Governing Synthetic Biology:

A Food Policy Approach

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Abstract

As synthetic biology develops, food and agriculture is one sector in which it can be applied. This thesis presents the findings from interviews of 30 synthetic biology stakeholders from the research community, policymakers, industry, funders and NGOs about the future of synthetic biology in UK food and agriculture. I answer three linked research questions: (1) *What are the ways in which synthetic biology is constructed by this sample of its stakeholders?* (2) *Why did these stakeholders construct synthetic biology in these ways?* And (3) *What are the implications of these constructions for UK food policy?*

Findings

This research finds that past experiences of GM controversies, which I summarise with the term 'GM Trauma', shape participant views about synthetic biology.

Past controversy experiences form part of a background framework of worldviews and understandings that in turn inform constructions of synthetic biology's definitions, boundaries and status as potentially controversial or risky or not. These long shadows of past controversy are cast as assumptions about others' knowledge (or lack thereof), perceptions about which types of views can be considered 'scientific' and 'unscientific', and what kinds of information and considerations 'count' as relevant for policy decision-making. This frames discussions about how publics might be engaged with, communicated with or managed; and underpins views about the status and value of scientists and science in policy arenas, sometimes leading to the exclusion of other stakeholders.

Participants also perceived past controversies to have resulted in a reactive, stifling and 'draconian' governance framework, but which is "probably strong enough" to manage synthetic biology's risks to food safety and the environment. In a policy landscape that participants sensed to be shifting, GM Trauma therefore has practical implications. Perceptions of past controversy and conflict seem to manifest as an expectation of future controversy and conflict. This contributes to a sense of insularity, driven by participant views about their own roles and about the attitudes and roles of others. The vast landscape of disparate stakeholders, insularity of scientific and policy communities, over-reliance on scientific expertise in synthetic biology-related policymaking spaces and the exclusion of other viewpoints combine to promote siloed thinking and a narrow focus on technoscientific notions of risk, safety and economic priorities. This has been found to be continuing despite the detailed scrutiny and advice offered by social scientists working closely with synthetic biologists for many years.

Conclusion

Synthetic biology's potential to play a part in food policy priorities around, for example, environmental sustainability, human health and nutrition, livelihoods, and social and ethical considerations, remains unclear. It is vital that stakeholders debate how to integrate these aspects with present economic and research priorities. A deeper consideration of the implications of past controversy on stakeholder thinking may open new avenues for questioning current policy approaches, who is involved in policy decision-making, and how relationships can be built, or mended, between stakeholder groups. This is something to be recommended and encouraged.

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With thanks also to all of the friendly faces at Newcastle University, particularly in Sociology, Geography and Politics, for your insights and kindness over the past few years, and for the support of Newcastle University, the Portabolomics team and the EPSRC.

Finally, to my family and friends, thank you for everything.

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Abbreviations

ACRE	Advisory Committee on Releases to the Environment
AEBC	Agriculture and Environment Biotechnology Commission (AEBC
ACT	Artemisinin-based combination therapies
BSE	Bovine spongiform encephalopathy
CRISPR	Clustered regularly interspaced short palindromic repeats
CSM	Case specific monitoring
DEFRA	Department for Environment, Food and Rural Affairs
DIY	Do-it-yourself
DNA	Deoxyribonucleic acid
EC	European Commission
EFSA	European Food Standards Agency
ELSI	Ethical, legal, and social implications
EPSRC	Engineering and Physical Sciences Research Council
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FSA	Food Standards Agency
GM	Genetic modification, genetically modified
GMO	Genetically modified organism
GRAS	Generally recognised as safe
GS	General surveillance
iGEM	International Genetically Engineered Machine competition
IP	Intellectual Property
ISP	Ice structuring protein
MIT	Massachusetts Institute of Technology
mRNA	Messenger RNA
NEST	New and Emerging Strategic Technologies
NGO	Non-governmental organisation
PLA	Polylactic Acid
R&D	Research and Development
RHC	Regulatory Horizons Council
RI	Responsible Innovation
RM	Raw material
RNA	Ribonucleic Acid

RRI	Responsible Research and Innovation
SDG	Sustainable Development Goals
SFA	Singapore Food Agency
SSK	Sociology of Scientific Knowledge
STS	Science and Technology Studies
UK	United Kingdom
UN	United Nations
USA	United States of America
USDA	United States Department of Agriculture

Transcription Marks

…	Short pause in speech
-	Abrupt stop or change of tack
‘text’	Quoted speech or reference to a concept
(text)	Transcriptionist comment, e.g., (Laughter)
[…]	Transcript text edited by author; text removed
[Text]	Transcript text edited by author
[Break]	Long pause in conversation

Chapter 1: Introduction

1.1. Scope and motivation

This thesis concerns the future of synthetic biology in UK food and agriculture, and possible implications for food policy. In what follows, I report on my conversations with synthetic biology stakeholders across a diverse range of roles and experiences, offering insights into the dynamics within, and views about, synthetic biology-related policymaking in the UK. My research is timely because the UK government, upon leaving the European Union, now has the scope to reconsider its governance of genetic technologies, and has begun doing so (DEFRA, 2021). Food systems in the UK and globally also face several pressing challenges to which synthetic biology is sometimes positioned as a solution. These challenges include the climate emergency, human health, as well as socioeconomic factors and supply chain disruptions arising from a convergence of political factors, conflict, and the COVID-19 pandemic.

Synthetic Biology is a loosely defined, interdisciplinary area of research in biotechnology (Pouvreau *et al.*, 2018; Gardner & Hawkins, 2013; Schyfter, 2012; Calvert, 2013). Synthetic biology is sometimes described as a "hybrid discipline" (Andrianantoandro *et al.*, 2006:12) which seeks to apply engineering principles to molecular biology, employing existing and novel genetic engineering techniques (Meckin & Balmer, 2017:2). Synthetic biology can also be described as "the designing and construction of new biological components, devices and systems that do not exist in the natural world and also the redesigning of existing biological systems to perform specific tasks" (Tyagi *et al.*, 2015:2).

Food Policy, broadly defined, includes public, institutional, or corporate policies, plans, strategies, standards, and guidelines for the governance of food and drink supply chains from input, through to production, consumption, and outcomes.

This research contributes to a project called Synthetic Portabolomics[1] (hereafter referred to as 'Portabolomics'), based at Newcastle University. Portabolomics is a complex project with several strands of work operating within multiple disciplines. The research strands include 'wet lab' work on bacteriology and genetic engineering, as well as 'dry lab' computing work on

[1] 'Synthetic Portabolomics: Leading the way at the crossroads of the Digital and the Bio Economies' is funded by the Engineering and Physical Sciences Research Council (EPSRC), award EP/N031962/1. Website: https://portabolomics.ico2s.org/

modelling, data, and verification. Underpinning the work across the whole programme of research, Portabolomics encompasses a strand of sociological study about Responsible Research and Innovation (RRI)[2]. My research forms part of the RRI strand by exploring synthetic biology's governance through food policies.

1.2. Personal context

In the months prior to the submission of my research proposal, the spectre of the UK's upcoming exit from the European Union (known as Brexit) was becoming ever more of a priority in my work as a food buyer in a small food import-export company in south London. I think partly because I had a master's degree in food policy research, but mostly because no one else wanted to do it, my boss at the time had left me in charge of developing the company's Brexit strategy. This work was mostly question-generating rather than strategic. Our suppliers were, for the most part, as confused and unprepared as we were, and as the UK government appeared to be. Indeed, in one memorable Brexit preparedness event targeted at the seafood industry, the civil servants chairing the meetings demonstrated how to use a new online system for fish importers and exporters. My colleague at the time and I were alarmed to note that none of the 'categories' on the form referred to ambient seafood products, like the tinned fish we traded in annually to the tune of millions of pounds and several hundreds of containers. Upon realising they had forgotten all about tinned tuna and sardines, the meeting chairs took hurried notes and moved the conversation on. It was no comfort when one of our direct competitors approached us in the buffet queue to thank us for mentioning it, because she was staring into the same red tape and uncertainty as we were.

Looking back, this experience inspired a drive to return to academia and research UK food policy. While I had not expected that this would take the shape of research on synthetic biology, (and, actually, the advertisement for this PhD position had not been focussed on food policy either) I was delighted when I was accepted. I felt that this was an exciting project in a time when food policy was facing an unprecedented period of potential change. Brexit was going to be something of an economic and political experiment, and I would be researching one little aspect of it as it unfolded. But, to quote one of my participants: "just as this has all happened, in comes our old friend COVID-19."

[2] https://portabolomics.ico2s.org/research/

COVID-19 (Novel SARS-CoV-2), a disease caused by a novel coronavirus that impacts the human respiratory system, was first detected in Wuhan, China in December 2019. I started my PhD in January 2020. By March 2020, the virus had spread to every continent except Antarctica, and on the 23rd, the UK government implemented a nationwide lockdown. It was a legal requirement for citizens to stay at home except in certain circumstances. Schools and universities were closed.

On the one hand, it is difficult to overstate the impact that a global pandemic has on both a researcher and their research projects. Setting aside the practical implications of working from home and physically distancing oneself from others, it is perhaps the shift in perspective that is the most impactful. A psychological block is created against approaching strangers to discuss something as seemingly trivial as the potential policy implications of a laboratory-grown chicken nugget when separated from family and friends, and when thousands of fellow citizens are fighting for their lives. It feels almost embarrassing in such a time to contact participants and ask for their valuable energy and help. On the other hand, 2020-2023, the span of this research project, pandemic included, have been fascinating years for UK policy, not least food policy, and for the health, social, cultural, economic and political lives of all global citizens. Synthetic biology became a particular point of conversation and policy interest at this time, due to its role in supporting research that contributed to vaccine development.

In short, my research took place within an unexpectedly interesting context. I was able to explore the role of synthetic biology during the pandemic, the political, social and economic turmoil of a global health crisis, the unprecedented introduction of Brexit-related barriers and opportunities and the hope that Brexit would provide rich new soils for policy change. Perhaps it was this context that encouraged participants to meet with me, despite the pressures and fatigue of the pandemic.

In the remainder of this opening chapter, I will provide some contextual and background information about my research, the importance of studying this subject now and the questions I will address throughout this work.

1.3. Introducing synthetic biology

This thesis will demonstrate that, as previously noted by prominent researchers like Calvert (2013), there still remains some debate among synthetic biologists over how synthetic biology should be defined. It follows, then, that there is also disagreement over where synthetic biology came from. In their "brief history of synthetic biology", Cameron *et al*. (2014:381) argue that

the origins of the field stretch back as far as 1961 to a landmark publication by Jacob and Monod titled "Teleonomic mechanisms in cellular metabolism, growth and differentiation" (1961). Monod and Jacob (1961) identify the existence of "regulatory circuits that underpin the response of a cell to its environment" (Cameron *et al.*, 2014:381). It was this discovery, according to Cameron *et al*. (2014:381), which sparked a "pre-genomic period" of genetic research approaches focussing on "programmed gene expression", including recombinant gene expression, and cloning. However, Cameron *et al*.'s (2014) proposed origin of modern synthetic biology is distinct from, and much later than, the coining of the term 'synthetic biology'. French biologist Leduc first used the term 'synthetic biology' in 1911 (in the book *The Mechanism of Life*). Leduc also authored *La Biologie Synthétique, Étude de Biophysique* (literal translation: Synthetic Biology, Study of Biophysics) (Leduc 1912). However, Leduc (1912) used the term 'synthetic biology' in reference to "inanimate things, such as crystals" (Meyer, 2013:373), meaning a line cannot be drawn to directly connect Leduc's synthetic biology with modern understandings of the field.

That said, a philosophical connection could be made from Leduc's work to the types of debates underpinning modern synthetic biology. For example, Leduc's rejection of vitalism (the idea that living things have a 'vital force' which separates them from objects and machines) is indicative of a paradigm shift towards reductionism and later mechanism. Mechanism emphasises the role of physics and mathematics in the organisation and existence of living things and argues that organisms are the product of definable, identifiable component parts. The assumption that these component parts can be characterised, abstracted and reassembled is viewed by Calvert (2013) as the basis of modern synthetic biology. Others argue that the work of Professor Wacław Szybalski (1974) on molecular biology is the precursor to modern synthetic biology, due to its acknowledgement of an aim that the field will one day enable the synthesis of biological parts (and whole genomes) from scratch (Benner *et al*., 2011).

Alongside Szybalski's work, the 1970s to 90s in particular produced several advances that arguably resemble synthetic biology's endeavours today, including the first engineering of genetically modified bacteria (Cohen *et al*., 1973) and animals (Jaenisch & Mintz, 1974). Sanger *et al.* (1977) developed the first viable method of sequencing DNA reliably and quickly in 1977. Genomic sequencing was developed by George Church in 1984, and Church's later contributions to the debate on open-source genetic information and open-consent have translated into drives towards accessible databases containing genetic information. The 1980s and 90s also saw advances in the genetic modification of organisms, leading some to position the origins of synthetic biology somewhere within this timeline of the development of genetic

engineering, including research and development of genetically modified (GM) crops. Furthermore, at this time, human insulin was synthesised in genetically engineered bacteria, and the Human Genome Project, as well as the Minimal Genome Project began. In particular, the work of George Church in the late 1980s and 1990s on the human genome has continued to be of importance for the development of the field.

Synthetic biology has since become differentiated from earlier genetic engineering research through its characterisation as a multi-disciplinary field, resulting in useful contributions in terms of principles and ideas from a range of scholarships. Meyer (2013) summarises that:

> The emergence of synthetic biology is at once a development pushed by biologists who […] started to join hands with physicists and computer scientists; an expansion of engineering principles into the realms of the life sciences; the institutionalization of a discipline through dedicated conferences, courses, journals, and research groups; and a cross-fertilization of biology, chemistry, engineering, and computer science. (Meyer, 2013:374)

I would add that today's synthetic biology is also shaped by commentary from the 2000s to the present day through social science research. Social scientists, as is the case with my supervisors and I, often form part of multi-disciplinary synthetic biology project teams, exploring the dynamics within them, the broader field and interactions between science, technology and society. This has in turn shaped understandings of conceptual, moral and ethical connections between previous research on human genomes, GM and relevant applications, and modern synthetic biology (Trump *et al*., 2019).

Synthetic biology today covers an expansive range of work, with a broad geographical spread, described by Trump *et al*. (2019:355) as "an initial period of incremental gains in basic science research from 2000–2008, followed by a sharp acceleration and a transition to applied research and product development beginning in 2008". In 2003 the first iGEM (International Genetically Engineered Machine) competition was held at the Massachusetts Institute of Technology. The iGEM competition has been credited with accelerating the development of synthetic biology, by educating young synthetic biologists, promoting multidisciplinarity within project teams and providing a platform for debate on advancements in the field. Not least, iGEM encourages and indeed relies on regular enhancement on the Registry of Standardised Biological Parts. In 2004, the first international synthetic biology conference (Synthetic Biology 1.0) was held (Trump *et al*., 2019). According to Cameron *et al*. (2014:382-383), "the meeting was widely lauded for its positive impact on the nascent field, helping to create an identifiable community."

The European Commission's NEST (New and Emerging Strategic Technologies) funding programme began investing around €32million into 18 synthetic biology-related projects from 2005 (Pei *et al*., 2012). Later, *A Strategic Roadmap for Synthetic Biology in the UK* was produced by an independent panel of experts and published in 2012 (Clarke *et al*., 2012). This roadmap set out ambitions and a likely timeframe for establishing "a world leading Synthetic Biology industry within the UK", though it is not without criticism. Marris and Calvert (2020), who were members of the panel, find the roadmap to be derived from a narrow focus on the economic benefits of synthetic biology's development. Marris and Calvert (2020) also observed an undue weight given to public acceptance and risk regulation, rather than broader deliberation about the motivations, purposes and implications of the innovation process from research conceptualisation through to potential application. Despite these criticisms, in 2013, the UK government allocated around £126 million for the development and promotion of synthetic biology as per the Roadmap (Marris & Calvert, 2020).

In addition to the advances in scientific research, synthetic biology has also developed some real-world products since the early 2000s. In 2008, the production of biofuels using genetically engineered *E. coli* was first described (Lee *et al*., 2008; Trump *et al*., 2019). Marking perhaps a critical juncture for product- and application-specific research and development, the "creation of [a] bacterial cell with a synthetic genome" was described for the first time by Gibson *et al*. in 2010. This was followed by Paddon *et al*.'s (2013) detailing of the production process of anti-malarial drug artemisinin using genetically engineered yeast. In addition, from 2013 onwards, CRISPR-Cas9 was increasingly explored as a tool to improve the speed and accuracy of gene/genome editing (e.g., Cong *et al*., 2013; Doudna & Charpentier, 2014) and would become a key enabling technology of synthetic biology (Trump *et al*., 2019).

Clarke and Kitney (2020:116) map the geographical distribution of academic research in synthetic biology. They found that the USA was, by a considerable margin, the most prominent source of both academic papers and funding, followed by China, the UK and Germany. They attribute this the USA's culture of risk-taking in financing start-ups and having an attractive regulatory system.

Today, particularly in the UK, synthetic biology is undergoing something of a rebranding, and is now often identified as 'engineering biology'. This name change[3] appears to be

[3] For my primary data on the topic of synthetic biology's change of name to engineering biology, please see Chapter Six.

spearheaded by some policy actors, including UKRI funders and the former Synthetic Biology Leadership Group (now the Engineering Biology Leadership Group) and will be explored later.

1.4. Synthetic biology in food and agriculture

Synthetic biology could have a wide range of potential applications in food and agriculture, being applicable to plants and animals. Research is ongoing into applying synthetic biology to improve the nutritional or enzymatic properties of foods for human and animal consumption (Jin *et al*, 2019; Goold *et al*., 2018). For example, in their paper, Liu and Stewart (2015) describe a case in which a biosynthetic pathway enabled a 3600-fold increase in the beta carotene content of potatoes. This has been suggested to be a useful nutrient source in some Western diets, as well as in subsistence farming communities. Some applications of synthetic biology in animals have also been suggested or trialled, for example engineering horned livestock not to develop horns, suggested to offer improvements to farm workers' safety. However, the bulk of applications currently involve applying synthetic biology to microorganisms.

In an edition of the National Academy of Engineering's *Bridge* publication, Patrick Boyle, an employee at Ginkgo Bioworks (an American biotechnology company involved in genetic engineering of microbes) summarises that:

> Many of the current applications of engineered biology are products of engineered microbes. Microbes have a number of properties that make them useful to engineers: they exhibit fast growth rates, have many genetic tools, and can produce products at commercial scale via fermentation. (Boyle, 2019:34)

Microorganisms can be engineered to synthesise ingredients for the food industry where non-synthetic biology-derived supply might be unstable, and to reduce cost and increase the "pace of manufacturing" (Goold *et al*., 2018; Tyagi *et al*., 2015). The most prominent of these applications involving microorganisms are fragrances, aromas and flavourings, like synthetic biology-derived vanillin (vanilla) and nootkatone (grapefruit), which can be manufactured using engineered bacteria and yeasts (Goold *et al*. 2018; Braga & Faria, 2020). Microorganisms can also be engineered to produce other food ingredients, like sweeteners (French, 2019; Cargill, 2020a). The Impossible™ Burger, which contains a brewer's yeast engineered to produce soy leghaemoglobin, is available at every Burger King in the United States (Impossible Foods, 2020a). Approval is now being sought to sell this vegetarian product, which 'bleeds' like a beef burger would, in the EU.

Other potential applications of synthetic biology involving microorganisms are agricultural or aquacultural inputs (Jin *et al*, 2019). Some groups are working on engineering

novel agrochemical inputs to promote nitrogen fixation in cereal crops, or engineering crop plants themselves to this end (Jin *et al*, 2019). Notably, in the United States, Joyn Bio (2020), a collaboration between self-identified synthetic biology platform Ginkgo Bioworks and the global agrichemicals company Bayer, are working on:

> Significantly reducing agriculture's reliance on synthetic nitrogen fertilizer. Our first product will be an engineered microbe that enables cereal crops like corn, wheat, and rice to convert nitrogen from the air into a form they can use to grow. This will significantly reduce the industry's reliance on traditional chemical fertilizer, as well as greenhouse gases produced by agriculture. (Joyn Bio, 2020. Accessed 2nd September 2020).

It is unclear what stage of development this application has reached, or whether there is evidence of proof of concept. Elsewhere, Knipbio (2020) are working on aquaculture inputs, producing fish food containing a protein made from engineered bacteria, which could negate the need to provide wild-caught fishmeal to farmed carnivorous fish (such as salmon).

Another ambition for synthetic biology is the production of bioplastics for food packaging, or additives to packaging and products that respond to individual needs or detect certain components in foods (Horner *et al*., 2006; Jung *et al*, 2010). Companies working on these products are based primarily in the UK, EU and USA. Some examples are Biome Technologies' biodegradable polymers (bioplastics) for beverage filter material, flexible films, paper coatings and Ecovative's mycelium packaging materials. Microorganisms can be engineered to facilitate plastic waste management processes, like breaking down plastics, or food waste management (e.g., through the use of food waste as feedstocks for the production of useful compounds by bacteria or yeast, for example biofuels).

There is also research and development in sectors such as analogues to animal-derived food products, for example, laboratory-grown meat (Froggatt & Wellesley, 2019:4). In one prominent example, a laboratory-grown chicken nugget was approved for sale and consumption for the first time in Singapore in 2020 (SFA, 2020; Waltz, 2021). Elsewhere, analogues to other animal products are emerging. Companies such as Perfect Day Foods engineer 'microflora' to produce whey and casein, mixtures of proteins naturally present in dairy products, to make analogues to cow's milk, yogurt, and ice cream (Perfect Day Foods, 2020). US company 'Every', formerly Clara Foods, produces egg albumin from yeast, to create an egg white analogue product (Clara Foods, 2020). Such developments are often claimed to be important in agriculture and aquaculture to meet sustainability and efficiency targets by contributing to a reduction in animal-product consumption (Froggatt & Wellesley, 2019; Waltz, 2021). This is debated and a subject to which I will return.

1.5. The policy landscape and its origins

Much of the current food policy oversight relevant to synthetic biology was designed to govern genetically modified foods and was developed and implemented while the UK was a member of the European Union. Genetic modification in food and agriculture has a complex policy history, which played out in various ways around the world. Breakthroughs in recombinant DNA technologies led to a moratorium on Genetic Modification (GM) research in 1974-1975 (Kuzma, 2022), culminating in what became known as 'the Asilomar Conference' and the introduction of new transparency and safety-focussed rules for laboratories. From a US perspective, Kuzma (2022:7) describes the Asilomar Conference as "narrow in scope and participants by design, with attendees largely […] an elite set of early developers and proponents of biotechnology, along with a few media representatives to publicize the event, while the general public was excluded (Hurlbut 2015)." For Kuzma (2022:7), "the biotechnologists' coalition excluded critics from the conference and tried to stave off onerous top-down government regulations for biotech by giving themselves a mandate for self-regulating laboratory safety."

In the EU in April 1990, the Council of the European Communities established Council Directive (90/220/EEC) on the deliberate release into the environment of genetically modified organisms. This directive set out rules on notification and approval processes relating to the release of GMOs and was taken on by the UK as a statutory instrument, the Genetically Modified Organisms (Contained Use) Regulations 1992, and Genetically Modified Organisms (Deliberate Release) Regulations of 1992. These regulations required applicants to obtain approval to release a GMO, usually including data from previous releases and a risk assessment. The Deliberate Release (1992) regulation also required applicants to publish a proposed release notice in newspapers circulating in areas near to the site of release, giving details about the applicants and describing the organism and the location and purpose of the release.

In 1997, the EU (and UK) introduced the Novel Foods and Novel Food Ingredients Regulations 1997, regulating food and feed that "had not been consumed to a significant degree by humans in the EU before 15 May 1997." When coupled with the GMO regulations, this provided the groundwork for today's governance framework, and this oversight is presently devolved to the administrations of Scotland, Wales and Northern Ireland. In practice, what is

widely described as an EU *de facto* unofficial moratorium[4] on GMO approvals was not lifted until the introduction of a new Directive on the Deliberate Release into the Environment of GMOs in 2001 (2001/18/EC).

In parallel, controversies around GM foods continued brewing in the UK, involving protests and the destruction of field trials (Yearley, 2005; Jasanoff, 2005). Supermarkets recalled the small number of commercialised GM foods (such as Sainsbury's GM tomato puree) from their shelves (Yearley, 2005). Concerns around GMOs, their relationships to society, and their risks and implications for nature were voiced by a wide range of parties including NGOs, some scientists, even King (then Prince) Charles, and were widely reported in the press. This opposition was in contrast to the government's own arguably pro-GMO position at the time, although robust EU rules were adopted and implemented in the UK (Jasanoff, 2005). In 2003, to cite Jasanoff (2005:127), "the British government launched a remarkable exercise in constructing a new deliberative politics around GM foods […] a coproductionist experiment that required the simultaneous constitution of a process, an interested polity, and a body of reliable knowledge." This is described as "a novel experiment in democratic governance" involving costs and benefits analysis of GM crops, as well as a science review, and thirdly a public debate which was in part prompted by the Agriculture and Environment Biotechnology Commission (AEBC), set up in 2000. AEBC could be understood as rather innovative (Jasanoff, 2005). It involved a multi-stakeholder commission presented to parliament as having "members [with] a breadth of backgrounds and skills ranging from experience of consumer and green issues to farming, science, ethics and industry" (Lord Falconer of Thoroton, Monday 5th June 2000). AEBC was a "catalyst for novel initiatives" such as a public dialogue on GMOs (Marris, 2001; Jasanoff, 2005) which enabled discussions about scientific unknowns, ethics, risks, morals, human health, the environment and the economic, social and political implications of GM foods. This has been praised by Jasanoff (2005) as an example of an attempt at participatory policymaking which also sparked active engagement from NGOs, like Greenpeace UK who organised their own citizens' jury to discuss GM foods. Nonetheless, the policy framework discussed in the previous paragraph remained largely static, except for occasional amendments, until the UK's departure from the EU at the end of 2021.

In 2016, the UK held a referendum on its EU membership, voting to leave the EU. A period of significant political upheaval followed, resulting in the European Union (Withdrawal)

[4] A CORDIS article in 2001 reports on the lifting of a *de facto* moratorium on GMO approvals, citing a leaked memo. https://cordis.europa.eu/article/id/17462-commission-confirms-moratorium-on-gmo-approvals-to-be-lifted

Act 2018 which provided for much EU regulation to be retained in UK law, facilitating the UK's transition out of the European union. EU regulation relevant to synthetic biology was generally retained in the UK but amended to remove mention to EU powers and institutions, with the exception of the much-contested Northern Ireland Protocol, which permitted some EU rules and regulations on food products and standards to apply in Northern Ireland. Between 7th January 2021 and 17th March 2021, the UK's DEFRA held a consultation on the regulation of genetic technologies and called for evidence on broad future approaches to the governance of genetic technologies in food and agriculture (DEFRA, 2021), indicating a political will to review the policy landscape. The UK formally separated from the EU on 31st December 2021. As one example of a post-Brexit shift in policy, the Genetically Modified Organisms (Deliberate Release) (Amendment) (England) Regulations entered into force in 2022. This amendment permits the deliberate release in England of genetically modified plants if such modifications "could have occurred naturally", without a risk assessment requirement (unless the plant is to be marketed). At the time of writing, this is at odds with EU governance.

There is also much activity in food policy across the UK, but few policy proposals have come to fruition. The past few years have seen an Obesity Strategy (DHSC, 2020), Environmental Land Management Schemes (DEFRA & RPA, 2021) and Food Strategy (DEFRA, 2022, in response to Dimbleby & DEFRA, 2021) only partially introduced, or shelved, reformulated or abandoned altogether. This chaotic landscape may in part exist due to the manner in which food policy is structured and implemented in the UK, complicated also by devolution. Food policy governance falls across several sectors and departments which results in a complex system with varying aims, capacities and responsibilities. Among others, Lang *et al*. (2009) and Hawkes and Parsons (2018) have been critical of the current approach and suggest a vision of food policy that meets economic goals along with environmental, social, cultural and health needs.

Those involved in future synthetic biology-related food policymaking will have to consider not only the technoscientific developments but also the (often competing) views of stakeholders, industries and publics about its products. Proposals for future governance have been made by the Synthetic Biology Roadmap Coordination group, who recommend incorporating "the views of a range of stakeholders and addressing global societal and environmental challenges within an effective, appropriate and responsive regulatory framework" (Clarke *et al.*, 2012:04). However, as Stilgoe *et al.* (2013) note, policy development needs to be as fast-paced as the science without being reduced to only risk management.

1.6. Research Questions

This is an original project, researching views about the future of synthetic biology in UK food and agriculture. I conducted 30 semi-structured interviews via Zoom videoconferencing software with members of the research community, policymakers, funders, industry and non-governmental organisations, guided by two broad research considerations:

A. What are the implications of synthetic biology for UK food policy?
B. What are the implications of relevant UK government policies on the development of food-related synthetic biology in the UK?

Exploring these questions generated a rich dataset that I first analysed thematically. This analysis, and later discussions about it, prompted me to develop a Finitist analytical lens, using my concept of GM Trauma presented in Chapter Five. I embarked on a second round of deeper, more explanatory analysis, focussed on three new and significant questions:

1. What are the ways in which synthetic biology is constructed by this sample of its stakeholders?
2. Why did these stakeholders construct synthetic biology in these ways?
3. What are the implications of these constructions for UK food policy?

1.7. Original contribution to knowledge

Within the vast and varied literatures on sociologies of science and scientific knowledge, this thesis contributes to a small body of knowledge on synthetic biology and its potential futures, and possible approaches to governance in the UK. My focus on food policy adds to the limited literature around the potential roles of synthetic biology in food and agriculture, and positions my thesis alongside previous explorations of governance in terms of agenda-setting and strategy (e.g., Marris & Calvert, 2020), responsible (research and innovation) (e.g., Taylor & Woods, 2020), and specific applications of synthetic biology (e.g. Stirling *et al*., 2018).

Also adding to a large, cross-disciplinary, international body of literature on GM, this thesis characterises the ways that past experiences of GM controversies, and the long shadows cast by them, manifested across my sample. This is something I term ‘GM Trauma’, which:

A) Contributes to views on what synthetic biology is, its definitions, boundaries and status as potentially controversial or risky or not,

B) Frames ways that participants felt publics should be engaged with, communicated with or managed,
C) Supports views about the status and value of scientists and science in policy arenas, often to the exclusion of other stakeholders.

GM Trauma has, I suggest, practical implications for governance, contributing to insularity and defensiveness across stakeholders, scientific and policy communities, an over-reliance on scientific expertise in synthetic biology-related policymaking spaces and exclusion of other viewpoints. This promotes siloed thinking and narrow focus on technoscientific notions of risks, safety and economic priorities.

To arrive at my thesis, I draw on qualitative data collected from a sample of thirty participants involved in the research community, policymaking, industry, funding and non-governmental organisations. The composition of this sample, coupled with the collection of data during a period of significant social, economic and political upheaval in the UK, provides an originality of scope and context that is to my knowledge unrepresented elsewhere in the literature.

1.8. Chapter outlines

This chapter has introduced some background information on the project, synthetic biology and its governance. It has also set out the research questions and a claim to originality.

Chapter Two explores the literature on synthetic biology and where developments in the field might go. This begins with a summary of some of the definitions proposed by commentators, as well as other frequently used language around the field's interdisciplinarity. I consider what this might say about the field's actors, their aims and intentions. I go on summarise existing research on attitudes towards synthetic biology and genetic modification. Then, I consider how sociologies of science, like the Sociology of Scientific Knowledge, can support understandings of these topics. Finally, I set out some of the gaps in the literature and explain where my research sits in the broader landscape.

Chapter Three turns to the literature on governance. I explore notions of science-for-policy, as well as discussions of the current governance landscape. This includes literature on the use of comparators, risk assessments, developments in research as well as policy, Responsible Research and Innovation approaches and the roles of expertise. I

go on to discuss food policy literature on the roles of science and technology in food and agriculture.

Chapter Four details the methodological approach and choices taken to collect and analyse data. I begin by reiterating the focus of the study and summarising how the methodological approach was derived from the research questions. I then describe the research design, giving contextual details about the periods of design and fieldwork. Practical elements of the fieldwork are explained, including the use of Zoom videoconferencing technology necessitated by the pandemic. Following this, data analysis procedures are detailed, setting out the use of NVivo 12 software to facilitate thematic analysis, followed by further analysis using the concept of Finitism and the analytical lens of GM Trauma. Lastly, I reflect on the ethical considerations and ethical approval of the research and discuss reflexivity and positionality.

Chapter Five is the first of three data and findings chapters, exploring the theme of GM Trauma, or participants' experiences of past GM controversy. I consider the views of participants with first-hand experiences of conflicts with other stakeholders, as well as those who were involved first-hand with GM-related work at the time of GM controversies but who did not report conflict experiences. I also detail the observations and views of (often younger) participants who have learned second-hand about the impacts and debates around GM controversies. This analysis informs a discussion of the ways in which GM Trauma influences thinking on synthetic biology, discussed in the chapters thereafter.

Chapter Six focusses on constructions of synthetic biology in the light of GM Trauma. I discuss participants' definitions of synthetic biology and the ways in which it was constructed as novel, promising or not. I discuss participants' sometimes conflicting characterisations of synthetic biology and their perspectives on possible trajectories of the field. I also present the various ways that participants drew on experiences of GM controversies to conceptualise publics and how this contributed to participant views on how publics might be communicated with or managed. This leads me to an exploration of views on what communication might achieve, and how this appears tied to notions of scientific progress.

Chapter Seven, the final findings chapter, explains how participants perceived synthetic biology in food and agriculture and its governance in the UK. I begin with the contextual information that participants raised, including the socio-political context of a convergence of Brexit and the COVID-19 pandemic, and the barriers and opportunities

that these were thought to present. I show how participants' perspectives on current governance were influenced by GM Trauma, including views on overregulation, reactivity, investment, funding, and the range of actors and institutions involved in oversight. I also explore factors framing participant views of synthetic biology's food policy implications, including perceptions of multifaceted risk, ethical considerations and conceptualisations of naturalness and unnaturalness.

In the discussion, Chapter Eight, I address my research questions. I explain my main argument, and the interpretation of the data that supports it. This includes participant views on the potential implications of synthetic biology for the environment, health, livelihoods and animal welfare. I also explore current and potential future governance, including a shifting policy landscape, expertise and insularity in policymaking as well as perceptions of past, present and future controversy.

Chapter Nine concludes the thesis with a summary of recommendations. These include recommendations for policy and further research.

Chapter 2: Literature review

2.1. Introduction

In November 2012, Synthetic Biology was declared to be one of the Eight Great Technologies set to propel the UK to future growth (BIS, 2013). At the time, George Osborne (2012), then Chancellor of the Exchequer, stated that "synthetic biology will heal us, heat and feed us", which has become something of a 'catchphrase' for the field (Marris & Calvert, 2020). The final part of this phrase, promising that synthetic biology will feed us, is underpinned by assumptions of a good grasp of what synthetic biology is and where it might go.

In this literature review, I explore the social scientific scholarly landscape relevant to synthetic biology's potential roles in food and agriculture. The scope of this review was chosen in order to best distil and find some touchpoints between the broad and varied literatures relevant to my research. To this end, I focus primarily on social science literatures specifically about synthetic biology. I also refer to literature by synthetic biologists covering the identity, promise and potential futures of the field, to reveal some of the dynamics and opinions within it. A very small subsection of these scientific and social scientific literatures encompasses synthetic biology applied to food and agriculture, particularly literature on attitudes towards these applications and the relationship between synthetic biology and genetic modification. In Chapter Three, I set out the relevant policy landscape and discuss the literature on how synthetic biology is governed in the UK.

2.2. Definitions of synthetic biology

According to Calvert (2013:2) "one of the immediately striking features of synthetic biology is that there is a great deal of discussion about what is and what is not synthetic biology, with competing definitions and border disputes". Even the term 'synthetic biology' itself raises questions. The conceptual origins of the word 'synthetic' in the context of synthetic biology are unclear, and the adjective has multiple connotations.

Szybalski (1974) used the term 'synthetic biology' to refer to his hopes of challenging existing understandings and theories of how chemical and biological material contributes to "the function of natural cells" (Benner *et al*., 2011:2). Benner *et al.* (2011) also suggest that the primary function of synthesis is to allow scientists to understand processes and components of biological systems, by attempting and often failing to re-create those systems. Benner *et al*.'s (2011) interpretation of synthesis as the defining feature of synthetic biology does not

emphasise Szybalski's (1974) end-goal of creating "new forms of life", but rather situates synthetic biology within the realm of a fundamental learning process. Braun *et al.* (2019) echo this, suggesting that one of the definitions of synthetic biology is:

> A more or less strict engineering approach in developing, redesigning, and building biological parts, devices and systems in order to better understand processes in nature, mechanisms of life and living, and concepts such as life on a conceptual level. (Braun *et al.*, 2019:2)

This distinction helps to conceptualise the act of synthesis (for research purposes within the laboratory) as separate from the perhaps more problematic 'synthetic artifact' which may exist outside the laboratory. However, in scientific communities, synthesis is, in most contexts, a contrast to analysis or observation. Synthesis is the act of hands-on production, resulting in an observable object or artefact.

Building on conceptualisations of synthesis (and design), Calvert (2013) separates the endeavour of 'engineering biology' into three distinct branches or schools. The first is the construction of standardised biological parts. Calvert's first school relies on the characterisation and synthesis of 'biological parts', which may refer, for example, to anything from DNA to plasmids to genetic sequences (Calvert, 2013). Gardner and Hawkins (2013:872) describe "the standardisation and abstraction of biological components" as the "distinct founding idea of synthetic biology", something which the authors claim has become clouded and confused by the emergence of other definitions. These 'biological parts' may permit the construction of complex, reproducible, genetic pathways into organisms for various purposes. For example, 'biological parts' (e.g., DNA) from external sources might be constructed in microorganisms (bacteria, yeasts and algae) for the biosynthesis of chemical compounds.

Holm and Powell (2013) differentiate this from systems biology (which according to the authors "aims to understand the causal structure of 'naturally occurring' biological systems" (2013:628)) due to the possibility that these biological parts, in theory, could also be combined to construct novel biological systems or whole genomes. This forms Calvert's (2013) second school - the synthesis of whole genomes. Some milestones of the field have involved attempts to engineer synthetic genomes, (e.g., Yeast 2.0), through the "design and construction of new biological parts (genes), devices (gene networks) and modules (biosynthetic pathways), and the redesign of biological systems (cells and organisms)" (Pretorius & Boeke, 2018:2). Holm and Powell (2013:638) suggest that it is the application of "rational engineering principles" to the practice of combining biological parts that gives synthetic biology the promise of "unprecedented control over organisms and their properties"., Reflecting this,

Andrianantoandro (2006:12) for example described synthetic biology as: "a hybrid discipline, combining elements of both engineering and science to achieve its goal of engineering synthetic organisms".

Braun *et al.* (2019:2) suggest that one "common denominator" of synthetic biology definitions is the aim of a streamlining approach to 'redesigning' biology. Braun *et al*. (2019:2) summarise this aim as the design and construction of "minimal structures, which are able to represent a functional unit by only comprising the lowest number of genes necessary to maintain it". Braun *et al.* (2019:2) describe two approaches to this process. The first is a top-down approach involving "trying to progressively simplify cells by removing parts and structures (Venter's approach) which are perceived to be unnecessary to sustain the essential properties of cellular life, such as self-maintenance and self-reproduction." The second approach is the creation of simple 'protocells':

> Protocell models, which are constructed by involving and combining simple membrane-bound and cell-like components, try to explain how both a pre-biotic—with regard to a more historical angle—and a synthetic cell—with regard to a more bio-technological perspective—can be designed and constructed. (Braun *et al*., 2019:2)

This strand of work on 'protocells' was previously identified by Calvert as the third school of synthetic biology (2013). From an engineering perspective, creation of 'protocells' may be an attempt to reduce chaotic biological systems to manageable parts, minimalised for efficiency and predictability. Working on 'protocells' can also permit a process of understanding how an artificial cell functions, with an end goal of "absolute control" (Calvert, 2013).

Other definitions of synthetic biology emphasise the field's interdisciplinarity. Meckin and Balmer (2019:2), citing Silver (2009), suggest that:

> Synthetic biology is *an interdisciplinary area of biotechnological research* in which long-standing and recently developed genetic engineering tools and techniques, alongside engineering and design principles, are employed in the hope of 'making biology easier to engineer'. (Meckin and Balmer, 2019:2, emphasis added)

Drawing on Silver (2009), Meckin and Balmer (2019) portray a complex mesh of disciplines, techniques and principles involved in synthetic biology by situating the field within biotechnological research and embedding the ideas of design and engineering biology as central components. Clarke and Kitney (2020) offer a similar representation of the fundamental role of design in conceptualisations of synthetic biology, stating:

> At the heart of synthetic biology is BioDesign, applying the engineering principles of modularity, standardisation and characterisation/abstraction to

> improve the practical capacity to programme and construct biological systems to produce specific human designed outputs with predictable properties and functions. (Clarke & Kitney, 2020:114).

Clarke and Kitney's definition (2020), like that of Meckin and Balmer (2019), places emphasis on synthetic biology's definition as an interdisciplinary field applying engineering principles to biology.

Social scientists like Jane Calvert and Pablo Schyfter have also researched synthetic biology's interdisciplinarity and the dynamics between the field's engineers and biologists. Calvert (2013) suggests that engineers in synthetic biology rely on the expectation that the uncertainty and unpredictability of living things can be overcome, controlled, or reduced, while biologists seek to explore and understand the complexity of the natural world. Calvert (2013) also argues that this difference in aspiration arises because engineering is instrumental by definition, meaning that knowledge is intended as a means to a certain end, often the (re-)design and construction of an artifact. Biology, on the other hand, accepts knowledge and understanding as an end in itself (Calvert, 2013). As such, there are marked differences in synthetic biologists' understandings of the aims of synthesis in their work, shaped by the ideological underpinnings of the fields and principles with which they align most closely. Schyfter (2012:31) suggests that:

> Synthetic biologists aiming to construct functional biological artifacts seek to design nature; synthetic biologists whose goal it is to comprehend existing organisms and processes seek to find their 'underlying' design. This focus on design leads many synthetic biologists to suggest—following engineers—that to understand an entity is to be capable of constructing it. (Schyfter, 2012:31)

Schyfter and Calvert (2015) later argue that individual synthetic biologists can be categorised according to their commitment to biological or engineering intentions (or ideologies). Schyfter and Calvert's (2015) approach divides individuals according to goals across an ideological spectrum where biology and engineering sit at opposite ends. To some extent, this emphasises what the authors describe as "fragmentation" across synthetic biology's main disciplines, and in-fighting among ideologies. However, the combination of such differences in goals is sometimes described as an overarching aim of synthetic biology as an interdisciplinary area: seeking both to understand (biology) and create (engineering) biological parts and systems.

Looking beyond biology and engineering, synthetic biology's interdisciplinary projects are arguably a menagerie of many more disciplines. The degree of diversity within synthetic biology projects means that it is difficult to determine the extent to which knowledge, methods and goals are *integrated* between disciplines, calling into question the definition of the field as

interdisciplinary. As one example from the biotechnology literature, Clarke and Kitney (2016:245) recommend defining synthetic biology as a 'translational field', building upon foundational research from "biochemistry, systems engineering, molecular biology, plant sciences, chemical engineering, informatics, microbiology" to address major problems (although undefined in any specific sense) using engineering design principles. This suggests the selective adoption of techniques and ideas from various fields, rather than the integration of concepts and ideologies.

Information and computer technologies play an increasingly large role in the reading and synthesis of DNA, meaning that these fields are usually included as part of the interdisciplinary team (Pretorius & Boeke, 2018; Balmer *et al*., 2015). Project teams often also feature collaborations with social scientists, policymakers, ethicists, lawyers, and designers (Balmer *et al.*, 2015). Controversially, the types of roles inhabited by practitioners from these varied disciplines may be designed at the grant application stage, without collaboration from relevant parties (Balmer *et al*., 2015). Taking social science (particularly sociology) as an example, the EPSRC's website states that "effectively engaging the public in a dialogue around their concerns and anxieties is the most effective way to address those anxieties and prevent public perception challenges", recommending that proposals request resources to "employ additional expertise to embed responsible innovation in your project. e.g., collaborators from the social sciences" (EPSRC, 2020a).

Within existing synthetic biology projects, Balmer *et al*. (2016a) recommend a neighbourly, understanding, and frank approach to shared practices of reflexivity in order to integrate colleagues and disciplines in collaborative working. However, if disciplines can be considered "neighbours" (i.e., each are separate but inhabiting the same broad area), perhaps a better definition of synthetic biology is that it is a multidisciplinary[5] area rather than an interdisciplinary one. On a semantic level, the term 'multidisciplinary' suggests several distinct disciplines working alongside each other and sharing knowledge, while retaining the implication that that there may be circumstances in which integration between disciplines is either impossible or undesirable. Recognition of the "fences" (Balmer *et al*., 2016a) between multiple disciplines, including understandings of epistemology and ontology, may open up the field to considerate and creative practices.

[5] The Oxford English Dictionary definition of 'multidisciplinary' is: "combining or involving several *separate* disciplines' (OED, 2020 - emphasis added).

The multidisciplinary nature of synthetic biology can be said to contribute in part to the vagueness of describing the field. Not only is there no single agreed definition of the field, but it is possible to deploy the term 'synthetic biology' to refer to an enormous range of activities (Gardner & Hawkins, 2013; Schyfter & Calvert, 2015). The field's expansion (sometimes described as fragmentation – e.g., Schyfter & Calvert, 2015) has led to efforts to categorise work, for example, into three branches of research (schools) underneath the synthetic biology umbrella term (Calvert, 2013). Gardner and Hawkins (2013:871) suggest that "the definition of the field has evolved to a breadth so extensive that it has become synonymous with the terms 'Biological Engineering' and 'Biotechnology'". There is a clear financial incentive for this, as projects operating within synthetic biology may be able to access a large pool of funding from various sources (Pei *et al.*, 2012; Marris & Calvert, 2020). However, the expectations and intentions across disciplines are often opaque and misaligned, resulting sometimes in a lack of the productive integration and collaboration implied in the term 'interdisciplinary'.

Kearnes (2013:455) argues that the sites in which the field of synthetic biology is "defined, debated and articulated … have largely been devolved to a range of intermediary organisations (research councils, learned societies and translational research institutions)". Access to these sites by scientists might be determined by the extent to which proposed projects purport to align with the priorities of these organisations. In turn, this can lead to wide-reaching promises about research directions, and the outcomes that may be achieved (Schyfter & Calvert, 2015). Such promissory rhetoric often has an economic slant, confidently suggesting that synthetic biology might bring about economic growth and jobs. The result produces a cycle of reinforcement:

> If a new field is expected to succeed, the more people will invest in it, which means it will be more likely to succeed. It is in this sense that expectations can be performative; the supposition that something will occur can bring that something into existence. Practitioner discourse, such as promissory rhetoric, can shape policy-makers' and funders' expectations. The expectations can in turn have material implications in terms of funding, organisation and resources. (Schyfter & Calvert, 2015:361)

Such claims about synthetic biology's promises are also highlighted by Yearley (2009). However, as synthetic biology's definition is uncertain, the field may be subject to redefinition by funding organisations, according to their own priorities, which in turn can alter the direction of research efforts and activities (Kearnes, 2013). In one example, Kearnes (2013:458) identified "the redefinition of synthetic biology as a national research priority" led to a dramatic alteration of strategic direction of many synthetic biologists. In the UK, a key component of accessing this funding was interdisciplinarity, partly through the active inclusion of social

scientists in projects to demonstrate consideration of the ethical, legal, and social implications of the funded work (Marris, 2015; Marris & Calvert, 2020). Furthermore, Kearnes states that this funding incentivised the standardisation of biological parts to progress on an 'open source' model, where data is held in the public domain, but with a change to an economic imperative. In so doing, "the terminology of 'open-source biology' has been replaced with an emphasis on possible industrial applications and forecasts of future market opportunities" (Kearnes, 2013:458). It could be argued that part of this change is the retitling of 'synthetic biology' as 'engineering biology'.

2.3. 'Public' attitudes

The topic of public attitudes (and implicitly, public acceptance) remains relevant as synthetic biology advances. Partly to gain insight into this, funders have long sought to embed social scientists into synthetic biology projects from the outset (Molyneux-Hodgson & Meyer, 2009).

2.3.1. Role of social science

According to Molyneux-Hodgson and Meyer (2009), to understand why many synthetic biology projects have integrated social science as a strand of work, it is important to look at experiences within the timeline of the field. Molyneux-Hodgson and Meyer (2009:145) summarise the role of social sciences in synthetic biology as follows:

> Perhaps this is a key difference between synthetic biology and other communities: the fact that the social sciences are posited as not only a legitimate but also a constitutive element of the community. This 'upstream' involvement of social scientists is commonly explained by the need to avoid controversies such as those around genetically modified organisms. Hence, it seems to us that, like other emerging communities, the synthetic biology community mobilizes hopes, expectations and promises, but unlike other communities, it has to a certain degree internalized a prominent fear[6] and is thus institutionalizing and policing the involvement of social science in a rather novel way. (Molyneux-Hodgson & Meyer, 2009:145)

Balmer *et al*. (2015) reflect on the types of roles that social scientists, in this case science and technology studies (STS) researchers, create and inhabit in an effort to collaborate with others in synthetic biology teams. Balmer *et al*. (2015) outline how STS scholars are included in synthetic biology projects as representatives of the public, foretellers of the ways the technology will develop, critics, troublemakers, educators, inducers of reflexivity, co-producers

[6] This notion, that GM experiences have been internalised by the 'synthetic biology community', is something that I later draw out from my own data. Please see Chapter Five onward.

of knowledge, colleagues and even gossipers and "trophy-wives". While some of these roles are hard-won and desired, others are forced upon social scientists and laden with expectations (which are often unattainable). These can be unreasonable and could be indicative of a lack of collaborative understanding between disciplines in the team, creating unsatisfying, restrictive, and unproductive partnerships (Balmer *et al.*, 2016a).

More recently, Marris and Calvert (2020) also describe a long-embedded framing of social scientists as practitioners in managing and assuring the 'downstream' success of synthetic biology. A key component of this involves understanding 'public' concerns through public engagement, underwritten with an expectation that these activities will ensure widespread acceptance.

2.3.2. Attitudes towards GM

Assumptions made about attitudes towards GM foods are sometimes employed as a cautionary tale within synthetic biology-related discussions (as described by e.g., Marris, 2013) to enforce the idea that public dialogue is a necessary component of ensuring public acceptance. Most recently, a study commissioned by the UK Food Standards Agency (FSA & Collingwood Environmental, 2020) with the title *Consumer Attitudes Towards Emerging Food Technologies*, gave the (arguably oversimplified) summary that:

> There is no clear consensus in the reviewed literature on consumer views towards synthetic biology in food. *Attitudes toward synthetic biology are similar to those to GM food* with concerns around 'unnaturalness' and 'playing God'. On the other hand, consumers express a sense of hope that synthetic biology could address issues such as food security. This suggests ambivalence about the technology. (FSA & Collingwood Environmental, 2020:5, emphasis added)

Clearly, attitudes towards GMOs are complex, as has been long expressed by social scientists, and which I will now explore. It is relevant to consider what can be learnt from research on attitudes towards GMOs (including a range of assumptions), acknowledging fully that the nuances of these views cannot be extrapolated to 'predict' attitudes towards synthetic biology-derived foods. I will then go on to explore the limited evidence base on attitudes towards synthetic biology.

Building on several decades of social science scholarship in this area, Marris (2001) identifies seven assumptions[7] arising from GM group discussion activities conducted in the UK,

[7] Marris uses the term 'myth' to reflect that such assumptions are largely unsubstantiated but nonetheless accepted as so 'evident' that they are not adequately interrogated.

France, Spain, Italy and Germany between 1998 and 1999, as part of the "Public Acceptance of Agricultural Biotechnologies" project. These assumptions remain relevant today. The first is that "the public is 'for' or 'against' GMOs" (Marris, 2001:545), which assumes a positivist view that there is a discoverable (real), homogenous public attitude towards genetic modification. This has been largely discredited, and it is well documented that attitudes towards genetic engineering in foods are complex and variable (for reviews of the relevant literature, see Frewer *et al.*, 2011, 2013 and Frewer, 2017).

