the question of social shaping. It is a debate not just about IVM, it is a debate about meat in general. And the debate about meat is the debate about how we eat, what we eat and how we produce it. Ultimately, it is a debate about how we humans of the 21st century live, and are going to live, with other animals, the environment and ourselves on this planet.

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ISSN 2372-6504
Produced and published by
The Center for Genomic Gastronomy
November, 2015

Editors
Neil Stephens, Cathrine Kramer, Zack Denfeld and Roger Strand

Design & Illustration
Cathrine Kramer and Marte Teigen

Print
Printed by Ditto Press, 2015

Support
Cathrine Kramer's work and printing of this publication was supported by The Office for Contemporary Art Norway (OCA).

The research leading to this publication has received funding from the European Community's Seventh Framework Programme (FP7/2007–2013) under grant number 288971 (EPINET).

Dr Neil Stephens' work was supported by the Wellcome Trust small grant (WT096541MA).

This support is gratefully acknowledged.

Thank You
David Benqué

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