Marris's second myth is that "the public is 'irrational and unscientific'" (2001:546) and that this is directly linked to a perceived lack of public support of technology. This idea that a deficit in knowledge results in rejection of scientific developments is known as the 'Deficit Model', which is discussed further in Chapter Three. The 'Deficit Model' implicitly relies on the assumption that biotechnological advances are beneficial and should be accepted, and this notion invites the deficit model to repeated challenges by social researchers exploring attitudes towards GMOs and biotechnology (e.g., Martin & Tait, 1992; Azodi *et al*., 2019). For example, in a recent paper on attitudes towards GM, Azodi *et al*. (2019) find the opposite to be true. Participants with a greater "ability to think scientifically" considered biotechnology, in a general sense, to be of high risk (Azodi *et al.*, 2019). Participants who self-reported greater trust in academia and industry scientists also suggested the technologies were riskier (Azodi *et al.*, 2019). Indeed, Marris (2001:546) argues that participants were demonstrating self-awareness of any lack of knowledge and were not holding "false beliefs". For the most part, beliefs were about the nature of the developments (for example "why do we need GMOs? Who will benefit from their use?"), not the specifics of the science (Marris, 2001:546). Despite this, it continues to be assumed that increasing public engagement equals increasing public understanding, which in turn (it is sometimes hoped) creates receptiveness and acceptance to a novel technology (EPSRC, 2020a).

Marris (2001:546) also conceded that a third assumption, that "people are obsessed with the idea that GMOs are 'unnatural'", has a kernel of validity. However, 'public' understandings of the 'natural' are often not application- or technology-specific, according to Marris (2001). While "directly modifying the genome was qualitatively different from any previously used technique", several participants' concerns were:

> also expressed in relation to other agricultural innovations, such as use of pesticides, animal-derived animal feed and antibiotics in animal feed. Participants felt that such developments were driven by the need or desire for increased productivity, regardless of health and environmental considerations, thus leading to uniform and tasteless food. The concept of organic agriculture

> was perceived as reversing or opposing this development, whereas GMOs were perceived as the ultimate incarnation of this trend. (Marris, 2001:546)

Perceptions of what is 'natural' or 'unnatural' are linked to individual interests and values, often related to the environment, human health, social and cultural factors. Interpretation of technologies may be filtered and shaped by these values and considered alongside judgements about the intentions of actors involved. The language of 'naturalness' is also evident in interaction between industry and consumers today and is sometimes deployed to differentiate biosynthesised products from the 'synthetic' or 'artificial', and which are discussed in Section 2.4.

Marris (2001) goes on to address another assumption about attitudes towards GM, which is that the 'public' is less opposed to medical than agricultural applications. Such a distinction between categories of application is often evident in GM attitudes surveys (Marris, 2001; FSA & Collingwood Environmental, 2020). However, the concerns attached to applications are nuanced. For example, while both medical and agricultural categories imply an element of consumption, "matters of choice, transparency and information are very differently treated in the two sectors" (Marris, 2001:546-547). Medical applications are typically viewed as consumed by "a small, targeted portion of the population who need it at a precise point in time and for a particular defined period" (Marris, 2001:547). By contrast, food-related applications may be widely available and unlabelled, and the production process perceived as being less contained (particularly in the case of GM crops). Such nuanced views suggest important ethical, social and values-based reasoning, which is difficult to dismiss as a misinterpretation of an application's safety.

Marris' (2001) final three myths deal again with perceptions of the public as uninformed and irrational about topics such as risk and benefit, shown not to be the case. Indeed, it cannot be assumed that "people demand 'zero-risk'" (Marris, 2001). Rather, the risks and benefits of technologies are weighed against understandings of concepts like trust in institutions, corruption and business motivations. These concepts also inform the rejection of Marris' last myth, that "it is selfish for citizens in First World countries to block technologies that could benefit people in the Third World". Instead of 'selfish' fears that GMOs could pose a risk to those in 'First World' countries, individual views tend to be sceptical of promises to "improve living conditions in developing countries", and mistrustful of private companies proclaiming such goals (Marris, 2001:547).

Overall, Marris' (2001) work offers a useful insight into assumptions about attitudes towards GM foods, a topic with a long history of research, also explored by Wynne (e.g., 2001),

Kearnes *et al*., (2006), Grove-White *et al*. (2000), among others. For Grove-White *et al.* (2000:7), some of the objections towards GM can best be distilled as public evaluation of and reaction to "de facto official denial of humanly significant dimensions of *uncertainty* or *ignorance* [which] has been acting to foment, rather than to alleviate, public scepticism and mistrust, where doubts have existed" (emphasis in the original). Wynne (2001:447-448) describes "the predicament that we can never credibly pretend to control (neither practically nor intellectually, in the form of prediction) the consequences of our decisions and commitments." In their overview of scientific risk assessment in food policy, Lang *et al*. (2009:205) also explain "the importance of the assumptions that inherently frame the scientific assessment of risk […] a lack of openness and a lack of clarity with the political risk managers seeking to promote scientific opinion as a concrete basis for policy decisions, while failing to acknowledge the uncertainties that may be involved." There remains nonetheless a wealth of often contradicting literature attempting to find trends in views towards GM. Some authors claim differences in attitudes towards GM according to age or gender, with younger people and men sometimes determined to be more willing to consume and purchase GMOs than others. This, taken alongside Marris' (2001) myths, offers a picture of attitudes towards genetic modification as varied and nuanced at the individual level, and context dependent.

Overall, the perceived public rejection of GM crops in the EU is often deployed as an example of the importance of public dialogue in the 'success' of novel technologies (Marris, 2015). Tait (2009:150-151, in Schmidt *et al*., 2009) describes a perceived "stigma that has become associated with GM crops" and how stakeholder engagement "may be important but it will not guarantee a smoother ride for synthetic biology compared to GM crops." On this topic, Pouvreau *et al*. (2018:10) claim that "once the current societal issues will be addressed, crop re-engineering will finally have the opportunity to fully revolutionise agriculture". Alternatively, de Lorenzo and Schmidt (2018:179) suggest that "early involvement of the public, amateur biologists and other stakeholders will help steer the direction of technology in socially acceptable and responsible ways, rather than simply avoiding a repeat of the European experience with GM crops". However, based on the assumption that synthetic biology is positive and should be supported, public dialogue initiatives often narrowly seek to reduce the (imagined) threat of public rejection to novel technologies (Braun *et al*., 2019; Marris, 2015). The literature calls for more open dialogue on synthetic biology, but it is suggested that the spaces for public involvement need to be reimagined (Marris & Calvert, 2020; Rosemann & Molyneux-Hodgson, 2020).

2.3.3. Attitudes towards synthetic biology

As demonstrated, several decades of research on attitudes towards GM foods expose a number of (persistent) assumptions about 'public attitudes'. Some parallels have been drawn recently between attitudes towards GM and synthetic biology, despite there being limited evidence to support this:

> Attitudes towards synthetic biology as an area of technology (rather than as applied to food) seem to be similar to those for other emerging technologies, and specifically GM technologies, and have not changed since 2009. However, the limited studies on specific food applications of synthetic biology suggest a nuanced and context dependent picture. (FSA & Collingwood Environmental, 2020:43)

The report cited above relies on six papers about synthetic biology applied to agri-food, two of which are reviews of the academic literature rather than attitude surveys. None of the papers reviewed ask participants to discuss attitudes towards GM *and* synthetic biology. As a result, it is unclear what informs the above conclusion when earlier in the report it is stated that:

> Since 2009 there have been papers on specific applications of synthetic biology in food and as predicted, views do have some similarities to attitudes towards GM foods. However, there is still a need for longitudinal studies and more systematic studies on specific food applications of synthetic biology. (FSA & Collingwood Environmental, 2020:21).

The mention of "studies on *specific food applications* of synthetic biology" (FSA & Collingwood Environmental, 2020:21, emphasis added) is an important point. The UK's Synthetic Biology Public Dialogue (TNS-BMRB, 2011) did not include food-related case studies, but rather considered 'food and crops' as a possible area in which applications may be developed. The result is that the findings are rather generic, highlighting concerns about food choices, traditional farming methods, environmental sustainability, land use, unintended release, commercial monopolies, company motivations increasing demand as populations increase, food distribution inequalities and waste. While at the time of the study (2009-2010) this may have been appropriate due to a lack of applications, possible case studies do now exist. However, the research has not been repeated.

In one example review of the literature on attitudes towards synthetic biology, Kamrath *et al*. (2019) attempt to identify the factors involved in the formation of views. Factors assessed include perceived benefits, familiarity with the technology, trust in institutions, environmental concerns, quality perception, health risk perception, sociodemographic factors such as age, gender, education, residence, income, as well as ethical and moral concerns (Kamrath *et al*., 2019). Kamrath *et al.* (2019) find that positive attitudes may reflect beliefs about the benefits

of scientific advancement for societal goals, such as alleviating hunger in the global south. Among the varied opinions, attitudes towards genetic engineering in foods may be based on concerns about observable issues like safety, health, the environment and farmer livelihoods. Negative attitudes may also be linked to less observable factors, like 'unnaturalness', neophobia (fear of novel foods), disgust (the 'yuck' factor) as well as moral and ethical objections.

Like the FSA and Collingwood Environmental (2020), Jin *et al*. (2019) also note that there is relatively little empirical research into attitudes towards applications of synthetic biology in the food industry. However, Jin *et al*. (2019) review the media portrayal of synthetic biology to date and summarise that media output thus far (in a primarily non-food context) is positive, in contrast to some publications about GM. In this review, attitudes towards synthetic biology are described as "uncrystallised", but the authors suggest views may be shaped by this positive press (Jin *et al*., 2019). Frewer (2017:690) similarly emphasises that further "primary research into existing attitudes and perceptions across different stakeholder, end-user and civil society constituencies" is important for assessing opinions over time and views in different social contexts.

Elsewhere, Dragojlovic and Einsiedel (2013) and Bauer and Bogner (2020) consider how synthetic biology is framed in discourse, often using problematising language. Dragojlovic and Einsiedel (2013) found (perhaps unsurprisingly) that when synthetic biology is framed as 'unnatural', participant attitudes towards certain applications (involving animals, but not plants) are less positive. Bauer and Bogner (2020) found that, in discussions framed around synthetic biology's ethics, risks or governance without specific example applications, participants referred to general debates about ethics that could apply to any biotechnology. This study also found significant optimism about synthetic biology as 'technology for progress' when this narrative was introduced to participants and examples given (Bauer & Bogner, 2020). Both papers emphasise that all framings of technology must be explicit and openly outlined, to promote creative discussion. Further, the papers highlight that attitudes towards synthetic biology – and arguably all emerging technologies – are highly context-specific and individual. Similarly, Azodi *et al*. (2019) find that participants did not typically have varied views across biotechnology products and processes, but that views instead vary across individuals.

Alongside framings, some papers consider risk to be a factor in attitude formation towards synthetic biology (Jin *et al*., 2019; Robaey *et al*., 2017; Liu & Stewart, 2015). It is worth acknowledging that Marris (e.g., 2001, 2015), for example, adds nuance to this, suggesting that risk is one narrow consideration among many others. Nonetheless, possible

risks raised in the literature include the release and loss of control of engineered microorganisms, or the transferral of engineered traits to natural populations (Robaey *et al*., 2017). There is also mention of the risks of interactions of unpredictable, 'mutant', engineered microorganisms with ecosystems (e.g., Liu & Stewart, 2015). Furthermore, antibiotic use during R&D, although somewhat commonplace, is discussed as a potential driver of antibiotic resistance which could pose risks to human and animal health, as well as in cases of the accidental release of resistant organisms (Braga & Faria, 2020). Finally, the role of computer technologies, particularly computer modelling, in facilitating synthetic biology experiments may also present risks (Liu & Stewart, 2015). Algorithms and models could (beneficially) permit market access to companies that may not have the funding or resources for prolonged periods of experimentation. However, such technology could also be accessed by individuals with 'dual use' intentions, or by organisations that do not yet have the expertise to use it (although unlikely due to other cost and resource limitations – Marris *et al*., 2014). While judgements of risk are considered to inform both policy decisions and assessments of trust and willingness to purchase/consume at the individual level (Frewer, 2017; Kamrath *et al*., 2019), Jin *et al* (2019) suggest that more research is required at the individual level on how judgements of risk are made.

More research is also required on the ethical concerns raised by synthetic biology in a food context. One application of particular ethical concern may be gene drive technologies, described by Goold *et al*. (2018). Gene drives are a genetic engineering technology that alters the allele transmission probability in desired populations, meaning engineered traits can be passed to offspring and designed to spread through a population rapidly. Gene drive work is ongoing in mosquitoes, for example, to limit spread of mosquito-borne diseases. Goold *et al.* (2018) also connect gene drives with possible improvements in human welfare at work, for example by breeding cattle without horns, meaning human workers would be less likely to suffer injury by horned cattle in the workplace. Attitudes towards such applications are unclear and would merit future research, particularly in the context of anticipatory governance.

Overall, there is insufficient evidence on attitudes towards synthetic biology, its roles in food and agriculture, and its governance. In papers about synthetic biology (typically focussed on the field's perceived promise) the controversy around GM is regularly referred to as a lesson in the importance of 'public acceptance' during the development of emerging technologies (Marris, 2013; Molyneux-Hodgson & Meyer, 2009). In my view, the GM debate is nuanced and varied across individuals within societies (e.g., Frewer, *et al.*, 2013 and Frewer, 2017) meaning it is difficult to crystallise the experience into specific 'lessons'. Nonetheless, some

commentators on synthetic biology's development consider that repeating the experience of the GM debate is a "prominent fear" which is "internalised" by synthetic biology's proponents (Molyneux-Hodgson & Meyer, 2009). This fear is described as underpinned by assumptions about the public as a threat to the development of synthetic biology, something Marris (2015) describes as "synbiophobia-phobia", or the fear that synthetic biology will be feared by publics, and ultimately rejected, as GM is perceived to have been.

2.4. Sociologies of science

As alluded to in the sections prior, two (diverging but interlinked) branches of thought on sociologies of science with most influence on social scientific scholarship on synthetic biology include Sociology of Scientific Knowledge and Science and Technology Studies. The main similarities between them, relevant to this project, are their considerations of the interrelationships between science, technology and public policy, as well as science, technology and society. Much of the synthetic biology-related literature explored thus far, and the policy-related literature in the chapter that follows, considers the contributions of STS scholars (notably Claire Marris, Jane Calvert and others) to the social scientific study of synthetic biology. Broadly, such literature focusses most closely on the social roles occupied by scientists, the "norms and values of science as a career" (Rees, 2019) and offers scant discussion of scientific knowledge itself. Of course, scientific knowledge and its generation are foundational to an exploration of novel technoscientific fields like synthetic biology, and often form the basis from which they are governed. Relevant questions can be asked of synthetic biology, not least: What is synthetic biology? How is synthetic biology constructed, defined, and classified? And how can these constructions be explained?

2.4.1. The Sociology of Scientific Knowledge

The Sociology of Scientific Knowledge (SSK) is most closely associated with British scholars Barnes and Bloor. In its simplest form, it is based on a non-linear theory of science (see for example: Barnes, 1983; Barnes, Bloor & Henry, 1996). SSK acknowledges that there are accepted understandings of 'truth' (as well as 'society' and 'nature') but argues that concepts and their meanings are never fixed. While such understandings are sometimes assigned the descriptor 'true' or 'false' (see Bloor, 1999:84), they may be better described as 'successful' and 'unsuccessful' claims to knowledge (e.g., Kusch, 1999b:239). For SSK scholars, it is the process of producing these descriptors (their causation in their social context), and therefore scientific knowledge as a whole, that is of interest, because understandings and uses of concepts

are always contested in continual, individual and collective processes of negotiation and adjustment. Therefore, SSK's focus is the generation of claims to knowledge and their transformation into accepted knowledge, or not (Bloor, 1999). The reasons why specific interpretations 'stick' lies in human interactions, negotiations, interests, power and normativity within communities (Bloor, 1999:89; Harris, 1994; Kusch, 1999a & 1999b).

At the University of Edinburgh since the 1960s, SSK scholars have developed the Strong Programme in the Sociology of Scientific Knowledge, which "provides sociological explanations for the achievement of the status of knowledge for certain claims at the expense of others" (Rees, 2019, no page). The Strong Programme can be understood as a reaction to what SSK scholars perceive to be 'weaker' programmes in sociologies of science. For example, Rees (2019) notes that "Max Weber's (1946) claims regarding science as a vocation and Robert Merton's norms of science (1942) […] did not interrogate the product of scientific work, only the values and attitudes of scientific actors." Other perceived 'weaker' programmes that do engage with the generation of beliefs and scientific knowledge often avoid interrogating or explaining accepted, mainstream, 'rational' or 'logical' scientific knowledge (i.e., assuming it is correct and needs no further explanation) but might subject 'irrational' or 'incorrect' scientific knowledge claims to scrutiny. Rees (2019) explains that Mannheim, "more traditionally known for providing causal social explanations for beliefs" was one sociologist that Bloor (1991) felt was "essentially arguing that the development of rational, scientific knowledge does not need further explanation". This positions Mannheim alongside Lakatos, "who suggests that the role for 'externalists' in the history and philosophy of science (i.e., those who have not trained as a scientific professional) is to understand and explain the presence of irrational or incorrect claims in scientific knowledge" (Rees, 2019).

To address these perceived shortcomings in existing and ongoing sociological studies of science, and to provide a methodological blueprint for the study of scientific knowledge more directly, the Strong Programme is based on four tenets:

1. It would be **causal**, that is concerned with the conditions which bring about belief or states of knowledge. Naturally there will be other types of causes apart from social ones which will cooperate in bringing about belief.
2. It would be **impartial with respect to truth and falsity**, rationality or irrationality, success or failure. Both sides of these dichotomies will require explanation.
3. It would be **symmetrical** in its style of explanation. The same types of cause would explain, say, true and false beliefs.
4. It would be **reflexive**. In principle its patterns of explanations would have to be applicable to sociology itself. (Bloor, 1991:7, cited in Rees, 2019, emphasis added)

In short, Bloor recommends that the causes of both 'true' and 'false' beliefs, treated impartially by the researcher, require explanation in 'symmetry', as both 'truth' and 'falsity' are ripe for exploration, and of interest due to their social construction as such. Bloor (1999:89) explains:

> There is, of course, a causal story to be told as to why discriminations of truth and falsity are made in the way they are, upgrading one theory and downgrading another. […] In general, the account would deal with the pragmatics and contingencies of belief which would, for both theories, involve the generation and processing of data, its selection and evaluation, its perceived relation to existing bodies of theory, a distribution of expectations and power, and a set of goals and purposes. All of these judgements and decisions would have to be anchored in the practices and purposes of the relevant groups. (Bloor, 1999:89)

This presents a development of Kuhn's arguments (1970, 1996) that scientific knowledge is not a linear accumulation of 'facts' ('truths') but a complex, non-linear negotiation of often competing aims and problems within and among communities and individuals. More specifically, Kuhn (1970) argues that scientific knowledge must be viewed in its historical and social context, and in turn can be understood through interrogation of social 'reality'. This offers a relativist understanding of 'truth' as a product of social relationships. Kuhn also explores how scientific revolutions are characterised by the interactions between 'paradigms' – the shared examples, values and ideas within a scientific community. For Kuhn (1996:10-11), this process is cyclical: there is always a dominant paradigm, and 'normal science' is the scientific problem-solving work happening within the parameters of these dominant ideas. Alongside a dominant paradigm, competing paradigms may develop among the scientific community which raise questions that cannot be resolved without challenging dominant, accepted understandings (Kuhn, 1996). Once communitarian acceptance of a competing paradigm overwhelms the dominant paradigm, this is 'scientific revolution'. In short, Kuhn's main argument is that such processes and ideas are socially and politically constructed (Kuhn, 1970, 1996). In this sense, it is through a process of negotiation, shaped by personal and historical action and circumstance, that one paradigm may dominate over another. Shifts from 'unsuccessful' to 'successful' knowledge claims can be conceptualised as follows:

> Paradigm debates are not really about relative problem-solving ability, though for good reasons they are usually couched in those terms. Instead, the issue is which paradigm should in the future guide research on problems many of which neither competitor can yet claim to resolve completely. A decision between alternate ways of practicing science is called for, and in the circumstances that decision must be based less on past achievement than on future promise. The man who embraces a new paradigm at an early stage must often do so in defiance of the evidence provided by problem-solving. (Kuhn, 1970:156-157)

Acknowledging SSK's Kuhnian inspirations, one of the most important fruits of "the methodological commitments to causality and impartiality" provided by the Strong Programme's four tenets (Yearley, 2005:161) is Finitism.

2.4.2. The Finitism concept

The Finitism concept constitutes in large part SSK scholars' understanding that the tensions between concepts and ideas, and judgements of similarities and differences between them, have an integral human component: it is the human induction, processing and negotiation of concepts which produces classificatory decisions and resolves classificatory dilemmas (Barnes, 1983; Barnes *et al*., 1996; Kusch, 1999b). Finitism offers a basis for investigating and explaining how classification is performed in particular ways, why, and how categories and kinds can be stable, and can come to change.

Finitism provides that, when confronted with a new 'thing' (perhaps a concept, a product, an object, a 'kind'), understandings of that 'thing' are developed using a number of individual, social and contextual resources. Barnes suggests one model of the individual, internal mechanics of classificatory decision-making using his notions of N-Kinds and S-Kinds. For Barnes, references, labels or terms are attached to 'things' on the basis of pattern recognition or noticing similarities and differences between them. This functions in combination with collective, social activities of labelling and categorisation (discussed in depth in the following section), which may also be understood as, for example, performative labelling, collective reference and social priming. For example, a small, shiny silver disc may be recognised by some simply as a piece of metal (something SSK scholars would call a 'Natural Kind', something labelled by virtue of its 'natural' properties). If the metal disc had a hole in it, it might also become labelled as a washer, perhaps (one possible 'Social Kind', in this case, a 'thing' labelled according to the human use associated with it). The metal disc might also be understood as money (another 'Social Kind') if collectively referred to as money, learned to be worth a certain amount, and confirmed as such repeatedly and collectively in social contexts, by its use in transactions, for example. These theories are about how 'things' are categorised and labelled in social contexts, and how these labels are then learnt and passed on. An individual or group may make judgements about the ways in which a 'new thing' is similar or different to other 'things' that the individual or group has previously experienced, which in turn will be attached to a web of theories, notions, conventions and norms.

In brief, the possible ways to understand or classify something are potentially infinite - different individuals can interpret things in a potentially infinite number of ways. However, each individual's own past pool of experiences (or examples, or classifications) from which to draw similarity and difference judgements is finite, hence the term 'Finitism'. Finitism provides a pathway to investigating the social construction of knowledges in all their forms because, for the Finitist, there is no straightforward, non-negotiable, stable line connecting an objective 'reality' with its human classifications or interpretations – meanings are not fixed – and equally "the finite set of existing classifications does not foreclose how the next classification is, or should be, made" (Agar, 1998:650). Rather, humans always negotiate and socially construct the classification of new examples based on judgments about their similarities and differences to other examples. Applying a Finitist lens to, for example, the resolutions to scientific controversies, also allows for the assessment that it is through communitarian agreement, or simply a decision by some parties not to contest a classificatory decision any further (Yearley, 2005), that classification is performed, and categories are stabilised. Following the same thread, Finitism can also help to explain whole fields and branches of scientific knowledge through a relativist lens. In a revisit of the term 'paradigm', Kuhn (1974:482, reprinted in Kuhn, 1977:293-319) is explicit that for scientific communities, shared examples, unstable and negotiable, of "successful practice […] were its paradigms and as such essential to its continued research".

Despite clear merits in permitting the interrogation of processes of scientific knowledge-building, as demonstrated in a number of empirical SSK case studies (see Barnes & Shapin, 1979 for examples), and its resulting influence on thought around science and technology policy (e.g., Jasanoff 1990, 1992 and Wynne, 1992), SSK remains contested. SSK's critics perceive it as fringe to mainstream sociology, in part due to "overpublicized 'warfare'" with Mertonian, structural-functionalist perspectives on the sociology of science, and of sociology as a science itself (Shapin, 1995). Its unpopularity is described by Shapin (1995:297-298):

> [E]arly SSK took it as a primary task to create a legitimate space for sociology where none had previously been permitted, in the interpretation or explanation of scientific knowledge. […] to show-both theoretically and empirically-how a sociology of scientific knowledge was possible, and not as a professional extension of mainstream disciplinary practices into this terrain. On the whole, mainstream sociological practitioners did not want sociology to go in such directions or did not believe that it could be so extended. (Shapin (1995:297-298).

Shedding light on some criticisms of SSK, Collins and Yearley (1992a, in Pickering, 1992) discuss calls by some for SSK's reflexivity, or consistency: the turning of SSK to the study not

solely of scientific claims to knowledge, but its own social scientific claims to knowledge as well. This suggestion of reflexivity can be useful (and was pre-empted for this reason by Bloor as one of the four tenets of the Strong Programme), challenging SSK scholars to interrogate their own claims and practices as also socially constructed. The merits of such reflexivity are the unpicking of any suggestion, implication or assumption that SSK might hold an epistemological "high ground", while science has been shown not to "occupy the high ground of culture" (Collins & Yearley, 1992a:308). However, "as SSK has no direct, unmediated route to nature, so reflexive study can expect no immediate access to the truths of the social world" (Collins & Yearley, 1992a:306). SSK has been viewed by some as an illegitimate, individualist framework for interpreting scientific knowledge (Shapin, 1995:300) and the importance of attending to social and political dimensions (like networks) in particular have been raised by its critics. However, SSK's main success is that it carves out a space for explaining and interpreting scientific knowledge itself as socially constructed. This in turn can accompany discussion of social and political dimensions relevant to science, scientists and their roles in society, particularly through notable contributions like the concept of Finitism.

2.4.3. A Finitist re-reading of selected literature

The synthetic/natural divide

Earlier in this review, I mentioned that Finitism can provide a basis for understanding how conceptual disagreements come about and can be resolved. One such disagreement, or 'controversy', in the case of synthetic biology may be whether new cases of synthetic biology products can be accommodated into the classification 'natural'. Individual conceptualisations of the 'natural' are closely tied to understandings of the ethical and moral implications of genetic engineering, and such framings can influence attitudes (e.g., Dragojlovic & Einsiedel, 2013). In addition, 'naturalness' is also a concept of policy relevance. A recent regulatory amendment, The Genetically Modified Organisms (Deliberate Release) (Amendment) (England) Regulations 2022 makes special provisions for the release in England of GMOs with traits "that could have occurred naturally". However, no explanation is given as to the regulator's meaning of the term 'naturally', and the literature depicts naturalness as a complex concept (e.g., NCoB, 2015).

In a 2015 review of findings from academic research, public consultation or engagement on (un)naturalness, the Nuffield Council on Bioethics (NCoB, 2015:5-7) identified a number of constructs of naturalness or nature. Nature was sometimes perceived as delicately balanced

("in a delicate state of ecological harmony") with a complex and dynamic processes happening in equilibrium. Nature was also conceived of as wise ("inherently good, whole and perfect"); traditional ("familiar", "slow"); and pure, three constructs that highlight ideas of naturalness as 'good', 'untainted' and 'revered' (NCoB, 2015:6-7). This review found that participants in academic research, public consultation or engagement on this topic "often equated naturalness with rightness, and unnatural with wrongness" (NCoB, 2015:4). It was often viewed that attempts by scientists to "manipulate […] uncontrollable and unpredictable nature […] could lead to unforeseen and potentially dangerous outcomes" (NCoB, 2015:5).

Objections to genetic modification relating to such notions of (un)naturalness are also covered in the literature. This is addressed in Deckers' (2005, 2021) work on (un)naturalness, alongside the question of why some activities and 'things' are considered more unnatural than others. Deckers (2021) conceptualises naturalness as a spectrum, with high levels of human influence resulting in high levels of unnaturalness. Activities and 'things' that would not exist externally to human culture and influence may be considered the most unnatural, and, Deckers argues, potentially the most morally objectionable (Deckers, 2021). Activities that could conceivably exist outside human influence (perhaps breeding flowers) are thought of as more natural and less morally objectionable (Deckers, 2021). However, this is complicated somewhat, as, for Deckers (2021), 'nature' is sometimes viewed as all-encompassing, human beings and their actions are all part of nature, and thus to some degree 'natural' (Deckers, 2021). It is clearly difficult to pin down the boundaries between 'natural' and 'unnatural' in the literature, but such a distinction is nonetheless made routinely in research about attitudes towards technologies like genetic modification and cloning, for example (Deckers, 2021).

The natural has long been constructed as opposed to, variously, the unnatural, synthetic, human-made, social or cultural. In the context of novel technologies in food and agriculture, if a label, or classification, is, for example, 'natural', 'artificial', 'synthetic', 'unnatural' – then perhaps synthetic biology presents a question: "what if you cannot tell the difference?" For the Finitist, the classification of something as 'natural' or 'unnatural', or of something like synthetic biology as itself (un)natural, is unstable and negotiable as shown by the range of understandings presented in the paragraphs prior. There are, to quote Bloor's comments in a 2010 interview, "always circumstances and causes and potential problems that stand between previous applications and the next application of a concept […] There are no fixed meanings that can be taken for granted" (Li *et al.*, 2010:420-421). In this case, individual and collective understandings of what is 'natural' and what is 'synthetic biology' are undergoing negotiation by scientists, policymakers, NGOs, industry and others.

In a food industry context, there are noticeable attempts to bridge a conceptual distinction between the perceived 'synthetic' and the 'natural' through use of terminology associated with nature. One prominent example of a commercialised product marketed using this language is Cargill and Evolva's EverSweet®, a stevia sweetener produced through the fermentation of "specially crafted yeast" (in other words, genetically engineered) (Cargill, 2020b. Accessed: 2nd September 2020). There has been little discussion of this product, as noted by French (2019:251), who states that "the competitive production of steviol glycosides by major chemical companies (for example, Cargill and Evolva) is a prime example of a synthetic natural product on its way to replacing its living counterpart that has received little attention". It is unclear whether EverSweet® will replace plant-derived stevia sweeteners. However, descriptions of the plant itself and its 'natural sweetness' appear to be the central focus of Cargill's marketing campaign. Cargill's deployment of the term 'specially crafted' to refer to the genetically engineered yeast used to produce the sweetener evokes images of traditional, small-scale production, something often connected with notions of naturalness (NCoB, 2015; Cargill, 2020). Furthermore, emphasis on the fermentation process in marketing generates conceptions of 'natural' processes, similarly to other companies (e.g., Impossible Foods, 2020).

This is not solely a marketing advantage, but also an important regulatory and labelling distinction. In the EU, 'synthetic' chemical flavourings or aromas derived from petrochemicals cannot be labelled as 'natural', but this is not always the case for those derived from synthetic biology (EC, 2008). Flavourings produced through what is described as a 'natural' method (fermentation) can be labelled as 'natural', irrespective of whether a genetically engineered or synthetic biology-derived microorganism was involved in the production process. This has provoked some interesting dynamics and responses from NGOs seeking, in part, to explore and set out their understandings of naturalness in relation to such flavourings. For example, a prominent non-governmental organisation which, broadly speaking, opposes synthetic biology, Friends of the Earth has published reports and started campaigns about biosynthesised fragrances and aromas derived from engineered microorganisms. These have largely focussed on Vanillin's potential use in ice cream manufacturing and involved applying pressure on industry to commit to a "zero synbio" ingredients pledge. On their website, Friends of the Earth published a call for members of the public to send letters to ice cream manufacturers requesting that they do not use what they term "synbio vanilla" in their products. This call was prefaced with the following explainer:

> A new ingredient straight out of a petri dish has just entered the global food supply in many of our favorite foods, from ice cream to birthday cake. And like many of the products of genetic engineering, it won't be labeled — instead it is being marketed as 'natural.' But this ingredient is anything but natural. […] Synbio vanilla was designed to replace natural vanillin flavoring from vanilla beans, and is made in labs using synthetic DNA and reprogrammed, genetically engineered yeast. […] synbio vanilla sets a dangerous precedent for synthetic genetically engineered ingredients to sneak into our food supply and be labeled as 'natural.' (Friends of the Earth, No date)

This reflects a view of unnaturalness as wrongness (NCoB, 2015).

Campaigns such as Friends of the Earth's were somewhat successful in drawing attention to synthetic biology-derived vanillin and its labelling with regards to naturalness. One example of an industry statement on "Ingredients Derived from Synthetic Biology" was made by Unilever's ice cream brand Ben and Jerry's on their website, which reads:

> [W]e prioritize natural ingredients that come from family farmers and smallholder producers pursuing sustainable agriculture practices. All of our products are made with Fairtrade certified and non-GMO ingredients. We are aware that some food ingredients may soon be available on the market that are derived from new applications of genetic engineering techniques and approaches sometimes referred to as synthetic biology. We consider the food ingredients produced in this way to be inconsistent with Ben & Jerry's criteria for sourcing and therefore we will not use them in our products. (Ben & Jerry's, 2020a)

Ben and Jerry's (2020a) synthetic biology policy appears to set synthetic biology in opposition to what they term "natural ingredients" produced through "sustainable agriculture practices", and the activities of "family farmers" and "smallholder producers". This perhaps signals a view of naturalness as linked to tradition (NCoB, 2015), and serves to characterise synthetic biology as something distinct.

In summary, notions of (un)naturalness are deployed in a range of ways by various parties involved with synthetic biology and can be interpreted using Finitism as a basis[8]. Friends of the Earth seem to suggest that others (industry, regulators of labelling) are attempting to construct synthetic biology products as 'natural' by labelling them as such, or not labelling them as 'synthetic biology', and that this should be resisted, and the distinction maintained. Others, notably industry (e.g., Cargill, 2020), seek to maintain a connection between the natural and synthetic biology, either to present synthetic biology as an extension of the natural, a way to control or enhance naturalness, or to market synthetic biology products themselves as natural. This derives from a scientistic worldview held by those in industry that a molecule (e.g.,

[8] This is not discussed at length in existing literature but will be explored further using my own data in Chapter Seven.

vanillin) can be considered the same whether it is produced from petrochemicals, a synthetic biology-derived yeast or a vanilla bean. Some regulators also appear to be adjusting the classification of naturalness to accommodate the products of supporting technologies of synthetic biology, like gene editing (discussed further in the following chapter).

Genetic modification and synthetic biology

In the sections prior, I also discussed how scholars like Marris, Tait, Molyneux-Hodgson and Meyer have alluded to the role that GM controversies might play in shaping the views of those working in synthetic biology. Existing literature considers how scientists make assumptions about publics and their views towards synthetic biology based on judgements that GM is something that was feared and rejected by publics (Marris, 2015). It also discusses scientists' perceptions about how to engage with stakeholders and social scientists, and how "avoiding a repeat" of GM crop controversies might have informed the ways that this is carried out (Molyneux-Hodgson & Meyer, 2009). Further, Tait (2009:150, in Schmidt *et al.*, 2009) describes some reasons why synthetic biologists might seek to construct synthetic biology as 'novel', for example, to differentiate it from GM:

> [T]wo agendas are being played out here. There is the desire to encourage investment by claiming novelty and also to differentiate synthetic biology, at least in Europe, from the stigma that has become associated with GM crops. However, playing with words and definitions has not in the past been able to divert public concerns away from specific areas of development and is unlikely to do so now. (Tait, 2009:150, in Schmidt *et al.*, 2009)

Taken together, and considered from a Finitist position, this existing literature base could be interpreted as suggesting that synthetic biology is viewed by some as similar to GM. Crucially, synthetic biology is considered potentially similar enough to GM to be treated by publics, regulators and other stakeholders in similar ways. However, this idea raises numerous questions that are not explored elsewhere in the literature. For example, and particularly challengingly, in my analysis chapters I draw out and explore queries like: What are the similarity judgements that practitioners and interested parties make between what counts as 'synthetic biology' and what counts as 'GM'? What are the boundaries of these classifications? Who might be challenging these boundaries, and what is driving that? And, ultimately, what are the implications of these understandings of the 'synthetic biology' and 'GM' categories for the field and its governance? The implications of such classificatory decisions can be broad, as categories are defined in relation to other categories, in networks of cases and analogies (Bloor, 1982, citing concepts developed by Mary Hesse).

2.5. Summary

The literature suggests that synthetic biology is an emerging field yet to reach a consensus on a definition. Literature about the field is often promissory, but it remains unclear to what extent synthetic biology is positioned to meet its purported goals. Marris (2013) notes synthetic biology's parallels with GM in this respect, stating that "the current controversy around GM crops developed partly as a result of similar, overblown promises, made in the late 1990s, about their prospects for 'feeding the poor' that proved out of step with what was actually delivered." Elsewhere in discussions of synthetic biology, reference is routinely made to GM, but particularly notably in discussions of 'public' attitudes towards emerging technologies. However, there are numerous 'myths' relating to attitudes towards GM which have been discredited as overly simplistic and inaccurate. Arguably, framing synthetic biology in the context of GM is influential in that, depending on context, it may problematise the topic or assimilate it to a technology that is relatively well-established and defined. As I have shown, synthetic biology is not well-established, nor is it clearly defined, but rather it is contested and under negotiation.

Finally, I set out the literature on the Sociology of Scientific Knowledge (SSK), the methodological symmetry principle, and its main finding: Finitism. Through this lens I presented a Finitist reading of the grey and academic literature on naturalness and the constructions of boundaries between the synthetic and the natural in the case of synthetic biology-derived foods and ingredients. Finitism as an explanatory analytical lens is further explored in Chapter Four.

2.5.1. Gaps in the literature

Some of the gaps in current research include:

- The bulk of the literature consists of promissory publications about how synthetic biology might fit into food and agriculture. There is a need for more research on attitudes towards synthetic biology's potential roles in UK food and agriculture, and there is an underrepresentation of food producers, farmers and processors in attitude surveys (Kamrath *et al*., 2019).
- There is little research on views about the potential implications of synthetic biology for UK food policy, but some literature which narrowly focusses on relevant governance as stifling for innovation.

- The roles of novel and emerging technologies generally, and of their practitioners in public policy, are widely discussed in empirical and theoretical literature. To the best of my knowledge, there is no similar literature in the context of synthetic biology and UK-specific food and agriculture-related policy.
- While experiences of GM controversies are sometimes cited as influential on the views of those working in synthetic biology, there is little detail on *how* these experiences shape opinions and actions. There is also scant information on how these dynamics might manifest in policymaking and views towards governance.

Aiming to address some of these gaps, in my upcoming data chapters I focus on the potential implications of synthetic biology, its practitioners and a range of other actors for relevant UK food and agriculture policy. I add to existing literature on views towards current governance, taking a food policy-specific approach. I also explore these actors' experiences of GM food controversies and the role that this might play in synthetic biology's futures, although this was raised spontaneously by participants and not an intentional aspect of the initial research design. First, in the next chapter, I present the literature on the relevant policy landscape and policy-related theory.

Chapter 3: Policy landscape and literature

3.1. Introduction

A descriptive overview of synthetic biology's governance can be found in the Introduction chapter of this thesis. There, I provide an indication of the complexity of synthetic biology governance in the food and agriculture context in the UK.

This policy landscape operates at various levels, from international policies to national, regional and local oversight. At the international level are global agreements on, for example, scientific funding (e.g., Horizon funding and international R&D funding agreements between the UK and specific partners, such as with Japan). Other international policy tools and strategies include climate-related targets and agreements. Some examples are the Paris Agreement on climate change and the Addis Ababa Action Agenda of 2015, both of which were designed by the UN to support member states to meet the UN Sustainable Development Goals[9] (SDGs; UN, 2015) within the proposed 2030 timeframe (UN, 2020). Furthermore, the UK's international food trade is governed by a range of individual agreements with trading partners, as well as internal rules, and, in the case of Northern Ireland. at the time that my data was collected, the Northern Ireland Protocol provided for a level of EU oversight of food standards in the region.

At the national level, the UK government provides funding to technoscientific areas like synthetic biology through its research councils under UK Research and Innovation (UKRI), as well as some investments and strategies in R&D typically distributed by the UK Government's Department for Business, Energy and Industrial Strategy. A synthetic biology steering group, the Engineering Biology Leadership Council operates at the national level and was established by the UK government to guide synthetic biology's development through strategy documents and roadmaps. In terms of food policy, importing and exporting rules are also set at the national level, with DEFRA as the central competent authority, and the Animal and Plant Health Authority ensuring standards on imported foods. Furthermore, the UK Internal Market Act (2020) also assures the food standards and free movement of goods across UK nations.

However, rules and policy approaches can differ across England, Scotland Wales and Northern Ireland, each of whom have numerous matters on which they self-govern under devolution agreements. Of the 'reserved matters', or those that are not devolved but are

[9] The UN SDGs are expansive, covering 17 goals (see Appendix 1). The most recent update on reaching the goals found evidence of inadequate data reporting in many countries (UN, 2020). In terms of progress, the UN's 2020 report found that advancement towards several goals had either slowed, stopped or been reversed as a result of the Coronavirus pandemic (UN, 2020).

managed by the UK government, the most relevant to synthetic biology and food policy relate to industry, trade, finances, the economy and foreign affairs. Critically, health and social care (including nutritional advice, labelling and health and safety), education, local government, food strategies, agriculture (such as GM regulations and subsidies) and the environment (including environmental health) are devolved matters.

This chapter reviews the STS/SSK literature which engages with 'science for policy', as well as aspects of synthetic biology-relevant science policy. I go on to illustrate these policy heritages by exploring the literature on some ongoing developments specific to synthetic biology's governance through food policy and other mechanisms. This covers aspects such as risk, benefit, innovation, anticipation, and responsibility.

3.2. Science for policy

This section considers some of the main, ongoing debates in STS and SSK around science-for-policy, primarily related to the roles occupied by science and scientists in public policy, and the responses of publics to these dynamics.

3.2.1. Science (and scientists) in public policy

The engagement of science and scientists with public policy is often supported by three problematic assumptions about how scientists 'do science' and what their scientific knowledge can offer to policymakers.

Yearley (2005) discusses one such problem: that scientists are often supposed by policymakers to be disinterested. That is to say, scientists are presumed to be motivated straightforwardly by finding out 'facts', rather than selectively presenting information in support of policy action that serves their vested interests. As discussed in the previous chapter, social science research has demonstrated the challenges involved in drawing a straight line from 'scientific work' to undisputed 'fact'. The generation of scientific knowledge is a social endeavour, fraught with disagreements. Further, it is improbable that scientists would be able to provide neutral 'facts' to policymakers, were such a thing to exist, because, in requesting that these 'facts' be provided in the first place, policymakers shape the spaces available to scientists and expectations are applied to their work. Yearley (2005:142) summarises that some "analysts in political branches of policy analysis" have acknowledged these problems inherent to scientific advising and they have suggested that:

> If only apparently reputable scientists would not act as experts for hire and if only the scientific community could overlook its self-interest as a profession,

> then scientists could get back to advising disinterestedly in those areas where scientific expertise was properly relevant. (Yearley, 2005:142)

However, by virtue of their engagement with policymakers in the first place, policy-relevant scientific work must provide information that is of use to policymakers, in turn requiring a demonstration of expertise, authority and usefulness. This is materially and personally important, as scientists might seek legitimacy and career benefits, and might help to secure further funding for their field. Therefore, it is difficult to view scientists, in their policy-relevant roles, as disinterested, despite the range of commercial, political and social interests inherent to their work, scientific communities and policy spaces. Indeed, "[s]cientific research is to be funded partly because research may lead to economic benefits, partly because it contributes to the advancement of civilisation and partly because of the policy-relevance of the knowledge produced" (Yearley, 2005:141). Therefore, to cite Jasanoff:

> [There are] unsuspected connections between power and knowledge: that states and other governing bodies construct the very sciences they claim to rely on, while invoking objective science to legitimize their actions; that rationality is multiple, and it takes work, both normative and epistemic, to generate univocal reason; and that the practices of politics, science, and technology work together to produce effects of naturalness, neutrality, facticity, objectivity and inevitability – as modes of depoliticization. (Jasanoff's 2016:266, in Felt *et al*., 2016)

This is a useful summary of the findings of STS research "encompassing a diversity of theoretical commitments, methods, and practices" since the 1960s, and on the interactions between science, scientists and governance, culminating in increasing effort spent discussing scientific knowledge-making itself[10].

A second problem, and linked to the first, is that there is an assumption (or myth, or hope) that scientific knowledge and expertise can lead adequately to policy 'solutions' to social 'problems'. This glosses over a number of challenges for scientists, policymakers and for the 'science for policy' enterprise more broadly. Not least, "the policy questions to which answers are sought are not the ones that science itself asks […] the question and timing of the query are selected by the nature and condition of society's problems, not the state of scientific knowledge and its internal trajectory" (Yearley, 2005:141). Scientists, presented with "apparently science-like questions but without the circumstances being suitable for authoritatively correct solutions to be devised" (Yearley, 2005:141) may become less-than-ideal policy advisors. In cases with insufficient prior research, or without mainstream scientific community agreement on a

[10] See Chapter Two for an introduction to the Sociology of Scientific Knowledge which has long sought to remedy this omission.

particular (e.g., emerging) topic, scientists must rely on their own best interpretations of whatever evidence they are able to identify, resulting in diverging or conflictual opinions, uncertainty, technical debates and a lack of consensus. As Collingridge and Reeve (1986) state, experts can be expected to disagree, just as they might be expected to agree. This is because, as discussed prior, science is multiple, social, and where it has agreements, these are unstable and negotiable (Kuhn, 1970, 1996; Rees, 2011, 2019; Yearley, 2005). Science and scientists therefore cannot, or should not, be relied upon for a single, universal 'truth', for those seeking one (Collingridge & Reeve, 1986).

A third problematic assumption is that scientists are expected to be impartial, or apolitical. Nonetheless, they often function as political actors in policy arenas without being subject to the same levels of accountability as others. This privileged level of access is enabled by notions of expertise and authority, long discussed by STS scholars, notably Jasanoff. For example, drawing on examples of US governance, Jasanoff demonstrates that scientific advisors often function as policymakers, "exercising a form of delegated authority", but are often unaccountable, or not "held to norms of transparency and deliberative adequacy" (Jasanoff, 2003:157). For Jasanoff (2003:159), expertise "is a product of politics and culture, and the role of expertise in specific contexts is thus a fit issue for political analysis and control." Inherent to STS-related questions around the GM controversy and to synthetic biology's future is the politicisation of science, and the politicisation, or perhaps self-politicisation of scientists (discussed by Jasanoff, as well as Nelkin, particularly 1987; and Marris & Calvert, 2020). This is because the politicised spaces in which scientists may influence policymakers tend to be set up by policymakers or by scientists themselves to achieve certain goals. Yearley (2005:141) explains:

> Scientists may act as guns for hire, willing to present the kind of evidence that partisan lawyers or other advocates would wish to hear. In the same way, governments may appoint people to advisory committees who are selected precisely because they are thought likely to give the kinds of advice politicians dearly would like to receive. In some cases, the scientific community itself may even generate incentives that threaten the ideal of impartiality. (Yearley, 2005:141)

Such complexity can result in information that is of little use to policymakers, and, when viewed alongside problematic dimensions of power like science authority, the politicisation of scientists has led some to advocate that "[s]ound policies should be as independent of scientific advice as possible" (Yearley, 2005:144).

Further, it is important to consider that, in drawing heavily upon scientific expertise to inform public policymaking, states risk privileging the inputs of scientific knowledge and scientists above other citizens. This is problematic not least because publics tend to be sensitive to, or sceptical about, specific 'expert' claims, and to have complicated relationships to expertise in general.

3.2.2. Publics and expertise

Taking debates in the UK around the safety of genetically modified foods as an example, Yearley (2005:102-103) explains that some industry representatives, government advisors, scientific community institutions and regulatory agencies "had taken the view that the new foodstuffs were essentially identical to existing crops and that there was no significant danger to consumers at all". Often the most vocal advocates for such an approach were biotechnology companies or those retailing GM products. 'Expertise' was called upon in occasional informational campaigns from supermarkets, like Sainsbury's (1996) for example, about the few GM products they had elected to sell in the UK. A 1996 customer information leaflet about Sainsbury's Californian Tomato Puree Double Concentrate, made with GM tomatoes, includes a diagram entitled "The process of transferring a gene to a plant", some "advice from the experts" on the product's regulatory approval and safety, and a statement of environmental benefits like efficiency, reduced losses during harvesting and a reduction in the energy needed to concentrate the puree due to a reduced water content per tomato. Further, the leaflet details an array of purported benefits of such a tomato:

> [I]t stays firmer for longer, tastes the same, it's environmentally friendly and cheaper for you to buy. This means that Sainsbury's Tomato Puree is a better puree – a thicker mixture that's better at coating foods like pasta or meat. (Sainsbury's, 1996, no page)

To complement these 'benefits', but studiously avoiding any mention of the word risk, Sainsbury's promises to seek ongoing case-by-case advice from their in-house Advisory Committee on Genetic Modification "composed of leading independent figures in the fields of consumer protection, ethics, nutrition and plant science", and to always label their GMO products, "to allow our customers freedom of choice".

This gives the impression of apparent consensus among government advisors, regulators and companies selling GM products to consumers about the risks, safety and benefits of the technology. Nonetheless, this 'expertise' contradicted the expertise of other 'establishment scientists' who considered that there might be environmental implications and "conceivable problems concerning the impacts of changing farm management practices on wildlife and about

the spread of introduced genes", leading them to recommend further assessment (Yearley, 2005:103). Adding to these diverging opinions were claims from a small group of geneticists, plant biologists, and some NGOs, somewhat amplified in the press, suggesting that GM foods might harm consumers. Yearley (2005:103) adds that "[s]hoppers appeared to take these concerns seriously and all the leading UK supermarkets competed with each other to withdraw GM foodstuffs from their shelves".

STS literatures provide a basis from which to interpret this apparent public rejection of scientific (and industry) expert claims. As discussed in the previous chapter, conceptualisations of publics as "either permanently clueless or eternally educable" (Jasanoff, 2016:274) tend to rely on discredited deficit model assumptions that publics, if provided the 'right' information, will react in predictable ways to scientific developments (refuted in e.g., Wynne, 2001). However, "repeated demonstrations of citizen competence" by STS scholars lead to alternative understandings of publics and how they receive and react to technoscience. For example, Jasanoff (2005:249) sets out a concept of 'civic epistemology' which describes how publics "assess claims by, on behalf of, or grounded in science [which] forms an integral element of political culture in contemporary knowledge societies." These publics decide "what credible claims should look like and how they ought to be articulated, represented, and defended" through processes of "culturally specific, historically and politically grounded, public knowledge-ways". These processes involve collective choices guided by cultural and political expectations "about how knowledge should be made authoritative", not by knowledge of techno-scientific specifics nor the 'right' public understandings of science, its products and implications (Jasanoff, 2005:249). Rather, Jasanoff (2016:274) describes a "*knowledgeable public* that can process information, learn, and produce or enrol expertise when the situation demands" (emphasis in the original). Just as scientists disagree with one another, so too have publics been shown to interpret information, assess risks (discussed in the following section) and determine benefits in different ways than scientific experts might, and depending on context, how the information is presented and which questions are asked of it (e.g., Marris, 2001; Yearley, 2005). They might also evaluate and simply reject the claims of scientific experts based on, for example, the institutions or organisations that they belong to, the perceived agendas of those experts and policymakers, or "any ulterior purpose which they believe they can spot" (Yearley, 2005:109).

Jasanoff also draws on Leach, Scoones and Wynne's (2005) concept of the *epistemic citizen* (Leach, Scoones, and Wynne 2005), which "draws attention to the crucial role of lay knowledge in good government […] citizens as lay experts are entitled to *epistemic justice* […]

that is, a measure of respect for the experiential knowledge they bring to politics" (Jasanoff, 2016:274, emphasis in the original). 'Lay' knowledge is routinely collected by policymakers through surveys (like the questionnaire deployed as part of the Synthetic Biology Dialogue, discussed in Chapter Two), public consultations by policymakers and (social) scientists via public engagement, which will be examined later in this chapter. However, it is questionable to assume that such strategies translate into the treatment of lay expertise in similar ways to scientific expertise, as scholarship on 'expertise-by-experience' has shown. Nonetheless, Jasanoff (2016:274) recommends that "[i]f states exert power through authoritative knowledge-making, then citizenship must include the rights and obligations of members of a polity to contribute to and act upon those collective ways of knowing."

In summary, the roles of science and scientists in policymaking are varied, complex and have been interrogated from a range of different perspectives since the 1960s. Numerous scholars have long sought to challenge conceptualisations of scientists as 'disinterested', 'objective' and 'impartial' (e.g., Jasanoff, Wynne, Yearley, Marris). Scientists might be called upon to provide evidence to policymakers or choose to contribute to consultations calling for expertise on a particular policy 'problem'. This can be because the designation of a scientific research topic as something of societal or policy importance, perhaps requiring additional research (funding), is of material interest to scientific communities (Yearley, 2005). Scientists, and notably scientific advisory committees, can also deploy their authority and expertise to consolidate significant power for themselves, enabling them to shape policy in their own interests, thus acting 'politically' but without accountability (Jasanoff, 2016). This is particularly relevant to the GM/synthetic biology policy space.

3.3. Governing technoscience

Building on the sections prior which discussed science-for-policy, the focus of the following sections is the governance of technoscience, particularly responsible research and innovation, and risk assessment, illustrated by one example of synthetic biology-relevant UK governance in practice.

3.3.1. Responsible Research and Innovation

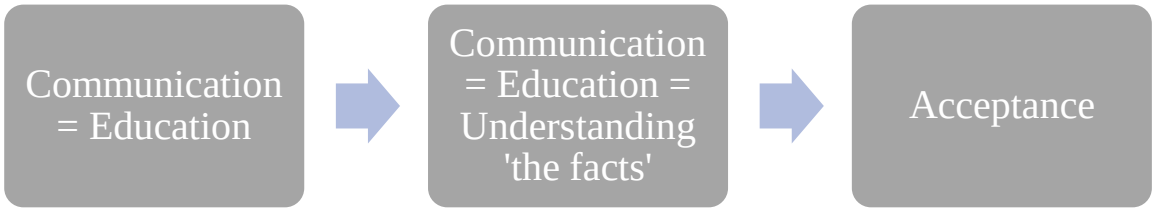
This section introduces a body of literature on Responsible Research and Innovation (RRI). RRI can be understood as one "mechanism for governing the future" (Marris & Calvert, 2020). It is also a base from which to explore concepts of responsibility and innovation. Further, it

encompasses scientists' negotiations of current and anticipated implications of synthetic biology research and development.

RRI has its roots in a long history of commentary from the social sciences, which has played a role in shaping understandings of the ethical and moral considerations relevant to advances in genetic sciences since the 1990s in particular. Perhaps the most prominent example is the 'Ethical, Legal and Social Issues' (ELSI) work, originating in the Human Genome Project, which can be linked to RRI commentary from social scientists today (Taylor & Woods, 2020). The ELSI approach has been the subject of much debate. For example, Balmer *et al.* (2015) argue that ELSI practitioners, and the ELSI approach itself, have a tendency to problematise scientific developments through a lens of risk and focus on negative implications at the output or application stage. Some have argued that such a focus on 'downstream' consequences of science is at the expense of ongoing and inclusive deliberations on processes and practices 'upstream' (Balmer *et al*., 2015). Further, Balmer *et al*. (2015) argue that ELSI approaches contribute to the placement of social scientists in restrictive roles as representatives of 'the public' to identify concerns, or even to remediate negative consequences of scientific developments. In practice, this tends to be operationalised in forms of public engagement, which scientific communities often hope will lead to widespread acceptance, smoothing the path for emerging technologies (Marris & Calvert, 2020).

The assumptions driving this share some similarities with widely criticised deficit model assumptions. Namely, it is assumed that information, communicated strategically to generate particular 'understandings' of scientific developments, will then prompt the newly 'informed' to accept these developments. Under the deficit model, such 'understandings' are that scientific knowledge is comprised of 'facts', themselves perhaps neutral descriptions of 'nature', but also 'good' as evidence for action (Martin & Tait, 1992). Assumptions underpinning more recent efforts at 'Public Engagement' are more that communication itself equates to or demonstrates transparency about scientific developments, that transparency equals trust, and that trust leads to acceptance (Marris & Calvert, 2020). Of course, this involves a deficit model-type leap such that transparency about scientific 'facts' will reveal them to be a good thing that should be supported.

Some 'Deficit Model' assumptions



Some 'Public Engagement' model assumptions

Figure 1 - Deficit model and public engagement model assumptions (Source: Author)

Taylor and Woods (2020) suggest that RRI is "[o]ne approach to address the deficiencies of the ELSI paradigm". The concept of Responsible Research and Innovation (RRI) was developed in the European Union in parallel with an independent and subtly different Responsible Innovation (RI), a term most commonly used by research funders and policymakers in the UK. Both RI and RRI share some similarities, summarised by Owen and Pansera (2019:26) as the following threefold ambitions:

> To foster the design of inclusive and sustainable research and innovation, with an emphasis on co-creation and co-production with society ('science with and for society') […] to align research and innovation to the values, needs and expectations of society (with a strong emphasis on 'societal grand challenges') […] to anticipate and assess broader implications of research and innovation in an ethical, inclusive and responsive way. (Owen & Pansera, 2019:26)

However, the major distinguishing aspect of RI from RRI is the latter's policy focus. RI discourse is described by proponents as "striving for innovation (and science aimed at this) that is more anticipatory, more reflexive, more inclusive, deliberative, open and, in total, more responsive. But RI remains largely an ideal, a guiding principle" (Owen & Pansera, 2019:27). By contrast, RRI was developed to deliver "specific policy goals" representing a translation "from theory to practice" (Taylor & Woods, 2020). Marris and Calvert (2020) describe technology roadmaps as another policy mechanism for governing the future and explain how notions of Responsible Research and Innovation were interpreted during their involvement with the UK Synthetic Biology Roadmap Coordination Group. Marris and Calvert (2020:55-56) summarise:

> [W]e became sensitized to the language of "roadblocks." For example, at the SB6.0 conference in London, one question raised by the organizers was: "What are the potential roadblocks which will stop synthetic biology becoming industrially successful and how can these be overcome?" The discussion quickly

> turned to the need to avoid public opposition of the kind encountered by genetically modified organisms (GMOs) in agriculture […]. Here, as with many other so-called emerging technologies, we see the idea of synthetic biology as a juggernaut, determinedly pursuing its singular path and treating everything else (recalcitrant publics and critical NGOs) as roadblocks obstructing its progress toward the Emerald City of industrialization, growth and jobs. This is very different from our interpretation of RRI, and from Owen, Macnaghten, and Stilgoe's (2012, 758) formulation of the key question driving RRI: "what kind of future do we want innovation to bring into the world?". (Marris and Calvert, 2020:55-56)

This is an important question which appears to be overlooked elsewhere in the synthetic biology-relevant literature. However, it has been argued that the shift from an ELSI paradigm towards an RI/RRI approach means that "scientific researchers themselves are thus encouraged to consider societal issues continuously throughout the research process, rather than rely on a stand-alone analysis conducted by specialist social scientists or bioethicists (as is the case with ELSI work)" (Taylor & Woods, 2020:133). This could be viewed as an empowerment of scientists with the spaces and tools required to reflect on their own responsibility for the implications of their research, and to consider questions like that raised by Owen, Macnaghten and Stilgoe (2012:758). However, this reflexive process is often enacted at the individual level, and scientists each view their work and their responsibility in different ways.

Through interviews with synthetic biologists, Taylor and Woods (2020) explore scientists' varying understandings of what responsibility - and, by continuation, 'being responsible' or 'behaving responsibly' – may mean. Taylor and Woods (2020) find that their participants often equate RRI with risk mitigation. Further, they highlight other aspects of scientists' feelings of responsibility, including:

> (i) remaining within the law, (ii) not causing damage to the University's reputation, (iii) to ensure that the work being done was making best use of public funding and (iv) that any outputs, either knowledge or products such as software and algorithms, should be freely available to anyone. (Taylor & Woods: 2020:138)

These feelings may derive in part from the expectations attached to scientific work, which are often determined by funders as a result of wider political agendas (e.g., Yearley, 2009). In a discussion about such pressures, McLeod *et al*. (2018:2) describe early-career researchers' feelings that they should prioritise "obviously marketable" research over "academically valuable research". McLeod *et al*. (2018:2) also detail how the "risk of industry's interests distorting research values also appeared in other stories about science over-promising solutions and then not being able to deliver". McLeod *et al*. (2018:2) go on to explore concerns about media output as public engagements, and participants described:

> [P]ublic engagements, such as television shows, in which science was abused as a way of, almost, distracting [the public] so they do not have to worry about the destruction of the world, or environments, or anything; they do not have to do anything, because some clever scientist has got the problem solved. (McLeod *et al*., 2018:2)

Although shaped in large part by the scientific and institutional pressures that scientists experience, understandings of responsibility can also be personal. McLeod *et al*. (2018:2) find that a "majority of participants focused either on personal risk to their own mental health or career, societal risk in relying upon a technological 'fix', or more ephemeral risks to science as the pursuit of knowledge." McLeod *et al*. (2018:2) describe responsibility as a "difficult path […] to navigate between economic expectations, work-life realities and the particular difficulties of cutting-edge science." This may also be tied to an element of personal risk, including worries about failure to meet research missions and expectations (McLeod *et al*., 2018).

Recognising the potentially disruptive nature of synthetic biology innovation, there is a drive towards RI/RRI in this field, which is supported (or driven) by UK funding bodies (EPSRC, 2013; Clarke & Kitney, 2016). Responsible Innovation is defined by RCUK as "a process that seeks to promote creativity and opportunities for science and innovation that are socially desirable and undertaken in the public interest […] Responsible Innovation creates spaces and processes to explore these aspects of innovation in an open, inclusive and timely way" (RCUK, 2010). The assumptions involved in defining what may be "socially desirable" and "in the public interest" are ambiguous. The term 'public interest' itself may be problematic as it suggests that the 'public' has relatively homogenous interests, which are not clearly articulated. Does this require synthetic biology simply to be safe, or perhaps to hold some health, economic, environmental or commercial benefits? Taken further, this definition of RI/RRI itself begs the questions: Are synthetic biology technologies socially desirable in the context of food? And if so, which specific outcomes are desirable? And why?

3.3.2. Amending the Genetically Modified Organisms (Deliberate Release) regulations in England

Since early-2020, when I began my research, the UK's political and policy spaces have been subject to dynamic fluctuations and speculative debates. The UK's exit from the European Union - colloquially known as Brexit - might represent a deviation from the favoured policy 'status quo' (the stability provided by the UK's adherence to EU laws for several decades), forcing more rapid, rather than incremental, policy change in areas like international trade.

Brexit, its associated legislative deadlines and their political importance might provide an opportunity for large areas of UK policy to be redesigned.

One such prominent example of policy redesign, discussed in the Introduction chapter of this thesis, is an amendment to GM governance in England post-Brexit. Under this amendment, *the Genetically Modified Organisms (Deliberate Release) (Amendment) (England) Regulations 2022* (S.I. 2022/347), 'gene edited' crops (a term used in government publications but not in the regulation) will be treated differently to those produced using established genetic modification techniques. Such 'gene edited' plants are defined as "a higher plant which is a genetically modified organism but which has not been genetically modified other than to make modifications (a) that could have occurred naturally[11]," or using a range of techniques such as in vitro fertilisation, mutagenesis or polyploidy which are already distinguished from established genetic modification techniques. The amendment provides that:

> persons are exempt from the requirements […] to carry out a risk assessment […] [and] to obtain consent […] insofar as those requirements relate to releasing qualifying higher plants (which includes the import or acquisition of such plants for the purpose of release) (S.I. 2022/347)

This is something of a departure from the precautionary principle, upon which other GM and Novel Foods governance in the UK is based. In short, the precautionary principle provides that, until the moment when risk is manifested in the present, it is always assumed that risk *may* manifest in future. Potential risks, hazards, dangers, problems or 'issues' arising from synthetic biology are the most common starting points from which synthetic biology's governance is discussed. Common topics in the literature include: potential for dual use (Marris, 2014); so-called 'DIY-bio' or the accessibility of synthetic biology "to those without specialist training" (Tait, 2009; Garfinkel *et al*., 2007); ethical and moral considerations around patenting life; unintended consequences (Dalziell & Rogers, 2022) and, broadly, challenges around governing the future. Taking a precautionary approach to the assessments of such risks in the face of their uncertainties can provide the time and space for rigorous oversight. Such processes can be reactive, slow and time-consuming, involving the gathering of scientific evidence, case-by-case scientific assessment of risk, and scientific debate, which may indeed involve contradictory expertise (Nelkin, 1987). Operationalising the precautionary approach in this way reconsolidates scientific ownership over scientific enterprise rather than enabling public debate (long discussed by Jasanoff – e.g., 1990, 1992, 2003).

[11] The concept of 'naturalness' is discussed in Chapter Two.

Nonetheless, unintended consequences of any applications are possible, particularly upon release into the environment (Dalziell & Rogers, 2022), and therefore a lack of oversight of gene edited plants prior to notification and release (permitted by the amendment) might place extra pressure on monitoring, evaluation and reporting procedures. Under current governance, there are provisions for monitoring, evaluating and reporting after a release into the environment. The Genetically Modified Organisms (Deliberate Release) Regulations 2002 also require unforeseen events to be reported, and "duty as regards preventing damage to environment". A recent provision in the same regulations in 2019 further requires the regulations themselves to be evaluated by the Secretary of State "from time to time", within each 5-year period. However, the FSA's (2022) flowchart for risk assessment[12], ends after the formulation of legislation and issuing of advice, failing to mention notification and monitoring. ACRE (the Advisory Committee on Releases [of GMOs] to the Environment) (2013) provides a 40-page advice document[13], which explains a range of tools and techniques for monitoring, including case specific monitoring, general surveillance, farm questionnaires (the content of which is not included) and collaboration with existing environmental surveillance networks. ACRE's advice mentions case specific monitoring "to confirm that any assumption regarding the occurrence and impact of potential adverse effects of the GMO or its use in the environmental risk assessment are correct" (ACRE, 2013:7)[14]. It also recommends general surveillance:

> to identify the occurrence of adverse effects of the GMO or its use on human health or the environment which were not anticipated in the environmental risk assessment" […] There is no reason to expect that GM crops would have adverse effects if risks have not been identified in the environmental risk assessment. [General Surveillance (GS)] is, however, in line with the precautionary approach set out by the legislation. As there is no hypothesis as to how adverse effects could occur it is challenging to determine what should be monitored. With finite resources it is not possible to monitor all aspects of the environment and it will be necessary to focus monitoring to maximise the potential to detect adverse effects should they occur. GS should focus on environmental parameters in close contact with the GM crop. (ACRE, 2013:7)

The framing of ACRE's advice (2013) suggests that environmental risk assessment prior to release should be assumed sufficient, and that the potential for unexpected adverse

[12] Available here: https://www.food.gov.uk/sites/default/files/media/document/fsa-risk-analysis-flowchart.pdf

[13] Available here: acre_pmem_of_GMOs.pdf (publishing.service.gov.uk)

[14] ACRE's guidance also adds that case specific monitoring "is not required in all cases. It is needed in situations where, following the environmental risk assessment, a specific hypothesis remains as to how GM crops could cause adverse effects" (ACRE, 2013:7).

effects can be considered from this starting point. This dynamic can be understood as self-referential. Kusch (1999) explains how such self-referentiality is performative. Kusch describes: "[w]hichever criterion [a given] community selects, the relationship between the criterion and the concept will be a social institution: it will be marked by self-reference and self-validation. The criterion will be the criterion because the collective takes it to be the criterion" (Kusch, 2005:194). For example, a scientific advisory committee, informed by a collective decision on the criterion or criteria by which something might be evaluated and labelled, evaluate and label according to those criteria. Those outside the committee also may conform to these criteria. Kusch (2005:196-197) describes how this is also normative:

> Each individual carries out only a small part of that collective stipulation and thus can learn, and draw inductive inferences, about the working of the system as a whole. Each individual sanctions—signals a sanction—on the basis of how the others have sanctioned or signalled […] consensus sets the standard for the sanctioning, and the sanctioning protects and recreates the consensus. (Kusch, 2005:196-197)

Shaping those criteria might not be immediately accessible to those outside the Advisory Committee, which could serve to embed the assumptions and biases of the scientific advisory committee in the framings and scope of future risk assessments. However, should those outside the committee conceive of their own criteria, this may shape views on criteria (and applying them) both within and outside the Committee.

Under the amendment, gene edited products would not be subject to the same comparative analysis as other products under GM and Novel Foods regulations. This approach, sometimes called the comparator approach, which can also be understood using the theoretical background presented earlier in this thesis. A comparator approach assesses products against others, chosen as reasonably similar benchmarks alongside which a prospective application is assessed. Current reliance on the comparator approach, conducted case-by-case by scientific advisory committees, may be problematic in that these processes are inaccessible, likely self-referential and often proceed without public scrutiny or accountability. However, the comparator approach does build in assessment of nutritional composition, potential toxicity or allergenicity, and aspects like whether the product has been consumed by humans elsewhere, for example. However, were synthetic biology to be capable of novelty, i.e., of producing something with no reasonable comparator, it is unclear how risk assessment would take place and with which scope. Negotiations of this sort would rely on past cases and analogies, like the treatment of similar products and assessments. Currently, some applicants provide their own evidence of laboratory trials in mice and rats to understand toxicity or monitor for unexpected

implications. This has typically been presented alongside examples where the application might arise in nature or through processing and be consumed by humans with no adverse effect[15].

Overall, current processes of case-by-case risk assessment by a scientific panel offer the time, control and opportunities for assessment of a given application. Exempting gene edited plants from this process in England is a departure from the precautionary principle. Without case-by-case oversight of these products, there may also be little room for consideration of their broader social and ethical implications. Such considerations are often overlooked when regulators take a risk assessment focus. Although risk assessments are important policy tools, Frewer (2017) identifies a distinct lack of formal 'benefit assessments' in policy processes. Frewer identifies a possible link between individuals' trust in new technology and effective regulatory frameworks, and advises scientists, industry and R&D actors to produce products that are in line with "societal expectations, requirements and priorities" (2017:699). This is reflected in the literature, which does not appear to examine the benefits of synthetic biology, or its trade-offs, merely to describe them[16]. An assessment of benefits could naturally extend to an exploration of these topics and could go some way to exploring messy interactions between health, social, economic and environmental implications of applications, while promoting reflective and anticipatory activities at the R&D level.

In summary, notions of expertise are embedded in current governance processes in this area and have been long explored and debated by social science scholars. If, like Jasanoff, we accept that scientific advisors can be considered (unaccountable) policymakers, "exercising a form of delegated authority", but not "held to norms of transparency and deliberative adequacy" (Jasanoff, 2003:157), then we must look critically at their status and power over GM/synthetic biology governance. This has important shortcomings in the context of a potentially controversial emerging technoscientific field like synthetic biology, whose controversy could

[15] A potential case might be Unilever's approval for Ice Structuring Protein type III HPLC 12, authorised as a novel food ingredient (for "edible ices", such as ice cream) in the UK and EU in 2009. While the supporting documents presented for this product authorisation do not appear to have been archived, information on the background and testing procedures can be gleaned from an EC scientific opinion and Unilever's patent filings. A range of tests were carried out, including on mouse lymphoma cells and *in vivo* testing in rats. Tests in humans with allergies to fish were also carried out, acknowledging that "[n]o method currently exists which can give assurance that a protein lacks the ability to induce an allergic reaction or sensitise an individual consumer to subsequent challenge." A decision to authorise was formed based on the results of the applicant's tests as well as a lack of reported adverse effects in countries in which the protein is commercialised in ice cream products, presumably by the applicant.

[16] Trade-offs have been alluded to on occasion in the literature. For example, Tyagi *et al.* (2016) discuss how plastic-alternative PLA packaging produced by engineered *E. coli* may be environmentally beneficial, but significantly more expensive than its oil-derived plastic counterparts due to repeated losses of bacteria from stress. This is an example of an environment-economic trade-off.

be said to have "little to do with science at all" (Nelkin, 1987:292). The literature over several decades suggests that objections to GM may be in large part situated not only in perceptions of potential *future* scenarios (risk, benefit) but attached to intangibles (like trust) (e.g., Marris, 2001). A parallel may be drawn there with synthetic biology, whose potential risks, benefits, problems and successes lie in futures, and is likely to be subject to similar intangible objections.

3.4. Science, technology, and food policy

This section provides an overview of some debates in UK food policy literature of relevance to synthetic biology, as well as other branches of science and technology. Food policy scholars, in turn, draw on the social scientific literatures discussed previously, such as Kuhn's notions of 'paradigms', to explore the ways in which science, technology and food policy intersect.

Lang and Heasman (2004), presenting their 'food wars thesis', use the lens of competing paradigms to situate science, technology and their experts variously within food policy approaches. These notions of paradigms are inspired by the works of Kuhn (discussed in the previous chapter). The authors suggest that science and technology have long been deployed as instruments of industrialisation (described by Lang and Heasman (2004) as the 'Productionist Paradigm'), or the prioritisation of increasing quantities of foods above other possible goals, as occurred after the World Wars. The Productionist Paradigm "goes far beyond the farm: it typified the whole 20th-century outlook […] It developed a science base to further the goals of increasing output" (Lang & Heasman, 2004:19). Increasing production involved scaling up agri-food businesses. This often entailed monocropping and the use of agrichemicals or other inputs as part of efforts to improve efficiency of supply. Efficiencies were also sought across processing, distribution, logistics and storage through technological advances and economies of scale. Although useful in addressing and preventing food shortages, the Productionist Paradigm considered human health benefits to be incidental to increasing supply (i.e., having sufficient food itself equates to a human health benefit), and did not focus on mitigating the impacts of increased production on the environment.

Building on the Productionist Paradigm, or rather seeking to address some of its ecological and human health shortcomings, Lang and Heasman (2004) also interrogate the roles of science and technology in their visions of new, competing food policy futures. One, the 'Life Sciences Integrated Paradigm' positions science and technology as central to "a body of thought that has as its core a mechanistic and fairly medicalized interpretation of human and environmental health. In this, food is perceived as almost like a drug, a solution to diseased

conditions, part of a planned, controllable and systemic manipulation of the determinants of health and ill health" (Lang & Heasman, 2004:24). This paradigm may be able to reinterpret and slot into (arguably, problematic) systems and processes created through the Productionist Paradigm, such as monocropping, large-scale production processes and global agribusiness (Lang & Heasman, 2004:24). Practitioners of science and technology, in this vision, have two roles: (a) Identifying what might be considered food system 'problems' for health and the environment; and (b) Developing technoscientific 'solutions'. Genetic modification has often been presented as one avenue to achieving these goals, even depicted as a 'perfect solution' by its proponents (Lang & Heasman, 2004:24).

Elements of this Life Sciences Integrated Paradigm are reflected in the literature on synthetic biology's goals, promises and potential applications, discussed above. Critically, Lang and Heasman (2004:25) observe that technoscientific developments under this paradigm, "far from freeing the world from the agricultural treadmill and the commercial dependencies of the Productionist paradigm, might chain us to them". Another concern is that such a paradigm "relies heavily on the laboratory", an often exclusive, inaccessible place for most in society, for research and development. This is something that Lang and Heasman (2004:28) describe as a disintegrative approach, neither driven by "consideration of the circumstances, experiences and dynamics of groups and populations […] [nor] the stocks of natural resources, the functioning of ecosystems and cohesive social relations".

The notion of 'disintegration', or the fragmented distribution of goals, actors and activities across food policy, is a challenge for food policymaking. Food policy scholars often seek to pinpoint ways that environmental, health, economic, social and other goals might be aligned to produce co-benefits (e.g., Lang *et al.*, 2009; Hawkes & Parsons, 2018). This is often hampered by a busy and fragmented policy landscape. In a 2020 policy briefing, Parsons *et al.* identify "at least 16 departments and public bodies" making food policy in England alone. Parsons *et al.* (2020) do not include in their overview the several committees offering advice on, for example, GM and Novel Foods. Sponsored by DEFRA, for instance, there is ACRE, the Advisory Committee on Releases to the Environment. There is also the Scientific Advisory Committee on Genetic Modification appointed by the Health and Safety Commission, which primarily advises on contained uses of GMOs. Further, the FSA's Advisory Committee on Novel Foods and Processes also offers advice on novel foods, food processes, genetically modified foods and feed.

Acknowledging the challenges of disintegration and "the agricultural treadmill" inherent to a Life Sciences Paradigm for food production and policy, one alternative, competing paradigm, described by Lang and Heasman (2004:25) as "so far marginal", is the 'Ecologically Integrated Paradigm'. This paradigm acknowledges criticism of industrialised agribusiness, controversy and activism in part arising from GM food controversies. It positions environmentalists, nutritionists, ecological and biological scientists alongside consumers, as resistors to the 'business-as-usual' approaches embedded in Productionist/Life Sciences paradigms. This is described as "on the outside track of mainstream policy-making" (Lang & Heasman, 2004:26), but reflects one of the main ambitions explored in recent food policy literature: how policymakers might take a systems approach to aligning ('integrating') environmental, human health, social and economic goals (e.g., Lang *et al*., 2009; Hawkes & Parsons, 2018). Food policy scholars often call for 'co-benefits' or synergies between goals, actions and responsibilities across dimensions like public health, environment, livelihoods and economies (Hawkes & Parsons, 2018). Lang *et al*. (2009) and Hawkes and Parsons (2018), and other food policy scholars, recommend integrated, cross-sectoral policies to achieve this vision, but optimal integration of goals in food policy is difficult to define (e.g., Barling *et al*., 2002). It is recommended that policymakers aim to align the goals, actions and responsibilities of actors at different levels of governance. Some extend this idea to refer to non-government actors and stakeholders, emphasising that public involvement can help to identify integration opportunities (Barling *et al*., 2002).

In a context of more integrative food policies, focussed on achieving co-benefits like those described previously, the roles of science and technology are unclear. Science and technology could be viewed as systems for learning, understanding, improving and working with nature in a "more integrative and less engineering approach", involving and harnessing symbiosis between humans and their environment (Lang & Heasman, 2004:26). Lang and Heasman (2004) suggest that, within their Ecologically Integrated Paradigm, emerging or novel science and technology for efficiency and increasing production might also be less called-upon, replaced by a need for traditional knowledge and local skills to optimise human health and ecological outcomes. Smaller-scale local agroecological methods might be favoured over industrialised, large-scale agribusiness (Lang & Heasman, 2004:26).

Despite the myriad potential futures and competing visions of the roles of emerging technologies in food policy, the implications of synthetic biology for food policy are not widely discussed in the literature. More specifically, there is little discussion to my knowledge of synthetic biology's potential position within, or implications for, 'horizontally' integrated food

policy recommendations with co-benefits for social, environmental, public health and economic dimensions. Later, in *Food Policy: Integrating health, environment & society*, Lang *et al*. (2009:7) describe food policy as an intersection point of often competing issues, one of which is Science and Technology. Lang *et al*. (2009) present a picture of food systems and corresponding policies that are complex and multi-level, with a range of conflicts and synergies. On science and technology, the authors focus on genetic modification and the precautionary principle as "one response to the advent of the risk society and the need to allow for wider societal discourse around new and innovative applications, not least to our food" (Lang *et al*., 2009:206). This refers to Beck's contested conceptions of a modern 'world risk society', wherein the concept of risk, according to Beck (2000:210, in Adam *et al*., 2000), "characterizes a peculiar, intermediate state between security and destruction, where the perception of threatening risks determines thought and action."

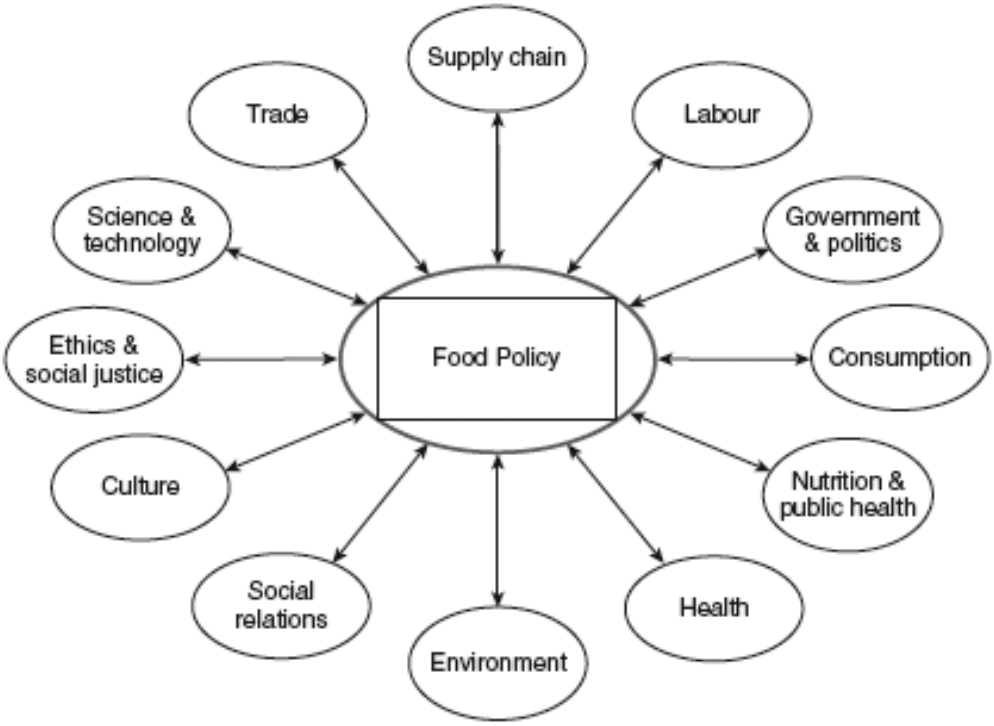


Figure 2 - Food policy as an intersection point of competing issues, in Food Policy: Integrating health, environment & society, (Source: Lang, Barling and Caraher, 2009:7)

Many of the 'issues' visualised by Lang *et al* (2009:7), in Figure 2, could be understood as relevant to synthetic biology. For example, synthetic biology's implications for the environment, human health, consumption and ethics are well-documented points of contention in debates about synthetic biology's future. Fragmented governance, politics and trade are others. Differing biotechnology governance regimes around the world, compounded by corporate policies on genetically modified food and feed, for example, affect trade and supply chains. There are also questions about synthetic biology's implications for labour, particularly

displacement of some jobs by science and technology, or labour conditions and livelihoods of farmers affected by target areas for synthetic biology's application, like within the flavouring, sweetener and animal product sectors.

In summary, the roles of science and technology, their practitioners, experts and risks are contested in food policy literature. Pragmatically, technoscientific developments like synthetic biology co-exist with competing ideals, approaches and paradigms. Synthetic biology is sometimes positioned as a facilitator for some ecological and health goals. However, paradigms like 'Life Sciences' and 'Productionist' remain constraining due to their focus on economic priorities above human health and environmental goals. Idealism around more 'integrative' approaches is often discussed in food policy literature, as well as the fragmented, complex food policy landscape. A key focus of food policy scholars involves highlighting opportunities to integrate environment, human health, social and economic goals in ways that generate co-benefits (e.g., Hawkes & Parsons, 2018; Lang *et al*., 2009). How synthetic biology might fit into these ambitions remains unclear and is not covered to the best of my knowledge in existing literature.

3.5. Summary

In this chapter, I discussed the existing literature on the governance of synthetic biology. This comprised a review of how science and technology is debated in food policy literature. I discussed risk assessment, including STS work on the roles of experts and expertise. I also reviewed policy developments and aspects of current thought on the comparator approach and Responsible Research and Innovation.

Internationally, regulatory approaches to GM foods vary widely, which has led to discrepancies in the development and pervasiveness of GM technologies in food industries around the globe. In the United States, for example, GM corn and soya beans are widely grown. Elsewhere, this is not replicated, particularly in Europe. Policy developments in this area, such as amendments to England's GM regulations, suggest a trend towards greater self-regulation by those seeking to research synthetic biology and other relevant technologies, based on the idea that gene edited crop plants are unlikely to be riskier than conventionally bred counterparts. This might present a conflict with some trends in the literature, much of which does position aspects of gene editing, genetic modification and synthetic biology as problematic or risky in order to discuss governance.

However, the synthetic biology literature is vague in terms of suggestions for a policy approach, and food and agriculture policy is sparsely discussed. Goold *et al*. (2018) reflect on how policies differ across countries but do not refer specifically to synthetic biology. Tyagi *et al.* (2016:1787). recommend a robust policy framework including: "new professional norms in the scientific community (e.g., codes of conduct concerning dual use technology), local and national research oversight, statutory regulation (e.g., new laws and formal regulatory agencies) and international co-operation and treaties." The authors suggest that this should be supported by stakeholders, and local implementation underpinned with training, although no clarity is given for who should be trained and on which topics. In short, the literature routinely advocates that the existing policy landscape be reviewed and updated, but the shape of an alternative policy approach is unformed.

In the following chapter, I explain the methodological approach taken to collect data and give details of the sample of 30 interviewees.

Chapter 4: Methodology

4.1. Introduction

This chapter details the methodological approaches taken during my research, including the focus of the study, the research questions, contextual aspects and the design of data collection and analysis methods. First, I explain the knowledge gaps in the literature around potential implications of synthetic biology for UK food policy, and how these are considered in the research focus and design. I then revisit my research questions, and describe my qualitative methodological approach.

Sections 4.5 onward focus on the practical steps taken to design the project, carry out data collection and analyse the findings. I set out the design process and explain how I then produced my interview questions. I go on to describe sampling, the purposive recruitment strategy and the resulting data collection which took place through online semi-structured interviews. I also detail the pilot interviews and data analysis procedures, explaining the process of coding in NVivo software. Finally, and to frame the findings chapters that follow, I set out the ethical considerations of the research and my reflections on the research process.

4.2. Focus of the study

During my initial review of the literature and scoping work it became clear that the evidence base on views towards how synthetic biology might be governed in a UK context is small. Synthetic biology is emerging and developing without clear boundaries or definitions. Disagreement exists on what synthetic biology is, what the field can do and where it might go.

Social science commentary also highlights the influence of research funding and political backing in positioning the field as a technology to "propel the UK to future growth." Literature on topics such as expectations, promissory futures and governance of synthetic biology reveals that the field is simultaneously forward- and backward-looking. Synthetic biology is promissory on the one hand, while on the other hand its proponents and critics look back on the GM controversy and have internalised a fear that synthetic biology will generate the same opposition (Molyneux-Hodgson & Meyer, 2009). This internalisation results in pervasive assumptions about 'the public' and repeated, vague reference to this experience. Indeed, synthetic biology in food is governed by GM food regulations, and, beyond this, it is unclear how the UK might go about governing any synthetic biology-derived foods in future. There is also a knowledge gap on attitudes towards possible approaches to such governance.

My research was initially designed to be a 'horizon scanning' project about views towards possible policy approaches relating to synthetic biology in food. This was to be exploratory in order to capture the evolving nature of the field of synthetic biology. I allowed for an open and creative stance to addressing both 'known unknowns', like those literature gaps mentioned above, and to exploring new 'unknown unknowns'. As the rest of this chapter will explain, in the end, the research involved two quite different rounds of analysis of the data gathered.

4.3. Conceptual and theoretical framework

A key ambition when I designed this project was for my research to be exploratory, with efforts made not to be unduly prescriptive within interviews and adherence to inductive analysis through an interpretive approach, 'grounded' in the data. However, there is a broad conceptual and theoretical framework that provides the landscape within which this research and analysis sits. This framework is visualised below, in Figure 3, highlighting the project's two key strands - synthetic biology and food policy - and some of the interfaces between them.

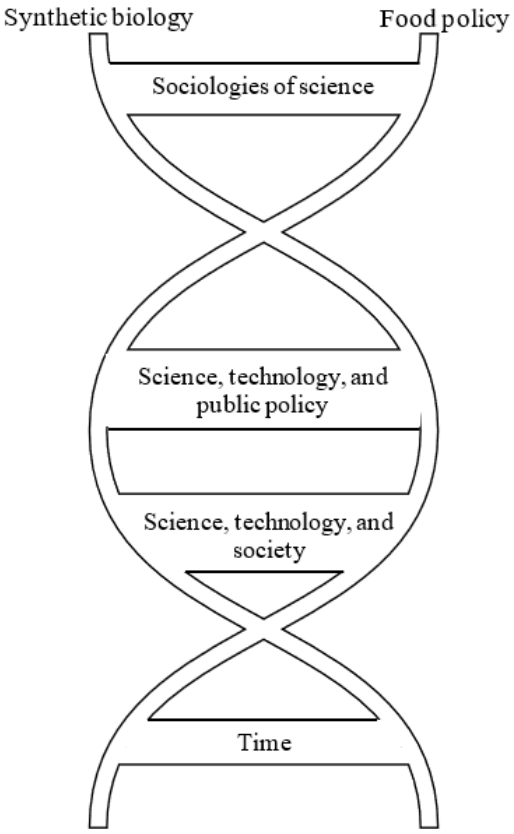


Figure 3 - Theoretical framework (Source: Author)

The influential theories and concepts explored in the literature review, drawn from STS, SSK, (food and science) policy and sociology scholarship, can be broadly grouped under the three

interwoven topics of (i) sociologies of science, particularly those concerned with scientific knowledge and its generation; (ii) science, technology and public policy, which encompasses work on the people and institutions involved in synthetic biology-related policy and their activities; and (iii) science, technology and society, emphasising the roles of technoscientific developments in society, particularly in relation to food and attitudes towards this. The final interface is *time*, referring to the concepts which were vital to the design of the project as horizon-scanning and to later analysis of the relationships of GM pasts to synthetic biology presents and imagined futures.

In a 2010 interview with Li *et al.* (2010:428), Bloor suggests that:

> [Many STS researchers] exploit a long-standing tradition in which it is said that causation applies in the physical science, but the social sciences are concerned with meaning, interpretation and understanding. According to those who follow this tradition those working in science studies [SSK] should use interpretive or hermeneutic methods *rather than* causal methods. (Li *et al*., 2010:428, emphasis in the original)

Bloor points to an interesting false dichotomy that some in the social sciences might perceive: that a choice must be made between interpretive methods - which Bloor considers "an evasion of the deepest and most interesting questions" (Li *et al*., 2010:428) - and causal methods, like those suggested by the Strong Programme of SSK. Clearly, this is a little reductive. The social sciences encompass a vast array of epistemic positions and methodologies. Causation, or the reasons why people think and act as they do, is of interest to many, if not all, social researchers. A researcher exploring perspectives on a given topic is likely to consider what might be shaping or influencing ('causing') these perspectives, for example. This researcher could, by following an interpretive or hermeneutic methodological approach, conceivably arrive at a conclusion about causation just as well as any SSK researcher might by following a Strong Programme-inspired methodological approach.

With this in mind, Bloor's sociology of scientific knowledge and the finding of Finitism are perhaps best viewed as one of many lenses which a researcher could use to investigate and interpret causation. If a relativist epistemological position, like that underpinning SSK, is to be accepted, then any claim to knowledge - like X causes Y, and any other (scientific, social scientific, etc.) concept or explanation - can itself be considered the researcher's interpretation, shaped by their (finite) prior knowledge, experiences, and always negotiable. Infinite other interpretations, applications of a concept, understandings or perspectives are always possible, or to use Bloor's own words:

> Different people shown the same examples or instances of a concept could apply the concept in different ways, because they have extracted different things from the examples. They have created a different understanding, or connected the examples to different purposes, or fitted them into a different background framework. All of these things are intimately related to the fact that "definitions are based on a finite number of examples". (Li *et al*., 2010:423)

In my work, it is not a case of choosing interpretive methods "*rather than* causal methods" (Li *et al.*, 2010:428) but instead considering the two as complementary approaches in the same sociological toolkit. Underpinning Bloor's sociology of scientific knowledge is the idea that "[t]here is always a question to be asked […] about why a concept is being applied in the precise way that it is" (Li *et al.*, 2010:420). It could be argued that it is only through, as Bloor states somewhat dismissively, "[moving] quickly from one thing to another showing the diversity of interpretations" that a researcher can begin to explore why such a diversity of interpretations may exist, what is causing them to be made, by whom, and in which ways. Finitism can then provide a basis, or an explanatory resource, from which to consider these interpretations, themselves knowledges, classifications, concept applications, definitions and more, as negotiable and potentially unstable. In short, Finitism enables a researcher to explore how classification is performed, and the ways in which categories and kinds can be stable *and* can change.

My research was initially designed to be interpretive, involving inductive analysis (step 1) of semi-structured interviews to derive themes from the data. I aimed to explore and demonstrate participants' varied interpretations and understandings of two broad, interlinked topics: (i) the implications of synthetic biology for UK food policy; and (ii) the implications of UK food policy for the development of food and agriculture-related synthetic biology. This first round of analysis led to the findings that participant definitions and characterisations of synthetic biology are multiple and contested, and that experiences of GM controversies from the 1970s onwards, or observations about their results, seem to shape participant views on synthetic biology. This in turn supported the early development of my concept of GM Trauma, discussed further in Chapter Five. These early findings required further exploration, in particular to understand my participants' constructions of synthetic biology, how GM Trauma shaped them, and in which ways this had implications for UK food policy.

As described in Chapter Two, Finitism provides one way of understanding how individuals, each with a finite set of past experiences, examples and learnings, construct knowledge, boundaries and situate the similarities and differences between concepts (like GM, synthetic biology) and objects (like a GMO, a synthetic biology product). In short, my second

level of analysis aimed to elucidate some of the ways that GM Trauma might form participants' 'background frameworks' and influence "conceptual change, adjustment, redefinition, reclassification and negotiation" in the case of synthetic biology (Bloor, in Li *et al*, 2010:421). Using my concept of GM Trauma along with a Finitist lens, my second round of analysis explored how past experiences of GM controversies were shaping, or causing, individual participants' views about synthetic biology.

4.4. Research questions and methodological approach

The following research questions guided the research design, data collection and first round of analysis:

A. What are the implications of synthetic biology for UK food policy?
B. What are the implications of relevant UK government policies on the development of food-related synthetic biology in the UK?

These questions were helpful tools for shaping the methodological approach of this project. They did not have quantifiable answers and thus necessitated qualitative research methodology. The broadness of the questions also hinted towards a methodology involving exploratory consultation with human participants: these were 'opinion' questions. Further, the research topic had not been explored in depth elsewhere, so my approach centred on a desire to speak to a relatively diverse range of participants, exploring the complex environments of both synthetic biology and food policy.

Following the collection and analysis of the data, and the development of my concept of GM Trauma, I embarked on a second round of analysis to address three new and significant questions:

1. What are the ways in which synthetic biology is constructed by this sample of its stakeholders?
2. Why did these stakeholders construct synthetic biology in these ways?
3. What are the implications of these constructions for UK food policy?

These questions, like those that guided the data collection and first step in the analysis process, are also open-ended, with an indefinite number of possible interpretations and responses. I take an interpretivist epistemological position wherein my analysis is just one of many possible others.

4.5. Design

There are several methodological options for exploratory research in the social sciences, and a number of designs were considered for this research. Quantitative methods were discounted, as mentioned previously, although I acknowledge that survey methods can provide useful overviews of views across potentially large samples.

The design of this project coincided with the start of the COVID-19 pandemic, necessitating a rethink on the types of methods I had proposed initially (focus groups). I could not ask participants to meet physically in groups, as this was both unethical due to health risks, and against the law, and while I could have conducted group interviews online, I chose not to for the following reasons. First, while there is some disagreement in the literature about heterogeneity vs homogeneity in focus group settings, it is generally accepted that homogeneity of participants is more conducive to fluid conversation. I was interested in conversations with a sample of participants representing a range of stakeholder groups, believing this to be the most fruitful way of discussing a complex policy topic of importance to many.

Another factor involved in my decision not to conduct group interviews was that certain participants may feel uncomfortable in a focus group setting, may not fit into homogenous groups or may be reluctant to take part (Hopkins, 2007). These participants may include:

i. Elites in industry or governance with busy schedules, or who perceive a commercial or reputational risk from discussing in a focus group setting;
ii. Participants who had a difficult experience in a focus group (or did not want to participate in a focus group) but still feel they want to contribute to the research;
iii. Individuals concerned about their anonymity.

Taking into account these disadvantages, and the practical considerations of the pandemic context, I instead focussed on conducting interviews individual participants online. One strength of individual one-to-one interviews is that participants each have a longer speaking time than individual focus group participants, enabling depth of discussion with each person (Barbour & Kitzinger, 1999; Morgan, 1998). Furthermore, an interview setting is appropriate for more sensitive discussion, such as company-specific practices, which can be anonymised (Barbour, 2007).

Specifically, I conducted semi-structured interviews, which are appropriate in this project for two main reasons. First, through a list of broad talking points, I was able to anchor the conversation around the key topics of synthetic biology and food policy. Simultaneously, as I

did not have a rigid aide-memoire, I could allow participants to 'wander', spontaneously raising topics they deemed interesting and allowing us to explore unexpected aspects of synthetic biology and food policy. Second, a semi-structured interview approach allowed me to ensure that broadly similar ground was covered by all participants, regardless of their background and area of expertise. This promoted the direct, constant comparison conducted through my first round of thematic analysis.

An example of the aide memoire is in Appendix 2. The aide memoire was updated prior to each interview with minor tweaks to tailor questions around a participant's particular area of work, for example. The aide memoire was considered more as a reminder of broad areas to cover, rather than a script. Questions were posed in a variety of orders depending on what felt natural in each interview.

4.6. Data collection procedures: sampling

Robinson (2014) recommends using the following four points as a framework for acknowledging the theoretical and practical aspects of a project's sampling approach: (1) define a sample universe; (2) decide on a sample size; (3) devise a sample strategy; and (4) source the sample (recruitment).

The sample universe

Robinson (2014:26) suggests that in order to define a study's 'sample universe' (target population), a researcher must consider two "key decisional issues". These are: (i) homogeneity vs heterogeneity, and (ii) inclusion and exclusion criteria (Robinson, 2014), which are interrelated. The more exclusion criteria there are, the more tightly homogenous the target population is likely to be. I was reluctant to impose a large number of exclusion criteria to avoid limiting the study's ability to generate unexpected threads of data. Further, exclusion criteria may inhibit contributions from a wide range of perspectives, and indeed, several stakeholder groups can be identified from the literature. These include:

- The research community (e.g. synthetic biologists, social scientists, policy researchers),
- Policymakers
- Industry (such as farmers, buyers, corporate policymakers, biotechnology industry, individuals involved in R&D)
- Funders

- Non-governmental organisations (NGOs) (like civil groups, charities, thinktanks).
- Citizen-consumers (without food policy or synthetic biology-specific knowledge or experience)

I decided that my 'sample universe', would include one or more of the abovementioned stakeholder groups (target populations). However, while all my participants are necessarily citizen-consumers of food, market research literature suggests exclusion criteria for 'consumer' participants could be employment relating to either the research topic, to market research or to media and journalism (Nilsson, 2018). In short, individuals with a vested interest in the research findings should be excluded from a consumer group. Thus, while the views of 30 food consumers are presented here, none of my participants can be said to fall solely into the citizen-consumer category. Future research could focus on citizen-consumer (lay) views more directly.

Efforts were made to recruit citizen-consumers on a voluntary basis to take part in semi-structured interviews. This group was approached online, through advertisements on social media and a website featuring project details, which included the text:

> If you are interested in talking to us about your views on synthetic biology in UK food and agriculture, please get in touch via email! We want to hear from you if you are UK-based, operating in the UK market, or looking to do so in the future, and are:
>
> - Working on synthetic biology-related business, research or policy
> - A consumer
> - A food producer[17]

These recruitment attempts were ultimately unsuccessful and no participants solely from the citizen-consumer stakeholder group volunteered. Due to the COVID-19 context, no funding was available from the university for more thorough digital marketing or communications activities to recruit citizen-consumer group participants. While other approaches are available in the literature, delays already posed by redesigning the interview fieldwork to take place online during the pandemic meant there was insufficient time to pursue the relevant training and to carry out these alternative methods.

The absence of citizen-consumer participants that do not also belong to other stakeholder groups produces two main limitations for my analysis. First, lay publics are often excluded from discussions relating to complex technoscientific developments and their governance. This serves to situate the topic as something for experts to discuss, rather than those perceived as lacking the knowledge to usefully contribute. The lack of lay publics'

[17] Available here: https://www.students.ncl.ac.uk/nataliepartridge/2020/11/03/get-involved/

participation in this research unfortunately reproduces these problematic approaches to debating technoscience and its roles in society, regardless of my best intentions to recruit lay participants. Second, throughout my fieldwork, participants routinely referred to (lay) citizen-consumers and made assumptions about their views. In omitting to recruit any (lay) citizen-consumers, there is no way to compare such assumptions with the responses of citizen-consumers to similar interview questions. As such, the voices of other stakeholder participants are privileged, and lay publics are not represented.

Excluding the (lay) citizen-consumer group, which was not represented in the final sample, the criteria for inclusion in the research were:

Category	**Inclusion criteria**
Demographic	Over 18 years old
Professional	Individual self-identifies (or belongs to an organisation which self-identifies) as working in/on food or synthetic biology-related projects or policies. **OR** Individual (or the organisation they belong to) is identified in the literature as working in/on food or synthetic biology-related projects or policies.
Referential	Individual (or the organisation they belong to) has been suggested by another participant.

Table 1 - Sampling selection criteria (Source: Author)

Sample size

My target sample size was flexible. I aimed to recruit between 15-35 interviewees, and finally conducted 30 interviews between November 2020 and December 2021.

Sample strategy

My strategy was two-pronged: (i) purposive sampling, leading often to (ii) snowball sampling (participants recommending others to contact). I began with a varied group of 4 participants, which I treated as pilot interviews, to enable me to assess my aide memoire and make changes[18]. Following this, the purposive sampling strategy involved sending out batches of emails to around six participants at a time, typically grouped based on their current work (synthetic biologists in research laboratories, businesspeople, policymakers etc.). The literature review enabled me to identify several individuals within these broad groupings. This is best described as a non-random strategy with the aim of:

> [E]nsuring that particular categories of cases within a sampling universe are represented in the final sample of a project. The rationale for employing a

[18] See section 4.9 for details of my pilot interviews.

> purposive strategy is that the researcher assumes, based on their a-priori theoretical understanding of the topic being studied, that certain categories of individuals may have a unique, different or important perspective on the phenomenon in question and their presence in the sample should be ensured. (Robinson, 2014:32)

Participants often mentioned other potential participants in interviews, enabling me to take a snowballing approach within groups that were more challenging to access, such as the civil service and non-governmental organisations.

Composition of the sample

The composition of the final sample is specified in Table 2 on the following page. Participants can be broadly grouped into the groups (1) Governance-civil service-advisory (Gov n=10); (2) Other public and private sector organisations (Org n=9); and (3) Scientists and scientist-advisory (Sci n=11). Participants belonged to a relatively diverse range of organisations, including the civil service, funding bodies, advisory groups, academic research institutions conducting scientific and non-scientific (social scientific) research, other research institutions, industry (farming, foodservice, fresh produce supply, biotechnology), non-governmental organisations, think tanks and international policy organisations. However, the sample is also relatively homogenous in the following ways: (i) all 30 participants have completed higher education to degree level, with several also to postgraduate degree (master's or doctoral) level. (ii) 24 of the 30 participants have academic training to degree level in a STEM (Science, Technology, Engineering, Mathematics) subject. Furthermore, (iii) 20 of the 30 participants were working or studying in a relevant field during the GM controversies of the 70s, 80s, 90s, or early 00s. Further participant attributes, such as demographic information relating to gender identity, age, race and ethnicity, were not collected as it was deemed non-essential to meeting the project aims.

The composition of the final sample is specified below.

Group	Alias	Participant description	Other details	Interview
Governance-civil service-advisory	Gov1	Advisor to UK government		12
	Gov2	Manager at UK funding body		14
	Gov3	Regulatory lawyer, UK	Advisor to UK government	16
	Gov4	Civil servant, UK		18
	Gov5	Manager at UK funding body	Environmental science background	19
	Gov6	Manager at UK funding body		21
	Gov7	Civil servant, UK		22
	Gov8	Advisor to UK government		24
	Gov9	Civil servant, UK		29
	Gov10	Civil servant, UK		30
Other public and private sector organisations	Org1	Academic non-scientist UK		1
	Org2	Academic non-scientist UK		2
	Org3	Foodservice industry worker	Law background	3
	Org4	Farm worker	Environmental science background	6
	Org5	Academic non-scientist, UK		10
	Org6	Manager at international NGO		13

	Org7	Academic non-scientist, non-UK		15
	Org8	Agricultural economist, international policy organisation	Economics background	23
	Org9	Advisor at European policy think tank		27
Scientists and scientist-advisory	Sci1	Academic scientist, UK	Computing background	4
	Sci2	Academic scientist, non-UK	Involved in a start-up	5
	Sci3	Academic scientist, non-UK	Advisor to European authorities	7
	Sci4	Scientist, UK		8
	Sci5	Scientist, UK	Advisor to UK government	9
	Sci6	Manager at UK industrial biotechnology company	Microbial science background	11
	Sci7	Academic scientist, UK	Advisor to UK government	17
	Sci8	Scientific consultant to international NGOs	Plant and soil science background	20
	Sci9	Manager at UK fresh produce company	Agrichemical company background	25
	Sci10	Academic scientist, UK	Involved in a start-up	26
	Sci11	Academic scientist, UK	Advisor to UK government	28

Table 2 - Participants, grouped (Source: Author)

4.7. Participant recruitment

Participant recruitment materials can be found in Appendix 3. Considering the volume of email traffic due to remote working during the pandemic, I was eager to avoid participants ignoring my invitations to interview and so, I chose to focus on a clear approach to communication during recruitment.

Firstly, I condensed the text of the email as far as possible, making use of bullet points and bold text to make it easier for participants to navigate. Second, I developed a participant information sheet, designed to be attached to the invitation email and viewed digitally. In recognition of the email recruitment method and 'cold-contacting' technique, I was keen to ensure that the sheet was as concise and visually engaging as possible. When producing this sheet, the following aspects were considered:

i. Text fitting on one single sheet, like a flyer
ii. Retention of the typical 'question and answer' format to make information digestible
iii. Use of colours and images
iv. Use of textboxes, different fonts and varying font sizes to break up the text
v. Use of hyperlinks e.g., for Portabolomics project website, Newcastle University policies on GDPR
vi. Use of colour to draw attention to key parts, such as the project title, introduction, contact details.

I also had many discussions with my supervisors about the content of this sheet. For example, we debated whether or not to include a definition of synthetic biology, with my supervisors suggesting that this might help participants to engage with the project, as the term synthetic biology is, for many, not well-known or widely used. However, I did not want to bias participants, having read about the influence of the researcher's framing of topics like genetic modification on participant attitudes. I am glad that I did not include this, as participants who were already familiar with the topic often offered definitions of synthetic biology that were very different to the definitions that I identified during my literature review.

My recruitment approach was successful, and 28% of participants approached agreed to be interviewed. Once agreement was indicated, participants and I would arrange a time to meet, and I then sent a calendar invite, Zoom link and a letter (see Appendix 3), including a consent form which was designed with ease of completion in mind, either digitally or in hard copy.

4.8. Data collection

My fieldwork involved conducting 30 semi-structured interviews one-to-one with participants via Zoom videoconferencing software. The Zoom platform is widely used and has gained increasing popularity in recent years. The decision to use Zoom was pragmatic. Unlimited free access to Zoom was available through Newcastle University and meeting in person was not an option during much of 2021, making videoconferencing a sensible, legal, and safe option. All participants had experience of using the software.

That said, the use of Zoom is problematic in its reliance on participants having a device through which to access the internet, and a stable internet connection, which is, of course, exclusionary. However, my participants, broadly working professionals, were likely to have access to suitable equipment. I was conscious of my internet connection, and about participants' too, particularly if based in rural areas. I did sometimes lose connection at critical moments, and the interview transcripts show at least six interactions similar to:

> **Org8 (Agricultural economist):** [P]eople don't care about it for that context, but for food, it is very sensitive. So, it might also be a bit domain-specific where we will see the biggest case.
>
> **Natalie:** Why do you think it is more of a sensitive question around food?
>
> **Org8:** There are a couple of good reasons and a couple of weird reasons. I think one of the weird reasons might just be that-
>
> **Natalie:** Oh, no. You have frozen. Oh.
>
> **Org8:** Oh, sorry. Can you hear me?
>
> [Break in conversation 0:49:37 - 0:49:52]
>
> **Natalie:** Are you there?
>
> **Org8:** Are you there?
>
> **Natalie:** Yes. (Laughter) Sorry, I think it's my Wi-Fi.
>
> **Org8:** No problem.
>
> **Natalie:** Sorry. Yes, I missed that. (Laughter)

In spite of technical hiccups, in practice, conducting interviews on Zoom provided significant benefits. I was able to record all interviews, a process which was mostly unobtrusive but obvious to the participant at all times, as a small "recording in progress" message and red dot were present in the corner of the screen throughout. Further, I was able to follow up on snowball sampling routes that might not otherwise have been possible. For example, I engaged with a small handful of participants based abroad, as far afield as the United States, the European Union and Israel.

Zoom interviews also gave participants options that they would not have had in person, such as switching off their video if they wanted a break from being observed, although all participants left their cameras on throughout our meetings. It was also easy for participants to share their screen with me, which was useful on occasion, or to send me links to online materials through the chat function. However, Zoom was no barrier to some of the same quirks as in-person interviewing. For example, when winding up interviews by asking whether participants knew of other potential participants I could speak to, I observed something similar to the 'hand-on-the-door' phenomenon. Participants would often relax and offer information that they had not raised during the interview. It was easier to keep recording throughout these interactions until the end of the call, where in an in-person interview, the recording would have been stopped.

Finally, and perhaps most importantly, a benefit of Zoom interviewing is that participants were comfortably in their own homes, they did not have to travel, and neither did I. This allowed me to carry out fieldwork during a funding freeze and travel ban at the university. Equally, for many, and for me, talking on Zoom from home helped us to relax and gave us a shared experience to chat about. Instead of the usual opening pleasantries about journeys or the weather, many opened with a quick comment on work-from-home setups, noisy neighbours or their preference for one video conferencing software provider over another.

4.9. Pilots

Pilot interviews were essential to highlight any shortcomings in my interviewing style, to understand how to use Zoom functions, and refine the aide memoire. I conducted four pilot interviews (Interviews 1, 2, 3 and 4), choosing to interview participants from a range of broad groups (social researchers, foodservice and a scientific researcher) to test my aide memoire across a range of participants.

I found that managing discussions and creating rapport can be challenging in an online setting. To a degree, moderators can promote rapport, depth of conversation, as well as dynamic, inclusive discussion through prompting and probing (Hopkins, 2007). However, not prompting or guiding sufficiently may mean the conversation goes off topic or leave key areas of discussion underdeveloped. However, while sufficient prompting is important, interviewers must be conscious of their own research interests, as prompting participants to develop one idea more than others is an example of moderator bias. These are all aspects with which I struggled initially. For example, I found taking notes during interviews and listening at the same time

difficult. I spent a lot of time on notetaking after the interviews but lacking notes during the interview meant I missed some opportunities to ask questions, probe or return to topics previously discussed. Based on the pilot interviews I devoted more time and energy into developing a relaxed, confident style. By the end of my fieldwork, I was not only more confident, but able to multitask and take detailed notes during interviews.

Inspired by the experience of my pilot interviews, I turned to some approaches developed in grounded theory literature, deciding to collect and analyse data concurrently. This process was creative and challenging but allowed me to monitor three things, making adjustments throughout the fieldwork: (i) my interview technique, (ii) quality of data, (iii) the construction of a bottom-up theoretical framework, particularly helpful later in signalling a need for a second round of Finitst analysis.

4.10. Data analysis procedures

Analysis Step 1

Following my pilot interviews, I established a process of collecting and analysing data concurrently. How this was operationalised was inspired in part by my readings on grounded theory, and I have borrowed some key principles (Bryant & Charmaz, 2019). My data collection and analysis occurred concurrently and were shaped by one another. My coding was inductive, carried out without a framework of pre-defined codes (Glaser & Strauss, 1967). However, I remain critical of Grounded Theory. I reject the inherently positivist assumptions underpinning some of the principles of its earliest iterations (Kelle, 2019, in Bryant & Charmaz, 2019). I do not think there is a single 'truth' or 'fact' that will 'emerge' from my data, but rather an interpretation that I have derived from my data.

Early analysis involved some note-taking stages: first I took rough listening notes, followed by more detailed fieldwork notes later. Then, upon receipt of verbatim transcripts from a transcriptionist, I listened to the audio again and made (typically minor) corrections to the transcripts and uploaded them to the NVivo 12 software package. NVivo enables researchers to code data digitally, providing a digital alternative to manual, pen and paper highlighting or underlining of quotes. NVivo is described as "widely used to analyse heterogeneous, qualitative datasets" (Pansera *et al*., 2020:391).

My analysis of the transcripts in NVivo began with line-by-line, inductive coding. My approach was mostly 'informant-centric', meaning I used words from the data as labels for the coded data, for example, I had a code called "That isn't what I do", and another called "brain

drain", terms introduced by participants. I also created some 'researcher-centric' codes to keep track of my ideas on certain aspects of the data. An example of this would be the code "Separation of science from business", referring to a distinction some participants made between their own laboratory activities and any eventual commercial applications that could conceivably be developed from them. These can be described as 'descriptive codes'. Once all 30 interviews were coded, I had a list of 190 codes (see Appendix 4). From these I began a process of categorisation. A coding matrix query in NVivo 12 (Table 3) shows the categories and codes that were most prevalent across interviews. The green colours represent the number of participant interviews coded to these topics, with lighter greens representing fewer transcripts, and darker greens indicating that more participants discussed the topic.

The "GMOs" code was investigated separately as it contained a large number of references and covered a range of topics like current governance, public perceptions and acceptance, and ethical considerations. I created a range of 'semantic' (focussed on meaning) and 'latent' (focussed on drivers of meaning) sub-codes, with the aim of deciding how best to interpret the data. The result was the broad theme of GM Trauma, detailed in Chapter Five, which in turn was developed as a concept underpinning the second stage of analysis.

		Number of interviews coded per participant group		
Code	**Category**	**GOV (n=10)**	**ORG (n=9)**	**SCI (n=11)**
GMOs	GMOs	10	8	11
Environment	Food policy priority areas	9	9	11
Commercialisation	Commercialisation	10	8	11
Current governance	Current governance	10	7	11
Ethical considerations	Ethical considerations	8	9	11
People & roles	People & roles	9	8	11
What synthetic biology is	What synthetic biology is	7	9	10
Potential future governance	Potential future governance	9	6	9
Risk, safety	Risks	9	6	9
Imagined synthetic biology futures	Imagined synthetic biology futures	7	7	9

Definition of synthetic biology	What synthetic biology is	7	6	10
Human health	Food policy priority areas	5	7	10
Policy priorities	Food policy priority areas	8	6	6
Public perception, acceptance	Synthetic biology-society interface	8	3	8
(Un)natural	(Un)natural	4	8	6
Disconnected	People & roles	7	5	4
Funding	Potential future governance	6	3	7
Dialogue (with publics)	Synthetic biology-society interface	5	5	6
Covid	Covid	8	3	5
Brexit	Brexit	7	3	5

Table 3 - Most common codes and categories across participant groups (Source: Author)

Analysis Step 2

The second level of my analysis built upon the inductive coding and thematic analysis of the interview data carried out in Step 1. I adopted my concept of GM Trauma (a finding from Step 1) and used a Finitist analytical lens to explore and explain participant constructions of synthetic biology. As such, I revisited the interview data with an explanatory, causal focus. How is synthetic biology constructed by a sample of its stakeholders? Why? And what are the implications for UK food policy?

I focussed on participants individually to analyse the characteristics of their GM Traumas, what they had experienced or observed about GM controversies, and how this influenced their constructions of synthetic biology. To manage the analysis, I built a table in Excel containing the following columns to categorise and sort the interview data, with explanations in italics:

- Participant alias
- Job description - *the role through which they had agreed to be interviewed*
- Other work details - *such as whether they are also involved in academic research alongside a government advisory role, for example*
- Experiences of GM controversies - *such as the type of work or research they were carrying out at the time, or where they had learned second-hand about GM controversies*

- GM trauma indicators or examples - *such as specific incidents of conflict or examples given about GM controversies and their effects*
- GM trauma type – *such as first-hand, having direct personal experience of conflict, or of observing the controversies as they unfolded, or second-hand, having learned about them*
- Constructions of synthetic biology - *like whether synthetic biology was considered similar or different to GM, or as risky, (un)ethical, (un)natural etc.*
- Notes - *such as whether participants focussed on particular topics, like definitions of synthetic biology or GM, or barriers to the economic success of the field, etc.*

I added some notes on participant attributes like their education level and any STEM training to degree level. I also included my interpretations where possible of: participant interests (such as career success, collective economic interests like involvement in farming cooperatives, positively impacting the world); values (such as Western capitalist neoliberal values around rights to property, and sharing benefits, preventing various harms); and beliefs or worldviews, which tended not to be religious, but rather scientistic, anthropocentric or not. As the data contained in this table are potentially identifying of participants' lives and experiences, a sample (not containing some of the most identifying details) is provided in Appendix 6.

The table was designed primarily to aid me in exploring participants' individual constructions of synthetic biology and to interpret how GM Trauma might be shaping them. It also enabled me to explore patterns in the data. For example, I could filter the data and consider how only participants with first-hand experiences of GM controversies constructed synthetic biology. I could then explore whether and how constructions of synthetic biology differed within the group, or from those of participants with second-hand GM Trauma, for example. Overall, this second step of analysis was effective in adding meat to the bones of the GM Trauma concept on the one hand, and on the other, in drawing a line from GM Trauma to participant constructions of synthetic biology, which in turn have policy implications.

4.11. Ethics

This project was deemed ethically low risk by the ethics committee in the Faculty of Humanities, Arts and Social Sciences as Newcastle University and approval for the research was granted on 30th October 2020. An amendment to this ethical approval was granted on 17th May 2021 to allow participants to proceed with verbal consent only, rather than a written consent form, in exceptional circumstances where participants requested this option.

The ethical approval process considered the following aspects, reflecting the broad principles contained in the British Sociological Association's Statement of Ethical Practice (2017).

Participant wellbeing

Even when a research project is deemed ethically low risk, and the topic is non-sensitive (like my research topic), something raised in an interview could affect participants emotionally, particularly if they feel uncomfortable, pressured, vulnerable or as though their private information may be shared (Sim & Waterfield, 2019). Participants could also be affected reputationally, which may extend to the organisations to which they belong or that they represent. To avoid this, I agreed to occasional participant demands to ensure that they were comfortable. For example, one participant requested that I forward them any of their direct quotes in their limited context within the thesis. Other participants would sometimes preface comments in interview with a request not to include the quote, for example.

Informed consent

To ensure participants were aware of the implications of participating in the research, it was vital to gain their informed consent (Sim & Waterfield, 2019). A consent form was circulated to all participants, along with my information sheet, which included details of anonymisation of data and instructions on how to raise questions about the study (Sim & Waterfield, 2019). It was made clear in these documents and at interview that participants could withdraw from the research at any time without giving any reason, until the point that the thesis was in its final draft (Hopkins, 2007). Participants received a copy of the information sheet and consent form for their records, so that they could remember what they had consented to (Hopkins, 2007). I also offered participants a chance to ask me any questions about the project at the start and end of the interviews.

Data protection

The online platform for my interviews, Zoom, does not store data to the cloud automatically. Instead, all recordings were manually downloaded by me, stored on my university-owned machine and used in line with the Newcastle University data protection guidelines. To enable participants to query this, if necessary, a telephone number for university data protection queries was provided in the information sheet.

Collected data was handled in accordance with the university guidelines on data protection and GDPR regulations. In my research, data was anonymised and participants were given an alias. General job descriptions were used to minimise identifiability. All data was stored securely according to the guidelines and will remain so for the specified period and then destroyed. Data storage took a 3-2-1 approach, whereby 3 copies of data were stored, with 2 online (one on my university machine and one on the university OneDrive cloud) and 1 physical copy. Physical copies were held in a locked cabinet in a file marked 'CONFIDENTIAL'.

Managing expectations

Participation in research can create expectations for an outcome or action, but participant contributions may be limited or misinterpreted in line with existing thought or the aims of research projects (McLaughlin, 2009; Freire, 1972). The informed consent process addressed any potential outcomes of my research, highlighting the purpose of the data collection and all likely uses of information gathered. Further, the consent process included a summary of the timeline of the project and my contact details, so that participants could request copies of a thesis abstract at a later date.

Incentives

Upon participation, the ethical implications of financially incentivising participants can be controversial (Barbour, 2007). Some think that participants should always be reimbursed for their time, and others believe that financial incentives are inappropriate or fraught with risks depending on the amount of money offered (Krueger & Casey, 2000). In my research, no financial incentives were offered for participation. There were no participant travel expenses to reimburse (Krueger & Casey, 2000). I also did not need to arrange refreshments with university catering staff, or staff at an off-campus venue (Barbour, 2007).

4.12. Reflections on the research process

There is no such thing as a 'neutral social researcher' (Scott *et al*., 1990). Individual experiences and personal, academic, social and political contexts play a part in a person's interests and understandings. These are multiple and evolving and they contribute largely to ideological and philosophical assumptions affecting research design and decisions. Threadgold (2018:39) suggests that we can "understand the Bourdieusian social subject as one that accumulates being, a cumulative self (Noble 2004) that gathers things, relations and experiences in the constant struggle for meaning and recognition." This in turn shapes understandings of sociology as a

discipline, acknowledgement of which has resulted in a certain requirement for reflexivity in sociological research (Kenway & McLeod, 2004).

A researcher's reflexivity on their approaches is variously "lauded as a necessary methodological stance" and "an imperative", but also "frequently deployed in a relatively weak and mono-logical sense" (Kenway & McLeod, 2004:527). Striking the right tone is a challenge, and in an effort to steer away from "vanity reflexivity" (Kenway & McLeod, 2004:527) I am reluctant to detail my autobiography here. However, Bourdieu's work on the tensions between social subject-object reveal this to be a key component of interrogating both sociology as a discipline, and the 'doing' of sociological research at the more local level of my project. Nowhere are these tensions more evident than in my interview transcripts. In particular, I reflect on the quotes which follow as snapshots of my position in relation to my participants and the research topic, including notions of insider-outsider relations, and 'researching up'.

Exchanges similar to the following, involving interrogating or questioning my understanding of technical, scientific specifics, or of policymaking processes, were common in interviews. The queries were often well-intentioned, because participants wanted to make sure that I was following the complex examples they were giving. Participants also sometimes sought a sense of how to pitch their responses in terms of level of detail, asking "I don't know if you know X" or "have you heard of Y?" When talking with participants with high levels of specialist expertise, this sometimes served to position me as an outsider, for example:

> **Sci11 (Academic scientist and Advisor to UK government):** So how are you finding the technical sides of [your topic] because synthetic biology is a pretty deep and complicated field. I mean, are you handling that okay?
>
> **Natalie:** Yes, it's a really steep learning curve, as you can imagine. Yes, but I'm handling it okay, I think.
>
> **Sci11:** Presumably, the project overlaps with people who have got the technical expertise, so if there are things you don't understand, there is someone you can go and talk to?
>
> **Natalie:** Yes, absolutely, and one of the great things about talking to people like yourself with the technical expertise is I'm helped along.
>
> **Sci11:** Right.
>
> **Natalie:** So yes, can we start with you and what you do?

There was also a reverse to this coin. Participants often mentioned topics that were "more your [my] area," or "I'm sure you know X," when referring to concepts they deemed to be related to social science. Participants rarely seemed uncomfortable discussing these, or to share in my sense of being an 'outsider'. Perhaps being situated as an 'outsider' was accompanied by a more uncomfortable sense of 'researching up' for me. For example, at the start of an interview,

I asked one participant, an academic scientist, if they had any questions. The participant stated "Yes, I guess, just around the remit of it. How wide are you looking in food, and also why this is worthy of a PhD, and what made it interesting?" The sentiment or implication was that the research was not obviously worthy of a PhD, or not interesting.

However, given the range of participants I recruited, my position in this research is more ambiguous than an insider-outsider distinction. For those with non-scientific expertise, sometimes I was queried about specifics of technical processes, including for example, cellular agriculture, cloning, as well as certain applications. Of course, participants asked about my funding, my supervisors and the Portabolomics project to which I am attached, suggesting that I need to be careful to balance the views of scientists and other stakeholders. For example, at the end of an interview, a participant spoke about: "how you actually balance up all of these… Because if you interview 10 scientists, you will have 10 scientists' opinions. If you interview 10 NGOs, you'll get all the NGO opinions. […] and that is where it is quite difficult, I think, actually. That is where the skill lies." Note the comment on skill.

Indeed, returning to the idea of 'researching up', framing my research around a desire to speak to a range of stakeholders, all skilled, experienced professionals in the area, positioned me (not least to myself, but likely also to participants) as quite inexperienced. While sometimes uncomfortable for me, this did have unexpected advantages. Participants were thorough in their explanations, generous with their time and patient with my probing questions and repetitions. 'Researching up' enabled me to interrogate not only policy in this area, but also the sentiments and the dynamics of the stakeholders I spoke to, including their interests, assumptions and relationships or disconnections from each other.

Overall, reflecting on the methodological choices that led me to my sample, I am pleased with the range of participants I recruited, and my relative success with recruitment in sometimes hard-to-reach groups like representatives from industry. I believe my sample is a fit source of useful data on synthetic biology-related food policymaking, and my participants offered a vast range of interesting insights, enabling me to draw fruitful conclusions across the sample.

4.13. Limitations and strengths

This section discusses the limitations of this research as well as its strengths. Some of these arise from the choice to take a qualitative approach. Others are owed to the challenging circumstances in which the fieldwork was carried out online, which presented both disadvantages and opportunities.

A limitation of this research, while openly recognised and emphasised throughout the thesis, is that my interpretivist approach is my own, and it is possible that another researcher would interpret the data differently. However, I consider my interpretation to be credible, although not generalisable, and it is often consistent with other studies or theories. Further, as my sampling strategy was purposive (convenience sampling), rather than a randomised approach, the findings cannot be generalised. Certain groups are also underrepresented in the sample, for example consumers who were targeted via a website and social media without success, and the farming community, although farming unions were approached. Politicians are also not represented, despite several being contacted. Furthermore, multinational companies operating in the synthetic biology food space, including those with high profile applications, were contacted without success, although some referred me to interesting online materials. It must be acknowledged that, due to my sampling approach, participants with particular interest in the topic might have been more likely to come forward, and so general disinterest or perceptions about irrelevance of the topic are some views likely to be underrepresented. In short, statements about the findings cannot be said to represent views more broadly than the sample and the specific context of this project, and no claims are made that the research is representative.

That said, the sample of 30 participants from a range of organisations is one of the main strengths of this research. The approach of purposive sampling combined with snowball sampling enabled access to harder-to-reach groups like those in industry and NGOs. Although being unable to meet participants in person felt like a missed opportunity, it is unlikely that I would have recruited such a breadth of participants were it not for the increased use of video calls during the pandemic, and participants' openness to being recorded in this way. The result was a large volume of interview data which was essential in exploring the array of rich, complex, and varied views of my participants. Therefore, another strength of the research was its qualitative approach, which provided both depth of data and some surprises. Of course, quantitative approaches involving, for example, survey methodologies might have yielded a larger or more representative sample of UK society. However, the data gathered would have been unlikely to permit the same exploration, wandering, unexpectedness, and richness as the interviews I conducted.

Chapter 5: 'Traumatised' by GM controversies

5.1. Introduction

The previous chapter explained the methodological choices taken in this study and described the steps taken to collect data through semi-structured interviews, as well as the approach to thematic and Finitist analyses. This chapter and the two following present the data from my fieldwork and explore the findings of my analysis, beginning with an exploration of a central concept and analytical tool, 'GM Trauma'.

5.2. GM Trauma

Genetic modification (GM), genetically modified organisms (GMOs) or terms of broadly equivalent meaning (e.g., genetic manipulation) were mentioned in 29 out of 30 interviews. The exception was Org1, a UK academic non-scientist who was one of the youngest participants, with no direct experience of the first GM debates and a primary interest in animal welfare. Otherwise, the majority of participants spoke unprompted about GM. Prior to interview, my interactions with two participants, Sci3, a non-UK academic scientist, and Org5, a UK academic non-scientist, involved discussion of GM. The topic of GM was introduced early into these two interviews by me.

As discussed in the literature review, it has been observed that experiences of GM controversies have been "internalised as a prominent fear" by some in the synthetic biology scientific community (Molyneux-Hodgson & Meyer, 2009:137). I too observed this across the diverse range of my participants during the thematic analysis of transcripts. There was a striking tendency for participants to be retrospective, referring to experiences of genetically modified foods controversies and the implications they might have for synthetic biology. For example, Sci8, a scientific consultant to international NGOs, mentioned that "the fundamental objection to GMOs being in the environment or in food stuffs [is] this idea that they have been created in the laboratory. And I think that would resonate very much with synthetic biology." Gov5, a manager at a UK funding body, commented that "if we're not careful […] society is going to look at synthetic biology, ally it to genetic modification and stop it dead." Furthermore, one advisor at a European policy think tank, Org9, mentioned that "[p]eople who don't like genetic modification and don't like genome editing are not going to like synthetic biology." All three of these participants experienced or were aware of conflict personally in the original debates. This prompted me to question whether similar sentiments were shared by others, such as those

who did not have these direct experiences. I found that indeed they were, but in different ways. This recurring theme signals something that I conceptualise as 'GM Trauma'.

Raising the subject of governance in interviews seemed to be a fruitful pathway into discussing the relationships between GM pasts and synthetic biology futures. Many of my participants lived through GM controversies, working as scientists, for NGOs, as social researchers or in arenas of governance and debate, such as scientific advisory committees. The phrase GM Trauma originated in an interview with Sci7, a UK academic scientist and government advisor, who described how:

> The scientific community, I think, was quite traumatised by the GM experience. Some of them quite bravely did what people said they needed to do and went and talked to people. The NGOs ran a very effective campaign. Any public meeting, they would turn up there. The ordinary members of the public who were at that meeting were not able to have their say. It just turned into a shouting match between the NGOs and the scientists. The scientists didn't really engage in shouting back, but it was really traumatic for some of these scientists, they had a tough time. They just didn't have the skills to know how to handle it. They were used to people taking what they said at face value, it was difficult. (Sci7)

The word 'traumatised', as it is used here by Sci7, is perhaps best characterised as everyday or colloquial, rather than an evocation of a formal psychological definition. Sci7's reference to trauma, and the sense of GM Trauma that I identified across my interviewees, conveys the feelings resulting from perceived negative or shocking experiences relating to GM controversies, and how they (i) are not forgotten, (ii) have been learnt and (iii) influence present thinking. It may be the case that individual scientists did suffer psychological trauma following attempts at public engagement during GM controversies, as in Sci7's account of meetings becoming "a shouting match", but that is not the sense in which I use the term GM Trauma. Rather, GM Trauma is a recognition of the impacts of these past controversies across my sample, and their shared effects on groups of participants, but which do not manifest in the same way in each participant. The sentiment that synthetic biologists' actions in the present might be influenced by past experiences - or assumptions about - GM controversies is also alluded to in notions like Marris' (2015) "synbiophobia-phobia", a fear that publics will fear synthetic biology, as they are perceived to fear GM.

GM Trauma can also be understood through a Finitist lens as a key part of the 'background framework' informing the ways in which participants construct synthetic biology and conceptualise its governance. GM Trauma is therefore also a useful explanatory, analytical tool which can illuminate the causes of participant constructions of synthetic biology. It provides a lens through which I explore and explain, here and in Chapters Six and Seven,

participant views on synthetic biology's definitions, boundaries and status as potentially controversial or risky or not. GM Trauma frames discussions about how publics might be engaged with, communicated with or managed and supports views about the status and value of scientists and science in policy arenas, possibly to the exclusion of other stakeholders. Participants perceived GM controversies to have resulted in today's 'reactive', 'stifling' and 'draconian' governance framework. As this chapter and those that follow demonstrate, GM Trauma, therefore, may have practical implications. Perceptions of past GM controversy and conflict manifest as an expectation of future controversy and conflict around synthetic biology. Driven by participant views about their own roles and about the attitudes and roles of others, and a feeling of being in conflict with others on the topic of GM, there is a sense of fragmentation across stakeholders. This may contribute to insularity of scientific and policy communities and an over-reliance on scientific expertise in synthetic biology-related food policymaking spaces. Such fragmentation and insularity promotes the exclusion of other viewpoints and siloed thinking, leading to a narrow focus on technoscientific notions of risk/safety and economic priorities. This persists despite the involvement, scrutiny and advice of social scientists working closely with synthetic biologists for many years.

5.3. Multiple GM Traumas

This section explores my interpretations of how GM Trauma manifests individually. I begin with the five participants that have first-hand experience of conflict with other individuals and groups during GM controversies. I then to explore the views of fifteen participants who describe first-hand experience of GM controversies, having worked in relevant fields at the time, but who observed the controversy unfolding rather than experiencing conflict themselves. Finally, I analyse the views of the ten remaining participants who were not working or studying in relevant fields at the time, due to their age or career trajectory, but who appear to have nonetheless learned and deployed a range of debates and impacts of GM controversies.

5.3.1. Participants with first-hand experience of conflict

Five participants described first-hand experiences of conflict with others during GM controversies. These participants are: Gov8, a UK government advisor; Org6, a manager at an international NGO; Org9, an advisor at a European policy think tank; Sci7, a UK academic scientist and Sci8, a scientific consultant to international NGOs. This section explores how experiences of conflict during GM controversies influenced these participants' discourses with

particular focus on patterns of discussing conflicting stakeholders, and framing synthetic biology in relation to GM.

Conflicting stakeholders

Gov8 has a background in academic scientific research and has experience as a government advisor. Through their research and government work on GMOs, Gov8 experienced conflict with NGOs and other individuals and groups both nationally and internationally during public engagement activities. Gov8 describes the impact of this conflict on them personally (in terms of a feeling of being unsafe) and professionally (being prevented from conducting their professional activities):

> Greenpeace International were there and they were waving flags and banging drums and generally making a hell of a row. And we all had to be led off, basically, for our safety, and ushered away to a hotel. But the next day […] the 'Hindustan Times', which is equivalent to our 'Times' really in New Delhi, had a headline and it said, "Greenpeace fascists tried to deny our country the food we need," and that editorial was making the point that if you could stop crops being ravaged by insects, or you could increase yield or put drought-resistant genes in, then they wanted them, thank you very much. So, the whole argument was swayed, not by ability or by NGOs or scientists but by need. And that is something, it is a very, very simple message but that is worth remembering (Gov8)

Gov8's focus here is that GM crops were (and are) wanted and needed, although controversial. In their opinion, GM crops could be desirable to small-scale subsistence farming communities abroad, to mitigate the implications of climate stressors and pests on yields and extrapolates these views to farmers in the UK. Gov8 also suggests that GM crops also outcompete their more conventionally farmed counterparts in terms of flavour or price. For Gov8, development and commercialisation of GM products in the UK was stifled by opponents like NGOs, perceived as angry, and 'vocal', 'loud', 'vehement'. Gov8 blames these groups for making it commercially unviable to develop and sell GM products in the UK despite a perceived need. However, Gov8 describes "[l]ooking back on my career, what I have tended to see is something being highly controversial and very much in the media for maybe three, four, five years and then dying down a bit because people realise, 'Oh it is not so bad after all.'" Gov8 feels that NGOs, once their "biggest opponents", no longer have such influence on the GM debate, and that the argument today is no longer binary but more nuanced, depending on the application.

Elsewhere in their interview, Gov8 cites conflicts with groups that did not "understand" GMOs, like the Women's Institute (WI): "I still had endless talks with WIs and women shouting at me and telling me I was a traitor and destroying their grandchildren's future, and stuff like

that." Gov8 adds that these concerns reflected views about perceived unforeseen risks posed by GM foods. Gov8 connects the prevalence of such views within society to later decisions by regulators, describing how "that is how we got on to things like labelling and things", which Gov8 perceives to be a flawed system because "you couldn't have such a thing as non-GM because you would need completely separate fields, completely separate harvest, completely separate processing plants". Gov8 depicts the labelling of products as "non-GM" as a way of "the most vocal and vehement critics" profiteering from and perpetuating GM controversies for their own benefit. Gov8 perceives a range of knowledge deficits, and feels that GM controversies arose in part due to a misunderstanding of what they believe was important to discuss, risk assessment:

> in those days it was, 'GM food is good or bad.' You either support the scientist or you support the social science community. And Greenpeace and organisations like that got well-known which did no one any good at all. There is never a binary argument to these things, and it is all about risk and risk assessment. And most people don't understand risk assessment. (Gov8)

This presentation of the social science community as against "the scientist" developing GMOs is not reflective of the varied roles of social scientists researching science and technology for many decades, reported for instance by Balmer *et al*. (2015).

Sci7, an academic scientist and government advisor, has a background in GM-related research and policy. Sci7 has experienced conflicts about GM between industry, scientists, NGOs and publics, and disagreements between scientists and policymakers over, for example, definitions and broad regulatory frameworks. Sci7 described the lasting emotional impact of this, presenting the scientific community as "quite traumatised" by conflict with NGOs during public engagement activities in the early debates. Sci7 characterises scientists as brave but "used to people taking what they said at face value", and companies as being "harmed" by conflicts around GM. Sci7 presents NGOs as instigating a "shouting match" with scientists and feels that this made public dialogue inaccessible citing one occasion where "ordinary members of the public who were at that meeting were not able to have their say". Sci7 suggests that, at that time, NGOs "ran a very effective campaign" but, like Gov8, feels they do not have the same power to influence the GM debate today, stating:

> I sense the public perception doesn't arise from the public, it arises from the people that frame the technology for the public. That used to be largely the NGOs, but it's not to the same extent. The NGOs don't have the megaphone effect of the newspapers anymore. (Sci7)

Sci7 goes on to describe the roles of newspapers (naming the Daily Mail) in "amplifying all the scare stories that came out" during early GM controversies, and notes that there seems to be less "anti-GM" press in recent years.

Org6 is a manager at an international NGO with a background in campaigning and environmental policy. Org6 continues in their daily work to interact with publics, policymakers, scientists and industry during campaigns about genetic technologies in food and agriculture. Org6 describes conflicts between NGOs (portrayed as acting on behalf of publics) on the one hand and proponents of GM and synthetic biology, including regulators, on the other. Org6 perceives others as 'against' NGOs, mentioning that the work of NGOs on GM is sometimes unfairly portrayed or misrepresented, and that their workers are misquoted or cited out of context by proponents of GM. This seems to have had a lasting impact on the ways in which Org6 engages with the research community. This participant did not give me permission to quote them in this research, perhaps due to my attachment to a synthetic biology project and a sensitivity towards what Org6 perceived as a pro-synthetic biology bias, which it was suggested I mitigate through interviews with a range of stakeholders.

Throughout the interview, Org6, like Gov8, presents stakeholders with different interests as opposing camps and feels that this causes conflict, and inhibits public dialogues. Broadly, Org6 identifies NGOs as advocates for public dialogue, acting on behalf of publics conceived of as disempowered to engage in meaningful discussion about the futures of genetic technologies because such conversations take place between regulators, scientists and industries, who have formed an alliance. For Org6, scientists and industry share similar interests in terms of scientific curiosity but are driven by a desire to win investment and to commercialise GM and synthetic biology. Drawing on examples from the USA where GMOs are more widely used in food products, Org6 feels that regulators favour scientists and industry over other stakeholders and have developed more facilitative governance approaches to cater to their interests. This includes factors like intellectual property rights, which mean that those that Org6 conceives of as 'independent' scientists cannot access enough information to highlight the risks of GM and synthetic biology. Org6 also describes ongoing conflicts or disagreements between NGOs and scientists or industry about access to information such as full scientific study data, a lack of transparency by companies in their labelling of products originating from or containing GMOs, and the desirability of GM or synthetic biology for publics and communities more broadly. In Org6's view, in the USA in particular, publics do not want to purchase products containing GMOs, but do not have the information to make informed choices. This imaginary

of publics as anti-GM does not reflect the long history of widespread GMO consumption in the USA with a relative lack of public movements against GM developments.

Sci8 is a scientific consultant to international NGOs with an academic scientific background. At the time of GM controversies, Sci8 had research and consulting experience within the GMO debates, giving evidence and opinions to NGOs and observing interactions between NGOs, publics, scientists, industry, regulators, farmers and organic farmers. Sci8 describes conflicts with the scientists developing GMOs at this time. For Sci8, GM developers are situated "on the opposite end of the spectrum" to NGOs, in terms of views on risks. Broadly, Sci8 feels that GM controversies arose because the scientists developing GMOs did not, and still do not in the case of synthetic biology, recognise the limits or uncertainties of their own knowledge and their capacity to understand and control risks. Drawing on concerns around GM crops, Sci8 describes:

> I think, if you were to ask an academic developing a synthetic biology organism, they would say, "Yes, we would do risk assessment, X, Y and Z steps and that would be fine." Whereas NGOs would much more come from the opposite end of the spectrum, they would say, "No." As we do with GM crops at the moment actually and say no risk assessment is going to be adequate enough with those sorts of genetically modified organisms. Because you simply don't know. (Sci8)

Most participants appealed to perceived knowledge deficits in order to create binaries between those who are knowledgeable or not, and between those who are 'correct', 'right' and those who are 'incorrect', 'wrong'. In this case, Sci8 presents scientists as 'wrong' to assume they can adequately assess the risks of their work, believing them to be too complex to adequately assess, particularly across ecosystems. Sci8 also suggested that NGOs' and scientists' opposition is marked by "mistrust":

> I am trying to imagine two apples, one that has been done with synthetic biology and one that has not. They look identical, maybe taste identical, which one would I go for? Definitely the one that hasn't been bred in the lab. And I think it is this concern about scientists not knowing what they are doing, the mad scientist in the lab, with the hubble-bubble and the test tube. I think that resonates, actually. Now, whether that is ethical or whether that is a mistrust, I'm not sure. Do I trust the scientists with the [COVID-19] vaccines? Well, not really, but I had it anyway, because the risk of not having it was too great. Now, with the food stuff, you do have a choice. (Sci8)

Here, Sci8 queries whether "not knowing what [scientists] are doing" is an ethical question, or one of mistrust, alluding to a notion of ethics that is reliant on objectivity. For example, the (perceived fallible) scientists developing GM do not have adequate knowledge of the potential harms of their work. Those expected to consume the products of their development, like vaccines or foods, imagine scientists to be "mad" and seek alternative products. Sci8 appeals to

imaginaries of scientists as unconstrained and hubristic, not knowing the limits of their own knowledge, but also as distant or inaccessible "in the lab", and not exposed to scrutiny. This, despite Sci8's own scientific background.

Org9 is an advisor at a European policy think tank with a background in UK policymaking. At the time of the GM controversies, and more recently, Org9 has worked with researchers, policymakers and governments on the governance of genetic technologies. Like all other participants with first-hand experience of conflict around GMOs, Org9 constructs a number of 'groups' involved in the controversy. Org9 describes:

> [T]here are lots of different views, but you could construct two groups of people, one of whom think that innovation is really neat and really important and genome editing is important. Those tend to be the science-y types, the academics, people like you, (Laughter) people like me. But then you have people who are opposed to this. And this is very similar discussion as went on in the 1990s with GMOs, especially in Europe. (Org9)

Org9 constructs a binary, "sides", of people that are pro-innovation (conceived as something technoscientific), and those who oppose it. For Org9, there are topics that these "sides" can agree on – "things they want to see" such as addressing climate change and reducing agricultural inputs- but the roles of innovation in achieving food system aims are contested. For example, some applications like GMOs are viewed as "contentious" by one side but the other says that "we cannot live without" them. Org9's construction of stakeholders as being 'for' or 'against' GMOs recalls Marris' (2001) findings, but here it is extended to being 'for' or 'against' wider innovation in agriculture.

Sci8, Gov8 and Sci7 also discussed another binary, one that they instead challenged and viewed as causing conflict: GMOs being viewed as 'good' or 'bad'. Sci8 describes how the wants and desires of publics and NGOs were (and are) sometimes reduced simply to not wanting GMOs, adding:

> I think more in-depth with that is, basically, what sort of agriculture and food systems do society want? And we have always come across it with GM, we have said, "No GMOs" and people say, "Well, what do you want instead?" […] So, we are saying, "Well actually, it is the whole revamp, you need to think about what society wants from agriculture, from biodiversity, from its countryside." […] I think, again, it goes back to seeing that bigger picture, rather than just the reductionist, "What are the scientific risks? And how can we reduce all these unknowns to something that we can do a risk assessment from?" (Sci8)

For Sci8, more nuanced discussion of GM's risks would be useful, as would consideration of the broader implications of agriculture on society and the environment.

In contrast to Org6's perception of an alliance between governments, scientists and industry in which regulators favour these stakeholders over others, Sci7 and Gov8 describe some instances of conflict with policymakers and politicians during their work. For example, Sci7 describes efforts at engaging with regulators to discuss changing the regulatory system around GM:

> I was side-lined most of the time, but from regulators I got a really hostile reaction. The idea you could change a regulatory system was just anathema to them. Their whole lives depend on this edifice they've been studiously building up. (Sci7)

Sci7's past experiences of being "side-lined" by "hostile" regulators, positions regulators as opponents of scientists and science. Sci7 suggests that regulators and government departments consider GM and synthetic biology to be publicly unacceptable and are reluctant to address or change either the perceptions of the technology or its surrounding regulatory system. For Sci7, regulators are difficult to communicate with because of their reluctance to change regulatory systems, and because of fear of public harms. Throughout the interview, Sci7 constructs of regulators as cautious and risk averse. As a result, "[e]very discussion about regulation at the moment always ends up with enormous arguments about how you define these technologies", rather than broad discussions about whether regulatory systems are facilitative or not of innovation. Such views do little to reflect the nuance and complexity of cases where scientific innovations approved by governments can and do sometimes harm publics or the environment.

Synthetic biology in relation to GM

Sci8 and Org6 – who work with NGOs – take a global view to present GM's development and commercialisation in the USA as progressing without scrutiny, resulting in negative impacts on farmers and publics. These participants feel that GM and synthetic biology are similar in terms of broad parameters of riskiness, ethical questions and public perceptions. Sci8 and Org6 construct synthetic biology as an expanding technoscientific area which is more advanced and complex than GM, and therefore more risky, potentially controversial and undesirable. These participants also draw attention to a need to consider broader issues than just risk, such as the structure of agricultural systems.

The three participants who did not work for NGOs, Gov8, Org9 and Sci7, take a more UK- and EU-focussed view, presenting GM's development as something that was stopped, harmed or thwarted, and its promises could not be delivered because of barriers set up by those outside the scientific and industry community, who did not understand the technology and its risks. For these participants, synthetic biology is conceived of as something that is likely to have similarities to GM in terms of (misunderstood or overestimated) risks, ethical questions

and receive similar treatment by publics and stakeholders like NGOs. Synthetic biology is constructed by Org9, Gov8 and Sci7 as more advanced, complex, precise, controllable than GM, or "if you like it is a constructive approach rather than a destructive approach which GM is" (Gov8). Gov8's meaning of a "destructive approach" refers to "doing things with nucleic acids - cutting them, joining them, modifying them, changing reading frames, […] changing bases", rather than what they view as the ambition of synthetic biology, which is "building things up from scratch", such as proteins. Gov8 uses this distinction in order to support their case that synthetic biology ought to be treated differently to GM.

Gov8 is nostalgic about symbols of GM's brief commercialisation in the UK, mentioning a Flavr Savr Tomato Puree tin that "had a yellow flash around saying, 'Made from GM tomatoes' and I had a tin for years but then the seam went, and I had to throw it away". This derives from Gov8's focus on the perceived injustice of the opposition towards the field. Deploying a rather oversimplified and inaccurate summary of how the GM tomato puree was made, Gov8 states:

> [I]n those days, we never really got to consensus and there was a large move to go away from GM. […] But the anti-GM Movement was so loud that the supermarkets decided to remove all the GM from their shelves, really for commercial reasons. So, it basically got banned. And [to make Flavr Savr Tomato Puree] all they had done- […] They weren't genes from any other organism or anything like that. So, you could argue- well it was still a tomato, and its genome is only still a tomato genome- but it had been manipulated so it had to be called GM. (Gov8)

These perceptions of 'those days' of GM controversy and the lost opportunities to realise what GM could have achieved are contrasted with Gov8's hope for the future of synthetic biology. Sci7 and Org9 also share similar hopes for synthetic biology-related policy to be facilitative of innovation and commercialisation.

Furthermore, Org9 describes GM controversies as highly important to their work in the 1990s, but once government guidance was produced and regulations implemented, conversations around GMOs quietened. In the current political and technoscientific context, Org9 feels that similar discussions began reappearing recently in relation to gene editing and synthetic biology. This is echoed by Gov8. Citing how the uses of genetic techniques in COVID-19 vaccine production were broadly positively received, Gov8 feels, or perhaps hopes, that "people do, I think, accept more now that the scientists are able […] [to] do something of use" with GM and synthetic biology, and that "in the light of climate change and all these other things", perhaps publics 'need' food and agriculture applications, and will be more likely to be accepting of them.

Summary

Participants with first-hand experiences of conflict during GM controversies tended to focus on stakeholder conflicts in terms of harm, blame and distrust. These were presented as rooted in reductive, binary arguments, rather than nuanced consideration of the field. Gov8, Sci7 and Org9 can all be described as proponents of synthetic biology who argue that it, like GM, is useful and worth pursuing. These participants hope that regulation and attitudes perceived as 'against' GM can be overcome with time, regulatory changes, adjustments in the distribution of power between stakeholders (disempowerment of NGOs), as well as strategic communication through the press and with publics, and that this will in turn enable synthetic biology to progress and fulfil its various promises. These participants shared a view that scientific progress in the UK and Europe was a casualty of the binaries constructed in conflicts about GM, and that scientists and proponents of GM 'lost' in the conflict but can reassert themselves in future because they now have the skills to better engage with publics and other stakeholders.

The participants with an NGO background, Sci8 and Org6, take a more global geographic view when they describe the ways in which GM was not stopped, but rather has progressed unabated and regardless of perceived significant disadvantages and harms to the environment, farming communities and society. Interestingly, then, these participants also feel that they 'lost' something in the controversy. They wanted the power to access information, assess and discuss the risks of GMOs to be distributed more broadly, and for NGOs and publics to be more influential parts of the conversation. They feel instead that GM controversies have pushed scientists, industry and regulators to form alliances and develop strategies that enable risk assessment powers to be concentrated within and restricted to perceived inaccessible places, like universities, government departments or advisory committees.

Overall, there is a sense from all participants with first-hand experience of conflict about GM that, despite their descriptions of actively attempting to generate balanced dialogue, accommodate a range of views in policymaking and engage with conflictual groups, they were unable to find ways to communicate their views effectively. However, all five participants hoped that more nuanced discussion, notably about risks, will promote less conflictual conversations about synthetic biology among stakeholders.

5.3.2. Participants with first-hand experience observing GM controversies

Half of all participants had first-hand experience of GM controversies and observed them unfolding while working in a relevant field. These fifteen participants did not mention direct personal experiences of conflict with other individuals and groups, unlike the five participants discussed in the previous subsection. Nonetheless, this group of participants routinely described their lived experiences of GM controversies and their influence on their research, policy, funding and industry work.

Oppositions to GM

Sci1 is a UK academic scientist with research experience in relevant fields. This participant has observed GM controversies and the conflicts between scientists and NGOs. Sci1 views NGOs as "pursuing just political votes", not doing "proper understanding of science" but rather "just being scaremongering". For Sci1, NGOs changing their stance on GMOs, becoming less "political" and improving their understanding of science could mediate ("help") dialogue between the public, corporations and governments.

> So, in a sense, [the application of synthetic biology to food and agriculture] is starting to become more acceptable. So, yes, I think it's going to happen and I think it should happen because we can get healthier products without destroying the environment, without animals suffering, so there are lots of reasons why we could do that. The point is whether there will be sufficient transparency on how this is done so people can trust the companies behind this, the governments that accept synthetic biology or engineering biology products in their food chains, there will need to be more trust with NGOs rather than pursuing just political votes actually do proper understanding of science and can mediate between the public and the corporations and the governments. I think they have a very good role to play but just being scaremongering and fanatics, "No, no, no, to GMO," doesn't really help them, or anybody for that matter. (Sci1)

Sci1 makes an assumption that transparency about scientific work leads to trust in the companies and scientists conducting it, making it more likely to be accepted. This is a variant of the deficit model and suggests that with sufficient knowledge of the technical specifics and scientific practices of synthetic biology and GM will come 'acceptance'. However, Sci1's characterisation of NGOs as fanatics seems at odds with their suggestion that NGOs could be brought 'onside' to "have a very good role to play" in mediating between publics, corporations and governments. Sci1 senses that synthetic biology in a food and agriculture context is "starting to become more acceptable", implicitly more acceptable than GMOs were, but the challenge to overcome is rebuilding trust between "people", companies, governments and NGOs through transparency and collaboration. This framing of NGOs as "just being

scaremongering and fanatics" suggests that Sci1 is wary of how NGOs communicated about GMOs as a binary argument – "no to GMO", versus perhaps 'yes' to GMO. Sci1, like Gov1, feels that the past involvement of NGOs in debates around GM "doesn't really help them, or anybody for that matter", because they are perceived as responsible for polarising the topic. Overall, Sci1 appears to deny the political views of NGOs while seeking political influence over other stakeholders. NGOs can perhaps only be trusted, for Sci1, to "have a very good role to play" in discussions about synthetic biology, if they surrender their political biases, fears, and develop an understanding of science that enables them to "mediate".

Gov1 is an advisor to UK government with a background in industry. Gov1 describes how their research, policy and industry activities enabled them to observe GM controversies and experience the policy responses that followed conflicts between NGOs, scientists and industry. Like the participants in the previous group, Gov1 constructs NGOs as opponents to GM developers. However, Gov1 is more explicit in their view that NGOs' objections to GM at the time were ideologically founded, narrowly conceived, unscientific and mistaken, and that this has become limiting to debates about synthetic biology today:

> [T]here's a real problem when ideology is the initiator of the challenge, rather than perhaps an inspiration to ask a question. […] I'm actually saying that the ideologists who claim an ethical issue, may actually be causing more problems […] Because they've defined a very narrow thing, whereas the real world is actually much bigger. (Gov1)

Gov1 goes on to suggest, for example, that one common anti-GM and anti-synthetic biology argument relates to the implications of the technology for farmers. For Gov1, this argument tends to take an illogical, complicated route that is not focussed on finding solutions for synthetic biology to progress, asking "if you can synthesise [palm oil] why wouldn't you?":

> [W]ouldn't you prefer that to chopping down tropical rainforests? The counter-argument, which always comes up, whether it's Artemisinin, vanillin, palm oil, anything else, from the NGOs is, "Ah, but you're putting these poor third world farmers out of business. Aren't you evil for doing that?" And I'm saying, "Well, hang on a minute. Farmers will grow whatever they can make money from." And so there may be- if there's an ethical issue, it might be someone going, "Okay, I can see there's a better way of doing this, but some small proportion of the development should go into helping retrain the farmers." Right. I mean, that would be the perfect ethical solution for me, or whatever it is. And so, I think just looking at it in a much more holistic, but balanced and less emotive way can probably, in most cases for me, perhaps I'm over logical, but there's usually a very simple, logical conclusion that could be drawn, which would balance the concerns. (Gov1)

This oversimple construction of NGOs suggests that their objections towards GM and synthetic biology's potential impacts on farmer livelihoods leads them to turn a blind eye to other

problematic practices, like "chopping down rainforests". However, this presentation of NGOs as focussed on single, specific issues at a time ("a narrow thing") enables Gov1 to advocate for the developers of synthetic biology to be prepared for challenges like this, which Gov1 expects will be mounted. Such arguments are described as "often used by some of the more strident NGOs against synthetic biology that has come up time and time again – and I can anticipate that they will always ask it – so I tell people, 'Before you do this, you better be ready to answer this question before you get challenged on it.'" In short, Gov1 has observed what they determine to be the 'ideology' of NGOs and relies on this to predict the types of questions that they might ask of developers of novel technologies in food and agriculture. What Gov1 has taken from this is that these questions must be pre-empted in order for developers to construct "a very simple logical conclusion" that "would balance the concerns" and prevent the argument becoming narrow, not holistic, unbalanced and emotive. This has the effect of constructing those who questioned GM - and may also question synthetic biology - as illogical, emotional, ideologically driven, or put simply, as 'unscientific'.

Sci4 is a UK scientist with experience in academic and non-academic laboratories. Sci4 has observed the interactions between publics, farmers and scientists in response to GM developments, and the policy responses. Like Gov3, Gov1, Sci1, Sci3 and Sci10, Sci4 focussed on their perception of synthetic biology as a force for good but felt that GM regulations, patenting, inequalities in accessing the technologies and public controversies make it difficult for synthetic biology to achieve its promise. Sci4 also discusses their views of debates as "politicised a long time ago" and the resulting regulation as unscientific, and "based on assumptions that are not scientifically accurate, for the most part, and are not supportive" of technoscientific developments. For Sci4, the evidence over the past "25 years" suggests that GMOs are not only safe, but beneficial for farmers and the environment and desirable, despite the protests of NGOs. Sci4 explains that such stories about the benefits of GMOs are not shared in part because it has taken time to collect supporting data and because "maybe we're just bad at storytelling as scientists":

Unlike other participants, Sci4 does not discuss the activities of NGOs during the GM controversies except to state that NGOs were active protesters in one specific instance relating to GM aubergines. Sci4 also does not speak about publics in broad homogenous terms like other participants sometimes did. Rather, for Sci4, there are many groups that might oppose synthetic biology for similar reasons to their opposition to GMOs, alluding to the roles of regulators, "existing industries" who might feel threatened, industry seeking new business opportunities, as well as presumably consumers and other interest groups. Of these objections, Sci4 mentions:

"[T]here'll obviously be people that either object to it either for… because they're concerned about the safety or because they have a belief system that they don't think that this is something that we should be doing, I guess." (Sci4). This participant makes a distinction between concerns about safety and concerns driven by a belief system that produces moral and ethical judgments about whether "this is something that we should be doing". Sci4 resists the evaluation of what they variously term "value judgments", differences in "belief system", or a "the dividing line […] [about] how people feel about genetic engineering as a technology and being able to manipulate DNA."

Sci3 is a non-UK academic scientist and an advisor to European authorities. Sci3 has experience researching in related fields and working in relevant policy spaces. This participant describes their experiences conducting public engagement activities, hearing concerns about their work, but mentions no personal experience of conflict during GM controversies. For Sci3, like others, there are groups, or sides, involved in GM controversies - something Sci3 refers to as "these groups" – who engaged in "nasty discussions" about GMOs. However, Sci3 apportions some blame for these "nasty discussions" to scientists themselves. Sci3 describes:

> I think that people or the general public from the very beginning had some reservations about the technology itself. I think the difference also between genetic engineering and synthetic biology is that the synthetic biology community from the very beginning has tried to involve all stakeholders in the conversation. The fact that I'm talking to you, for instance, is an indication of that, right? So formerly in the in the early times of genetic engineering, biology will despise entirely public opinion and ramifications and the public. It was just ignorant people, they didn't know about biology, they didn't know of anything. We do our things and ignore them. We see the consequences. The consequences have been this very, very serious backlash about genetic engineering in many countries. (Sci3)

Sci3 assumed an initial public opposition towards GMOs, but blames the scientists involved for causing a more severe "backlash" than might have happened had they engaged with stakeholders rather than ignoring them. Sci3 points to this treatment of publics as a lesson, and that synthetic biology stakeholders have a chance to rectify these mistakes going forward:

> I think that this second or third wave of genetic, say, science that is connected to synthetic biology has this historical memory of what went wrong at the beginning and I think every effort is being done in every synthetic biology project to bring in all the stakeholders, identify end users and make sure that no one is left aside. That everyone participates in the conversations. I think this is very good and I'm sure, not I'm sure, I am confident that the next- I mean synthetic biology will eventually be accepted, not only accepted but adopted enthusiastically by sectors that maybe before were very sceptical about genetic engineering. Obviously, you always have some groups that will oppose anything

> basically but probably the influence of these groups will be less and less with the time. That's my expectation, maybe I'm too optimistic. (Sci3)

Sci3 describes a "historical memory of what went wrong", and that the developers of synthetic biology must and do behave differently, seeking to "bring in all the stakeholders, identify end users and make sure that no one is left aside", to avoid repeating history.

In a similar vein, Gov5 also thinks that publics misunderstand science and are swayed by headlines in the press, but that this can be addressed through education or engagement. Gov5 is a manager at a UK funding body with work experience relating to GMOs and public responses to them. Gov5 describes their observations about GM controversies:

> [W]hen I started doing a precursor to this job, 15, 20 years ago, too long ago, genetic modification was the thing and we're doing lots of work on understanding genetic modification. The key thing, I think, that came out of that was that the tool is okay, and it's just a tool, and it's how we utilise that tool. We utilised the tool all wrong and we didn't explain to… or the people who made the tool, used the tool, made money from the tool did not explain it to the public and to society at large. So, there was this big scary thing. So, I think what's going to happen now, if we're not careful, is society is going to look at synthetic biology, ally it to genetic modification and stop it dead. (Gov5)

Here, Gov5 implies that "society" has the power, through their attitudes towards a technology, to "stop it dead". Gov5 goes on to explain:

> I just see it as if we're not careful, it's a re-run of the genetic modification thing, so the Frankenstein foods If you're making a whole artificial organism and releasing it into an environment de novo synthesis or something, there are a lot of frightening things, a lot of frightening potentials that people could see. […] I think there's a lot of management of understanding that needs to be done, but, yes, I think the word Frankenstein food is probably the one that'll come back again, unless […] an educational system is put in place. […] I think it needs an active dialogue at all levels of society and all levels of society goes right from government down to the public, down to the media, you know, the Daily Mail needs to be educated, in many ways, down to children. (Gov5)

By suggesting "active dialogue" to educate those who might otherwise oppose the technology, Gov5, like Sci2 and Gov1, implies that oppositions based on fear arise from a knowledge deficit, and may need to be addressed widely including in government, the press and "all levels of society". In short, deficit model-type ways of thinking prevail despite social science commentary for many decades.

Like Gov5 and others, Gov9 also views publics and their views as able to be shaped through informational campaigns. Gov9 is a UK civil servant with government work experience around GM, and who has observed some of the debates and disagreements on the topic as well as some more recent public opinion surveying activities. Gov9 constructs GM controversies as

a form of "suspicion" arising from "mystique", a lack of "clarity of understanding" or sufficient information about the technology, which bred mistrust of "the GM industry" and conceptualisations of GM products as "Frankenstein" or "freaky" foods, but their views can be "changed" if they are given information:

> It's not for us to promote the GM industry, but we want clarity of understanding so where we have the opportunity to do, we do. We did some workshops back in the earlier part of the year where we looked at people's attitudes to GM and GE. […] we had three workshops per group and the first one was like a set[ting] up information one, the second one was to look at stuff. Even over the two workshops, views changed quite a bit. Some didn't […] They could see the pluses and minuses, but yes, and with GM, it's a slow process. (Gov9)

This serves to position publics as opponents to GM but suggests a kind of hopefulness that this opposition can be overcome if publics can better understand the technology and its uses. It also positions governments, proponents of GM and industry in a form of alliance based on similar interests, where it is "not for [the civil service] to promote the GM industry" but they are also interested in understanding and shaping public opinions through educational workshops on the topic. Later in their interview, Gov9 also describes how this is difficult because of a perceived lack of interest by publics to engage with information or education about the topic. Gov9 appeals to "public interest" as something that can be obtained, and that through interest will come knowledge, but that it is a challenge for proponents of GM to generate this interest. Gov9 states "it's almost like trying to get public interest is one hell of a challenge, we all know that. You can only get knowledge through interest really, trying to find a way of actually getting that idea in there", which is conceived as a challengingly and perhaps frustratingly "slow process".

Org5, like those participants with first-hand GM conflict experiences, feels that unnaturalness objections to GMOs were (and are) not valued by scientists and policymakers. Org5 is an academic non-scientist who has observed the views of scientists and non-scientists about GMOs through their research. Org5, like Sci1 and Sci2, discusses fears that are connected to genetic engineering and its developers, whom this participant describes as "playing God" or playing a role in producing a world that "bears the mark of humanity" and is "unnatural":

> I think it makes sense to associate the cultural with what you might call the unnatural, and which is what people, when they get asked about GMO, say, for example, relate to as the unnatural. It's something that bears the mark of humanity. […] [O]nce we've intervened in that way, we may create species that are new and that will forever bear the mark of humanity. Not just bear the mark of humanity by human beings influencing the course of nature, but by us engineering nature. And this is something that makes me very uncomfortable, and I think it makes the non-scientists – well, as well as some scientists, actually – that we interviewed also very uncomfortable. (Org5)

Here, Org5 makes a distinction between the non-scientists, who are more likely to be "uncomfortable" but points out that "some scientists, actually" are perhaps surprisingly also uncomfortable about this. Org5 later in the interview alludes to other groups of stakeholders and the differing ways and amounts that they might "have thought about these issues". For Org5, food policymakers "should really rely a lot more on getting the views of ethicists who have thought about these issues, rather than rely on the scientists, and the views of common folk, as well. The views of people who develop more natural ways to produce human goods." This suggests a perception that the views "of common folk", ethicists and those working on alternative farming methods are not afforded a platform to influence policymakers, who instead "rely on the scientists". Org5 goes on to state: "I really fear that these people are being ignored in the policy debate, which is all about short-term, high-yield, unsustainable patterns of productivity" and "I think the big agricultural companies such as Monsanto, Dupont, etc, they wield so much power over politicians." This echoes Org6's perception that regulators and scientists formed an alliance that is exclusive to the views of publics and other stakeholders, following the GM controversies. Such an alliance is also indicated in Gov9's descriptions of public opinion surveys conducted by the civil service to understand public attitudes and obtain 'public interest'.

Sci2 is also a non-UK academic scientist with experience in microbiology, who has observed GM controversies unfolding and developed opinions about the responses of publics "officials" and "decision-makers" to GMOs. For Sci2, objections to GM food played out as a form of "fear". In an email prior to our interview, Sci2 explained how this "fear" is the result of a knowledge deficit:

> In general, in most parts of the word there are various major concerns related to genomic engineering. Some of them make some sense in my opinion (e.g., the fear to generate deadly virus or antibiotic resistant bacteria) but some are not rational (e.g., the fear of GMO food). I think we should approach this issue by better and deeper education of the relevant officials, decision-makers, and the "general" public. They should understand basic mechanisms and aspects related to the way DNA "works", basic topics related to virology, mechanisms related to antibiotic resistance, introduction to molecular evolution. When you better understand the topic it is less "scary". In addition, synthetic biology should work on developing proven solutions that convince both scientists and officials that a synthetic solution is "safe"; specifically, it may be a good idea to define a clear set of rules related to decisions related to safety in this context. (Sci2, email correspondence 21st January 2021)

Sci2's decision to frame the subsequent interview in this way reflects that they perceive the treatment of GMOs by officials, governments and publics to be relevant to a discussion about synthetic biology, and to the ways that we "should approach this issue". Furthermore, Sci2

suggests that policymakers may also have a form of knowledge deficit which causes them to impose strict regulations over applications that are more controllable (such as contained milk proteins), assuming them as similarly risky as those that are less controllable (such as deadly viruses).

Sci2 segments concerns about GMOs as "rational" fears (engineering deadly viruses or antibiotic resistant bacteria) and "irrational" ones (GMO foods). In the interview, Sci2 goes further to emphasise that the safety of GMO foods is a given, particularly in contained use situations where the GMO is not released alive into the environment or is not eaten only its products ("you generate a protein and then you sell the protein"). For Sci2, debate around the safety of contained uses of GMOs is not "relevant" whereas questions about releasing viruses, for example, are "more problematic", but because the weighing up of relative risks across categories of GMOs is flawed by misunderstandings of science:

> Currently many times my feeling is people do not understand the difference [between riskier and safer applications]. Everything sounds scary. Even with GMO, GMO food. We take a crop, change a little bit of DNA and you get a better crop, faster growing or whatever. This is also a process that is actually occurring in nature all the time. There is evolution, selection and mutation. Selection and mutation. If I understand better how the genetics work and introduce the mutation by myself, it is very similar to what has happened for billions of years in the earth. If you are scared of this, you are scared of evolution itself in the plants that you see in nature. In some cases, it's really not relevant, the concerns. (Sci2)

Sci2, like Gov1, conceptualises risk, safety and benefits as something that can be technologically, scientifically or economically defined. Sci2 also believes that fears of GMOs, or "major concerns" about the technology's safety, are something that can be overcome through education in some cases, or through evidence ("proven solutions") that "convince both scientists and officials that a synthetic solution is 'safe'". Sci2 explains: "if the, you know, the general public will learn more about what is gene expression, what is bacteria, what is virus, how evolution works and understand the details, they will not be scared. Most of them. It will work. This is the way. This is the way to solve the problem."

Associations with GM

For Sci2 it is the labelling or naming of something as GM that stops others from perceiving it or understanding it as a process analogous to genetic mutations and selections occurring in nature ("Everything sounds scary" if it is described as genetic modification). For other participants, defining something as GM is a barrier to its acceptance. Such labelling designates

it as something "to worry about" (Sci5), because the label "GM" is attached to negative sentiments, unscientific views and emotional, political or ideological reactions.

Gov3 is a regulatory lawyer and advisor to UK government who has worked with scientists, policymakers and government on GM regulations, and observed arguments against GMOs. Gov3 believes that knowledge deficits and "enshrining non-scientific principles" has led to misinformation and binary or reductive discussions about GMOs, rather than equipping consumers with the details to make informed choices. Gov3 adds "I'm a great believer in making an informed decision rather than taking the supermarket approach where you say, 'There's no GM here'. 'What's wrong with that?' 'There's none. Don't worry. Don't ask.'" Here, Gov3 is imagining an interaction between supermarkets and consumers where the supermarkets, through their use of labelling, designate GM as something "wrong" and make it something that consumers might "worry" about, but without giving consumers the information to understand "[w]hat's wrong" or to ask about it. Gov1 feels similarly:

> [W]e've seen it with the regulations in Europe over gene edited food. Is it GM or is it GE and should you label it? […] Is it a safety issue or is it ideological? I'd like to know the answer to that before we… obviously, post-Brexit, maybe that is less of a threat here, but it still remains a massive threat if we develop a fantastic low carbon, high nutrition and healthy, sustainable, low [impact on] biodiversity food that we're not allowed to put into Europe because it has some bizarre labelling attached. (Gov1)

Gov1 seems to imply that labelling products as GM or GE would be undesirable, "a massive threat", dismissing the rights of consumers to make informed food choices. For Gov1, unless it is for safety reasons like avoiding an allergen, most labelling is redundant because "how many people study all the E-numbers". Sci5 also expresses a similar view that "it's going to be very, very challenging because just putting labels on things, when people don't understand what that label is telling them, is not really going to help." However, Sci5 is sensitive to the right to make informed food choices, supported by labelling, and feels that publics and groups like WI, farmers, organic farmers and the Soil Association object to GM, and are likely to feel similarly about synthetic biology. Gov1's experience observing controversy around GMOs leads them to construct publics and NGOs as threats to synthetic biology, and to assume that they will view developers of genetic technologies in food and agriculture as "evil" and challenge them. Learned from the GM experience, Gov1 is sensitive to (anticipated) arguments against GM and synthetic biology and by extension to conflict over these technologies and to opening the field to challenge by labelling products.

Sci10 is a UK academic scientist with research experience relating to GM in both human health and food contexts. This participant has observed controversy around GMOs and the implications for businesses, particularly those developing lab-grown meats. Sci10 describes:

> I'm talking about biotechnologically modified, not the, 'Oh, we've grown rice. We've crossed it with a different rice…' You know, I'm not talking about that type of stuff, because genetic modification is part of evolution and all the rest of it, so I'm not talking about that. Nonetheless, it's obviously a red button issue. For a new, emerging technology, no one wants to overtly talk about GMO in the cells used. (Sci10)

Sci10 equates genetic modification with evolutionary genetic mutations or crossbreeding varieties of rice. Sci10 shifts the language of GMOs to emphasise that this indicates "biotechnologically modified", suggesting that genetic modification itself should perhaps not be something of concern ("most people are eating it"). Sci10 goes on to describe that the use of cells which are "genetically modified to grow in low serum conditions, or to use cheaper growth factors, or more complex by-products of another industry and break those down into its food" would make "a lot of sense". More specifically, Sci10 feels that "if you really want to achieve the ambitions in that lab-grown meat, in terms of the environmental benefits, I think it's difficult to see how they're going to do it, without using genetically modified cell lines". However, because of the "sensitivity" to GMOs, and the status of GM as a "red button issue", businesses cannot do this because it could provoke a negative reaction from publics. Sci10 describes:

> [C]urrently, you would not be able to advertise that final product as being a genetically modified meat. People start going crazy. So, I don't know how they're going to get around that. To be clear, as far as I'm aware, in terms of the really advanced commercial companies, none of them are using genetically modified cells, currently. It would be ruinous for them to do it today. But, as I said, it will need to come, in order to meet the expectations of the lab-grown meat, in terms of the environmental impact and cost, and things like that.

Sci10, like other participants in this group, constructs objections to GM as "going crazy", and causing "all sorts of problems in the past". For Sci10, the risk of similar reactions to lab-grown meat endures today, and the result is that "no one wants to overtly talk about GMO in the cells used". This has some parallels with Gov1's position that publics may be a threat to synthetic biology, as they were a threat to GM, but that their views are "crazy" or "illogical", and implicitly technically, scientifically and economically unjustifiable (there is a technoscientific and economic need for GMOs to help lab-grown meat achieve its promised environmental impacts). This is a construction of publics as both powerful and mistaken, which contrasts the views of the five participants with direct conflict experience who described how publics were

disempowered during GM controversies and unable to have their views taken seriously into account.

Sci5 is a UK scientist and an advisor to UK government with research and policy experience in a relevant field. This participant has observed objections towards GMOs, regulatory responses to GM and the outcomes of these responses on the field's development. For Sci5, defining something as a GMO designates it as something "to worry about" and regulate:

> [I]f it's not a GMO in the first place, then it doesn't fall under the regulations, so you shouldn't have to worry about it. […] If it doesn't fall under the regulation, then it doesn't have to be regulated as a GMO in the simplest form, but, of course, some people disagree with that and think actually that they should all be considered GMOs, regardless. (Sci5)

Sci5 uses the words "worry", "worrying" and "concerns that people have had in the past" about GMOs throughout their interview. For Sci5, if something can be defined as non-GMO then this detaches it from the related "worry". However, Sci5 acknowledges that "some people disagree" about where to situate the boundaries of what is considered a GMO, with some including gene edited organisms and others not, and therefore disagreeing over what is considered worrying. Adding to the sense that people disagree over the concerns around GMOs, this participant describes the worries of other people variously as being about genetic modification producing unexpected consequences, or off-target edits to genomes. By contrast, Sci5 also talks about "[t]he sort of things that would concern *us*" (emphasis added) in their advisory committee, which are limited to risks around allergenicity and toxins.

Org7 feels similarly that the lines between GM and synthetic biology, for example, are arbitrarily drawn by policymakers, politicians and scientists but that these distinctions are not relevant to publics. Org7 is a non-UK academic non-scientist who has engaged with publics and scientists about genetic modification, synthetic biology and a range of other relevant technologies including gene editing. For Org7, it would be beneficial to define GM and relevant technologies in a more nuanced way, rather than "GMO/non-GMO", because with technological developments like CRISPR, the picture is more complex. For Org7, discussions about the governance of gene editing signals a reopening of the GMO debate, characterised by reductive arguments about whether to "support" "GMO/non-GMO", but also by perceptions about industry "control" and other concerns:

> it was very much the same discussion you find around GMOs. That's also why I ended up thinking that there's really not that large a difference, even though the scientists were like, 'This is synthetic biology. They're doing GMO somewhere

> else.' It was the same concerns and the same issues came up, also about social fairness and, 'Will this be developed by western companies who will then somehow gain larger control over agriculture like we've seen with the multinational companies within GMO and so on?' (Org7)

Org7 goes on to describe that publics are likely to consider synthetic biology and CRISPR in similar ways to GM, and that scientists seek to distinguish their developments from GM to avoid this, because those with a "societal point of view" treat concepts differently and use different analogies to those with a "technical point of view", and that such contests can be problematic. From a "societal" viewpoint, Org7 feels that biotechnological developments can carry similar implications and operate in similar systems of inequalities, power dynamics and concerns, regardless of whether they are defined differently "from a technical point of view".

Elsewhere, Sci5 focussed on perceived inconsistencies in how some genetic technologies are treated by regulators, in contrast to other technologies. This was also presented as unjust or unfair, described as "problematic", nonsensical or not scientific by Sci2, Sci4, Gov1 and Gov3, for example, who construct GM as just one method of genetically changing an organism, like evolution. For these participants, GM is conceived as controllable, intentional and precise, rather than random mutagenesis for example which is viewed as riskier but governed less strictly. Gov3 also views publics as "all so misinformed" and suggests that in response to public controversy over GMOs, regulators have created a system of governance that is illogical, "[t]he GMO case is a very good example of something that's out of kilter with science". For Gov3, this governance system is viewed as leading to 'insane' outcomes like scientists moving overseas to be able to proceed with or commercialise their work, something that Gov3 describes as "ludicrous" and "a problem". Sci4 also advocates for regulators to base their governance approaches on "a better understanding of what has happened in the last, you know, 5,000 years of plant breeding and how that compares to genetic technologies".

Controversy as an economic or political barrier

Sci6 focusses on the potential barriers to the economic success of the field, and considers that consumer acceptance, and marketing to secure it, will facilitate industry together with more favourable regulations. Sci6 is a manager at a UK industrial biotechnology company who has research and industry experience in relevant fields. Sci6 reports having observed public and policy responses to GM developments as well as the implications of relevant governance approaches on industry. For Sci6, GM controversies relating to food are characterised by concerns that are not extended to GM-related medical applications, because "taking a pill is more of a transactional relationship" to address a specific "need", while eating GM food

involves more "choice" making it a "more emotional experience". Drawing on this distinction, Sci6 frames publics as not accepting of GM foods while they "wouldn't be concerned about GM medicine":

> I mean the regulations probably add small difference but certainly in terms of GM, people wouldn't be concerned about GM medicine whereas GM food, although certainly within the UK it's not necessarily regulated any differently but it's really more about public acceptance. […] in a lot of ways what's holding it back is the public acceptance and so the priorities should be knowing that what is trying to be achieved is demonstrating the benefits of those things. (Sci6)

Later in the interview, Sci6 describes regulations as "big" and says that regulating a GM product "doesn't seem to be a very clear process". Despite these practical challenges for industry, Sci6 focusses on public acceptance and publics "holding […] back" GM-related technological developments because the benefits have not been demonstrated, and publics do not know the intentions and ambitions of developers. Sci6 goes on to explain their perceptions of how citizens and groups in the UK relate to GM products differently to those in the US:

> I wonder if there are things to learn from the US where, for instance, […] there was a big hoo-ha about this impossible burger which is a vegetable derived burger that's got a protein that's genetic manipulation, it's a GM thing. It seemed like that got people excited and interested and people were happy to go out and eat that. […] is it just the marketing of that, that's made that more successful or is it because it's a much bigger country and a relatively small amount of people are really enthusiastic about something, making more noise about it. Whereas here you seem to get the opposite, you'll probably get a small amount of people who are really against something making a lot of noise. I don't know, but in the world today things that are trying to counter other people's arguments with facts and things doesn't seem to work as well. […] It's almost like you need to get some celebrities or some Instagram influencers to endorse your product. (Sci6)

Here, Sci6 suggests that in the UK, unlike in the US, it is more challenging for those who are "enthusiastic about" a GM product to dominate discussions about it ("making more noise"). This demonstrates an observation that during GM controversies, proponents of the technology were unable to make "more noise" than their opponents, because their strategies were, and continue to be, inadequate. Sci6 finds that the technology's benefits and the intentions of its developers were not demonstrated in the past, and that today an approach of "trying to counter other people's arguments with facts and things doesn't seem to work as well". Changing public opinions by marketing GM products using celebrities or via social media, and countering "a small amount of people who are really against something making a lot of noise", is something that Sci6 considers a priority based on these observations.

Sci11 is a UK academic scientist and government advisor with industry, research and policy experience relating to GMOs, including the development of regulations and guidance.

For Sci11, anti-GMO views are not always represented in advisory processes. This is because Sci11 feels that perceptions about who is an "expert in the technology" tend to combine with views about who or what should be excluded from panels, typically "activists" and people who "say all GM is bad", as well as "political interference":

> I'd say, very importantly, as long as [the scientific advisory process is] immune from political interference – I think it's pretty good. Now, the downside, obviously, is that because you're bringing in experts in the technology, you're not going to get people there who are going to say all GM is bad or all GE is bad or we should go back to growing everything organically. Although I'd say there's a pretty broad spread of opinions on the committees about good agriculture […] I think it was when, maybe, ACNFP was first set up. I think the first chairman was John Beringer and somebody asked him about this. He said, 'Well, you don't want to pack a committee with activists'. But of course, 'Who is an activist?' depends on your point of view. So, if you're coming at it from a very strong Friends of the Earth/Greenpeace point of view, well, yes, you're an activist, but you're also an expert on the environment. You could say, 'But these are molecular biology activists. They're promoting the molecular biology viewpoint'. (Sci11)

This indicates a nuanced view about activism as something that all stakeholders engage in, and that there can be a range of valuable expertises. Sci11 implies that there was previously less tolerance of "a pretty broad spread of opinions" in advisory committees than there is now, adding that these advisory processes should be "immune from political interference". Sci11 repeats a distinction between "molecular biology activists", a trait which permits access to advisory committees, and what might be described as more antagonistic or anti-GM or anti-GE activism, which is characterised as challenging to work with and to be excluded.

Later in their interview, Sci11 added that publics, particularly those with anti-GM opinions, are not as vocal, "have dropped off the radar" and that the topic is "not a big deal in the way that it used to be":

> I think the real anti-GM thing seems to have dropped off the radar quite a bit, and I think the opinion surveys say the same thing as well. It's not a big deal in the way that it used to be. So, if you've got the combination of growing trust in biotech because of its demonstrated aptitude at producing something incredible valuable like a COVID vaccine, coupled with people saying, 'Look, we're not talking about the old GM here. We're talking about something new and much more sophisticated,' you might not get… There will still be a backlash because there are people who are very, very vested in being opposed to it, but it may not be on the same sort of scale. (Sci11)

This is more indicative of Sci11's hope that the backlash towards synthetic biology "may not be on the same sort of scale" as the opposition towards "the old GM", meaning that a reduced likelihood of controversy means fewer potential barriers to the field's development. For Sci11,

this is because the circumstances of the technology itself have changed - it has been demonstrated to be "new", "much more sophisticated" and valuable in producing mRNA COVID-19 vaccines. Sci11 also perceives that the circumstances surrounding GM have also changed because of "growing trust in biotech" and shifting public perceptions and priorities which may outweigh some stakeholders' "vested [interests] in being opposed to it".

Similarly to Sci11, Gov7 discusses that synthetic biology is likely to be subject to similar objections to GMOs, and to be treated as politically risky as a result. Gov7 is a UK civil servant with government work experience observing the treatment of GM by government, and some of the debates and disagreements about it. Gov7 also discusses their experiences of activities within government during GM controversies, such as attempts to implement citizen juries. Gov7 is hopeful, like Sci11, that the political circumstances today might enable regulatory changes to pass through without publics getting "cross", "letters turning up in MPs' offices", or asking questions that they are perceived to have posed "with the GM debates earlier". Gov7 mentions two questions that may stoke public debate or controversy: "Is this really giving me a benefit, or is it giving a benefit to big corporations? Am I bearing the risk while they're getting all the benefit?" and states that these are something that "you have to be quite careful with" during debates about gene editing and synthetic biology. Gov7 expects that publics would react similarly ("get worried") and ask similar questions ("with all of these things, it's similar to the debates around GM") but suggests that the circumstances may have changed because of the convergence of Brexit and the COVID-19 pandemic:

> I haven't seen much comment. Just, in a way, it's an ideal time to be doing these things, because I don't think people have as much bandwidth to campaign about stuff or get worried about stuff, because there's so much else to worry about. (Laughter) So, I'll have to see how that goes […] Yes, I think that gene editing is the debate to watch. What happens with that is going to probably influence how people think about synthetic biology. (Gov7)

This participant constructs publics as distracted - or distractable – from campaigning or getting worried about synthetic biology as they are perceived to have been worried, "cross", about GM.

Summary

In summary, unlike participants with first-hand experiences of conflicts with other stakeholders during GM controversies, these fifteen participants did not tend to express similar, direct personal, professional or emotional impacts felt during the controversies. However, they did seem to have internalised a range of understandings and 'lessons' from observing GM controversies that may shape their professional activities, personal views about the positions of

technoscientific developments in society, and emotional attachment to the hopes and intentions of their varied work.

The use of binaries, while prevalent elsewhere across the sample, was most prominent among this group of participants with experience observing GM controversies first-hand. This group of participants also appealed more directly to knowledge deficits of others, although again this was a theme across participant interviews. In particular, for the scientists and some participants working in policy spaces (Gov1, Gov3), there was a sense of injustice in the perceived triumph of 'unscientific' views over 'scientific' ones in terms of shaping policy. This may be because these participants feel that these 'unscientific' views are mistaken, or less important than 'scientific' ones. Supporting this suggestion, these participants sometimes segmented views according to whether they are considered 'legitimate' oppositions (typically relating to risk) or perceived as 'illegitimate' (like views about unnaturalness). Org5 and Org7 seemed to have noted the effect of these views on dynamics within policy discussions, suggesting that there are groups of stakeholders, such as ethicists, which are 'ignored'.

Participants in this group have also constructed the perceived 'opponents' to GM in multiple ways. For the scientists and governance participants, there seemed to be some resentment towards, or blame apportioned to, NGOs for what are perceived to be their roles in polarising the debates on GMOs, "opposing anything basically" and engaging in "nasty discussions" (Sci3). However, all participants characterised those outside the scientific community - publics, regulators, NGOs and others displaying 'unscientific' views – as nonetheless powerful, because they are perceived to have shaped the development of GM based on their (for some, 'mistaken') views. Participants in this group also tended more commonly to blame the communication skills of scientific communities and other stakeholders in contributing to deficits in knowledge, transparency and trust that they believe contributed to the controversy.

The result of this, combined with constructions of opponents and opposition, is that participants in this group often described 'solutions' to controversies, or ways to avoid them in future. They constructed public dialogues as a resource to be utilised or carefully negotiated to achieve the aims of synthetic biology. There was a sense that engagement with publics could be potentially beneficial to synthetic biology's development either by facilitating public acceptance (persuading) or by securing access to what publics consider to be more acceptable, useful applications.

5.3.3. Participants with second-hand experience of GM controversies

The ten remaining participants had no direct experience of GM controversies during the 70s-early 2000s, either because of their age, or because they were not working in a relevant field at the time. These participants instead have learned and deployed some debates about genetic modification that were discussed at the time. Many described their observations about the implications of GM controversies on synthetic biology/GM technologies, their governance, and their practitioners and stakeholders. Others observed the impacts of GM developments, for example on farmers.

GM debates

It was common for participants with second-hand experience of GM controversies to discuss their understanding of debates around GM. Typically, discussions of this sort involved participants sharing their views on common objections and arguments about GMOs, or why these debates engendered controversy. Participants also often described which stakeholders were on which perceived 'side' of debates and considered what might be informing their positions. There were some common debates or terms which seemed to stand out to participants and that they repeated in interviews. These included comments about "Frankenstein", "Frankenfoods" or "Frankenstein foods"; notions of (un)naturalness; the company Monsanto, their controversial business practices and perceived "evilness"; and what GM commentators often refer to as food 'neophobia', which participants discussed as a fear of novel foods based on intangible factors like the 'yuck' factor; as well as comparisons between the risks and ethical implications of 'traditional' or 'conventional' foods and novel ones.

Org2, like many other academic non-scientists interested in this field, moved from a STEM career to work in social science research. Org2 did not work or study in a relevant field at the time of the GM controversies, but nonetheless reports having "seen some conversations about similar areas [to synthetic biology], like GM crops and stuff like that." Org2 also draws on deficit model-type assumptions about publics lacking education about GM and synthetic biology, "why it is being done" and "what is going on around it", prompting people to make uninformed judgements about the technoscientific developments based on buzzwords in the media (notably referencing "Frankenstein"). Org2 appears to be repeating common arguments following the GM controversies by GM's proponents, and positioning the experience as a cautionary tale to the developers of synthetic biology. Org2 describes:

> I think if people are educated about it and what it is for… I think it is the unknown. That people do not really know what is going on in these labs, and

> they think things are being done behind their back. Whereas I think if people know what is going on, and what it is for, if we are talking about sustainability, so, "If we do not do this, you won't be able to eat" is like a very different thing than, "We are creating our own Frankenstein." It is a very different education. I think education is really important for the future of it, really. I think a lot of people do not really understand why it is being done, and I do not necessarily fully understand what is going on around it. (Org2)

Org2 is also promissory about synthetic biology here, and views the field not only as potentially useful, but arguably essential: "If we do not do this, you won't be able to eat." Org2 identifies applications in food and agriculture as solutions to the sustainability challenges posed by existing food production practices and to future climate-related food shortages, if education can steer perceptions away from inflammatory associations with 'Frankenstein'.

Org1 is a UK academic non-scientist with experience researching food and agriculture. Org1 is the only participant not to refer to GM by name, but in their work, they are likely to have been exposed to research on GM controversies and relevant ideas. When discussing lab-grown meat, Org1 repeated some similar arguments to those mentioned by Org2 about unnaturalness, and used the term 'mad scientist', sometimes associated with GM debates:

> I can see the arguments against [lab-grown meat] but I think they're very poor, to be honest […] I think one of the arguments people might make is it's grown in a lab. So, it's not natural. […] They probably think this a mad scientist or something, you know, and I'm like, you know, so? Like almost everything we do is not natural nowadays. And certainly meat that we eat now isn't. It's probably the least natural thing you can imagine. (Org1)

While it is not possible to determine whether Org1 is drawing directly on prior knowledge of GM controversies and the debates around GM because they do not use this terminology, they refer routinely to the same arguments that others deem to be common anti-GM objections. Org1 deployed these against synthetic biology applications ("the arguments people might make") and developed some rebuffs to them to dismiss them as "poor" arguments.

Gov4 is a UK civil servant with prior experience conducting relevant scientific research and talking to publics as a scientific researcher. Gov4 framed objections to GM on the grounds of perceived unnaturalness as based on knowledge deficits, or uncertainty around the technological specifics of genetic modification, its uses and its developers. Gov4 describes the following debates:

> From my experience, [barriers to acceptance are] around being unnatural. I think a lot of it is not knowing. Not knowing about how products have been made. Not knowing about what the terminology means. And it is very complex. […] There's a lot of problem with the way that GM was originally proposed, and that potentially then impacting on other technology processes. I do think it is a bit of

> the unknown and not really knowing what the impact will be on their own health. Or I've heard things said like, "I wouldn't want cultured meat because it would mean there would be no cows in the field." […] with GM cows, you still have cows in the field. I think it's the misconception of how the processes actually happen. When we've spoken to the public about these kinds of things, they've got it into their heads that it's all multinational corporations. It's all to do with pesticides and fertilisers. Then if you start to present things such as golden rice or […] you could have the cultured meat, and then you wouldn't have the animal welfare aspect, it does change perceptions. […] I think if the public shut it down very early and don't accept it […] then companies just won't produce products. A lot of it does rest on public perception. (Gov4)

Here, Gov4 constructs publics and their perceptions of GM (and synthetic biology) as potential barriers to the field's development, affording them the possible power to "shut it down very early" and making it undesirable for companies to produce products. Gov4 also seems to blame "the way that GM was originally proposed" for generating public concerns. Gov4 does not explicitly state who they believe was responsible for proposing GM in a way that became controversial. However, later in the interview, Gov4 presents its developers as responsible for constructing the field for publics as something beneficial to industry, generating the relevant debates around distribution of benefits:

> I think what we've seen previously has been a lot of focus on GM for increasing yield, and I think we'll probably move away from that to making sure that products work with the environment, making sure that products work with people, making sure they have those health benefits and environmental benefits. And the cost is reasonable, and it's not being seen as something that isn't openly available. (Gov4)

Gov4 does not mention particular corporations in relation to this claim, but other participants like Org8 and Org3 did discuss specific businesses often associated with GM controversies, such as Monsanto - now owned by Bayer - with a long history of controversial agrichemical production.

Org8 is an agricultural economist at an international policy organisation with experience researching the views of policymakers, publics, scientists and other stakeholders on genetic modification and other food-related controversies. Org8, like Gov4, discussed the sharing (or not) of GM's potential benefits, as well as disagreements between stakeholders over the differing values and interpretations of information intrinsic to GM debates, as drivers for controversy. Org8 also referred to industry interests and lobbying. They pointed towards power imbalances and a lack of deliberation as explanations for why controversy occurred, has endured, and is likely to reoccur in the case of synthetic biology. Org8 routinely mentioned Monsanto as an example company when discussing conflicts between differing interests, values, perceptions of what constitutes "trusted sources of evidence" and transparency:

> [T]here are always different interest groups, like Monsanto wants to sell more GMO products, because that is what they do. And then you may have organic farmers who don't want that because that would actually undercut their own business models. So clearly, you have different interest groups. And that is fine. This is just how the world works, and you can sort of deal with that. […] But with values, it is very hard. If somebody says, "Well, no. We really don't want Monsanto to be in charge of what goes into our food," then how are you going to convince that person that GMOs are a useful technology? Or even stronger, if somebody says, "It is immoral to play God with genetics." How are you going to convince that person to allow GMOs? So, all these ethical questions are really hard to resolve. […] it is important that you have trusted sources of evidence […] And it also includes things like integrity policies for scientists, things like conflict of interest statements and so on, because you don't want somebody who is actually secretly on the Monsanto payroll to write the review paper of whether GMOs are good, right? (Org8)

Org8 constructs several aspects of GM controversies here. First, there is a sense that companies like Monsanto are viewed by others as self-interested, untrustworthy and undesirably powerful both in terms of lobbying and being "in charge of what goes into our food". In doing so, Org8 also alludes to several perceived 'sides' involved in GM controversies, including GM developers who may form alliances with or influence scientists and governments, other industry like organic farmers, and publics with a range of views, values and ethical perceptions. Org8 goes on to mention "a register for lobbyists" as an example of "good practices that you can do in terms of transparency" to illuminate how stakeholders are influencing regulators:

> [I]n some countries there are rules that say, "If somebody speaks with a minister, or cabinet officials, or civil servants, that there must be a record of that somewhere," so that you could always consult on why and say, "Oh, some guy from Monsanto went to have a chat with the person in charge of…" this or that. At least then it is out there and sort of… sunlight being the best disinfection and so on. (Org8)

This mention of "sunlight being the best disinfection" suggests that secret or non-transparent alliances between GM developers and governments or scientists might 'infect', undermine or sow (implicitly public) distrust in relevant policymaking or research. Furthermore, Org8 suggests that there might be investigation or research ("review papers") seeking to demonstrate that "GMOs are good", or a need to "convince" publics that "GMOs are a useful technology" or to "allow GMOs". This implies that Org8 feels that the binary that GMOs are either 'good' or 'bad', 'acceptable' or 'unacceptable', may be relevant and important to those developing, investigating or regulating the technology, but that publics have nuanced views about GM based on their ethical perceptions and values.

Impacts of GMOs

Org3 is a foodservice industry worker with knowledge of the arguments around GM crops and experience discussing these with GM stakeholders, including plant biologists, during their education both in the UK and USA. Org3 describes GM as "a force for good" in terms of increasing yields. However, Org3, like Org8, also discussed their observations about the impacts of GM controversies on farming communities, the (lack of) sharing of benefits and disagreements over the focus and trajectory of GM developments. To exemplify industry practices that they view as giving GM "a really bad reputation", Org3 discusses Monsanto. This participant mentions "Monsanto evilness", and contrasts Monsanto's work to that of plant biologists who aim more directly to produce consumer-focussed improvements to the taste and nutritional composition of foods:

> [GM] gets a really bad reputation, doesn't it, I think? It's also a force for good. The problem with GMOs is the business practice behind it, the seed companies that stop plants from being able to make viable seeds just so people can buy more of their products. […] I spoke to a professor in the agriculture department at Madison University of Wisconsin. She was a plant biologist and she made a squash, the delicata squash, which is really tasty. She was talking about just creating a squash for sweetness. That's a nice example, none of Monsanto evilness. It's not just bad stuff. […] I've never extensively looked into them [Monsanto]. I just know all the key things, that they're evil. They make the seeds that only grow once and just keep people stuck in a loop of buying from them. They've something to do with Roundup, like Glyphosate, the pesticide that's cancer causing and is in every food ever. Yes. They don't seem like a good company. (Org3)

Here, Org3 makes connections between GM development, farmer exploitation ("[keeping] people stuck in a loop of buying from them"), and the use of pesticides, viewed as "cancer causing and […] in every food ever". These connections are very similar to those that Gov4 assumes publics have "got […] into their heads" as a result of "not knowing" about the technology and its uses. However, it is difficult to dismiss these points as the result of a knowledge deficit. The connections between GM and pesticide use (e.g., Roundup Ready crops) as well as the implications of the patented seed market, are observable and challenging for some farmers notably in the USA.

This is discussed by Org4, a farm worker with an environmental science background who has spent time working on farms in the US and discussed the implications of GM seeds for US agriculture. Org4 states:

> [GM is] feeding people for sure. But also, there is probably a food system where you don't need GM and you can still feed people. […] I know for me the biggest issue I have with it is how it takes away sovereignty over seeds. That's a crazy thing where these agribusinesses can patent seeds, sell them to people and are forcing farmers into this relationship where they need to use their seed and they

> have to use it in specific ways and they have to have certain infrastructure in order for it to work. It's factory farming, even though it's not for animals and it's not indoors and stuff like that. (Org4)

Similar arguments are used by a range of participants in this group as examples to underscore why they perceive GM as problematic in some circumstances ("it takes away sovereignty over seeds"), but potentially useful in others ("feeding people"). Org3 and Org4 are also sceptical of the capitalist prioritisation of profit over other benefits, emphasising that GM developers were and continue to be overly focussed on self-interest, which generated GM controversy or "backlash" (Org3). Such perceptions look at GM controversies at a global level, using examples about the impacts of GM development overseas, where GM crops are currently grown. Through this lens, Org3, Org4 and Org8 give a sense that GM is (in their view rightly and supported by evidence, not mistakenly as suggested by Gov4) viewed as controversial by some because of the ways in which some prominent stakeholders have been seen to use it to wield (economic, social, political) power over others, rather than to benefit others. These participants feel that synthetic biology developers could act similarly and invite similar controversy.

From GM controversy to synthetic biology debate

Also conscious that synthetic biology might be controversial as GM is perceived to be is Sci9. Sci9 is a manager at a UK fresh produce company with a background working at various agrichemical companies, and academic STEM training to degree level. Due to their age, Sci9 was not working or studying during the time of the GM controversies. Nonetheless, Sci9 has learned about publics' responses to GM technologies and the implications for businesses and regulators of these reactions. Typically, Sci9 framed GM (and other novel food technologies) as potentially inflammatory or alarming to knowledge-deficient publics, who might "freak out" about them. For Sci9, such reactions to GM technologies are likely if publics are confronted with labels or other public-facing "noise", such as a "headline" in the press, or a government decision about "controlling something very closely", rather than "quite an open governance". Sci9 explains that this is based on a lack of understanding of GM technology, but also that GM has negative perceptions attached to it that people "think about", while they do not attach similar negativity to "vegan food and fake meat […] [which] use some kinds of synthetic compounds and things":

> I think a lot of the time, a lot of things to worry about with synthetic biology and use in food and you hear 'GMO' or see a GMO alarm, people freak out. I think it's just because people don't really know what it is or the fact that, actually, I think, a lot of vegan food and fake meats, they're going to use some kinds of synthetic compounds and things. I guess, I don't know, people don't really think about that. If people don't think about it, they don't worry, but if they see a big

> label on it saying, 'Warning: This has been modified in some way', then that's when they start to worry. I think, yes, a lot of people don't understand what it's like being in the food industry itself, so all they want is just clean, healthy food or they want it as cheap as possible and they […] can't marry the two up, it doesn't quite work as something like 'organic but cheap but also not full of pest holes'. (Sci9)

Here, Sci9 attaches a likelihood of negative public reactions to the term or label 'GMO' itself, conceived of as a warning, believing that if GM or GMOs are discussed - people "hear" or "see" them - they will "freak out" or "worry". Sci9 also frames publics as misunderstanding of GM technologies, the contents of vegan food and "fake meats", GM labelling and the challenges facing the food industry to meet public demands. This participant suggests that this is a barrier to GM, that GM could in fact be a tool to meet some of the demands of discerning or idealistic consumers for cheap, "clean, healthy food" and "not full of pest holes", but incompatible with public demand for organic produce. Later in the interview, Sci9 applies similar logic to a discussion of synthetic biology:

> [I]f there's too much noise around one thing, then that's what the rest of the public listens to. So, if they hear a little bit of noise and that's the thing that then escalates, saying, 'Synthetic biology is coming into everyday life,' and people start to panic and everyone is just going to listen to that and think, 'Oh my God, this is happening and we're going to end up growing mutations because we're eating synthetic food.' I guess it's the headline that starts out. If you shout loud enough saying, 'It's a great thing,' then people are going to listen to that. If you hear the government is controlling something very closely, then you've got to think, 'Why are they controlling it that closely? Is there something wrong? If something goes wrong, how is it going to affect me, my family and the world?' Whereas, if, I don't know, you don't hear much about it or it's got quite an open governance on it, then it's, kind of, 'Okay, if the government aren't worried about it going into everyday life, then I don't need to be, either,' which then gives it free rein to develop and become something useful. (Sci9)

Like other participants with second-hand experience of GM controversies, Sci9 resists presenting public debates as binary, 'for' or 'against', instead framing reactions as likely to be nuanced, such as querying "if something goes wrong, how is it going to affect me, my family and the world?" Here, Sci9 also connects government action – choices between "open governance" or "controlling something very closely" – and public reaction to synthetic biology and its risks. For example, government mandated GM labelling could lead to negative public reactions and constructions of GM as something to "worry" about.

Gov10 similarly considers government actions and public reactions as central components to GM controversies, conceived of as ongoing. Gov10 is a UK civil servant who has observed arguments against GMOs. This participant assumes that publics oppose GM.

Gov10 perceives there to be a potential risk to authorities from negative public responses to GM technologies, something which also affects synthetic biology. Gov10 explains:

> [S]omething that always gets mixed up into the synthetic biology discussion, for good or bad, I'll let you tell me, whether it should be or not, is obviously GM and GE, and maybe we want to talk about that later, and people's views on new food technologies. And when GM food was last tried to be introduced to this country, and there was all that discussion on Frankenfoods foods and the 'yuck' factor and stuff like that. And so, as an organisation, we need to take that consumer interest piece into account as well. […] It's a constant and iterative process of looking at the wider challenges and opportunities out there in the food system and seeing how they will not just impact the organisation, so the institutional risks of dealing with opportunities and risks, but also the societal risks as well, so how they will impact both positively and negatively on our experience as consumers of food. (Gov10)

Here, Gov10 discusses their perceptions of GM controversies ("when GM food was last tried to be introduced") and, like others, repeats the terms "frankenfoods" and "yuck". Gov10 frames these negative responses in terms of "consumer interest", "our experience as consumers of food" and "societal risks", which must be taken "into account" by their organisation within government. Gov10 is suggesting that authorities are conscious of how GM technologies in food and agriculture were received negatively as not in the interest of consumers, and that there is some likelihood that similar controversy will get "mixed up into the synthetic biology discussion", which must be treated more in terms of weighing up potential risks and benefits. Gov10 repeatedly mentions "wider opportunities and challenges", "opportunities and risks", "positively and negatively" impacting consumers. For this participant, such weighing up of ("dealing with") opportunities and risks, or risks and benefits, could carry institutional risks if novel food technologies like synthetic biology are negatively perceived by publics, as GM is perceived to have been.

Gov2 also views synthetic biology as potentially risky to the reputation and public perception of regulators if it is received negatively by publics, like GM. Gov2 is a manager at a UK funding body who repeated a range of vague arguments against GMOs, such as those around unintended consequences of releasing organisms into the environment, or the implications for human health of consuming them. Gov2 conceives of public opposition as a likely barrier to synthetic biology as a result of similar, broad arguments being applicable. For Gov2, these arguments are valid but flawed, as they are applied to genetic technologies (depicted as "robust" and "predictable") but not to other production methods like random mutagenesis, which are "not challenged":

> I recognise the concern they have around genetically modified organisms. If they don't fully know what's going on inside that organism, how can they trust its release, and its use, and the consumption of those products? That is an entirely valid concern. I would raise a very similar point, though, of how much do they know about what's going on in any living organism, let alone the one that has been modified? […] I think it's going to be a long, hard-fought battle. I don't necessarily think there's an easy win to it, but I completely understand why people have concerns with these products and processes, but I don't, personally. I don't have an issue with them. I think that the processes are as robust, if not more robust, than others that are currently accepted and not challenged. So, I wish I could convey that message to communities and make people see it my way, but there are going to be some diehard people that are set in their ways and probably won't accept that, even if the evidence was presented to them, and maybe rightly so. They might be more informed than me. (Gov2)

Here, Gov2 echoes Gov3, Sci4 and Sci5 (participants with first-hand experience of GM controversies) who feel that some of the questions raised in opposition to GM and other genetic technologies are unjust or flawed because they are not also applied to other breeding methods. Gov2 resists presenting publics as mistaken in their views ("[t]hey might be more informed than me", "[t]hat is an entirely valid concern") but rather as inconsistent or lacking the knowledge to question other technologies or evaluate genetic technologies in the context of others. As a result of this, Gov2 advocates for more education, viewing some publics as persuadable that GM is no more or less concerning than, for example, mutagenesis. Like some participants with first-hand experience of GM controversies and conflict, Gov2 also refers to a likelihood of conflict over these technologies, "a long, hard-fought battle", and hopes to avoid these by educating or persuading publics, accepting that "some diehard people" may not be convinced.

While Gov2 did not elaborate on the source of the perceived "misinformation that goes around" fuelling ongoing opposition to genetic technologies, Gov6 feels that opposition to GM was informed by the press during GM controversies. Gov6 is also a manager at a UK funding body with research and industry experience in a relevant field. Gov6 has observed the impacts of GM controversies and public objections to the technology on industry and research. In a discussion about DEFRA's 2021 consultation on genetic technologies, Gov6 describes this as "an opportunity to reframe the argument" and steer "rhetoric" away from "Frankenstein foods":

> **Gov6**: I think you have to be aware of the political landscape, you know, because we have had decades of the Daily Mail saying, "Frankenstein foods." So, these new genomic techniques that are very specific, it would give the government an opportunity to reframe the argument. […] I think, in the UK, we have been exposed to a lot of rhetoric about GMOs that isn't helpful. (Laughter)
>
> **Natalie:** What do you think people think about synthetic biology?

> **Gov6:** I think the general public don't know. I think one of the great things is that people have all heard of RNA vaccines now, which is great because I think it probably gives people a way into discussing it. But people don't know. The general public know what has been in the newspapers for years, which is 'GMO bad'. So, yes, it will be a challenge. (Gov6)

Gov6 is aware of binaries like "GMO bad". This participant feels that this message, which "has been in the newspapers for years", underpins public understanding of GM, and that this in turn will frame views on synthetic biology, unless "the argument" is reframed. Of all the participants with second-hand experiences of GM controversies, Gov6's views are the most closely similar to those of the participants with first-hand experiences. Gov6 makes comments about public knowledge deficits and blames the press for negatively influencing public opinion on GM, something which "will be a challenge" to change.

Summary

For participants with second-hand experiences of GM controversies, there appears to be more of a focus on nuance in GM debates. These participants place less emphasis on binary arguments about GM technology as 'good or bad', although some did allude to others having interest in such binary debates in order to present their work or products as roundly "useful". Instead, there tended to be more discussion of the concerns associated with the roles, interests and values of different stakeholders (often challenging industry), as well as the potential benefits of GM and synthetic biology in certain circumstances, applications and under specific economic, social and political conditions. Participants did compare aspects and applications of GM that would be 'concerning' versus those that would be less so. Where these participants did construct binaries was typically between what they perceived as 'traditional', 'conventional', 'natural', 'smallholder', 'collective' or 'organic' food production processes and those involving GM and synthetic biology. The latter were viewed more often as unnatural, exploitative, harm-producing and dominated by a self-interested 'big agriculture' industry often exemplified by reference to Monsanto, a company name which in turn seems to symbolise corporate greed, something that participants viewed as controversial.

Overall, like the participants with first-hand experiences of GM controversies, these participants constructed other stakeholders in a range of ways. Agricultural or biotechnology companies are viewed as untrustworthy and unscrupulous by some, and by others, as under increasing pressure to adapt to a climate changed world and ensure a stable food supply that is acceptable to discerning consumers. Similarly, government is depicted as multifaceted, at once conscious of consumer interests and seeking to shift public perceptions to facilitate the

development of novel food technologies, and under lobbying pressure. The press is conceived of by Gov6 and Sci9 as powerful, stoking concerns and generating negative public opinions.

Publics are portrayed as concerned, conflicted about GM's applications and usefulness depending on their values, beliefs and ideas about ethics and, for some, deficient in certain forms of knowledge. These characterisations of others, and of the range of concerns about or objections to GM (often exemplified using terms relating to 'Frankenstein' or 'yuck'), give the overarching sense that these participants have understood GM and its development to be problematic and complex, and that synthetic biology is likely to be viewed similarly. This is presented as evidenced, by both the complexity of the surrounding debates and by the impacts on farming communities of GM's applications in agriculture abroad.

5.3.4. Summary

This chapter explored the importance of GM pasts to discussions of imaginary synthetic biology futures, something I have termed 'GM Trauma'.

It was apparent that the noisiness and complexity of the GM controversy and debate were pertinent to my participants. Experiences of the controversy looked different to different groups, and different individuals. However, there are some common themes. For example, across participants with first-hand and second-hand experiences of GM controversies, there was a sense that something went 'wrong' during this time. Notably, those with first-hand experiences of conflict with other stakeholders all felt that they had 'lost' their arguments or not achieved their aims. In turn, this is likely why they remain so 'alive' for participants, playing a prominent role in framing their discussions of synthetic biology. This is centred on a breakdown in communication, an inability to generate fruitful, calm dialogue with others or to achieve their aims. GM Trauma for them is characterised by feelings and language of conflict and harm between proponents and opponents of genetic modification. Others allocate blame for the controversies surrounding GM (e.g., to NGOs or the media, or to scientists and regulators).

Overall, marking this sense of unresolved controversy across participants, was reference to obstacles to overcome, such as injustices they perceived about the treatment of GM by publics or other stakeholders, or unfairness that they feel ought to be rebalanced. Some scientists and those working in governance pointed towards GM being treated differently by regulators than mutagenesis in conventional plant breeding. Many of those with first-hand experiences also constructed or reproduced binaries ('for' or 'against'; 'good' or 'bad';

'scientific' or 'unscientific') that they perceive were deployed at the time, presenting them as unfairly or wrongly reductive and polarising.

Those with second-hand experiences tended to present GM debates as more nuanced, or a range of 'problems' to solve that may also apply to synthetic biology. These participants constructed some slightly different binaries in order to challenge them, such as between novel technologies as other farming methods, or perceptions of 'natural' versus 'synthetic'. Many positioned negative public perceptions as 'obstacles' to overcome. Often participants described binaries as unhelpful, too simplistic or mistaken, but reconstructed them nonetheless. Binaries may have been used by participants to help simplify and relay GM controversies, converting the complexity into various 'lessons' in order to discuss them in relation to synthetic biology. Further, participants routinely described how they did not understand the views of others or expressed uncertainty about how synthetic biology might be perceived or regulated. The presentation of GM controversies as rooted in binaries might suggest participants aimed to take GM controversies from something challenging to comprehend, unmanageable, chaotic and conflictual towards something more actionable, instrumental, or, more cynically, to dismiss objections as 'illogical', 'invalid' or 'unscientific' and something to be ignored or altered. Constructions of binaries also lends itself to constructions of 'sides' of the debate and participants often depicted other stakeholders or allocated them to 'camps' and 'alliances' that did not reflect the complexity of GM controversies and GM's ongoing development and governance.

In short, this chapter introduces one of the main findings of my research – the impact of the genetically modified (GM) foods controversies on my participants' views about synthetic biology futures. The following chapters demonstrate that GM Trauma is important because, for my participants, it:

A. Contributed to views on what synthetic biology is, its definitions, boundaries and status as potentially controversial or risky or not (discussed in more detail in the following chapter).
B. Framed discussions about ways that publics might be engaged with, communicated with or managed.
C. Supported views about the status and value of scientists and science in policy arenas, sometimes to the exclusion of other stakeholders.

Chapter 6: From Genetic Modification to Synthetic Biology

6.1. Introduction

The previous chapter presented the central theme of my thesis: GM Trauma. This chapter explores how participants constructed 'synthetic biology'. I explore how definitions of synthetic biology indicate participants' conceptualisations of a space for the field in relation to others like genetic modification. I summarise constructions of synthetic biology in light of GM Trauma as novel and growing, promising and potentially controversial. Another component of discussions about synthetic biology's potential positions in society was participants' perceptions of others, notably publics, informed by their views of GM controversies. I present the varied characterisations of publics as passive, mistaken, threatening and powerful, informed by GM experiences. I demonstrate how these perceptions of publics (and sometimes other stakeholders) interface with judgements about synthetic biology's similarities or differences from GM and are revealing of views about how the field might be 'treated' by publics as a result.

6.2. Definitions of synthetic biology

I asked all participants how they might define synthetic biology. I did so because previous social science literature on synthetic biology identified that there was no consensus on a definition for the field. Many commentators also construct synthetic biology as a new or emerging field, which implies movement or dynamism in the present in terms of the field's shape and identity, the boundaries of which were constructed in a variety of ways by my participants. This despite the field being generally recognised as beginning in its present form two decades ago.

I begin this chapter with participants' reactions to being asked to define synthetic biology, which were varied, and the wide range of definitions of synthetic biology offered. I include analysis of how synthetic biology classifications and categories are performed in relation to similarities and differences between the field and GM, a theme which runs through the remaining chapters.

Initial reactions

Consistent with prior research, such as Taylor and Woods (2020), participants' initial reactions when asked to define synthetic biology often involved a laugh or a surprised "oh", suggesting difficulty in defining the field. For example, when asked to define synthetic biology, Sci11, a UK academic scientist and government advisor who had first-hand experiences of GM

controversy, responded "Oh, I knew you were going to ask that. It's such a hard question to answer. (Laughter)". Sometimes this was the case even after prior prolonged discussion about the field. Throughout the interview, Gov10, a civil servant with no first-hand experience of GM debates, spoke confidently about the field's potential governance implications and described synthetic biology as "molecular biology meets engineering". However, when asked to define the term synthetic biology, Gov10 responded "Oh, dear God. (Laughter)." Such reactions were common across participants with first- and second-hand GM controversy experiences.

Participants who indicated that they were less familiar with the topic sometimes asked me for my definition or offered an example application instead. In one example, Org4, a farm worker and researcher, mentioned a friend "who works in a lab […] they do yeast research, and what they are trying to do is create a synthetic alternative to palm oil. That is the first thing that springs into my head." Org4 connects this to a view that the term synthetic biology for them indicates broad acts of "creating or fabricating things that have biological applications, or can be either replacements to, like, for example, food or additives." Org4 thus appears to define synthetic biology by its products rather than in relation to other similar technologies. This is a contrast to Sci8 who discussed apples "done with synthetic biology" compared to other apples, suggesting that for them, their definition of synthetic biology relies on a perceived qualitative difference between foods that are the product of these processes and those produced through other means.

The first reaction of Org3, a foodservice industry worker and researcher, was to be interested in the words synthetic and biology in juxtaposition, drawing on notions of naturalness and linking the term to GMOs, which they considered to be similar: "That kind of sounds like two conflicting concepts. […] biology is natural and synthetic is the opposite […] the only thing that would spring to mind practically about that is GMOs." Org3 understands synthetic biology and GM to be similar because this participant's conceptualisation of both is based on their understanding of risk, economic harms to farmers and ethical questionability, rather than the technical specifics which some consider to be a differentiator.

These initial reactions point to the difficulty participants felt when attempting to define synthetic biology. However, most did then attempt to do so, but with various approaches and in ways that demonstrate differences that may have significance in policymaking and funding.

Attempts at definition

Definitions of synthetic biology fell into several distinct approaches. This included those that were (i) complex and uncertain (though important), and those that focussed on (ii) the tools and

techniques used or on synthetic biology products, their relationship to conventional approaches and what might be considered natural. A third approach considered (iii) synthetic biology in relation to other terms like 'engineering biology'.

(i) *Complex and uncertain definitions*

I observed a strong sense of uncertainty from many participants around their definitions, for example one civil servant, Gov10, was not confident:

> I'm familiar with the term, and you'll be delighted to hear that it is a phrase that I've heard within [UK government department] as well. And *correct me if I'm wrong, because I am no expert on synthetic biology, but I think what it does cover is an absolute huge area of interest, doesn't it?* It's molecular biology meets engineering. It's incredibly exciting and all the possible applications are possibly far more than I can consider in one sit-down. (Gov10) (emphasis added)

And, after a lengthy description of the field drawing on technical specifics and applications, such uncertainty was often followed by a response like "[d]oes that all make some sort of sense?" (Sci5, a UK scientist and government advisor), as if seeking reassurance on their views.

For Sci5, definitions were seen as essential and important but a source of conflict between the approaches of lawyers and scientists in producing them, particularly in the context of GMOs:

> Yes, the text from the lawyers gives me a headache when I look at it, (Laughter) but yes, definitely, it's interesting just to get the lawyers' view of it, because scientists will tend to look at things in quite a straightforward and logical way, but then the lawyers pull apart the wording and come up with a different conclusion. (Sci5)

Sci5 presents definitions as complex, 'a headache', and a point of contention, even an annoyance, a sentiment that was echoed elsewhere. For example, Sci11, a UK academic scientist and government advisor, described definitions as "important", and mentioned "I can see why people have come up with them, but I think they're quite limiting." Despite this, Sci11 also said that synthetic biology needed to be defined "purely because the regulation, ultimately, has got to have a legal aspect to it. Just don't ask me to be the one that defines it. (Laughter)". Both participants have first-hand experience of GM debates, a factor that may influence their views of the importance of ensuring that definitions are 'right'. For instance, Sci5 used the area of genome editing being defined differently to GM as an example of the complexity of arriving at a definition:

> If the definition of a GMO, if you look at something and you think, "This does not really fit this definition of a genetically modified organism," if it's not a GMO in the first place, then it doesn't fall under the regulations, so you shouldn't

> have to worry about it. Some of the genome-edited material doesn't easily fall under the GMO regulation […] it doesn't have to be regulated as a GMO in the simplest form, but, of course, some people disagree with that and think actually that they should all be considered GMOs, regardless. (Sci5)

Of course, in Europe, genome edited organisms have been defined as genetically modified organisms, by virtue of the similarity of the technologies. There is a political and economic motivation for defining the two differently in the UK to facilitate the commercialisation of gene edited products without the controls of GM regulation. Alluding to this, Sci5 implies in their interview that defining something as a GMO means identifying it as something "to worry about" and because of this it is important that "genome-edited" organisms are not considered GMOs.

There was a sense that participants had difficulties with the term 'synthetic biology', because they felt was not attached to a clear definition. For example, when approached for an interview, Org9, an advisor at a European policy thinktank, mentioned via email that:

> I would offer a word of caution. There is still quite some debate about the meaning of the term synthetic biology. Going back to my [previous work at an international thinktank] the US delegation would always object to discussions on synbio (and even use of the term) on the grounds that "we don't know what it means". (Org9, email correspondence 6th September 2021)

Org9 elaborated on this in our interview, indicating that some "stakeholders […] mainly governments" had "difficulties" with the use of the term synthetic biology. For example, "whenever somebody mentioned synthetic biology, the US would always say, 'We don't want to talk about it, we don't even know what it means.'" (Org9). Org9 went on to describe synthetic biology in general terms "all I understand it to mean is sophisticated forms of using living materials and genetic materials to do sophisticated things," offering the example of "multiplexing, which is the fancy name for doing lots of edits in the same thing, you may be altering lots of different sequences, you may be affecting multiple traits. At that stage, I guess, that's moving in the direction of synthetic biology." But Org9, like many others, preferred to define synthetic biology in terms of specific tools and techniques.

(ii) *Tools, techniques, products*

Overall, it seemed important to many participants to discuss what were seen as the differences between synthetic biology-relevant tools, techniques or technoscientific fields and GM. Many characterised synthetic biology as something more advanced, sophisticated or complex than GM. Scientists with first-hand experiences observing GM controversies were the most likely to define synthetic biology as different to GM in this way. Following a lengthy discussion about how the term synthetic biology "means different things to different people" and "covers a lot

of anything […] we're doing in the lab", including GM, I asked: "what's the difference for you between synthetic biology and GM?" Sci5 responded:

> I think GM is a part of synthetic biology, really. Synthetic biology is just much wider than just GM because synthetic biology, obviously, includes GM and genome editing. So, yes, I think it's GM and genome editing are just a synthetic biology technique, if you like. (Sci5)

This implies that Sci5 perceives there to be something of an overlap between the areas of genetic modification and synthetic biology, but that synthetic biology is "just much wider". This is something I observed in other interviews. For example, Sci10, who has observed GM controversies first-hand, felt that GM is a supporting technology for synthetic biology. Gov4 felt that most examples of synthetic biology application would "fall under" the category of GM, and Gov2 felt that synthetic biology and GM are "hand in hand". Both of these participants have second-hand experiences of GM controversies.

Another way of defining synthetic biology is exemplified by Org5, a UK academic non-scientist, who mentioned naturalness in opposition to synthetic or artificial. For Org5, synthetic biology signifies "artificially, culturally […] modifying [something] for human ends" with the nuance that this must take place "in a way that is different from conventional breeding technologies". Like Org4, Org5 thus compares synthetic biology with "conventional breeding technologies" though perhaps their use of the term differs slightly from comparisons that other participants sometimes drew between perceived "natural" aspects of food and agriculture, which were more often signalled using language of tradition, small-scale agriculture and organic farming, consistent with research from NCoB (2015), and not terms like "breeding technologies".

Some consider that synthetic biology might be thought of as a "type of genetic engineering", viewing it as unnecessary to make distinctions between synthetic biology and genetic engineering. For a campaigner and programme manager at an international NGO, Org6, the term 'genetic engineering' is attached to ongoing debate about GMOs and other aspects of genetic science. Org6 also felt that synthetic biology, being a less familiar term, might not make debates accessible to publics. Like other participants, and perhaps cynically, Org6 also indicated that the label 'synthetic biology' (or indeed the newer term 'engineering biology') is merely a device for attracting funding or conveying technological specifics to regulators, rather than signifying a technological difference between concepts. Such cynicism might result from this participant having had first-hand experience of the early GM debates on the NGO 'side'; experience that still colours their outlook. Sci1, a UK academic scientist, stated that "funding

councils in the UK needed to get money from the ministers to keep sustaining synthetic biology […] they need to create a new term to develop something flashy and new to the ministers", leading to use of 'engineering biology'. Again, Sci1 has long experience of GM debates and this perhaps explains a similar cynicism as Org6, though directed at government ministers.

Foodservice industry worker and researcher, Org3, and UK academic scientist and government advisor, Sci11, expressed that some GMO products might count as products of synthetic biology ("A first-generation GM plant would count as synthetic biology" – Sci11). Others felt that the term 'synthetic biology' was a "rebranding" of other fields and the products they aimed to make. For example:

> For me, this synthetic biology is just like a rebranding of something that's been around for quite some time before anybody coined that, kind of, phrase. For that, that was really trying to engineer- I was involved in a lot of projects trying to engineer microbes to produce different kinds of molecules that could be used as drugs. (Sci6 – a manager at a UK industrial biotechnology company)

Such a "rebranding" was also evident in one of the major themes that emerged in the discussions, the change towards describing synthetic biology as 'engineering biology'.

(iii) *'Synthetic biology' vs 'Engineering biology'*

The term 'synthetic biology' has recently been accompanied by or replaced with the term 'engineering biology'. Sci7 felt that the two terms could be used interchangeably, or according to preference. When asked whether they preferred the term synthetic biology or engineering biology, Sci7, a UK academic scientist and government advisor, responded "I'm happy for you to stick with synthetic biology if that's the title of your thesis."

For Gov1, Gov2, Gov6 and Gov9, 'engineering biology' was viewed as the more up-to-date term, and was the term more commonly used, rather than 'synthetic biology'. This was sometimes attached to a view that the field is nearing a more industrial phase. By this logic, 'synthetic biology' was perceived variously as more instrumental, a "tool" to drive 'engineering biology', which in turn was synonymous with industrial applications. For example, Gov6 describes: "as far as I am concerned, synthetic biology is built on molecular biology, and engineering biology is built on synthetic biology."

For other participants with primary roles in governance, synthetic biology sits on "more of a continuum" (Gov9, a UK government advisor) of technologies, including (or sometimes refining and developing) established tools and techniques, like genetic modification, as noted above, and these all fit under the umbrella term 'engineering biology'. One manager at a UK

funding body, Gov2, presented a similar view, suggesting that "engineering biology is a bit more all-encompassing [than synthetic biology]", and combines complementary technologies like data science, modelling and genetic modification. This collection of technologies and techniques "[makes] sure that there's the support for the range of technologies necessary to fully enable synthetic biology" in "food systems" among other sectors (Gov2). This view places emphasis on the synthetic biology being applicable, while engineering biology is a catch-all term for supporting technologies. This indicates a particular view of the term 'engineering biology' held among those involved in governance which does not seem to be shared by participants working in other roles.

A UK government advisor, Gov1 characterised 'engineering biology' as representative of a shift from "technology push to market pull, where 'synthetic biology' has somewhere played an important role in getting to the final operating solution." Similarly, when asked "is there a difference between synthetic biology and engineering biology?", Gov5, a manager at a UK funding body, although suggesting that I should seek external confirmation, explained:

> Yes, you're going to have to Google it. I'm going to read this to you. This is a call, there's a [funding] call out at the moment on engineering biology, it's the transformation biology call, I think it's called. You can probably Google it and find out, but it *defines engineering biology as a process of taking synthetic biology concepts and translating them to real-world solutions*. So, what we're trying to do is use synthetic biology, but address something that's a real problem out there. That's why it's interesting, because taking synthetic biology to address potential environment, using it as a tool to address potential environmental problems. (Gov5, emphasis added)

Consistent with work by Schyfter and Calvert (2015) on the engineering and biology "ideologies" within multidisciplinary synthetic biology spaces, it appears that perspectives on the term 'engineering biology' reflect a range of views about and interest in engineering and biology principles, including from those outside the academic community. One UK scientist, Sci4, considered synthetic biology simply as "an approach of whether you're using, like, an engineering mindset to understand your problem." Gov1, Gov2 and Gov5 have clear interest in industrial end-goals reflecting a preference for 'engineering biology' shared among those whose primary concern is governance, but which differs from those scientists currently working in synthetic biology.

Sci1, a UK academic scientist, explains that, although useful, the term 'engineering biology' fails to convey certain ambitions of synthetic biology, such as the integration of the biological and the digital spheres ("there is this integration, this very deep integration between the biological world and the digital world that is happening for the first time in, I don't know, 3

or 4 billion years history on the planet." – Sci1). This participant stated that "the way you engineer software is more similar to the way you engineer biological organisms than the way electronic engineers build stuff and mechanical engineers build stuff or civil engineers build stuff […] it has much more to do with computational design and simulation than actually engineering" (Sci1).

Summary

In brief, there is disagreement about the definition of synthetic biology, indicative of the unsettled nature of synthetic biology as a concept, category or classification, consistent with earlier research over the past several years, for example, Calvert (2013). There remains a lack of consensus on a definition, and the field continues to be shaped through negotiation. The gradual updates in terminology, as well as reference to certain goals and applications, form part of participants' views about what synthetic biology might be, informed in part by their past experiences: their GM Trauma, and also differs depending on their professional role at the time of interview. Of relevance to policymaking, there remains some disagreement over whether synthetic biology equates to genetic modification. For some, synthetic biology can be distinguished from GM technically. For others, GM is part of synthetic biology. Interestingly, there was also a sense from several participants whose primary roles were in other public and private organisations (Org2, Org3, Org6, Org7 and Org8) that synthetic biology and GM cannot be distinguished. This is because these participants do not construct their similarities and differences in terms of technical specifics, but rather in terms of their riskiness, unnaturalness and ethical implications, which are perceived to be indistinguishable. As I describe later, current work in the synthetic biology field is presumed to be adequately regulated under GM regulations, given the rather broad definition of genetic modification and its implementation under current policy. However, a clearer definition of synthetic biology might be useful to food policymakers and those seeking to fund research in the field.

6.3. Constructions of synthetic biology

The tables in this section present a summary of participant constructions of synthetic biology and how this relates to GM Trauma. They include participant details, their experiences of GM controversies, the ways in which they constructed synthetic biology and some explanatory notes.

Participants with first-hand experiences of conflicts during GM controversies

Alias	**Role(s)**	**Experience of GM controversies**	**GM Trauma indicator/examples**	**Constructions of synthetic biology**	**Explanatory notes**
Gov8	Advisor to UK government	○ Conflict with NGOs and other groups ○ Research and government work experience	Feels that GM was wanted but industry was stifled by angry opponents like NGOs making it commercially unviable.	○ On a continuum with GM, but synthetic biology is more of a constructive, controlled, precise approach, GM is more of a destructive approach ○ Both are useful, so their risks should be weighed against their benefits ○ Promising in food, agriculture and medicine	Feels that attitudes towards GM are shifting because of positive COVID-19 vaccine experiences, and that NGOs are not as powerful as they once were in swaying public opinions.
Org6	Manager at international NGO	○ Campaign work with publics, scientists and policymakers	Discusses scientists' hubris, deficiencies in risk assessments, lack of transparency and trust in GM developers. Perceives a lack of constructive dialogue with publics.	○ Same as GM (both genetic engineering) ○ Same negative implications as GM in terms of risk, ethics, public perception ○ Not necessarily novel technology but expanding and capable of being applied in new ways	Is concerned about relationships between policymakers and industry, and considers industry and scientists to be non-transparent, ethically questionable and overly accommodating of broad uncontrollable risk while presenting these risks as non-existent.

Org9	Advisor at European policy think tank	○ Conflicts during work with researchers, policymakers and governments on governance of GM, genome editing and synthetic biology	Remembers the heat of controversies in the 1990s and feels that the GMO conversation is being opened up anew in debates about similar technologies.	○ Similar to GM in terms of controversy, risk assessment and challenges for policymakers ○ More sophisticated, complex, precise and controllable than GM ○ Promising in environmental applications	Questions definition of synthetic biology and finds the term problematic. Presents policy approaches elsewhere e.g., Argentina as logical because they consider risk more proportionately and provide market access more easily to smaller corporations, not only those that are wealthy and powerful.
Sci7	Academic scientist, UK (and advisor to UK government)	○ Research and policy work in relevant field ○ Conflict between industry, scientists, NGOs and publics ○ Conflict between scientists and policymakers on definitions and regulatory responses	Suggests that NGOs and the media stoked controversy on GM, and that regulators became hostile. This traumatised scientists, silenced publics and harmed businesses.	○ Synthetic biology and engineering biology discussed interchangeably ○ Different to GM - more advanced and controllable ○ Similar risks to GM - not particularly risky except possibly 'weediness' ○ Similarly challenged by regulations as GM ○ Promising in environmental applications	Very reluctant to focus on risks, but rather on risks and benefits being weighed; the quality of science involved in assessing risks; overestimations of risks; what past experiences tell us about how non-risky GM is. Essentially advocates for a more nuanced treatment of risk, rather than the assessment processes derived from fear of GM and fear of GM going wrong.
Sci8	Scientific consultant to international NGOs	○ Research and NGO experience objecting to GMOs ○ Experienced conflict between NGOs, publics, scientists, industry, regulators and farmers	Discusses common objections to synthetic biology and GM and the similarities between them, and the NGO stance on both.	○ Synthetic biology likely novel and more complex than GM and therefore even more objectionable and risky ○ Similar ethical concerns to GM ○ Overhyped and not necessary to develop	Considers that scientists are detached from public scrutiny and do not adequately reflect on the implications of their applications for the world. Scientists are encouraged by systems of research funding and requirements to create outputs and build reputations to win more funding, rather than considering the downsides of their work and how it will be received.

Table 4 - How participants with first-hand conflict experience GM Trauma construct synthetic biology

Participants with first-hand experience observing GM controversies

Alias	Role	Experience of GM controversies	GM Trauma indicator/examples	Constructions of synthetic biology	Explanatory notes
Gov1	Advisor to UK government	○ Research, policy and industry experience ○ Observed NGOs challenging scientists and industry, and policymaking responses	Feels that ethical, risk and unnaturalness objections originating in GM controversy are mistaken and limiting. Thinks that the regulatory response is ideological, bizarre and that GM labelling is a 'threat' to synthetic biology.	○ Different to GM, and different to engineering biology which refers to commercialisation. ○ Growing and expanding but could be growing faster ○ Potentially useful economically, for public health and environment ○ Potentially risky use of public funds ○ Risks and ethical concerns can be managed through RRI	Views GM debates as 'ideological' and NGOs are seen as opponents. Feels that responses to NGO arguments and objections need to be prepared, to defend against them, but that public opinion may be shifting to be more positive because of COVID-19 vaccine development.
Gov3	Regulatory lawyer, UK (and advisor to UK government)	○ Advisory work with scientists, policymakers and government on GM regulations	Describes publics as 'all so misinformed', and feels that regulators have created a system of governance that is illogical and leads to 'insane' outcomes like regulating GMOs differently to mutagenesis.	○ Synthetic biology, like GM, is easy to control and precise, and its risks are overestimated ○ Likely to be subject to similar (perceived mistaken) public opinions about risk, ethics, unnaturalness	Discusses deficits in publics' knowledge as the cause of public opinions on GMOs. Advocates for more scientifically-informed policy and a balancing of risks and benefits.
Gov5	Manager at UK funding body	○ Observed treatment of GM during work and publics' responses to GM	Suggests that publics oppose GM/synthetic biology because of a lack of information and headlines in the press, and that they might ally synthetic biology to GM and 'stop it dead'.	○ Different to GM, and different to engineering biology (tied to industrial end goals), but similar in terms of potential controversy ○ Risks and ethical implications likely to be perceived as similar to GM ○ A 'tool' in its nascency so not concerning, but has downstream potential to generate novel organisms with environmental risks	Views synthetic biology as misunderstood and thinks that if it is viewed as engineering biology then it might provide access to funding and enable the field's tools and developments to be applied.

				○ Potentially beneficial to the environment	
Gov7	Civil servant, UK	○ Government work experience of treatment of GM ○ Observed some of the activities in government at the time, such as trying to implement citizen juries	Explains that GM controversies put pressure on government and that today, gene editing and synthetic biology are also likely to be politically risky.	○ Synthetic biology, like GM is politically risky, but it is downstream, not yet something to focus on ○ In its nascency, only concerning when applications are developed ○ Like GM it is likely to be subject to similar objections regarding risks and sharing benefits, but also policy 'excitement'	Suggests that the treatment of gene editing will give a good indication of where things might go policy-wise with synthetic biology but characterises synthetic biology repeatedly as a non-issue yet so it is time for government to be in 'learning mode and listening mode' because applications have not yet been developed.
Gov9	Civil servant, UK	○ Government work experience of treatment of GM ○ Observed debates and disagreements about GM ○ Observed behaviour in government more recently, like consumer interest/education workshops on GM	Feels that ethical, risk and unnaturalness objections originating in GM controversy are mistaken, arising from 'mystique', and can be challenged with education, and that publics' accepting the technology is the most important barrier for the field to overcome.	○ Synthetic biology, like GM, are beneficial and likely safe ○ Not developed well enough to assess risks ○ Potential to pose some risk e.g., to animal welfare, persistence in the environment, and to trust in government if something goes wrong ○ On a continuum with other technologies like GM ○ Uses term 'engineering biology' to denote synthetic biology being industrialised	Champions public interest but also views public interest as something that can be shaped by their department through informational campaigns, rather than accepted and respected. Also views publics as trusting but potentially threatening to government and synthetic biology if trust is lost. Thinks public interest in genetic technologies might be growing because of COVID-19 vaccines.
Org5	Academic non-scientist, UK	○ Researched the views of scientists and non-scientists on GM and unnaturalness	Discussed objections to GM on the grounds of unnaturalness and suggests that scientists working on GM and synthetic biology have a different worldview that frames perceptions differently, and that policymakers and scientists therefore do	○ Similar to GM ○ Highly unnatural in a way that is different from conventional breeding ○ Similar implications to GM in terms of risk, unnaturalness, ethics and perception by publics ○ Might have useful environmental applications and produce alternatives to meat products, improving animal welfare	Sceptical of scientific work on GM/synthetic biology as highly unnatural, although potentially beneficial, and feels policy debate is captured by scientists so ethicists and publics are not heard. Advocates for people to have the ability to grow food autonomously and connect to food systems.

			not value these objections.		
Org7	Academic non-scientist, non-UK	○ Researched publics' and scientists' views on GM, and now synthetic biology, and supporting technologies like CRISPR	Discussed how publics and scientists had different perspectives. Publics object to GM on the grounds of unnaturalness and risk, while scientists are hubristic, and driven by economic and personal career motivations.	○ Same as GM (both are biotechnology) ○ Same implications as GM in terms of risk, ethics, unnaturalness public perception ○ Similar public perceptions like scientists' hubris, control, power and playing God, and feels that the reaction to and research on synthetic biology in society is not revealing anything new vs research on GM	Perceives financial and social motivations to distinguish synthetic biology and gene editing from GM for funding and eventual commercialisation. Questions definitions of GMOs in Europe and feels that the lines drawn between GM and synthetic biology for example are arbitrarily drawn by policymakers, politicians and scientists when these distinctions are not relevant to publics.
Sci1	Academic scientist, UK	○ Research experience in relevant fields ○ Observed GM public controversy, and conflict between scientists and NGOs.	Views NGOs as anti-GM and anti-synthetic biology and suggests that there could be cooperation or collaboration between NGOs and scientists as synthetic biology will progress and be impactful in novel ways.	○ Different to GM and to other fields as it is entirely novel, a transition in evolution ○ Does not view engineering biology as different to synthetic biology, just a new label ○ Views synthetic biology as intentional design of nature ○ Potentially risky, controversial ○ Potentially beneficial for the environment	Feels that NGOs could be cooperative and helpful to promote synthetic biology in society, instead of treating it as they did GMOs, if they understood the technology. Believes that synthetic biology can be a technological solution to the climate crisis, and believes that synthetic/engineering biology is revolutionary, combining the digital and biological worlds, in a way that GM did not.
Sci2	Academic scientist, non-UK	○ Research experience in relevant fields ○ Observed public responses to GM controversies	Acknowledges objections to GM and synthetic biology as 'fear' but dismisses these as irrational and a barrier to the field's progress and based on knowledge deficit.	○ Synthetic biology is different to GM, more complex, based on models, more controllable but might be viewed similarly as 'scary' by regulators and publics ○ Some applications e.g., in viruses are potentially risky, but food applications produced in containment are likely safe ○ Potentially useful medical and food applications ○ Still relatively far away from real-world applications	Focussed on segmenting different types of application according to their controllability. Discusses how education might help publics and regulators to treat synthetic biology and GM with less 'fear'. Suggests that policymakers may also have a form of knowledge deficit which causes them to impose strict regulations over applications that are more controllable (contained milk proteins), assuming them as

					similarly risky as those that are less controllable (viruses etc.).
Sci3	Academic scientist, non-UK	○ Work experience in relevant fields and policy spaces ○ Has conducted public engagement activities and experienced others' concerns about their work but has not encountered conflict themselves ○ Observed conflict between NGOs and scientists	Mentions 'nasty discussions' that polarise GM as something that is or is not wanted. Feels that synthetic biology's success will depend on public acceptance but that publics have nuanced views on GM/synthetic biology.	○ Synthetic biology is an engineering mindset, rather than a novel technology ○ Synthetic biology different to GM but 'one more step in the flow of science' ○ Potentially controversial and viewed by regulators as the same as GM in terms of risk ○ Potentially useful environmental and human health applications ○ Distinct from nature or naturalness, but lessons can be learnt from nature by synthetic biology developers	Frames synthetic biology as something useful for human objectives in relation to the environment, health and the economy. Suggests that it can be risky but that these risks are controllable because of laboratory practices and biological challenges engineering microorganisms, making them less adapted to survive on release. Discusses publics as potentially useful or beneficial to scientists for raising new questions.
Sci4	Scientist, UK	○ Research experience in relevant fields ○ Observed public, farmer and policy responses to GM development	Considers GM and synthetic biology to be a good thing and of benefit to farmers and subsistence smallholder farming communities, but which have been stopped by unscientifically-founded regulation and politicisation of the debates.	○ Synthetic biology and GM are both ways of modifying and engineering genes ○ Synthetic biology is different to GM because of its engineering principles ○ Like GM it is potentially risky and controversial, with similar challenges around benefit sharing and regulations ○ Promising economically and environmentally	Focussed on synthetic biology as a force for good but feels that regulations, patenting, inequalities in accessing the technologies and the controversies around GM mean synthetic biology may not achieve its promise.

Sci5	Scientist, UK (and advisor to UK government)	○ Research and policy experience in relevant field ○ Observed publics' objections to GM ○ Observed disagreements between lawyers and scientists on definitions, regulatory responses and outcomes of those on the field's development	Considers GM and synthetic biology to be different but that association with GM might make synthetic biology prone to concerns and disagreements over risks and ethics.	○ GM and genome editing are synthetic biology techniques, a part of synthetic biology ○ More complex and sophisticated than GM and genome editing ○ Might be viewed similarly to GM by regulators and publics, although both might be misunderstanding the risks, benefits, similarities and differences ○ Potential to benefit the environment, human health, smallholder farmers ○ Off-target edits might be potentially risky	Focussed on regulations as inconsistent across technologies and not adequately scientifically 'sensible' or flexible depending on perceived different risks of gene editing, GM, and synthetic biology. Believes that synthetic biology can benefit the world and the resilience of food systems, but people must have choice over their foods. Accepts that some publics and groups like WI, farmers organic farmers and the Soil Association object to GM.
Sci6	Manager at UK industrial biotechnology company	○ Research and industry experience in relevant fields ○ Observed public and policy responses to GM development, and the implications of GM governance on industry	Considers the regulation resulting from GM controversies to be arduous, arbitrary in parts, unclear and challenging to navigate. Suggests that public opposition of genetic technology is the barrier to be overcome for the field to succeed.	○ Synthetic biology and GM discussed interchangeably ○ Term 'synthetic biology' is a rebranding of more established technoscience ○ Risks and ethical implications viewed similarly to those associated with GM ○ Synthetic biology and GM both challenged by regulations ○ Potential to benefit the environment, industry and to produce meat alternatives	Focussed on barriers to economic success of the field, challenging regulatory processes, a lack of clarity on how to sufficiently prove safety; and considers that marketing for consumer acceptance and less arduous regulations together would facilitate industry.
Sci10	Academic scientist, UK	○ Research experience in fields relating to both human health/medicine and food ○ Observed conflict and arguments against GMOs in the food space and the impacts on business practices	Suggests that because GM is controversial, those working on lab-grown meat cannot use or admit to using GM cell lines even though GM would facilitate scaling up. Does not agree with anti-GM arguments.	○ GM is a supporting technology for synthetic biology, and this association carries implications for public acceptance and ethics that might impact development of applications ○ Potentially useful in producing meat product analogues with benefits to the environment	Highly focussed on economic aspects, like how businesses operate in the face of GM controversy, the implications of GM controversy on commercialisation of lab-grown meat, the implications of GM regulations on ability to sell products. Feels that most people are eating food containing or produced through GM in some form, so objections are unfounded.

Sci11	Academic scientist, UK (and advisor to UK government)	○ Has (US) industry and (UK) research and policy experience relating to GMOs ○ Observed arguments against GMOs and experienced the development of regulations and guidance	Describes conflict between scientists, NGOs, publics at the time of GM controversies, objections to GM regulations and slippery slope arguments about applications to animals, humans and risks.	○ Synthetic biology different to GM, more complex and controllable ○ Synthetic biology's risks and ethical implications might be viewed similarly to GM's by regulators and publics ○ Risks might be discussed in the press, leading to similar controversies to those around GM ○ Potentially risky for animal welfare, and controversial if so ○ Potentially risky if released, particularly if on a large scale into the environment	Believes the context is different for synthetic biology versus GM because of COVID-19 vaccine development changing synthetic biology's public image. Very focussed on definitions and navigating the differences between synthetic biology, GM and gene editing, for regulatory purposes. Is a proponent of a precautionary approach to governance to preserve public trust and avoid an incident that 'kills the technology'; but doesn't support restrictions on genome editing.

Table 5 - How participants with first-hand observations of GM controversies construct synthetic biology

Participants with second-hand experience of GM controversies

Alias	**Role**	**Experience of GM controversies**	**GM Trauma indicator/examples**	**Constructions of synthetic biology**	**Explanatory notes**
Gov2	Manager at UK funding body	○ Has learned some arguments against GMOs and thinks publics oppose them	Refers to public acceptance as something that will be a 'long, hard-fought battle'. Understands objections to GM but does not share them, and wishes 'diehard people' could be convinced of the benefits of synthetic biology.	○ Engineering biology, synthetic biology, gene editing and GM are different but 'hand in hand' ○ 'Engineering biology' is the more up-to-date term as it is more all-encompassing of all supporting technologies than 'synthetic biology' ○ Likely to be subject to similar (perceived mistaken) objections as GM ○ Potentially beneficial for the environment ○ Potentially risky use of public funds	Discusses deficits in publics' knowledge, and advocates for education campaigns against 'misinformation' on synthetic biology and GM and gene editing, which are 'arguably more predictable' than others. Highly promissory about synthetic biology's potential benefits and feels scientists, regulators, industry and funders are all eager to help it fulfil its promise.

Gov4	Civil servant, UK	○ Has research experience in the field ○ Has researched and observed publics' arguments against GMOs	Suggests that publics object to GM and synthetic biology on grounds of unnaturalness or because they don't understand it, or because it threatens traditional/familiar farming communities. Feels that GM governance is extremely complex and robust but may struggle with novel products.	○ Most synthetic biology likely to 'fall under' GM and to be similarly viewed by publics ○ Potentially harder to assess the risks of synthetic biology vs GM ○ Potential for novelty	Synthetic biology is viewed as potentially being of 'public interest' and useful to consumers but likely to be treated similarly to GM, and with similar misunderstandings. However, synthetic biology, if novel and complex as promised, might be ungovernable under current comparator approaches.
Gov6	Manager at UK funding body	○ Has research and industry experience in a relevant field ○ Has observed the impacts of GM controversy and publics' objections to GM on industry and research	Describes GM and synthetic biology as different but likely to be treated similarly by publics; views regulations as a barrier to the field, and does not think that regulations treat GM proportionately to its risks.	○ Different to GM, and different to engineering biology, but similar in terms of potential controversy ○ "[S]ynthetic biology is built on molecular biology, and engineering biology is built on synthetic biology" ○ Potentially useful medical and environmental applications	Suggests that some opposition to GM is informed by the press, but government wants to support synthetic/engineering biology and has an opportunity to reframe the argument given COVID-19 vaccines success.
Gov10	Civil servant, UK	○ Has learned arguments against GMOs ○ Assumes public opposition and risk to regulators from doing something not in line with public interests	Discusses Frankenfoods, 'yuck' factor, and risks, including risks to regulators from approving novel foods and facilitating technoscience.	○ Different to GM, with potential to produce 'entirely new approaches' ○ Likely to be similar objections to synthetic biology as to GM in terms of risk, ethics, naturalness, desirability or otherwise ○ Promising for food industry ○ Risky to reputations of regulators if something goes wrong	Suggests that public interests, or doing things that are in the assumed interests of publics, are regulators' main concerns, but that synthetic biology might be useful or beneficial if public interest and safety and scientifically informed policymaking remain priorities.

Org1	Academic non-scientist UK	○ Unclear, too young but has experience in sociology and food-sector research so likely to have come across GM controversies and ideas	Does not mention GM by name - but refers routinely to common anti-GM arguments and deployed them against synthetic biology. Has perhaps assumed these and developed some standard rebuffs to refute them.	○ Potentially risky for animal welfare ○ Potentially beneficial for animal welfare if it can produce meat alternatives ○ Potentially ethically questionable and guided by industry profit-making over other considerations ○ Promising for the environment and the economy ○ No more unnatural than other practices like 'battery' farming	Sceptical and distrustful of (some) industry, government and (some) scientists to align with perceived important interests like veganism, intersections between animal welfare, environment, economy. Views GM/synthetic biology as a potential helping hand to improve an unsatisfactory food system more broadly, but could fit into existing systems of exploitation and harm.
Org2	Academic non-scientist UK	○ Has heard some of the arguments against GM crops ○ Describes linked or analogous debates around slippery slope-type arguments about implications of GE if applied to humans	Refers routinely to common anti-GM arguments and sentiments and felt them to be relevant to synthetic biology, such as Frankenstein, 'mad scientists', playing God, unintended consequences, and slippery slope (human applications).	○ Similar to GM ○ Like GM, potentially risky for human health, ethically questionable ○ No more unnatural than other practices like traditional breeding approaches ○ Potentially beneficial for the environment, human health and food security	Highly focussed on risk/safety and potential unexpected, long-term consequences, particularly on children and on humans if technology applied.
Org3	Foodservice industry worker and researcher	○ Has heard some of the arguments both for and against GM crops e.g., through meeting with a plant biologist to discuss GM	Discusses 'Monsanto evilness' and is very focussed on the powers held by corporations over farmers in the USA, and how these were enabled by the US government through subsidies, government inaction, lack of transparent labelling.	○ Similar to GM in terms of risk of economic harm to farmers, ethically questionable ○ Potentially beneficial for the environment and animal welfare if meat alternatives can be produced ○ Potential human health benefits	Views GM/synthetic biology as fitting in to an unsatisfactory food system that is detrimental to the environment and farmer livelihoods, but as having the potential to be a 'force for good' as well.

Org4	Farm worker	○ Has heard some of the arguments both for and against GM crops ○ Observed impacts of GM crops and monocropping on US farms and farmers (lack of resilience)	Discusses negative implications of GM seed industry and patenting for US farmers and consumers, and importance of labelling.	○ Different to GM, but similar implications in terms of risks to farmers' livelihoods, unnaturalness, ethics and sustainability, but also in terms of potential usefulness ○ Potentially useful for the environment, food security and animal welfare ○ Potentially harmful culturally and spiritually, 'far removed' from traditional practices and foods ○ Products potentially inferior to natural, whole foods	Sceptical of capitalist priority of profit above others and views GM/synthetic biology as unnatural, and a little off-putting although potentially beneficial. GM/synthetic biology viewed as somewhat unstoppable. Personally favours organic foods, smaller scale agriculture and collective organising, cooperatives for farmers, and for people to have the ability to grow food autonomously and connect to food.
Org8	Agricultural economist, international policy organisation	○ Researched the views of policymakers, publics, scientists and non-scientists on GM ○ Researched policy challenges around controversial technoscientific food developments	Discusses publics' objections to GM on the grounds of benefits not being shared, and risks being too high compared to more familiar foods. Also explains views of farmers, policymakers, scientists etc and values all arguments. Repeatedly mentions industry influence over policymaking, particularly Monsanto	○ Same as GM in terms of public perceptions, arguments and controversy ○ Challenging to govern due to similar controversy and influence of industry over governments as during GM's development ○ Views synthetic biology, like GM, as a symbolic issue representing distrust in institutions and experts and different risk assessments by publics and a failure to stop polarisation by scientists and policymakers ○ Potentially beneficial to industry and large corporations	Discusses limited benefits of GMOs for consumers but benefits instead for corporations and farmers. Views controversy itself as a barrier to policymaking because values, interests and facts are in conflict.
Sci9	Manager at UK fresh produce company	○ Has learned about publics' responses to GM technologies ○ Has learned about the implications for businesses and regulators of these	Discusses publics being alarmed by and likely to 'freak out' about technoscientific developments and by high levels of regulatory controls over them. Considers that publics are deficient in	○ Does not distinguish between GM and synthetic biology ○ Both GM and synthetic biology are positive but too expensive and likely to be subject to similar responses from publics	Highly focussed on economic benefits to retailers, consumers, farmers or lack thereof - considers that price of food and its quality and familiarity are key factors in decisions to buy and consume, but that synthetic biology/GM can be positive for environment, healthy food, packaging etc. Views publics as deficient in knowledge about food industry and fussy about price,

		○ Discusses implications of regulations on publics' opinions	knowledge about GM/synthetic biology and the food industry more generally, and that publics' fear can be stoked by labelling and by 'noise'.		quality and appearance of supermarket produce.

Table 6 - How participants with second-hand GM controversy experience (GM Trauma) construct synthetic biology

The following patterns can be identified. Firstly, scientists with first-hand experiences of GM controversies (both those who experienced conflicts and those who observed them unfolding) were more likely to construct synthetic biology as something different to GM, and typically as more advanced and complex. By contrast, participants working primarily in policy contexts, who also had first-hand experiences of conflict and of observing GM controversies, were more likely to construct synthetic biology and GM as similar to each other. This took the sense that both fields are potentially beneficial, promising, and misunderstood by publics. Most participants across groups constructed synthetic biology as something potentially promising, but with varying degrees of cautiousness, as discussed later in this chapter. However, participants working in governance with second-hand GM controversy experiences did tend to point towards some technological differences between synthetic biology and GM, but with little detail. This may be influenced by close working relationships with scientists holding these views, or by STEM training, which all of them had.

The participants involved in UK government advisory roles, Gov1, Gov3, Gov8, Sci5, Sci7 and Sci11 all have first-hand GM controversy experiences. These participants all constructed synthetic biology as complex and sophisticated technology, but with controllable risks. These participants also all constructed synthetic biology as something potentially controversial, like GM, with the potential to be misunderstood by others.

Participants working in other public and private sector organisations (non-scientific and non-governance) had the clearest views of GM and synthetic biology as similar. This derived from a sense that the risks, ethical implications and public perceptions of both fields were likely to be the same. As such, it was less pressing overall for these participants to distinguish between synthetic biology and GM in terms of technical specifics. The exception was Org9 who experienced conflict in policy spaces during GM controversies, and has views more broadly aligned with Gov8, Gov1 and Gov3, governance participants with first-hand GM controversy experiences. Namely, Org9 shares their views that, while GM and synthetic biology may be techno-scientifically distinct, GM was treated unfairly by opponents and regulators at the time of the controversies, so the governance approaches towards both fields ought to be reviewed.

For those with second-hand experiences, a perception of GM controversies as something complex and nuanced was most prominent, and synthetic biology was constructed as something likely to face similar debate. These participants tended to establish a similarity relation between synthetic biology and GM's risks, ethics and likelihood of being perceived similarly by publics.

The remainder of this chapter discusses constructions of synthetic biology in more detail, exploring participant views of the field as variously as novel, growing and expanding, promising and potentially controversial. Constructions of synthetic biology as potentially controversial tended to centre on public controversies, and perceptions about publics and their views of the field. Risk, ethics, (un)naturalness and the implications of these varied understandings of synthetic biology on governance are discussed in Chapter Seven.

6.3.1. Novel, growing and expanding

One common idea among interviewees was that synthetic biology is exponentially growing and developing and could be applied in "lots of different fields". For example, Org6, a manager at an international NGO discussed how synthetic biology (synonymous with 'genetic engineering' for this participant) means genetic engineering will no longer be focussed primarily on GM corn, soya and cotton, but applied to many other areas. This participant mentions animals, fish, insects, soil microbiomes, pesticides, agricultural inputs, nitrogen fixation and enzymes, expressing that synthetic biologists may aim to engineer entire ecosystems. For Org6, the perceived exponential expansion of synthetic biology was attached to a feeling of risk, "putting the cart before the horse," conveying potential for concerning unexpected consequences.

This view is likely the result of Org6's personal experiences during the early GM debates, where their interactions would have been with the scientists involved in the commercialisation of first-generation GM crops. During this time, debates about GMOs and their novelty led some to advocate for a precautionary approach to their development and commercialisation. Org6 also attached the notion of synthetic biology's novelty to similar uncertainty, mentioning a need for independent, robust, risk assessment. For Org6, this would involve transparency, liability and public participation in debates to counter what they perceive to be developers' lack of transparency. Org6 felt that it was difficult to discuss the technology's potential benefits in this context of risk, novelty and uncertainty.

A view of novelty as concerning is something echoed by both Sci8, a scientific consultant to international NGOs, and Gov4, a UK civil servant. For Sci8 and Gov4, a particular quality of synthetic biology that may have policy implications is its potential for novelty, or for practitioners to produce products without 'substantial equivalence' to existing products and without reasonably similar comparators. For these participants, this was linked to the idea of synthetic biology as risky, and capable of producing risky products, and to the perception that the comparator approach-focussed regulatory system would not be capable of assessing risk of

such novel products (e.g., of toxins, or of the introduction of gene drives into the environment). For example, Sci8 queries "if you have got synthetic biology, it necessarily can't have your substantial equivalence […] what will we do with plants, where the metabolism was altered? […] you actually need to [assess applications] much more a priori, basically, so from first principles". This participant adds that this "means not only looking at the molecular characterisation, but really thinking about, what could this organism do […] what could it be, if it was either accidentally or deliberately introduced to the environment?" (Sci8).

Gov4 explains in more detail some of the processes that the regulatory system follows in assessing a 'novel' product against a comparator[19] saying,

> I think most synthetic biology would fall into a GM area. You would need a comparator […] to show that compared to your comparator, compositionally it's the same, nutritionally it's not any worse […] sequencing of the area that you've changed. Potentially, if you were doing a lot of modifications, a whole genome sequence. And then checking that against libraries of known toxins and known allergens and identifying if you have any more of those than you do in your comparator. […] [The regulation] wouldn't work if you didn't have a comparator. I don't know how you would [assess] a product that didn't have a comparator. It might be that you would have to find the closest common thing. But it's not set up for a non-comparator-based system. If you were designing a completely synthesised product, it would be tricky. (Gov4, UK civil servant)

These examples highlight these participants' tendencies to perceive risk in novelty. It is unclear from Gov4 and Sci8's comments how an advisory committee would situate the similarity and differences of foods or ingredients to identify a comparator for the type of novel synthetic biology product imagined by these participants.

However, in contrast to this, Gov5 and Gov7 (both having observed GM controversies first-hand) used the idea of novelty or nascency to express a non-immediacy of concern. Gov5, a manager at a UK funding body, indicated that synthetic biology is "just a tool, *that's all it is*. A tool that is at its early stages of being developed" (emphasis added), implying that novel or nascent 'tools' are not particularly concerning. For another UK civil servant, (Gov7), until applications emerge, synthetic biology was not something to "start worrying about". Gov7 mentioned that government ministers will "only start worrying about it when you start seeing applications getting nearer to the market and people start asking questions about, 'How is this going to be…? Is the regulatory system as it currently is, is that fit for purpose?'" (Gov7). This description of a reactive approach to governance not only supports previous findings in the

[19] The Comparator Approach is also discussed in Chapter Three.

literature on technoscientific developments, and how little has changed, but also the importance of bringing horizon scanning research into policymaking processes.

For Gov1 and Gov10, synthetic biology's growth and expansion, as well as its novelty, was not a cause for concern, but rather enthusiasm, excitement and expectation. Gov10, a UK civil servant, used the "production of entirely new approaches" as a central aspect of their definition of synthetic biology, and viewed this positively and in terms of "more efficient" food production and a "reduction in pesticide use":

> Well, like I say, I see synthetic biology as that link between molecular biology and engineering. It's bringing different disciplines together, which traditionally you might not have seen, and *seeing how those disciplines can lead to the production of entirely new approaches*, not just in food, but obviously across a whole range of different domains […] Those *new and differing* molecular structures that we can produce, what does that impact on the food industry, in terms of, lab-grown meat, in terms of more efficient farm production, in terms of the crops that you might produce, and their reduction in pesticide use? So, it's absolutely huge as far as I'm concerned, and its uses are manyfold. (Gov10, emphasis added)

Gov10 has no first-hand experience of early GM debates but has developed an understanding of the arguments against GMOs. Their views of synthetic biology are focussed on the imagined products and outcomes of the technology and how these might be perceived by publics. They broadly ignored the deeper questions raised in public debates around ownership of the technology and where benefits might be concentrated, instead viewing novel synthetic biology applications as likely to have positive impacts, but be viewed negatively by publics.

Linked to this excitement, for Gov1, a UK government advisor who observed the early GM debates, there was a sense that synthetic biology was growing, with applications emerging, but "could be growing faster". This participant later explains that "to some extent, I feel that it's the market which is now pulling and therefore incentivising those applications […] some things could be growing faster if there was a clear vision." Gov1 does not describe their idea of "a clear vision," instead stating later that "what the market wants isn't necessarily going to deliver everything we will need in the future, because some things take longer." The use of the phrase "everything we will need in the future" is telling. This participant expresses a view that synthetic biology could be growing faster to fulfil a future technological need, with the implication, of course, that the field could "deliver" things that are needed (as they feel GM might have in different circumstances).

6.3.2. Promising

Most participants constructed synthetic biology as something with potential to be promising, positive and beneficial for UK food and agriculture, drawing upon a number of imagined and actual applications to support these assertions. As such, most participants could be considered proponents of the technology, but with varying degrees of (often cautious) optimism. The most promissory and optimistic about synthetic biology's environmental and economic benefits were Org9, Sci7, Sci3, Gov1 and Gov3. All these participants have first-hand experiences of GM controversies, STEM backgrounds and work experience in government and policymaking settings. However, not all participants fitting this description (like Sci5, Sci11 and Gov8) were as promissory. The least promissory participants, and those that could be most clearly described as opponents of synthetic biology's application to food and agriculture were Org4, Org6 and Sci8. These participants all constructed synthetic biology as something unnecessary for food and agriculture. Org6 and Sci8's long-term work with NGOs who, broadly speaking, oppose the technology, likely affirms this view for them. Org4 has experience working on farms with particular focus on regenerative agriculture and may have arrived at this viewpoint because of this experience. Sci8 and Org4 are STEM trained.

Discussions of synthetic biology's promise often focussed on the sector in which it might be applied. Synthetic biology was sometimes positioned as a technological solution to what were viewed as major global problems, like climate challenges. This view often had a sense of idealism or utopianism, with claims wrapped alongside promissory language, as discussed previously, and indications of the expectations and intentions of proponents. Synthetic biology applied in such areas was considered particularly "good" or "useful" in contrast to applications that were perceived more critically as, for example, "flights of fancy" or "completely useless".

Every participant except Gov3 mentioned the impact of humans on the environment, and linked this to current practices in agriculture, food production, food manufacturing, food consumption and food waste. Gov3 did discuss international governance mechanisms like the Convention on Biological Diversity, but only to explain the complexity of layers of policy around synthetic biology. When asked what food policymakers should focus on (if anything), all other participants referred in some way to sustainability of the food system or other environmentally related aspects. A number of participants also expressed views that synthetic biology might be usefully applied in the context of environmental concerns, including, biodiversity-related aspects (Org9, Org5, Sci7, Sci4 and Gov5) around land (mis)use, intensive

agriculture, monocropping, the application of agrichemical inputs and associated impacts on soil health. Gov10, a UK civil servant, pointed towards a range of ways in which synthetic biology might "play an absolutely huge role" in terms of the environmental aspects of food and agriculture:

> Well, I think it will play an absolutely huge role. I think it already does just in terms of the fantastic promise that it shows with regard to- that there are obviously lots of issues linked to food production today, whether that is land use, whether that is water use, whether that is greenhouse gas emissions, whether that is just talk of availability, cost, God knows how many things.
>
> And I think you could take synthetic biology, and you can say, "Well, there is a solution there. You don't need huge agricultural land holdings, when you can grow things in a lab, and you don't need to be as concerned about pests and pesticides, once again, when you can much better control the conditions in which things are grown. (Gov10)

Sci4 in particular also raised the risks of the climate crisis on food and agriculture (including the potential need for crops resistant to weather-related stresses, for example), and particularly impacts on farmers, positioning synthetic biology as a solution to these.

Animal agriculture was also routinely discussed. Org1, Org3, Org4, Org5 and Sci10 in particular wondered whether synthetic biology's potential to offer animal product analogues might contribute to reduced emissions associated with animal agriculture and consumption of animal products. It was also suggested particularly by Org1 and Org5 that this would reduce harm to animals. This suggests that through discussions of environmental implications of farming, participants sought to situate some boundaries such between ethical and unethical activities, and to classify synthetic biology products and processes within these boundaries. I will discuss this in the following chapter.

Discussions about environmental implications of food systems often involved participants making comparisons between imagined synthetic biology-inclusive agriculture and conventional farming practices. Participants used these comparisons to construct a range of boundaries and divides. For example, Sci3, a non-UK academic scientist and advisor to European authorities, portrayed imagined agricultural landscapes involving synthetic biology as more targeted to specific human needs:

> [N]ow we have bacteria that can do things that before could not be done, simply because evolutionarily, there wasn't enough time for the development of any spontaneous capability to do this in. So, we have now bacteria able to degrade highly chlorinated aromatic compounds, for instance, who have other bacteria that can now degrade some types of plastics, not all of them, but some of them. We can also produce plastics that are programmed to be biodegradable because

> they are produced by bacteria themselves. We can replace many chemical processes that have been, that are very, very pollutant and very environmentally unfriendly. We can replace them by same reactions or similar reactions run by bacteria in a more environmentally friendly fashion. (Sci3)

Through the use of the word "programmed", Sci3 suggests that goals like producing biodegradable plastics or bioremediation can achieved with precision by developers. The implication is that this will result in food systems that are less harmful and more biodiverse than large-scale industrial farming involving use of chemicals like pesticides or monocropping.

Participants also viewed human health as another sector to which synthetic biology could be usefully applied. Gov1, Gov6, Gov8, Sci2 and Sci11 in particular mentioned synthetic biology in medical applications like immuno-oncology, vaccine production (often citing the mRNA vaccines for COVID-19, although it is unclear the extent to which the processes used might be labelled 'synthetic biology' by vaccine manufacturers), as well as gene therapy and personalised medicine. For example:

> I think immuno-oncology is another area where I think… When you see the innovation strategy from the government, they will talk about, 'The government is going to produce missions that it is going to focus on,' and I think one of those is going to be immuno-oncology and basically trying to find cures for cancer, and I think synthetic biology is going to be a big part of that. (Gov6, Manager at UK funding body)

This was sometimes coupled with comments that applications in the health sector would be most lucrative. For one non-UK academic scientist, this contrasts with environmental applications, which are "considered in the biotechnological landscape like a very low added value sector […] [often] you do an environmental treatment just to avoid being fined and then objectively the market for this is much lower than the market for other types of biotech" (Sci3).

For Sci6, medical applications were also assumed to be the most acceptable to publics, compared to less desirable food applications, a view informed by this participant's first-hand experiences of GM controversies. This reflects the position of many in early discussions of GMOs, in which medical applications were considered more acceptable than food applications (e.g., Wynne, 2001; Marris, 2001) although similar distinctions have not been as widely discussed in the scant research on attitudes towards synthetic biology. While Sci3 and Sci6, discussed medical applications in opposition to those in food and agriculture in terms of their acceptability and economic benefit, others mentioned possible human health benefits arising from food applications. Org2, Org3, Sci3 and Sci5 discussed using synthetic biology to improve the nutritional content of foods (vitamins, for example) and medicalising foods such as lab-grown meat (for improved digestion, drug delivery etc.).

Supported by perceptions that human health and environmental applications might offer societal benefits, Gov5, Sci11 and Sci8 described examples of applications of synthetic biology or GM that were viewed as "useless" by contrast:

> Can you bring back a mammoth, you know, all that sort of stuff, but the question is why and then where would you put the mammoth? What ecosystem is it going to sit in and poo in or whatever it's going to do? So, yes, they're all, sort of, flights of fancy, really. (Gov5, Manager at UK funding body)

> [T]here has been some really cool stuff. A lot of it is proof of principle, so there's a great deal of 'Oh, let's build a new *E. coli* that can cycle light.' So, you hit the culture with a molecule and it starts flashing on and off, which is really cool and it makes for a good story. It's completely useless, but it's kind of nice. (Sci11, UK academic scientist and government advisor)

> I remember, we had this with the GM, I was phoned up one day by a journalist. And she said, 'I want to ask you about this new GM plant that people have got. And they said it can detect landmines, the leaves turn red in the presence of a landmine.' I said, 'That's great, how do you plant it?' A complete disconnect. (Sci8, Scientific consultant to international NGOs)

In some cases, these participants imply that these "useless" applications themselves are not inherently undesirable but "kind of nice". However, the observation or opinion that they are "useless" or that there is a "disconnect" from the integration of that application into society is revealing of a view that, for some, scientific endeavours ought to have a "useful" application, offer societal benefits, or be shown to do so in order to obtain approval from publics.

This was accompanied by discussion of synthetic biology uses (either existing or potential) that they viewed negatively, or not of societal benefit. For example, Org1, Org3, Org4 with second-hand experience of GM controversies, Org6 (GM conflict experienced) and Org7 (GM controversies observed) mentioned actors and actions motivated primarily by profitmaking or increasing productivity as not benefitting society. Drawing on observations about the impacts of GM work of US multinationals like Monsanto, foodservice industry worker and researcher, Org3, describes how governance of synthetic biology should proceed "without only profit in mind, just to make sure that things remain healthy and sustainable, with more of that thing in mind rather than just making more and more food with no other thoughts" (Org3). Org3 suggests that it would be undesirable for the benefits of the technology to be concentrated in the hands of the recipients of economic gains and profit. This view is perhaps informed by their understandings of vertical integration in the GM industry, perceived as concentrating economic benefit in the hands of companies like Monsanto.

For Org5, a UK academic non-scientist, for example, the suggestion was made that increasing productivity without consideration of soil health is undesirable, has "no point" or "no use":

> So, there's no point in producing a highly productive potato without thinking of the soil because the potato might be very highly productive for a little while but, if your soil keeps degrading, it'll be no use. (Org5)

The implication is perhaps that applications addressing soil degradation, for example, would have a "point" or "use", beyond economic benefits such as productivity.

As well as describing broad sectors in which synthetic biology could be promising, participants drew on existing or imagined synthetic biology objects (like a specific product, plant or animal) to discuss promise. Participants could imagine a vast range of potential products in food and agriculture, as well as in areas of human health and environment, which can broadly be categorised as microbial, plant, animal or 'other' applications. Microbe-derived products mentioned included flavourings and fragrances, production of biosynthetic palm oil, production of milk proteins and bioremediation (e.g., breaking down plastics or agricultural run-offs in the environment). Some of the plant applications discussed were engineering novel traits in crops, like nitrogen fixation in cereals, resistance to diseases or pathogens, tolerance to climate conditions like drought, and herbicide resistance. Participants also mentioned so-called sentinel crops, which, when planted, can help to detect contaminants in soil, for example. Applications in animals included livestock vaccines, cows without horns, and gene drives in species perceived as pests, like mice and mosquitoes. Some of the most common other example products were lab-grown meat and animal product analogues. Applications like medicalised foods (foods engineered to meet specific medical needs or deliver medicines) were also mentioned in passing.

The raising of these imagined synthetic biology objects had the effect of focussing discussions of imagined futures on the potential benefits and limits of the technology, as well as technological specifics, scientific knowledge, risk assessment, public (mis-)understandings of science and perceptions of scientific progress, which will be discussed in the following chapter.

6.4. Constructions of publics

Many participants constructed synthetic biology as potentially controversial based on experiences with past GM controversies, and a judgment that synthetic biology might be treated similarly to GM by publics and other stakeholders. To conceptualise how publics might respond

to synthetic biology as something controversial, participants constructed publics in a range of ways.

Participants typically referred to "the public" or "the general public" in the singular, rather than the plural 'publics' used here. My use of the plural indicates a heterogeneity of publics rather than a single "general public" with an assumed relatively homogenous set of values, views and beliefs. Indeed, participants, despite using the term "the general public" or similar clearly viewed publics as complex and heterogenous, referring to a range of imagined views of groups and individuals within it, and sometimes also conceptualising them through the lens of consumers, as interested or disinterested, and with a range of understandings or misunderstandings of science.

Passive publics

Marris (2015:90) noted the portrayal of a "disembodied public that is conjured up during discussions among scientific and governmental elites […] [and may be] represented as a passive (unmobilised) and malleable entity, easily swayed". The sentiment that publics were passive, 'unmobilised' and malleable was most common across participants primarily working in science and governance. Accompanying this, a number of participants, including some with no first-hand experiences of GM debates, referred to rhetoric that emerged during GM controversies and was viewed as having "swayed" public opinion. This included terms such as 'Frankenstein foods' (Org2, Gov5, Gov6, Gov9 and Gov10), pinpointing this as a catalyst for public opposition to genetically modified foods. This type of language was most often used by those primarily working in governance. Younger individuals working in governance roles may have been influenced by those with first-hand GM experiences in the workplace to highlight these as important terms.

This focus on 'Frankenstein foods' conveys that 'unmobilised' publics were 'mobilised' by such rhetoric in the press, and by NGOs and other groups through the use of this type of language. Participants suggested that if public views can be swayed against GMOs by the media, NGOs and other groups, then they can also be swayed in favour of synthetic biology by scientists, governments, the media, NGOs and other groups. This was a view shared by Sci7 and Sci11, for example, although scientists did not use similar 'Frankenstein' rhetoric as often. Drawing on this assumption, several of these participants appealed to the idea of 'reframing the argument' around GMOs and synthetic biology. This positions passive publics in a kind of tug-of-war between competing 'active' groups and individuals. This competition was viewed to provide opportunities for proponents of synthetic biology to mould public opinion to their ends.

For example, Gov5, a manager at a UK funding body, described how the government ought to take 'public opinion' into account around synthetic biology:

> I think you have to be aware of the political landscape, you know, because we have had decades of the Daily Mail saying, 'Frankenstein foods'. […] from a completely political point of view, there may be other things that the government has to take into consideration, and one of the big things is public opinion. And I think, in the UK, we have been exposed to a lot of rhetoric about GMOs that isn't helpful. (Gov5)

Gov5 suggested that the Daily Mail as well as NGOs (both conceptualised as vocally anti-GMO) were no longer as powerful in shaping public perceptions as they had been during GM controversies. There is little research on representations of synthetic biology and its applications in the media, so it is unclear whether this is the case, although Jin *et al.* (2019) suggest that media coverage of synthetic biology has been relatively positive thus far. Nonetheless, Sci7 explains:

> I sense the public perception doesn't arise from the public; it arises from the people that frame the technology for the public. That used to be largely the NGOs, but it's not to the same extent. The NGOs don't have the megaphone effect of the newspapers anymore. Is it the Daily Mail, is that the one that used to be anti-GM? It was just amplifying all the scare stories that came out. […]
>
> I was in touch with one of the NGOs. Before getting in touch with them I wanted to find out what their thinking was, so I was looking on their website. There was a lot of agonising about the fact they weren't getting their message across the way they used to. It's a bit like the scientists say, 'It's terrible, we can't get our message across. These NGOs have grabbed all the attention and we can't get our message across in competition with theirs.' It was the complete reversal of that. […] I think a lot of the NGOs are feeling under a lot of pressure. Also, I think they're feeling this is an opportunity. It's back in the public eye again and they're feeling if we play our cards carefully, we can get the attention back. We can get people back into a position where they're focusing on the negative side and so on. (Sci7)

Here, Sci7's statement that "the public are not nearly as bothered as they used to be, certainly in the UK" is mirrored across participants. For example, those with first-hand conflict experience perceive publics to be slightly less focussed on genetic science controversies now than then. Other participants who had observed GM controversies or learned about them second-hand also talked about uncertainty about publics and their views and suggested that perhaps publics 'don't care' as much about certain topics relating to GM and synthetic biology, with the passage of time. There was a sense that publics are not currently mobilised, or are passive, unaware of or ambivalent about synthetic biology, and that their attention or interest is for the taking, "if we play our cards carefully" (Sci7). This view was shared by civil servants, for example, who would more typically perceive publics as passive and trusting, but volatile

and whose trust is easy to lose, particularly when made aware of food safety concerns. For many participants, there was a similar sense that publics could be 'easily swayed', or told what to think, for example through PR or marketing by industry. This implies that publics in their passive state can be 'carefully' managed, whether to mobilise them 'for' or 'against' synthetic biology, or indeed to avoid them becoming focussed on the 'negative side'.

Mistaken publics

Integral to some participants' understandings of GM controversies was a sense that publics were mistaken in their opposition to genetic modification, and that they could mistakenly oppose synthetic biology as well. These ideas of mistakenness may be tied to similar assumptions that 'unmobilised' publics (perceived, for example, as "ignorant") were passively vulnerable to "unscientific" "misinformation" from the press or "scaremongering" NGOs.

Participants across groups mentioned and attempted to unpick several common anti-GM arguments in order to portray them as mistaken. For example, in a discussion about the dichotomising of nature and GM, a UK regulatory lawyer, Gov3, described a perceived mistaken view:

> [T]here was an example that was given about challenging the presumption that natural breeding was always good as opposed to GM. It was an example about; I think it was an American crop. It wasn't the tomato. It was some other crop. There was this beautifully bred melon, or whatever the hell it was. Quite naturally bred. It just happened to be poisonous, and they had to take it off the market. Yes, it looked good. It tasted delicious. It was poisonous. But there was no GM. So, the assumption that nature is always benign is obviously a bit naïve. […] Should products be labelled with 'GM' or 'gene edited'? I don't know. The consumer has the right to know. But I just regret that consumers are all so misinformed. (Gov3)

This participant made an unevidenced assumption that all consumers are misinformed, without recognition that even members of the public without scientific training will know that some natural products are poisonous. Publics, by and large, also know, or assume, that there are regulations in place to ensure food safety of both 'natural' and GM or gene edited products. Gov3's implication that this is not the case contrasts with social science work over several decades on attitudes towards food and food safety, particularly in a GM context (e.g., Frewer *et al*. 2011 and 2013).

Such depictions of mistakenness and ignorance were not limited to lay publics, but also regulators as well. Another anti-GM argument that some participants considered to be mistaken relates to risk, or the perceived over-estimation of risk and the resulting treatment of risk in the regulatory system. Sci7, a UK academic scientist, explained:

> If you look at the history of GM crops, they're one of the least risky things we've ever invented. Almost everywhere in the world they're the subject to really fairly draconian regulatory measures considering the amount of risk. We didn't know that at the beginning when we started developing them, so it was quite sensible to do it that way. We don't need to stay stuck in that time warp, we can move on, and we can recognise these technologies are not dangerous. You could do dangerous things with them, but you could very easily use them safely to do useful things. (Sci7)

Sci7's perception that "draconian" regulatory measures were introduced at a time when "[w]e didn't know" whether the technology was safe or not indicates a view that regulators were mistaken at the time, although cautious and their actions justifiable. By contrast, the retention of these measures today, despite Sci7's view that "they're one of the least risky things we've ever invented", and "not dangerous", was viewed negatively as unjustifiable, and being "stuck in that time warp". The presumption here is that because current policy is mistaken about risk, then publics may be influenced by that policy and take on mistaken understandings of risk.

Threatening publics

Many participants discussed how synthetic biology might (or might not) be rejected by publics, as GM was perceived to have been. This idea was used to imagine publics as a threat to synthetic biology. Org9, for example, presents a dichotomy:

> People who don't like genetic modification and don't like genome editing are not going to like synthetic biology. It is a very unfortunate term, it's not very public relations friendly. 'Synthetic', it sounds immediately suspect for those people who are going to be looking for suspicious things. (Org9)

This imaginary of publics as 'for' or 'against' technologies remains consistent with work by Marris spanning two decades (e.g., 2001 and 2015). This was notably connected to an idea that if publics do not trust synthetic biology, its developers and regulators, then they may become a threat to the field through not accepting its products. Gov5, a manager at a UK funding body described how "if we're not careful, is society is going to look at synthetic biology, ally it to genetic modification and stop it dead." (Gov5) Continuing the theme of language of conflict, Gov5 uses the phrase "stop it dead", equating public rejection of synthetic biology to a cessation of scientific activities in the field.

This became linked to an assumption for Org9 and Gov5 that political and policy actors may treat the technology according to publics' views, citing the GM controversy as a precedent. Other participants felt today's "onerous" regulation to be the result of public opposition to GMOs translating into a "political storm", suggesting that public opinions influence

policymakers, resulting in policy regimes considered stifling or threatening to the field's development.

Controversy as a threat

Controversy was conceptualised as a cause of publics shifting from passive towards being mistaken and/or threatening towards synthetic biology's development. For example, some participants mentioned ways in which discussions about synthetic biology could be excessive, overly vocal, or detrimental to acceptance of the synthetic biology. Sometimes this was described as 'noise', a word used denote panic for some, but for others, the arguments that ultimately sway public opinions or policy. In this sense 'noise' might be considered analogous to controversy, as explained by a manager at a UK fresh produce company, Sci9:

> [I]f there's too much noise around one thing, then that's what the rest of the public listens to. […]. If you shout loud enough saying, 'It's a great thing,' then people are going to listen to that. (Sci9)

Sci9 introduces 'noise' as a negative, but then explored how 'noise' can be positive, as if "you shout loud enough" about synthetic biology being "a great thing", the loudest voices might be heard and more likely to get their views across.

For Sci8, a scientific consultant to international NGOs, a similar notion to 'noise' was described as 'hype'. Hype may refer to promises about the technology that reflect intention or expectation but may be overblown and unlikely to be achieved. For example:

> Again, that distrust, and the scientists coming out very much- 'We know everything, here is our great invention. And we are going to save the world.' You know, these overblown claims, that we have heard again and again and again. […] it really adds to that hype. And I think basically, it just- Well, for them, I think it backfires. As soon as some NGO says, 'Well, actually, this is what you said about your last one and that went wrong, this is what you said about your last one and that one went wrong.' (Laughter) So, I'm not sure if they will learn. But I don't think it really helps their case to make overblown claims. (Sci8)

Sci8 later describes some claims about what genetic modification and synthetic biology might achieve as 'myths. The use of language relating to deception, dishonesty or mistruths ('overblown claims', as above, or 'myths') suggests that for Sci8, communication intended to generate hype around synthetic biology's achievements or promise can be understood as an attempt to persuade or mislead publics about what synthetic biology can or might do, which may damage trust. This sits in contrast to perceptions about communication as a precursor to transparency as linked to integrity and trust.

Due to this, some considered high levels of scrutiny to be "sensible" and tied to building public trust, and mitigating the threat posed by public oppositions (e.g., Sci 11, a UK academic scientist and government advisor). Sci11 stated "I think it would be sensible to keep a level of scrutiny at the moment which may be a little bit excessive, purely to build trust in the system", to manage the threat posed by public controversy and a resulting rejection of synthetic biology. As someone who observed the early GM debates first-hand, this is an interesting point of view. While recognising that trust was damaged, Sci11 appears to think that 'excessive' regulation could help in restoring that trust. However, as research over two decades has shown, trust is not based simply on controlling the products of genetic research but depends on answers to questions like 'who benefits?'.

Summary

Through the perception of publics as threatening, there is also an important insinuation that publics are powerful, and particularly influential on policymakers in the wake of GM controversies. This is in contrast to portrayals of passive and mistaken publics described previously, although assumptions that publics are irrational, fickle and "ignorant" persist. Imaginaries of publics as passive, mistaken and threatening continue to influence views on how publics might be interacted with. Many participants implied that through public relations or communication, publics might be managed to achieve certain scenarios on synthetic biology futures. This is indicative of views rooted in deficit-based assumptions that publics lack information, education or awareness, and perhaps also that publics are malleable and may be managed strategically for certain goals. As discussed by Marris (2015) among others, such assumptions drive strategies for engaging with publics by synthetic biology stakeholders, and in policymaking spheres.

6.5. Communication

I have shown that constructions of publics by participants were based on individuals' understandings and experiences of controversies around GM in concert with their constructions of both the field of synthetic biology and of publics. Participants often offered ideas on how publics should be interacted with or treated, with the implication that the nature of this treatment depended on desired outcomes for synthetic biology.

6.5.1. Deficit model

Imaginaries of publics accepting or rejecting synthetic biology also formed an important factor in most of my participants' views of how synthetic biology might or might not integrate into UK society and policy, and the ways in which that would be in the public interest (as opposed to the controversial ways). Participants working in governance, as well as both NGO participants, would often refer to the "public interest", typically with a sense of safeguarding publics as consumers. The roles of publics as voters were also sometimes highlighted through notions of public interest, where participants discussed how synthetic biology's governance might guide the field towards a 'common good'. In addition, Gov9, a UK civil servant, refers to 'an interested public' which may seek knowledge on synthetic biology and come to accept it:

> You can only get knowledge through interest really, trying to find a way of actually getting that idea in there. That's the trick to me […] as I say, we're not here for promoting. But if you're talking about acceptability […] then I think other policymakers have got to be thinking about, what are we doing 5 years, 10 years, 20 years down the line? (Gov9)

This example suggests that Gov9 believes that policymakers "have got to be thinking about" how to engage publics and drive public interest in and awareness of synthetic biology, while treading a fine line of not "promoting" the technology. Gov9 links public interest and knowledge to the potential acceptability of synthetic biology and alludes to this being necessary ("the trick") for policymakers "5 years, 10 years, 20 years down the line". In short, Gov9 suggests that if policymakers want to increase public knowledge of synthetic biology, then it is necessary to generate public interest in the subject, and acceptance of it. This is another example of a deficit model approach to public engagement. Drawing on deficit model assumptions (Marris, 2015), other participants also shared opinions that communication or dialogue with publics would be an avenue not only to "understand" but also perhaps to "get public interest", "promote", "educate", or, in other words, convince the 'public' of the benefits (or otherwise) of genetic technologies, and prevent controversy. The implication is that publics simply do not know enough about (or are not interested in) synthetic biology, and that this lack of knowledge in turn drives 'threatening' types of public opposition or disinterest, particularly when influenced by opponents of the technology.

Many discussed communications with publics with a view to improving understanding of synthetic biology tools and techniques. For example, Org2, a UK academic non-scientist describes how "education is really important for the future of [synthetic biology]", because

publics can be informed about its uses and why it is being developed. Sci3, a non-UK academic scientist, discusses how all "stakeholders" need to be engaged in conversations from "every synthetic biology project," for example from scientists themselves, because this could lead to reduced scepticism about the technology. Similar assumptions were common across several interviews, suggesting that ideas about publics' knowledge deficits underlie motives for communication or engagement with publics. This is consistent with other research in this area (e.g., Marris & Calvert, 2020) highlighting the lack of knowledge transfer from social science to the wider population of scientists and policymakers.

Transparency was also mentioned in name or in implication by most participants and was typically viewed positively as something of interest to publics, but also as something which may support public trust in synthetic biology's development. Transparency, and views about which information and practices should be transparent, often exposed participants' views on integrity, interests and activities that might be understood by publics as 'good' or 'trustworthy'. For some, transparency was tied to the idea that more information about activities in laboratory settings would result in greater understanding of (and the development of "informed" opinions about) the technology. For scientific community participants, this was linked to the communication of the benefits of the technology (which have been explored earlier in this chapter) and of its safety. These participants also felt that this could help to communicate that synthetic biology was different to genetic modification in the sense that it was "more sophisticated" and easier to "control". This may be indicative of language used in models of communicating science and technology which are designed around the assumption that transparency builds trust (e.g., Wilsdon & Willis, 2004). Viewed as a variant of the deficit model, this suggests that a public deficit in knowledge is accompanied by a deficit in transparency among scientists, and that improvement in transparency will lead to greater understanding and trust.

For the two participants from NGOs, the idea of transparency or the provision of more publicly available, detailed and accurate information was linked to comments around "informed consent" and "informed" discussion of the technology's desirability or otherwise. This is a version of the deficit model, suggesting that publics are deficient in information about developing technologies. However, often this was not about "understanding the science" from the perspective of its proponents, but rather about presenting this alongside opposing views (often also framed as 'scientific'). Both NGO participants routinely suggested that "transparency" would enable publics to assess the limitations of claims about aspects such as benefits, risk and safety, and to consider the technology's potential implications, typically its

potential harms. They also suggested that transparency would expose (implicitly hidden) perceived negative motivations of scientists or industry actors, such as marketing and lobbying in pursuit of profitmaking, rather than activities perceived as for public benefit. For example, marketing or lobbying activities masked such motivations, and were sometimes viewed negatively as not in the public interest. Org8, an agricultural economist at an international policy development organisation mentions registers for lobbyists as an avenue through which to promote transparency.

It is interesting, though, that transparency was not considered desirable in some contexts, because of a perceived risk of inviting further GM controversy. When discussing lab-grown meat, one UK academic scientist, Sci10, said that "[i]t would be ruinous" for developers to use GM cell lines, or to advertise their products as GM, although this would likely facilitate scaling up. There is a suggestion here that transparency about the technology might be "ruinous" and result in "people […] going crazy", meaning its developers' ambitions are not realised. This, in turn, positions publics and their misunderstandings of science as a roadblock to synthetic biology achieving its proponents' ambitions. Such an imaginary of publics is another example of how GM Trauma influences the way that scientists think about their synthetic biology work, and how their actions can be understood through this lens.

Some participants from industry (e.g., Sci6 and Sci9), but also from policymaking (Gov9 and Gov10) and research (Org8) talked about communication from a position of conceptualising publics as consumers. Gov9 and Gov10, working in government, tended more often to use the terms "public interest" and "consumer interest" interchangeably, and to focus the safety of food when consumed. Participants from industry (Sci6, Sci9) sometimes viewed publics as consumers to be sold something, mentioning the importance of marketing as communication, or telling publics stories about how food is produced, or where food comes from.

Furthermore, Sci4 also used the word "storytelling" to describe how benefits of GM technologies might be communicated by scientists to their intended consumers (in this case, smallholder farmers). Sci4 states "I don't think the positive impact stories get out into the public domain, even though there are people collecting the evidence about that […] maybe we're just bad at storytelling as scientists." (Sci4) The assumption here, informed by GM Trauma, might be that with better communication, publics can be persuaded of these benefits and would view the technology positively, avoiding the negativity associated with GM controversies.

6.5.2. Dialogue

Other participants focussed more on what might be considered 'dialogue', rather than more unidirectional attempts to persuade, educate or provide transparent information to others. Many suggested that dialogue, for example between publics and policymakers, social researchers, NGOs or the scientific community, might instead simply achieve greater understanding of a range of views about technologies, positive, negative or ambivalent. A UK civil servant involved in research called this "learning mode and listening mode" (Gov7), drawing on GM controversy experiences to highlight their uncertainty about public perceptions of synthetic biology, and therefore its potential status as politically risky. These listening and learning activities were not typically viewed as neutral. It was often implied that understandings could be deployed to guide or legitimise activities like designing policy approaches or the development of applications.

Gov10 and Sci4 described how dialogue between the scientific community, their funders and civil servants about research developments would facilitate certain approaches to policymaking. Gov10, a UK civil servant describes:

> It [policy] needs, as best as possible, to stay ahead of the curve. That's tricky, because of course, you have some really huge players who are investing heavily, industry players who are investing heavily in synthetic biology. And sometimes as government, you don't receive all the data you want to receive it as quickly as you want to receive it. (Gov10)

UK scientist Sci4 described how staying "ahead of the curve" or keeping abreast of developments in scientific research and industry investment would achieve policymaking processes that are a "little bit more agile for new technologies and more responsive" (Sci4). This scientist goes on to say that "it feels like [policymakers] are completely totally detached from what's being funded in science. It feels like something happens and then they go, 'Wow, we've never heard of this new thing. How are we going to regulate it?'" (Sci4).

Gov2, a manager at a UK funding body, described activities like "community consultation" to decide strategies underlying funding allocations. Gov10 discussed civil servant-led workshops to gain "insights" for government, and Org8 described similar activities as useful for policy researchers. As mentioned, some participants suggested this may enable policymakers and the scientific community to define and act according to perceived "public interest." Such findings may thus be useful to the scientific community and industry to identify opportunities for activities that could have popular appeal. In one example, Sci4 described how this might present a different direction of information to current situations in plant breeding:

> I think it'd also be nice if farmers would actually tell us exactly what traits that they wanted, because I don't think that the traits that scientists are engineering are necessarily what farmers actually want, because there's not very much dialogue that goes from consumer to farmer to scientist. It all goes in the other direction, which may be why when people get the products, they're like, 'We don't want this. Why did you make this?' […] Our conversations may not go in the right direction, I suppose. (Sci4)

As mentioned, synthetic biology was routinely framed as something about which to communicate with publics in a more unidirectional manner, educating publics or promoting greater understanding of the technology. Vagueness about dialogue, coupled with characterisations of publics as ill-informed, mistaken, malleable and volatile, likely also belies deficit model-type assumptions about the treatment of publics in dialogue around emerging scientific developments. In short, while dialogue with publics was viewed positively by most participants, this was tempered by a desire to instrumentalise discussion as a way of guiding the emerging field of synthetic biology towards a range of imagined futures, traced against a backdrop of GM Trauma.

6.5.3. Public debates and consultations

Another communication type focussed on communications between a range of stakeholders, often including public debates. Participants sometimes referred to public debate in vague terms as something ongoing and obvious. For example, Sci11 discussed "the big debate about genetic modification versus genome engineering with CRISPR and so on" and Gov10 mentioned that "[synthetic biology] brings an entirely new angle to the meat or vegetarian debate." These debates, presumed to be active, were not often specific to synthetic biology. That said, there was a sense from some (e.g., Org6, Org9, Sci1, Gov5 and Gov7) that debate (described vaguely) might be a useful path towards understanding views on synthetic biology.

Past debates on GMOs were discussed, with a focus on who contributed to them. For example, discussing early committees about GM governance, Gov8 described the involvement of:

> [A] nutritionist, a paediatric nutritionist, a vegetable nutritionist and food manufacturers and various people that could contribute to the debate, but there were no social policy people and there were no general members of the public. And I just thought that it was really, really important to bring in an independent view, so to get a lay member on the committee. Someone that was completely not scientifically trained, was bright and that could pick up the debate but could give us an insight into how people might think. (Gov8)

It is open to question whether one 'lay member' would be able to offer insights into "how people might think", but this nonetheless indicates some acknowledgement of views outside the specialists'. However, more generally, there was scant discussion of the forms that public debates on synthetic biology could or should take, on which specific topics and who might be involved.

Public consultations in policy contexts (for example, the DEFRA consultation on gene editing, discussed in Chapter One) were mentioned by several participants, but often accompanied by comments about them serving to 'rubber stamp' policy decisions rather than shape them. Sci7 felt that DEFRA's gene editing consultation was not designed for public participation, despite being presented as such:

> DEFRA's report was criticised quite a lot for not being a consultation that was public friendly. It was definitely a consultation for experts, and it was a consultation about how we should regulate these crops. I can't imagine how they could do that with a questionnaire that would get expert answers of the kind we were looking for and would still also be something the general public could openly participate in. (Sci7)

Gov6 felt similarly, talking about what "government wants" somewhat in contrast to "public opinion", which was not genuinely being sought by the public consultation, but is rather something that they are "trying to change":

> If the government wants to do this, then they will have to do a lot of work in the media on trying to change opinions, I think. And I think this is possibly why DEFRA led that consultation as they did. (Gov6)

Elsewhere, Gov7, a UK civil servant described an environment of political drivers shaping the consultation process, like "political will", aversion to controversy, and adherence to manifestos. This presents consultations as more of an exercise to assess public opinions in order to understand how politically risky a course of action might be, rather than to shape a policy approach from the outset:

> [I]f they were changing the regulations to allow a novel food created by synthetic biology, there would almost definitely be a public consultation. It just would because it's a major change. There will be significant political risks involved, and ministers will want to know what they're getting into. I think some things are in political manifestos, so, certainly in our adversarial system, if a party wins power, then their manifesto will be – should be – implemented. (Laughter) […] in normal, previous times, you pretty much, 'Here's the manifesto. We said we're going to do it. We'll put it in primary legislation. We'll consult on it, but we're going to do it, whatever you say in the consultation. We might change how we do it, but we're probably going to do it, because that was our manifesto and we got elected on it.' (Gov7)

In this example, consultation is presented almost as a box-ticking exercise, or a way of legitimising regulatory decisions that may have been taken externally to consultation processes, and sometimes influenced by the interests of scientific communities or others. When rounding up an interview with a manager at a UK funding body, for example, the following interaction took place:

> **Natalie:** Is there anything important that we haven't covered?
>
> **Gov5:** No, I don't think so. Just from my perspective, we are… I mean, this is at a very early… synthetic biology, from my perspective, the environment perspective and from a food perspective, it is at a very early stage of use, but it is at a critical stage now. It's something we need to consider as a society, what we want it to do, what we want it to achieve and how we want to do it. I think, yes, that's what we need to be aware of. Good stuff.
>
> **Natalie:** Yes. How do we make these decisions?
>
> **Gov5:** Conversation, again. I think it's not about the research scientists, it's not about the businesses, it's not even about government, it's about society, whether society wants it, whether society understands and accepts what needs to be done. Synthetic biology has a great offer in the food space.

The phrase "understands and accepts what needs to be done" indicates a view that the direction of travel "needs to be" towards the entry of synthetic biology into the UK food space, where it "has a great offer", regardless of what the outcome of public debates may be. This view was shared widely among participants from policymaking circles, funders, industry and the scientific community, all of whom possess significant levels of power and influence over such a scenario. Therefore, any influence that public debates may have on policymaking will also coexist and compete with other influences. For example, the power and norms inherent to scientific influence in UK policymaking are also described by Sci5, a UK scientist:

> I think the people responsible for making these decisions, they do really listen to the scientists and listen to… Yes, and also just listen to the farmers and to what the problems are of the industry, and just… Yes, but, hopefully, take the scientific evidence and base, which is obviously what we like to see, base everything on the evidence from the science. (Sci5)

Some participants questioned this. One UK civil servant suggested that policymakers need more discussions with "innovators from a position of good knowledge and a position of strength […] rather than relying on our scientific committees to be the bastions of all knowledge on the subject" (Gov10).

Inherent to these views, there appears to be an assumption for some that synthetic biology simply *will* progress, guided by roadmaps, unless "stopped", "hindered" or "stifled" by publics and/or policy, as GM was presumed to have been. Sci11, for example, shared that:

> So, what I'm saying is, from a regulatory point of view, ACRE's view is there's no reason to treat genome engineering any differently from conventional crossing, except to be aware that it's still a process that's relatively new. And so, as part of that process, you want to keep an eye on the field and see if someone reports something unexpected somewhere, see if modifications come in that make it more precise, which is actually happening all the time. So, it's not like it's a closed book. It's a process whereby you keep on looking at the regulation and how you're doing it. You do *keep your finger on the pulse of techniques as they develop*, so you make sure you're using the best available methods for the best available outputs. And I think *as long as your regulatory system allows that to happen, it's good*. I think it's fit for purpose. (Sci11, UK academic scientist and government advisor – emphasis added)

While such a view of scientific progress as inherently good ("right") was apparent in some interviews, several participants raised questions about developments in synthetic biology like: "why are we doing this?" (Sci4, Gov1), "why is this suddenly a problem?" (Sci8) and "what are the sorts of entities that we will be creating?" (Org5). In such a context, communication may be viewed as an instrument for shaping how scientific progress might look, or to identify avenues down which to channel scientific progress, thus ensuring scientific progress itself. If these are the drivers of communications strategies like public engagement or stakeholder consultation, (i.e., if communication is intended to persuade, or to protect technoscientific development from threatening publics, legitimise activities furthering scientific progress) it perhaps leaves little room for debate and appreciation of alternative views, particularly of opponents of the technology.

6.6. Summary

In this chapter, I characterised synthetic biology as a field with unsettled boundaries. There was a sense from participants that the terms 'synthetic biology' and 'engineering biology' can be both difficult to define and may represent different conceptual spaces and different goals for different people. For many, both synthetic biology and engineering biology were understood as umbrella terms for a wide range of research and practice and may encompass aspects of genetic modification and gene editing.

I presented participant views on synthetic biology as novel (or not), growing and expanding, as well as the challenges that synthetic biology's novelty might present for the existing comparator approach. Although novelty was sometimes viewed as potentially "interesting" or exciting, a theme of risk often accompanied discussions of synthetic biology's commercialisation, notably that practitioners might do something unexpected or new that either escapes scrutiny or cannot be assessed through current regulatory

processes. I went on to explore the idea of synthetic biology's promise, a notion discussed by, for example, Meyer and Molyneux-Hodgson (2016). The literature emphasises that actors in a given field may use promissory language or discuss imagined futures in order to gain funding or to generate expectations about the future which are then more likely to come to fruition through said funding.

I also expanded upon the ways in which publics were constructed as passive, mistaken, threatening and ascribed interests and power, rooted in GM Trauma. Some participants also suggested that controversy and opposing opinions might threaten synthetic biology's progress. This was based in experiences and perceptions of GM controversies, with past debates viewed as uncollaborative, unproductive, noisy and chaotic. Further, there was some indication that ambitions exist that through communication, public opinion could be moulded into something non-conflictual with scientific progress. This suggests a view that publics must be treated and communicated with, or to, in strategic ways.

The following chapter focusses on imagined synthetic biology futures, beginning with an overview of the socio-political context, governance and funding.

Chapter 7: Imagining synthetic biology in food and agriculture

7.1. Introduction

In the previous chapters, perceptions of GM pasts were discussed in relation to synthetic biology, something I term 'GM Trauma'. Drawing on GM Trauma, this chapter focusses on further aspects of synthetic biology that participants construed as having implications for UK food policy, and some aspects that I have determined to be potentially of note for policymaking. The first of these, Section 7.2 *Context*, considers participant perspectives on relevant socio-political contexts, such as views about Brexit and the COVID-19 pandemic. I also explore practical considerations like funding, both public and private investment, and the types of funding priorities that participants imagine.

Furthermore, I draw together participant notions of risks and conceptualisations of synthetic biology as variously risky or not, or perhaps, 'at risk'. Participants tended to discuss risk and ethics in conjunction, and this chapter also explores views on the ethical implications of fundamental science, distribution of benefits, power, inequalities and speciesism. The SSK concept of Finitism is a particularly useful lens through which to interpret some of these findings. For example, this chapter explores how participants discussed the ways in which they would assess synthetic biology products' risks and ethical implications in relation to those associated with other products and technologies. I also present findings about the formal spaces and processes in which these classificatory decisions are, and might in future be, carried out. This includes discussions of product-focussed governance and case-by-case risk assessments. Finally, I discuss how the concepts of the natural and synthetic biology are situated, and conversely unnaturalness, is explored.

7.2. Context

Important to any discussion of how participants constructed synthetic biology and its governance is the consideration of contextual socio-political factors (Barnes *et al.*, 1996). In interviews, participants often mentioned Brexit (the UK's exit from the European Union) as well as the COVID-19 pandemic.

For a number of participants involved in governance or policy research work (and indeed as exemplified by certain government outputs) Brexit was presented as an opportunity to change policy approaches and take a "different trajectory" to the EU. For example, an advisor at a European policy thinktank, Org9, refers to a report published in September 2021 by the

UK's Department for Business, Energy & Industrial Strategy called "the Regulatory Horizons Council report on genetic technologies," which discusses the governance of genetic technologies post-Brexit. As much of EU law had been broadly retained in the UK post-Brexit, Org9 believes that the aforementioned report "is trying to figure out if we want to go in a different direction on genetic technologies," considering how best to "promote UK-based innovation." Based in their experiences first-hand of GM controversies, Org9 expressed that the existing GM-relevant policy regime is too restrictive on GMO development (see the following section) and that such an approach is exclusionary to smaller companies due to cost. This, for Org9, has contributed towards opportunities for smaller companies to develop GM being 'lost'.

This not to say that Org9, or others, described themselves as in favour of Brexit, per se, despite such language of promoting innovation. Views on Brexit varied. Sci11, a UK academic scientist and government advisor, alluded to some conflicting opinions about Brexit, its controversiality, and its potential to be perceived positively in some contexts but perhaps not in others:

> [T]he UK government would love to have something at which we can say we're really leading the world, and they'd love to have something at which they could say, 'We're leading the world in a way we couldn't have done while we were members of the EU.' And actually, it pains me to say it, it really does pain me to say it, but in this case, they could be right – that it could have been that being in the EU would have been a little bit too restrictive. But we'll have to see how that pans out. I don't know a single plant biologist – and I know several – who were remotely in favour of Brexit, but they all have the same sort of feeling. They wish it hadn't happened, they think it's, generally speaking, very bad, but it might just be good for their research (Laughter). (Sci11)

This sentiment may derive from Sci11's perception of GM controversies as having resulted in barriers to the commercialisation of GM, and later synthetic biology, products.

By contrast, for Org3, a foodservice industry worker and researcher, the potential for the UK to take different regulatory approaches to the EU post-Brexit presents a step into the unknown. Org3 mentions: "The EU obviously does a lot of governing on food standards and agriculture and that kind of thing. Really hoping that the UK continues to do that kind of thing on its own. […] I think they'll go backwards a little bit, but generally, people seem to want things to stay at a higher quality of food and everything" (Org3). This participant later clarifies that Brexit signifies "leaving a whole body of legislation and I don't know what kind of backup or supporting regulation the UK has or whether they have to write something new". For Org3, this "sounds like it's going to be a fiasco in many ways. Whether food will be a priority, I don't

know". Org3 feels that developers of GMOs like Monsanto have negatively impacted farmers abroad and is likely concerned about similar circumstances occurring in the UK should GM become more widely applied in UK agriculture.

Adding to a sense of post-Brexit uncertainty were participant views on devolved governance across the UK. Some participants discussed potential barriers to internal and international trade, potentially isolating England from the rest of the UK, or isolating the UK from international trading partners like the EU. For example, a UK regulatory lawyer and government advisor, referring to Brexit as a "crisis", described "looming Brexit talk about having barriers" between Great Britain and Northern Ireland (Gov3). This participant went on to concede that "[Brexit] looks ideologically good. It plays to the gallery of people in, 'Jolly good. Getting back control.' But in terms of actually meeting the requirements for trade, it's just bloody hopeless because it's just England. It's just little England" (Gov3). When pushed on the subject of devolved governance and the early impacts of the Northern Ireland protocol on policy differences across the UK, they added:

> I think it will be a bloody nightmare. […] We have this incredible explosion of red tape. Just incredible. […] rephrasing everything so that everything's difficult to understand […] correcting amendments, and amendments of amendments. […] I think that if we have this regime, and this would happen because you'd find that if we do have a new EU regulation on GM products, or GEO [gene-edited organism] products, well Northern Ireland will be following those rules, I think. Unless there's some change. Scotland, well, they can do what they want. I can't remember the position of Wales. I think Wales is also a bit autonomous. I think it's part of its remit. So, you have this ludicrous patchwork. (Gov3)

For this participant, among others, the governance arrangements within the UK add to the international trade dilemma of Brexit, as regulation cannot be changed without impacting the ability to trade with the EU. Nonetheless, Gov3 perceives that GM regulations are the result of policymakers overestimating risks, due to being influenced by GM opponents' 'unscientific' arguments during controversies. This participant is broadly in favour of policy change but concedes that the context may be challenging.

Elsewhere, the combined effect of the COVID-19 pandemic and Brexit was viewed as an opportunity for synthetic biology. A UK civil servant involved in research (Gov7) mentions that the lack of time and energy for many to devote to conversations about synthetic biology might limit the likelihood that opponents will "campaign about stuff or get worried about stuff." This participant mentions that they "haven't seen much comment. Just, in a way, it's an ideal time to be doing these things, because I don't think people have as much bandwidth to campaign about stuff or get worried about stuff, because there's so much else to worry about" (Gov7).

This participant mentions that this may mean that controversies, the likes of which occurred over GMOs, would be less likely to reoccur in the present socio-political context because of these competing priority issues. Indeed, at the time of my research, the war in Ukraine, as well as political instability and leadership changes in Westminster, had not yet happened, but for some participants there was already this sense of there being "so much else to worry about."

Gov7, and others, also perceived the co-occurrence of Brexit and the COVID-19 pandemic as a challenge for political and policy agenda-setting as well as policy processes. One of these perceived challenges was civil servants' capacity for work within government. Gov3 mentioned "god knows what will really happen […] because we're in the middle of a pandemic, so things are knocked around a bit", echoed by Gov7, who described:

> It is just mad at the moment. Part of the problem is COVID. Part of the problem is Brexit. With Brexit in my area, essentially, the rulebook on the environment, in terms of legislation, is having to be rewritten. It's constantly shifting, and there is so much change going on, keeping track of everything is nigh on impossible. I'm just rushed off my feet, working at the moment. (Laughter) Then, on top of that, you have net zero, and Cop26, and all the changes going on around that, so it's just the level of change is like nothing I've experienced before. It is just nuts […] civil servants are equally overloaded […]
>
> [T]he attention span of your average parliamentarian [is about a one-page briefing] because they're all really busy people. (Laughter) So, ideally, they'd rather be told things as they're going to a meeting, orally, I think, rather than having to read anything. (Gov7)

For this participant, this meant that synthetic biology was unlikely to be on parliamentarians' radar.

Setting synthetic biology in a broader food policy context, for Gov7 and Gov4, there was a perception that the pandemic (or a combination of Brexit and the pandemic) also shone a light on other competing aspects of food and agriculture that might merit policymakers' attention. Gov7 discussed restaurants and cafés being closed, and the impact of this supply chain disruption on farmers, who often received better prices from hospitality venues than supermarkets, and on logistics of increased demand in retail settings. This civil servant also mentioned logistical challenges relating to Brexit, food insecurity and the National Food Strategy (now unlikely to be operationalised, as the Conservative party increasingly favours a trend towards deregulation). Similarly, when talking about what food systems should look like, another UK civil servant (Gov4) described a desire for food systems to be "more resilient" after the COVID-19 pandemic, stating that "there are a lot of areas of the food system where if it has a shock and you lose your supply chains it has quite a big impact." Although this had not yet happened during my fieldwork, we also today see the impact of conflict on UK food supply

chains, global food security and food poverty, including substantial increases in the cost of food to UK consumers. These examples were used to reflect how synthetic biology is just one of many policy questions for food policymakers to address.

I also asked participants about whether the contexts of Brexit and the COVID-19 pandemic (or "the COVID/Brexit era", to borrow a term from Gov7) may affect the political will to focus on synthetic biology-related food policy. Often participants would refer to indications made in speeches by politicians, like Boris Johnson's first speech as Prime Minister (2019a)[20], or government strategy documents that mention the field. For example:

> It's always hard to gauge what's going on behind government doors and who, you know, the ultimate holders of purse strings deciding how much money comes into the science budget and then how much of that science budget is then allocated to specific science areas. I would say that it's hard to know exactly what the [political] will is, but there's a recent publication […] 'The Innovation Strategy' [which] name-checks engineering biology as one of the seven – I think they refer to them as 'transformative technologies' – that the UK could benefit from. As far as I can tell, it doesn't refer to there being any dedicated investment associated with that, but I think it indicates a will and a recognition from government that engineering biology has a part to play in science and potential transformation of sectors, through technology in the future. **(**Gov2, Manager at UK funding body)

Like Gov2 above, Gov3 describes GM regulation as a "hot political issue" discussed by former PM Boris Johnson as a "great opportunity for the UK." However, one of the perceived barriers to garnering political will to further the development of synthetic biology was "political capital" or "political risks." This is described by one civil servant and informed by GM Trauma as this participant refers to avoiding controversies of the type relating to GM: "There will be significant political risks involved, and ministers will want to know what they're getting into" (Gov7). This exemplifies again the tendency to problematise synthetic biology and its potential applications as risky, in this sense, politically.

Despite this, some viewed the pandemic as an opportunity for improving public perception of genetics and raising awareness. This is described by Gov9, a UK civil servant,

[20] Boris Johnson's first speech as Prime Minister, made on 24th July 2019 and mentioned by Gov3, a UK regulatory lawyer, included the following statement: "let's start now to liberate the UK's extraordinary bioscience sector from anti genetic modification rules and let's develop the blight-resistant crops that will feed the world," (Johnson, 2019a) This is indicative of promissory language and 'saviour' rhetoric discussed by e.g., Marris (2013). The phrase was used to explain how Brexit could be an opportunity for the UK as legislators could take governance, like "anti genetic modification rules", in new directions that may differ from those in the EU. It sits in interesting contrast to another speech made by Johnson to the UN in New York two months later in which the Prime Minister asked: "What will synthetic biology stand for - restoring our livers and our eyes with miracle regeneration of the tissues, like some fantastic hangover cure? Or will it bring terrifying limbless chickens to our tables?" (Johnson, 2019b).

who explained that "[g]enetics seems to be the flavour of the day at the moment on the news, obviously because of the COVID variants, etc. I don't think genetics have been discussed so much on the telly ever, so it's obviously in the public's interest, and that can only be a positive." Similarly, one advisor to the UK government mentions "an evolution […] in the medical area, we're already saying, 'Wow, we've won, we've got the vaccines. We've shown how synthetic biology can develop mRNA vaccines and isn't that fantastic?'" (Gov1). This participant later describes this as a "silver lining of the COVID crisis […] a recognition of science, the need for cutting edge science to deal with massive global challenges and how synthetic biology has played a major role in developing these vaccines". The term 'synthetic biology' has not been widely linked with mRNA COVID-19 vaccine development, although the tools and techniques relating to the production of this type of vaccine (i.e., not protein-based or attenuated pathogen vaccines) have previously been described as being enhanced or developed through synthetic biology research (e.g., Andries *et al*., 2015[21]). Informed by first-hand observations of GM controversies, Gov1 and Gov9 appear to hope that others might situate synthetic biology applications in food and agriculture as similar to COVID-19 PCR testing and mRNA COVID-19 vaccines ("positive", "fantastic"), rather than to GMOs (presumably 'bad'). This does not reflect several decades of social science research which suggests that agricultural and medical applications tend to be treated differently by publics (see e.g., Marris, 2001).

For Gov1, this may lead to other opportunities for the field: "if you can do that for that [COVID-19 vaccine development], what about all these other sustainability and net zero challenges and bio manufacturing?" Furthermore, one manager at a UK funding body (Gov6) described the potential that government actors might "reframe the argument" on synthetic biology because of the pandemic. For Gov6, "we have had decades of the Daily Mail saying, 'Frankenstein foods.' So, these new genomic techniques that are very specific, it would give the government an opportunity to reframe the argument. […] one of the great things is that people have all heard of RNA vaccines now, which is great because I think it probably gives people a way into discussing it." Gov6's argument to be reframed refers to perceived negative responses to GMOs ("Frankenstein foods"), an example of how GM Trauma influences participant discourse on how synthetic biology might be treated similarly to GM by publics.

In summary, participants with a range of experiences of GM controversies positioned the future potential of synthetic biology-related policymaking within a context of changing

[21] Andries *et al*. (2015) place particular emphasis on the value of synthetic biology's purported "unprecedented precision, predictability and sophistication".

political priorities that have resulted from Brexit and the impact of the COVID-19 pandemic. Some expressed rather cynical views about this socio-political environment as a challenge for agenda-setting, limiting the bandwidth for politicians and policymakers to engage with synthetic biology and for publics to take notice of it. Others were more optimistic about opportunities to promote UK innovation and COVID-19 vaccines shifting public perceptions of synthetic biology. With this in mind, the following section explores participants' views on current governance.

7.3. Perspectives on current governance

Current governance in relevant to synthetic biology in food and agriculture sits across several policy domains. This includes food and agriculture, science and technology, health, economic policy, also education, as well as international trade. Each of these areas involves, produces, shapes and implements laws, regulation and policy (guidelines, strategies, advice etc.).

Current UK regulatory frameworks were generally viewed by participants as "probably strong enough" and wide enough in scope to manage the environmental and human health risks posed by the types of developments that they could imagine being produced in the near future. For most participants, governance's primary role was viewed as mitigating or managing risks to the environment and human health, although the latter was narrowly understood as relating to food safety. However, despite this, current governance was not viewed favourably. For Sci9, a manager at a UK fresh produce company, strict controls were perceived to signal concern, giving rise to questions from publics like "Why are they controlling it that closely? Is there something wrong?"

Current governance was also viewed as slow, reactive, fragmented, overcomplicated, time consuming and difficult to navigate, but with an abundance of guidance and advice. For Sci11, this was attached to a sense that commercialisation might be difficult under current governance, "because you're interpreting a regulation that was written before the technology existed". Using language of threat, for Sci11, a UK academic scientist and government advisor, the "danger" with current governance is that "the legislative process trails behind the scientific progress by about a decade." Sci11 added that "you're stuck with sets of regulations, unless you're very, very careful, which can […] prevent a lot of useful work from being done or from being commercialised." This is attached to Sci11's view that GM controversies resulted in restrictive regulations that "prevent a lot of useful work from being done".

Gov4, a UK civil servant, summarised some of the regulatory framework and guidance which might be "complicated" for those seeking to commercialise an application:

> I think it is complicated. I think it's quite complicated because if you have a synthetic biology product that will fall under a GM regulation, you have the regulation for environmental release. Underneath that, you've got the regulation for food and feed. And then underneath that, you've got an awful lot of guidance. […] if you're not aware early on in the process that your product will have to go through quite significant regulation, you miss out on the chance to get a lot of that data at an early stage. […] [But] there are definitely gaps because the guidance is updated as the products come along, rather than the guidance is already sat there waiting for the products to come along. I think it's quite complicated to know where your product fits and exactly what you need to do to get your product regulated. (Gov4, UK civil servant)

In this example, Gov4 builds a picture of complex, reactive processes, though later they noted that guidance was generally "very good, it's just there's a lot of it". Gov4 exposes something of a paradox, placing an emphasis on the importance of applicants collecting "data at an early stage," despite the reactivity of the process, that "the guidance is updated as the products come along". This reactivity (or a lack of adequately specific guidance for certain products) means that applicants might not know which data to collect, how much of it to present at application stage or how to present it. This likely derives from Gov4's construction of synthetic biology as something similar to GM but capable of novelty, meaning that there is potential for novel "products to come along".

Discussing how applicants might navigate a system with these inherent uncertainties, or lack of specificity, Sci6, a manager at a UK industrial biotechnology company, described looking through past approvals for guidance on how to prove safety in their own applications:

> Whenever I've got close to regulations and looking at that, you realise how big a lot of the regulations are. So going into it naively you think, 'Okay, it's going to be pretty clear what the regulations are.' Then when you look at it you think okay, actually what they want is for you to prove that something is safe. So, then it's how do you do that, how one person does that and how another person does that is quite different. You're trying to look at what other people have done and say, 'Okay, if they did that and that was approved then that must be sufficient, so that must be what we've got to,' but it doesn't seem to be a very clear process to me. (Sci6, Manager at UK industrial biotechnology company)

The referencing of past approvals that Sci6 describes can be understood through the lens of Finitism as involving establishing a prior application as an example of what regulators classify as 'safe' or 'sufficient' in order to build a new application which demonstrates safety in a similar way. This is problematic, as products and processes are likely to vary significantly, and may be indicative of patterns of assessment and approval becoming 'locked-in', or self-referential. One

applicant might have chosen parameters to demonstrate their product's safety that might be inadequate for another applicant. Although sufficient to obtain approval, an applicant's primary aim, one application could lack content or detail that might be useful or question-generating for the scientific advisory committee. Indeed, generating potentially challenging questions from a committee about a product is not often in the interest of the applicant seeking a process of approval and, later, commercialisation that is as smooth, rapid, and cost-effective as possible.

The matter of the costs for businesses around regulation is alluded to by UK scientist, Sci4, who expressed a view that "the only people that can actually afford to start investing in a crop are those big companies." For Sci4, "the current regulatory process excludes anyone except huge companies with enormous pockets from bringing everything to market […] it's a self-fulfilling system." Reaching for an alternative to this system of governance, perceived as prohibitive to small companies and possible to change in the Brexit context, an advisor at a European policy thinktank (Org9) described approaches taken in Argentina. The Argentinian approach to relevant genetic science governance involves no mandatory labelling of end products and aims towards product approval in 24 months. This process involves case-by-case product assessments with regulations not applied to many applications of 'gene editing', determined as distinct from GM. For Org9, that would be a preferable governance approach "not just because it looks nice and even a little bit logical, which is not always the case in these things, but they have had sufficient experience now." Presenting GMOs as too strictly controlled in the UK, Org9 describes:

> [I]t basically takes this route, 'If something can be achieved, something could have arisen in nature, or something could have been developed through traditional plant breeding, if something doesn't have extraneous DNA,' all those kinds of things, 'then we're going to treat this differently from GMOs and treat it in a lighter way.' […] they have figures and data which will show that in terms of genome editing, it's much more local companies. It's small and medium-sized enterprises. It's not the big multinationals […]it shows exactly what kind of regulatory structure you have will decide what comes out at the other end. [..] I think in Europe, a lot of people are going to have difficulties with accepting these types of technologies and other innovations if they think this is only going to benefit big agriculture, industrial agriculture, multinationals, and that type of thing. (Org9)

On the subject of genome editing, Org9 felt it was positive that UK policy in this area was changing to "treat it in a lighter way" than GM. This drive towards "lighter", looser restrictions, or more scope for self-regulation by synthetic biology researchers, was considered to have been regulators' political stance prior to the consultation on gene editing, and an approach that would be favourable in facilitating scientific progress. One UK academic scientist and government advisor describes the consultation, stating that "DEFRA, who are the main people in charge of

the regulation, would like to see change. They're in favour of change. Hopefully, it will happen" (Sci7). Sci7 hopes that this will address some of the overestimations of risks that they perceive as overhanging from GM controversies. For Sci7, this might represent a shift towards more nuanced assessments of a product's risks, for which they advocate.

The participants involved in governance, and scientific advisors to government Sci5, Sci7 and Sci11, were in favour of product-based approaches to governance. This was viewed positively by Gov9 who felt that "[the approach suggested in DEFRA's gene editing consultation] seems logical based on the science" (Gov9). Gov9 feels that synthetic biology and GM are both potentially beneficial and likely safe, and that existing governance approaches originate in 'mistaken' objections towards GMOs originating in GM controversies, rather than based in scientific evidence of risk. This participant added that gene editing (GE) is "sufficiently different than GM to warrant a separate approach" because:

> There is no way that you could conceive to prosecute somebody if they put a GE product out [and] you couldn't tell [that] it is, because the gene sequencing, etc., wouldn't help, because it could be a spontaneous mutation. There would be no way of proving it other than going into the labs and proving it was done deliberately. From a practical point of view, it's a nonsense. From a scientific point of view, the risks are disproportionately low to what the regulatory process is from our perspective. We believe that if the definition goes as it's likely to in the changes, then it's likely that we'll probably need a new Regulatory Framework to accommodate that. (Gov9)

Gov9's approach may combine elements of both product-based and process-based regulation. In short, a crop plant with a 'novel trait' derived through gene editing would be treated in the same way as a plant with a 'novel trait' achieved through other methods, such as cross breeding (a product-based governance approach). Other GMOs produced through, for example, transgenic methods will be subject to a different governance stream based on the process used to produce them (process-based governance).

For these participants (all 'Gov' participants, as well as Sci5, Sci7 and Sci11), case-by-case assessment of risks and ethical implications of particular products were viewed as essential aspects of governance which should be maintained. These participants described how a product-focussed governance approach would promote the case-by-case consideration of an application's (product's) individual traits and novelty, rather than the process by which it was produced. This can be understood through the lens of Finitism as a way for regulators to determine, case-by-case, how a product can be classified or understood. This was viewed as a "logical," "sensible" approach, more conducive to discussion of risks, benefits, and "other

legitimate factors" (a term used by civil servant participants) such as implications for communities and animal welfare. One manager at a UK funding body describes:

> The concern from the policy perspective is around the technology being used at the moment, but I know, from having engaged with the UK stakeholders, their interest is for it to be a more trait-based policy or regulatory system. So, if the traits of the plants or the crops are the same as what you could currently achieve through random mutagenesis, then perhaps we could consider that in the environment. Then there wouldn't be any concern about release. Or not saying, 'Any concern,' but, from a regulatory standpoint, that might be appropriate. (Gov2)

A UK regulatory lawyer and government advisor (Gov3) also mentioned mutagenesis to underline a perception that genetic modification processes ought not be treated differently to (or implicitly be viewed negatively in relation to) other approaches:

> I think I would want to focus more on the product than on the process and I'd like to knock away some of the quaint elements of the GMO directives. I'm referring to mutagenesis and this is a history that goes back to atomic gardening in the 1950s, which is why it's okay, because it's a peaceful use of a by-product of the nuclear industry. Nuclear; good. So that's why that's in there. I'd like a more rational approach to it which takes into account actual risk, but also goes back to what I sort of said about the treaty provisions. What's actually in the European treaty on the function of the European Union about the precautionary principle. Which is that the precautionary approach takes account of scientific knowledge. But the one thing I didn't mention to you earlier, and I should have mentioned, is it also requires you to take account of the danger, it doesn't use that word, of the impact, if you like, of not adopting something. That's what it actually says. (Gov3)

A UK government advisor (Gov1) mentioned a similar notion of weighing up benefits and safety as part of a product-focussed governance approach.

Experiences of GM controversies also help to explain other reasons why this group of participants (all 'Gov' participants plus Sci5, Sci7 and Sci11) felt that a focus on synthetic biology products might be preferable, rather than determining whether its processes 'count' as GM processes. They often sought to distinguish synthetic biology and its processes from GM and its processes, making various technological or political arguments for such a boundary. For example, Sci5 and Sci11 constructed synthetic biology as more techno-scientifically complex than GM, more sophisticated and its risks more controllable. Gov3 takes a similar position, but additionally presents GM as easy to control, with its risks overestimated, constructing both fields as unproblematic in terms of risk, as did Gov8 and Gov9 who constructed both as useful. Gov4 expressed the reverse, that it would be potentially "harder" to assess synthetic biology's risks than GM's because of its complexity, but that case-by-case risk assessment of products could facilitate this.

Others discussed how the risks of synthetic biology and GM are overestimated or a source of potential controversy as they are viewed similarly by publics, other stakeholders and regulators. For example, Gov2, Gov5, Gov6, Gov10, Sci5, Sci7 and Sci11 constructed synthetic biology and GM as distinct but that their risks, ethical implications and potential for controversy are similarly perceived (based on GM Trauma). Similarly, Gov1 conceptualised synthetic biology as different to GM, perceived as attached to controversy and ethical and risk objections that this participant considered limiting to a field which can be commercialised in "useful" ways. In short, it was important particularly to participants actively involved in the field's governance to establish the extent to which synthetic biology processes are or are not similar to GM processes, and elsewhere also to mutagenesis, in order to discuss why product-focussed regulation would be preferable. Often this was conceptualised as a way to better control complex (techno-scientifically conceived) risks or to facilitate commercialisation by distancing synthetic biology products from the negative opinions associated with GM processes, resulting from GM controversies.

In summary, despite challenges defining the term 'synthetic biology', most participants agree that synthetic biology falls within the scope of existing UK GM and Novel Foods regulation. Current governance was viewed negatively despite this, as reactive, "onerous" and "draconian", with repeated reference to the ways in which GM controversies were seen to have contributed to existing policy frameworks. Perceived governance challenges for synthetic biology included difficulties navigating guidance and regulations, untimeliness in approval processes and the possibility that applications might be novel and unsuitable for comparator approach-based governance. Participants also referred to difficulties in trade, due to mismatching approaches to governance across territories, including devolution within the UK nations, international governance, particularly EU regulations.

Participants involved in governance, including scientific advisors, and most of the scientists constructed the risk assessment of synthetic biology products as something for scientific experts to carry out. Current regulatory processes were viewed by many as robust ("probably strong enough") for this reason, due to their focus on case-by-case assessment of risks, and there was a sense that there was no immediacy of concern around existing process-focussed governance in terms of its capacity to contain or mitigate the risks posed by synthetic biology processes. However, these participants tended to advocate for a product-focussed policy approach, because it was viewed that there was too little scope to assess the risks, ethical implications and benefits of particular synthetic biology products under the current regime.

7.4. Many actors, many roles

Synthetic biology, as exemplified by the pool of interviewees for this study and the wide range of definitions that they in turn offered, is a varied space with many actors and many roles. Alongside conceptualisations of stakeholders being on opposing 'sides' (such as NGOs as opponents to scientists and industry) discussed previously, another of my main findings is that participants across my sample regularly sought to construct the boundaries of their particular roles. They did this most often by indicating aspects that they would not consider to be theirs to "worry about". This contributed to a sense of fragmentation between actors and groups in the synthetic biology space.

Notably, some participants perceived there to be a separation of fundamental science and scientists from any resulting industry and applications, and relevant regulation. For example:

> **Natalie:** Do you have any thoughts on current regulation in this area?
>
> **Sci10, UK academic scientist:** No, not really. I mean, I've been avoiding thinking about it, to be honest with you, and just letting other people worry about that.

Like Sci10, other participants used the word 'just' to downplay their position on a certain topic. This dynamic was not limited to scientist participants, but rather present across the sample. Gov3, a UK regulatory lawyer and government advisor, prefaced their opinion on future policy priorities with "first of all, I'm just a lawyer. I think, as a policymaker, I think I'd focus on actual risks." Similarly, when asked for more detail about a comment they had made about synthetic biology's application to food and agriculture as "another step down a wrong road," Org7, a non-UK academic non-scientist, responded "I don't know. I'm just an ethicist. (Laughter)." Often these comments were accompanied by participant explanations of their notions of expertise, and of having expertise in some areas but not in others. For example, Gov6, a manager at a UK funding body, responded to one question with "I am really not the best person to ask." Gov6 went on to offer their opinion on a topic they viewed as "not [their] area of expertise at all":

> **Natalie:** Do you have any thoughts on how you might want synthetic biology derived food to be regulated in the UK?
>
> **Gov6:** Yes, that is not my area of expertise at all. So essentially, I have got an opinion, but it is just a member of the public opinion, I think. My personal opinion is, I think it should be done, but it should be labelled, and I think that is in terms of how the public view food that has been made synthetic.

Similarly, another manager at a UK funding body (Gov5) indicated that a question about environmental risk was beyond the limits of their own perceived expertise, despite discussing at length the potential risks of releasing synthetic biology-derived applications into the environment at other points in their interview. Gov5 then offered a detailed response to my questioning regardless, recommending deliberative approaches to considering potential future risks, and alluded to anticipatory methods of risk management reminiscent of those sometimes advocated under Responsible Research and Innovation initiatives:

> **Natalie:** You mentioned risks. I don't know if you want to expand on what potential risks you could see in an environmental space?
>
> **Gov5:** I don't know. I'm not an expert in these things, but you can see if you release… you're creating a de novo organism or something quite radical, or something with a totally new gene to do something else gets into the environment, evolution is going to start hitting on the organism and it has never hit on it before and it's going to change rapidly and quite frequently to adapt to its new environment. Then, it's going to adapt to another new environment. […] you need to be comfortable that it's not going to distort the system that you're trying to support and manage. It's a very vague thing, but that's the essence of it in my view. […] Do we have a mechanism that we really think we can control it or […] restrain where it goes and what it does? That's the real challenge. I don't know what the solution or what the answer to that is at all. I can't do that, but people that actually create these ideas, create these changes, create these gene sequences are better placed than I am to talk about those sorts of things.

While Gov5 suggests that developers and scientists should be responsible for thinking about such matters, the scientists I interviewed broadly did not conceptualise themselves as responsible for discussing the implications of applications arising from their research. Shedding light on this, one UK academic scientist (Sci1) implied that some actors could take on more responsibility than others for roles such as communication with publics. This participant suggests that **"**NGOs could be of great help because we cannot ask always the scientists to [consider through public engagement whether their innovations are 'responsible'], and if we expect the companies to do it, well, you can expect until the end of the day and probably they won't do it. So, somebody needs to put their feet to the fire" (Sci1).

Sci1's views appear to conflict with one of synthetic biology's purported goals of responsible innovation and public engagement, suggesting that scientists cannot always be relied upon for such engagement. Sci2, a non-UK academic scientist also involved with a start-up in the field, echoed this to an extent when questioned about potential social and ethical aspects of their work. Sci2 situated responsibility for discussing "sociological challenges" with those "from maybe sociology or something similar to your background," while scientists instead focus on "engineering challenges and the scientific challenges […] the real battle,"

which is telling of the participant's view of what might be considered important for scientists to do. Sci2 also expresses that's synthetic biology is "still relatively far away from the real economy, real people." This was similar to another comment about focussing attention on ongoing scientific work, rather than potential governance implications:

> I feel like in an academic lab, you only ever really get to the point of a proof of concept […] whether the actual process of scale-up is safe and whether there are contaminants or not is always downstream. I think we recognise that's not something we'd be involved in, so we never really think about regulation of a particular product, but we do talk about regulation of new foods and genetic technologies that are applied to crops quite a lot. (Sci4, UK scientist)

This is reminiscent of the 'decoupling' of research science and scientists from the downstream effects of applications noted by e.g., McLeod *et al*. (2018), Robaey *et al.* (2018) and Calvert (2013).

Across several interviews, participants placed responsibility for policy activities on a wide range of actors, but most felt that food policy, or discussions of synthetic biology's food policy implications, were not their individual responsibility. For example, Sci4 recommended that authorities themselves take proactive, anticipatory approaches to governing synthetic biology, collaborating with scientists and funders in the field to find out about developments in the science or potential future applications. Gov1 and Gov4 also placed emphasis on reactive, collective processes like "stakeholder push" (and particularly driven by actors with certain expertise), relying on stakeholders working together "in order for the cogs to start going" (Gov4) on governance discussions. Gov4, a UK civil servant, suggested that stakeholders could aim for consensus ("enough acknowledgement that [current governance] no longer works") on regulation and then push government "to change legislation", stating:

> My knowledge on the policy side isn't that great. I think if you take the genome editing, which is an area I'm familiar with and you take what's happened in Europe, and the fact that they're now acknowledging that there needs to be a change to the regulation in order for it to work. I think there needs to be enough acknowledgement that something no longer works, and then probably a stakeholder push really, to get it to change in order for the cogs to start going in government to change legislation. (Gov4)

Gov4 gives the impression that it might be difficult to persuade government to make this "change" and "for the cogs to start going." Further, Gov4's initial reaction is that their "knowledge on the policy side isn't that great" suggests that they conceive of their civil service work as separate from 'policy' work.

In summary, participants often perceived themselves as not responsible for actions or discussions relating to synthetic biology-relevant policy. The implication of this was threefold:

(1) the construction of synthetic biology governance as a topic for experts to discuss; (2) reconstructing potential approaches to governance processes as reactive (i.e., as per current evidence-led approaches to policy) or the result of others collectively pushing for policy change; and (3) a tendency towards non-critical presentation (and active enactment) of synthetic biology as a fragmented space with disparate actors responsible for working on and discussing different aspects but not for engaging with one another. This furthers the GM Trauma theme of discord and competition between synthetic biology stakeholder groups. Further, in the context of currently 'siloed' food policymaking, developed and entrenched in a fragmented institutional landscape (discussed in Chapter Three), this provides the groundwork for synthetic biology-related food policies to be shaped by a small handful of actors and interest groups.

7.5. Investment and funding

Several participants when asked what the future might hold for synthetic biology focussed on economic aspects, like funding, investment and "market pull"[22].

Sci11, a UK academic scientist and government advisor, described how prior funding allocated from 2013 onwards had supported the establishment of a number of synthetic biology centres across the UK, leading to incremental scientific progress in the field. For this participant, the UK is "a science powerhouse. We still punch way above our weight in biology. I like to think that will last" despite Brexit-related challenges (Sci11). This participant also described how the centres established as a result of this funding "have sort of got a bit long in the tooth now, and these things have a shelf life of about five years, then they have to reinvent themselves" (Sci11). The phrase "reinvent themselves" is reminiscent of some participants' views about the term engineering biology as a rebranding of synthetic biology, as discussed in Chapter Six. It also alludes to a perception that more funding is required to support the future of synthetic biology's development, particularly in a Brexit context: "[T]he risk of falling out of European programmes [like Horizon] is really serious. There's a lot of money tied up in that […] the big players, for the most part, you're talking about the UK, Germany, the States, South

[22] The notion of 'market pull', also called 'demand pull' or 'need pull', can be defined as the recognition of a need to satisfy existing and new markets with products that are either new or modified, to solve a particular consumer or market problem (Brem & Voigt, 2009). These products are sometimes new versions of, or replacements for, familiar products, but often with improvements for efficiency, costs, or to address another consumer demand (e.g., 'plastic-free'). 'Market pull' is sometimes opposed to 'technology push', which refers to the development of a technology being followed by a desire to find a way to use it, which then drives the generation of new products and processes, "to make commercial use of new know-how" (Brem & Voigt, 2009:355).

Korea, China, obviously, and they're coming up fast on the inside and overtaking many people" (Sci11).

Alongside the perceived need for more funding generally, participants often expressed views on funding priorities or the types of applications that might be prioritised. One of these was climate change and the impact of food systems on the environment. Typically, notions of funding for environmental applications were driven by perception about a desirable synthetic biology future focussed on alternatives to animal products and animal farming (viewed as polluting and resource-intensive), as well as environmental remediation. One UK academic non-scientist, Org2, mentioned the former, stating that synthetic biologists "are just trying to replicate what we already have" in more environmentally-friendly ways, citing synthetic biology-derived meats and cheeses (as well as fruits and vegetables). For Org2, "the funding is probably more restrictive than the actual technology. I think if the funding was there we would be doing loads more" to direct synthetic biology towards topics that were perceived as "quite high on the agenda" (Org2). The participant went on to describe priorities like "[s]aving the environment," sustainability, and being "able to feed the world in, what, 20, 30 years […] that will be where the focused funding should be."

A similar sentiment was expressed by Gov5, a manager at a UK funding body, who cited a review on spending and identifying "what's important", including biodiversity, pollution and "can we manufacture organisms that could go into an ecosystem and sort [it] out" (Gov5). For this participant, these ambitions could support, and be supported by, Net Zero climate goals and "COP15 and COP26 coming on" at the time. Gov5 describes the kinds of questions that this raises in funding circles:

> [W]e need to understand what is biodiversity, what's the importance of biodiversity and how can we use biodiversity? So, you can imagine synthetic biology coming into that sort of question and saying, 'What do we need?['] […] Are there organisms, ecosystems that you can set up which are modified systems that can therefore assimilate carbon, a soil system which is even better than peat at assimilating carbon, but has synthetic organisms in there to do that? It's that sort of thing. Can you make a tree with a modified C4 synthesis pathway that takes in far more carbon? It's all those sorts of opportunities, isn't it, really? […] playing to big strategic goals that the government […] Well, the big [priority] is climate change, so it's adaption to climate change. From an agri-food perspective, it's, as I just mentioned, the making plants resilient and sustainable to that changing climate. (Gov5)

Alongside notions of funding priorities, supported by (international) policies, driving synthetic biology in certain directions, for other participants like Gov1, the field might be entering a phase of "market pull" (in contrast to the perceived "technology push" discussed by

Gov1, Gov5 and Gov6). This was considered a different context in which synthetic biology can develop, rather than the controversy context in which GM's opportunities to arrive on the market were perceived to have been 'lost'.

Furthermore, "market pull" was seen as being driven by social, environmental and economic priorities. A UK government advisor, Gov1, describes "market pull" through the lens of start-ups attracting industry funding, and this cementing their legitimacy:

> [Synthetic/engineering biology is] no longer just a research topic, but very much we- if you're going to put things into market, you probably need to bring in a lot of other technologies and therefore it could be broader than just pure synthetic biology alone. The main thing is to deliver things to market. […] somewhere around a year or two ago, it became increasingly clear that we were shifting from technology push to market pull. […] When I segment the market, the fastest growing area is in, what I call, alternative food. So, it's attracting billions over the last couple of years. […] The academic world is moving at pace. Initially, there was a lot of development of what I call tools and services, you know, being able to synthesise DNA and stuff like that. And I am seeing this shift towards applications and those applications are emerging differently in different parts of the world. […] And so, to some extent, I feel that it's the market which is now pulling and therefore incentivising those applications. And that's led to the growth areas I've talked about. (Gov1)

Gov1's comment serves to position synthetic biology-related industry as dynamic and responsive to a perceived "market pull", interpreted as demand for more sustainable foods. However, there is little detail given of how judgements are made about what might be desirable for consumers, or how they might react to the novel processes deployed for "alternative food" (Gov1), perhaps indicating more of a sense of "technology push", rather than meeting specific consumer or market needs implied in the term "market pull" (Brem & Voigt, 2009). Nonetheless, in terms of "incentivising those applications", for another manager at a UK funding body, Gov6, attracting private investment is a priority. Gov6 describes that one of the UK government's priorities "is getting [R&D investment] as a percentage GDP of GDP up to 2.4%."

Another notion of 'market pull' was alluded to by a UK academic scientist, Sci1, but viewed as "radical" and under "very little scrutiny", in contrast to Gov1's view that this is "really interesting" or Gov6's perceived "priority". Sci1 describes a view that "we are [at] risk of repeating a similar mistake as we did with the lack of responsible innovation with the development of the internet. So, the internet pretty much has been the Wild West and all the technologies associated with and derived from the internet". The participant adds that "the field is accelerating so rapidly," suggesting that synthetic biology progress without "scrutiny" may present a challenge for controlling both risk itself ("we need to be very careful," alluding to the

internet as the "Wild West") and perhaps perception of risk ("the public communication of science").

In summary, it is unclear whether the field could be said to be "accelerating" as Sci1 suggested, not least in the UK, perhaps supporting views that more funding and investment is required to promote acceleration. The 2013 investment in a network of UK Synthetic Biology Centres for Research Excellence, set out in the Roadmap of 2012, remains the most significant funding drive for synthetic biology, although further funding is in discussion.

7.6. Multifaceted risk

The following sections consider the ways that participants constructed synthetic biology as risky or ethically problematic, and the implications of these views for policy. Of interest was the way in which most participants spoke vaguely or non-specifically about risk and ethics, and often conflating the two. This is something noted by Bauer and Bogner (2020) as a tendency for those discussing synthetic biology to debate at a high level of abstraction. Although I noticed this during interviews, I did not provide participants with example applications in order to generate more specific conversation about risks. Instead, participants often reached for particular imagined examples of their own (imagined risky applications or products). For example, Sci2 drew on an imagined risky application in order to comment on weighing up risks and benefits:

> To get an answer you need to perform more experiments. For example, I generate a virus, an oncolytic virus. In my lab I see that this virus can cure cancer. It can kill cancer cells. […] For one, this is great. A lot of profit. Okay. I will save human lives and we can live forever. But since cancer and healthy cells are similar maybe this virus eventually will mutate a little bit and kill us all. (Sci2, non-UK academic scientist)

As this example sharply demonstrates, conversations about risks, although vague, were multifaceted and connected to other ideas about risk, with emphasis on scientific expertise and catastrophic or utopian thinking.

In another example where a participant drew on an imagined application to discuss a range of risks, one UK academic scientist and government advisor (Sci11) described a crop plant to which synthetic biology could be applied. For Sci11, a UK academic scientist and government advisor, this imagined crop plant could have unintended consequences ("something turns out to be wrong with it") which may present a risk to the future development of synthetic biology (its scientific progress). Sci11 then connected this to the risk of the technology being negatively portrayed in the media, tied to an assumption that this would generate negative

public perceptions, linked to past experiences of GM controversy. This is another example of how my concept of GM Trauma influences current thinking about public attitudes:

> It could happen really quickly, or the awful thing, at least from the scientific point of view, would be it gets rushed through, a crop is brought in, something turns out to be wrong with it and that kills the technology for a decade because it then becomes a bad example and everyone says, 'Right, we're not going to do that again.' So, people will be careful about what the first example is because an awful lot hinges on it. (Sci11)

Further discussion of their imagined crop plant then inspired Sci11 to consider some potential risks of applying synthetic biology to animals and human beings, not just crops, raising 'slippery slope' arguments around the ethical concerns of doing so.

In addition, the non-specific nature of many participants' imagined risky applications placed focus on the future applications of synthetic biology as the primary source of risk. Gov7 and Gov9 in particular viewed synthetic biology as too nascent to assess its risks, but felt that it was likely to have similar risks to GM. There was a sense from those primarily involved in governance, that the science was not developed enough to have specific discussions around risk, conceived of as 'downstream'. One civil servant involved in research (Gov7) was emphatic about synthetic biology not being an immediate concern and suggested that as the technology develops, better understandings of risk should be formulated. It was unclear by whom. Gov9, another UK civil servant, also reinforced a reactive approach to governance, for example:

> [P]eople like me, in terms of risk managers, would come in and say, 'Okay, is the science developed well enough now that we can think about this or the consequences of that? Or we need to start planning for that.' I suppose that's how I view it, it's something that I've got an interest in how it develops. But until somebody comes up with something that's actually going to be an application, then my work side doesn't kick in, just general interest in terms of, yes, it's another field of science, and it's a particularly interesting one. (Gov9)

A UK scientist (Sci4) suggested that, to be more pro-active at risk management, policymakers should review research grant applications and, at that stage, consider whether there will be any future risk-related governance implications if a product is developed from the research.

In several interviews, there seemed to be a particular focus on the risks associated with releases of applications into the environment. This was clear among some of the scientists, with Sci7 discussing 'weediness', as did Sci8, who also referred to invasiveness and persistence of synthetic biology products in the environment, as well as their potential impact on other organisms like bees and butterflies. Sci11, a UK academic scientist and government advisor mentioned that a decision about "'What is it sensible to do on a large

scale?' is a much bigger, much harder decision and you don't want to delegate that to a bunch of scientists. That's a decision for people with a very broad range of expertise, and of course, it's a hugely political decision as well."

To mitigate these risks of releasing synthetic biology products into the environment, Sci3 described how microorganisms escaping may seem "horrendous" to some, but typically they are "way less adapted" to surviving outside the laboratory. Similarly, Sci8 mentioned that risks were perceived as lesser in cases of contained use, seeing containment itself as a safety mechanism, and stating that "some NGOs are fine with that [contained use]." Sci11 discussed different mechanisms of containment, including both physical and biological containment (such as an organism being reliant upon a laboratory condition to survive), but mentioned that these measures must always be viewed as fallible even when used in combination. "[P]laying around with the germline" (a term used by Gov9, a UK civil servant), and gene drives, were some of the few specific applications of synthetic biology that numerous participants routinely described as risky and difficult to contain. For a manager at an international NGO (Org6), such applications were a red line, considered 'too far' due to containment challenges and would require ecosystem-wide risk assessments, as well as consideration of unspecified risk to the future, communities, livelihoods, human health and the environment. For Org6, informed consent of affected communities would need to be sought, and that could potentially include the whole world. Elsewhere, Org9, an advisor at a European policy thinktank, in particular mentioned the benefits of being able to control risk through containment. Org9 suggested that this makes contained uses potentially less controversial because they are viewed as posing fewer risks, meaning that "people tend to worry about [contained use] less". Such a perception that means that the risks associated with contained uses might be overlooked.

Scientific expertise and risk assessments were considered vital to mitigate risks around (a) toxicity or allergenicity of edible applications; (b) the potential for dual use (e.g., bioterrorism and deadly viruses discussed by Sci2, a non-UK academic scientist); (c) any unintended consequences of applications in the environment (examples given included bacteria designed to eat plastic waste escaping and consuming non-waste plastics e.g., in computers or buildings – Sci3, non-UK academic scientist); (d) off-target genetic changes or mutation (Sci5, a UK scientist and government advisor); and (e) antibiotic resistance. Several participants recommended genome sequencing as a potential method of mitigating "concerns" attached to these potential risks. Sci5, a UK scientist and government

advisor, mentioned that to facilitate that, sequencing could be deployed for "dealing with some of the worries that people have", referencing concerns about the unintended consequences of GM and synthetic biology:

> [I]n terms of sequencing capability, it's just looking at the advances that have been made so far. I think in the future we just won't think twice about just sequencing the whole genome of whatever it is we want to look at. I think that will go a long way to dealing with some of the worries that people have, because with genome editing there are always people who say, 'But what about all those off-target edits, things happening that you're not expecting?' It's the same with GM. It's unexpected consequences, but if you can sequence the whole genome, and maybe you can just have a complete overview of, perhaps, the whole metabolome, all of the compounds, these things are becoming so much easier. […] It should completely reassure people that there's nothing untoward in the background. It has been checked, the sequence. Nothing else has happened. (Sci5)

Genome sequencing is something that a manager at an international NGO (Org6) also suggested as a tool to support governance, as did Gov3, a UK regulatory lawyer and government advisor, who expressed a view that mandatory sequencing should be carried out:

> I think it's something which I haven't seen any proposals. And which, to my mind is sort of screaming. We are living in the genomic age. Sequencing is much cheaper than it was. Why wouldn't we want to do it? (Gov3)

On the question of "why wouldn't we want to do it?", one UK civil servant, Gov4, explained that the volume of sequencing data would be large and possibly not useful, or that it would not be evident to assessors which parts needed to be reviewed, making it "very tricky" to check an application's risks and safety. Gov4 describes:

> [I]f you start submitting large amounts of sequencing data for every application, you have to know what is of use when you're doing your safety check, and you have to know what you're looking for because if you don't have experts in the regulatory system who are used to large amounts of sequencing data, it's going to be very tricky to do those checks.
>
> I think that's probably where we're moving to […] so I think the regulatory system needs to be prepared to deal with large amounts of sequencing data. (Gov4)

For Gov4, there was a sense that the regulatory system was unprepared for applications featuring large amounts of sequencing data.

There were other comments around current governance too. As mentioned earlier, for example, on the processes and practicalities of risk management, a manager at a UK industrial biotechnology company, Sci6, described the challenges of assessing safety. Sci6 described how workers at their company would look through other applications that had been

approved and frame their own safety assessments around them, deeming them to have been "sufficient". An advisor at a European policy think tank (Org9) felt that the concepts of risk and safety are broadly internationally similar, as are practices of assessment, and this can form a basis of international cooperation, rather than a barrier to international trade. However, the sentiment was not always shared. One UK civil servant in particular, Gov9, was critical of the American approach of classifying foods and ingredients as 'Generally Recognised as Safe' (GRAS), or assuming safety unless there is evidence otherwise. Gov9 indicates a preference for proving safety first because, along with another UK civil servant, Gov10, they prioritised maintaining consumer interest around choice, labelling, linked to consumer trust which was viewed as 'expensive' to build and easy to lose, as had occurred during GM controversies

Org2, Org3, Org4 and Org6 - all participants who felt that synthetic biology's risks and harms were indistinguishable from those associated with GM - also discussed risks in broad, non-specific ways. For example, while Org2 mentioned safety being a primary concern this was with no specifics, discussing instead 'slippery slope' arguments about applications of synthetic biology in humans. Org3 discussed safety in very general terms as well, but placed the importance on not economically harming farmers, citing "Monsanto evilness". Like Org6's view that it would be impossible to conduct adequate risk assessments for the all the potential, future, ecosystem-wide implications of applications released into the environment, Org4 and others described risks of less tangible harms, including cultural and spiritual concerns. For Org4, a farm worker and researcher, this took the shape of "connection to food", perceiving a growing disconnect between people and food, or a lack of understanding of food production:

> **Org4:** I think the majority of people don't care at all what their food looks like or where it comes from, as long as it's there and it's cheap. But for a lot of people, yes, it's a problem.
>
> **Natalie:** Why do you think a lot of people don't care?
>
> **Org4:** It's convenient. It's like, you know, it's one of those things that just exists. Now we have, I'm an adult and I could have grown up my whole life without ever knowing where my food came from, never visiting a farm or anything like that, being connected to zero food producers, whereas yes, probably my parents, that generation probably similar, probably less so. My grandparents' generation, they were probably more connected to their food producers. But yes, now people are going to grow up and never have a connection. That connection is just not going to be important. It's going to be there. It's going to be all the nutrition they need. It's going to be more calories than they ever need. It's going to be super cheap. It's going to taste ridiculous. It is going to taste good. It's going to be fatty. Those are all the things. It checks all of the boxes that people want. I just also think that, as a value, being connected to the earth and having empathy for

> animal rights and stuff like that, that just as a value is going away because people can just hide and never see that. Or those things can hide from people.

For this participant, an intangible risk of applying synthetic biology to food and agriculture is that it might limit or draw focus away from "being connected to the earth" and "empathy for animal rights". This highlights the emotional significance of food to the participant, perhaps attached also to nostalgia for "[m]y grandparents' generation". There was also an implication that "things" may be hidden, like practices and motivations, as well as questions around who is hiding (or hiding from) these aspects, alluding to ethical implications related to harms, power and transparency, discussed in the following section.

Alongside risk and safety, for many participants there was a focus on balancing concerns with considerations of potential benefit. Gov2, a manager at a UK funding body, and Gov1, a UK government advisor, both discussed risk in the sense of risky use of public funds for highly experimental but potentially beneficial research which had been limited by its association with GM, viewed in turn as undesirable or controversial. Sci4 expressed a sense that concerns about synthetic biology are overblown or based on misunderstandings of science, rooted in GM controversies. For Sci4, there is "definitely potential for positive impact, definitely potential for concern" around "manipulating DNA" (Sci4) which must be balanced. Sci4 implied that there is very little scientific evidence of risk of GM and synthetic biology products, but more evidence of benefit ("the evidence of 25 years of growing genetically modified crops and safe use and also showing in most cases, in fact, that they've reduced the amount of agrichemicals and increased farmer income in small-holder farmers" – Sci4).

Therefore, for some there was a perceived risk arising from *not* developing synthetic biology. For example, Sci7 mentioned that alongside risk, potential benefits must be discussed:

> You can never say there's no risk of getting it wrong. […] you should be willing to balance the risks and the benefits. At the moment, regulators only pay attention to risk and they don't pay any attention to the benefits. It should make a difference if something has a high probability of a significant benefit. Compare that with a minute probability of a potentially very significant disbenefit. It's all in the probabilities. If the probability of the harm is infinitesimal, then you shouldn't measure it as equal against the probability of the benefit. It has to be a judgment at the end of the day, it's not something you can do on the basis of half science. They have to be willing to do it and they have to be protected from the consequences of doing it if, with the best of intentions, something should turn out to be hazardous. It's hard to imagine it being… Hazardous to humans I guess is a more serious problem than hazardous to the natural environment or to the farming environment. There are a lot of things to weigh up there and we

> manage to do it […] with other technologies. (Sci7, UK academic scientist and government advisor)

This view likely derives from Sci7's perception that synthetic biology, like GM, is not particularly risky but that its risks may become overblown if similar conflict, fear and controversy surround it, as surrounded GM.

In summary, discussions of risk had the effect of focussing conversations on expertise, centring the role of scientific authority in determining what risks there might be, or assessing safety. As will be explored in more depth in the following section, participants also often conflated aspects of risk and ethics. Risk was conceptualised as complex and multifaceted, also connected with ethical questions like which risks could be justified, which steps should and should not be taken, and who might benefit or be harmed, and in what sense this might manifest.

7.7. Ethics

Building on the previous section, the ethical questions discussed here include views about the implications of fundamental (or "basic") research, perceptions about responsibilities, harms and distribution of benefits.

When asked about any potential ethical implications of synthetic biology, several participants across the sample, but predominately those working in scientific roles, suggested that "fundamental science" could be considered ethically unproblematic, while certain applications were more likely to be problematic. This, as with some of the discussions of risk in the previous section, had the effect of constructing ethics as something to discuss 'downstream'. This was the case for Gov1, a UK government advisor, who stated that "a fundamental level, the science itself doesn't [raise ethical questions] because fundamental science doesn't […] otherwise you'd say, 'Is mathematics ethical?' It starts to get silly." Gov1 later indicated that scientific progress was always "going to happen", and that ethical discussions should thus focus less on process and more on product, and "ethical issues" are "[u]ltimately […] always in the application."

One UK scientist (Sci4) described similar ideas, suggesting that "maybe synthetic biology in itself doesn't raise ethical questions" because they viewed it as an approach, using "an engineering mindset to understand your problem". This view was voiced elsewhere and might be attached to a view that basic science or fundamental science is itself a public good, and therefore ethically sound. This is in conflict with the purported need for 'responsible

research' throughout scientific research and development, mentioned by one UK government advisor, Gov1, who stated that synthetic biology "raises questions about ethics […] introducing responsible research [is] about ensuring that we actively ask that question every time" (Gov1).

Furthermore, for several participants, there was a sense that ethical considerations of benefits and harms were conceptualised as dependent on application. A significant aspect of this was the distribution of these benefits and harms, and to whom. Many participants agreed that ethical questions about synthetic biology were best approached as application-specific, because they perceived food systems, ecosystems and organisms themselves as too complex for detailed, specific discussions of ethics. For one UK government advisor, Gov8, the application of synthetic biology within food systems was connected to questions about economic cost, equitable access and distribution of potential benefits. Gov8 began with a discussion of cost-benefit analysis and suggested that this would be "very, very difficult to do" when considering scaling up applications like "synthetic proteins, synthetic meat." This participant went on to describe the ethical implications with this background, using the phrase "more your domain" to suggest that these aspects are the domain of social scientists to discuss:

> And then you get into more your domain, the social policy arguments. Well, if you can do it and it is available but only the richest people can afford it because of cost, how does that impinge on the ethics? Should you carry on because there is usually economy of scale on the basis that you put all this money in and do this stuff for rich people because, ultimately, people have come and thought it might be able to and they will be benefit. Or, do you say, 'No, that is the wrong way to approach it. Start at the bottom, start where there is most need.' And that is way out of my remit. (Gov8)

A UK scientist felt similarly, asking "is there any hope of fair and equitable access to the products of biotechnology or is it just always going to be out of reach of most of the people, you know, that we thought that we were helping to start with?" (Sci4). This language of "the people […] that we were helping" is indicative of the 'saviour' rhetoric sometimes deployed by scientists to suggest that their work offers societal goods for countries and peoples perceived as in need of its applications (described by Marris, 2013). It is important to acknowledge that much of the power and resources to research and produce synthetic biology applications is concentrated in the UK, USA and China (Clarke & Kitney, 2020).

Alongside democratisation of benefits, when questioned about ethics, some participants perceived potential disadvantages of synthetic biology for other communities. Referring to past experiences of GM controversies, Org3, a foodservice industry worker and researcher referred to "Monsanto evilness," mentioning that "[y]ou don't want [synthetic biology] to hold the farmers prisoner economically or make it so that they have to grow the same crops all the time."

Org1, a UK academic non-scientist also mentioned the ethical considerations around profit-making and tied this to questions around transparency or the hidden interests ("smokescreen") on the part of industry actors, who use claims of "helping the planet" as "marketing". For this participant, "there's demand for more ethical products from people and the market has responded and they've come up with more ethical products. But I think if there was no demand for it, then they wouldn't make them. […] I think the priority for the lab-grown meats would be to make money and capitalise on whatever the particular demand is at that moment in time" (Org1). Org7, a non-UK academic non-scientist, suggested a similar view could apply to scientists and researchers, who were perceived as trying "to contribute to the world with something good and they want sex, drugs and rock and roll. They try to solve what they see as problems with their ideas. At the same time, they want to be paid for what they do and many of them want to start a private company and make a lot of money as well."

Taking a similar stance on the potential implications of synthetic biology for farmers, Org4, a farm worker and researcher, described a potential scenario involving alternative milks. For Org4, the use of the label 'milk' on synthetic biology-derived products could disadvantage cattle farmers, prompting them also to raise questions around the exploitation of people and resources, as well as connection to food:

> **Natalie:** [F]or you, does synthetic biology raise any ethical questions?
>
> **Org4:** Probably, yes. I mean not any that I directly agree or disagree with, but like the first one off the top of my head is the whole can you call alternative milks milk? Maybe that's ethical just for dairy farmers. That's a big thing for them. That's a big part of their marketing. That's a big part of how they make money. […] Surely, of course this synthetic biology could be exploited, or scaled to the extent, scaled to this place where it is exploiting resources and exploiting people and stuff. That's definitely a possibility for synthetic biology like it is for anything really. Also, I don't know if this is considered ethical, maybe it is more spiritual, but connection to food and food grown from the earth and natural food and whole foods and stuff like that is really important for a lot of people. Synthetically derived substances […] It's not food. It's an edible food-like substance. That distinction is really important for a lot of people, like culturally and spiritually and stuff like that. A world in which we move towards majority edible food-like substances as opposed to food, that's a big problem I think.

This participant also makes a distinction between food "from the earth and natural food and whole foods" and implied disconnect from "synthetically derived substances… edible food-like substances," which is a notion of (un)naturalness shared by others (typically non-scientists) and discussed in detail in the following section.

Org4's opinions on the impacts of synthetic biology's development on farming communities is echoed by Org7 with reference to organic farmers, stating that the labelling (or

lack thereof) of synthetic biology products as GMOs could be economically important to these communities. Org7 added that "they see it as GMO. If you regulate it as GMO, the technology will probably not be very widespread in Europe […] If you don't regulate it as GMO, the organic community has a problem in that they cannot keep something out of their production that they think is GMO." For this participant, a lack of labelling would mean that consumers would "experience that they can no longer choose whether they want to support GMO or not through their consumption, which will basically, I think, in the long run, undermine the trust in the food system." Org7 went on to use the phrase "catch 22", assuming that GMOs are unpopular based on their experiences of GM controversies, and therefore that not labelling them "can very easily convince a large group of people that this is sneaking a technology through the backdoor, that they can no longer escape." This draws together a number of challenging ethical considerations, including the impact of labelling decisions on organic farmers, the freedom of choice of consumers and the mitigation of potential harms to humans and ecosystems. This complexity informs Org7's perception of how labelling policy should be approached, and how technologies should be categorised (i.e., not "GMO and non-GMO" but perhaps "in 5 boxes now").

Org7 also raised ethical questions around the roles of human beings in relation to other species and the planet, discussed in more depth in the following section on (un)naturalness. For Org7, speciesism may be a potential ethical question:

> [Synthetic biology raises] risk questions, the questions around our relationship with nature. Then it also raises questions around what is - because very often, as I remember it, they wanted to rebuild bacteria to start with. That was the easy thing to begin with and they could make them eat oil or plastic. That makes me think around whether it makes a difference whether it's a goat or pig or bacteria you're changing. Could you say that, 'Well, you can't really change goats because we need to respect goats, but bacteria doesn't matter and they also exchange genes all the time'?
>
> […] I'm beginning to think about bacteria as 'alien others', if that makes sense. Are they others? Is there something to relate to from an ethical point of view? What is it and how should you do it? […] Insects are also one of the, 'Oh, we'll all eat insects and climate change will go away.' There is this idea of 'alien others' that I find interesting from synthetic biology. (Org7, non-UK academic non-scientist)

Here, Org7 implies that those applying synthetic biology to bacteria think that a microorganism like this "doesn't matter and they also exchange genes all the time", viewing them as "alien others". The phrase "they could make them eat oil or plastic" suggests that bacteria are viewed as alien but instrumental, useful for human ends, in a way that is sometimes perceived as less ethically questionable than applications in other creatures, like a goat or pig. McLeod *et al*. (2017) researched synthetic biologists' views towards the microorganisms they

used in their laboratories, finding that this ranged widely from conceptualisations of bacteria as "personified agents (that deserve care and respect)" and sometimes vulnerable, to helpful "co-workers", to "a bag of nuts and bolts" or useful tools and a means to an end for human applications.

Discussing the ethical considerations associated with non-human animal applications of synthetic biology, and potential animal welfare concerns, Gov9, a UK civil servant, states:

> Well, we don't specifically lead on animal welfare, for instance, but obviously we've got a real interest in the areas as well because one thing that we wouldn't want is that… Take GE, for instance, one of the things that we're aware of is that if you did an alteration to an animal, to animal DNA, where the purpose of that was to allow the farmers to have far worse husbandry conditions, then you're straight into animal welfare areas. Clearly, we couldn't countenance that. That would be like some of the legitimate factors where we would say, 'Well on safety grounds, for the product that comes out at the end of the day, you can argue that maybe it is safer than a traditional one. But it's at the cost of animal welfare, all the rest of the stuff.' We're not saying no, because we couldn't say if the safety case was proven, but we wouldn't be strongly recommending that because of A, B, and C. (Gov9)

Gov9 uses, for example, the word "countenance" to indicate a level of ethical or moral unacceptability related to approving applications carrying the potential for harms to animal welfare. The implication here is that the application's benefit would apply solely to farmers who might, presumably, keep costs and effort low through "far worse husbandry conditions." Clearly, what could be considered 'poor' husbandry conditions are commonplace in some branches of conventional farming, like intensive, caged egg farming, for example, but Gov9 does not discuss these in terms of moral acceptability.

Elsewhere, one UK academic scientist and government advisor, Sci11, described "a whole separate area of opposition to do with playing around with the germline [a reference to gene drive technology], even though conventional breeding is doing exactly that, but people feel much less happy about it with animals than with plants" (Sci11). When asked why that might be, the participant responded initially that animals "are kind of cuddly" and suggested that people would be "fired up" by headlines in the Daily Mail, a response indicative of GM Trauma and a perception of certain newspapers as influentially 'against' GMOs. However, they also added a question: "[people] say 'Well, why don't we do it in people as well?'" Sci11 went on to describe:

> That's a much trickier [question]. So, there's a viewpoint that says, 'Nothing wrong with engineering animals per se,' but it would bring the prospect of

> genome engineering humans that much closer because, again, technically, all the technical problems you've got to solve wouldn't apply to just animals. They'd apply to humans as well as they do to cows, sheep or whatever, so let's just leave those problems in place because if we don't, we're then going to have to deal with that whole question about 'Is it ethically okay to play around with the human germline?' That's a whole step beyond that. (Sci11)

There is a sense here that problems "apply to humans as well as they do to cows, sheep or whatever", and that humans can choose either to "just leave those problems in place" or recognise their dominion over the directions and questions asked about human science, technology, design and control, including having "to deal with" human applications, also discussed by Org2.

To summarise, when asked about ethics, participants often wanted to talk about the roles of humans, powers of different groups and individuals, and the potential for synthetic biology to generate or exacerbate inequalities, harms or exploitation between humans and between humans and non-humans. A strand of this involved notions of nature and (un)naturalness, discussed in the following section. These aspects, when coupled with previous discussions of risks, bring to mind a number of possible ethical considerations. First: Who (if anyone) might benefit from the application of synthetic biology to food and agriculture? Second: Who (if anyone) might be harmed? And third: What is at stake? There appears to be an assumption that scientists and industry may benefit financially, through sales, legitimacy and associated emotional, social and economic benefits like career success, at the expense of farmers, who may be subject to contractual obligations to powerful industry or scientific actors or usurped or squeezed out of the market by these actors. This is likely rooted in GM Trauma, with many citing experiences of GM controversies ("Monsanto evilness"). There is also a sense that what might be at stake is the wellbeing or livelihoods of humans and the wellbeing of non-humans, as well as potentially the very survival of human beings in the cases of either adopting or not certain aspects of the technology.

7.8. (Un)naturalness

In the literature review I detailed how the concept of unnaturalness has policy relevance, and notions of 'the natural' are included in synthetic biology-relevant governance, such as labelling regulations and recent amendments to England's GM Deliberate Release Regulations.

While some participants primarily involved in governance did discuss naturalness, it was typically only in three senses. The first has been mentioned previously: the perception arising from GM experiences that publics might view synthetic biology as 'unnatural', and

therefore object to it (Gov1, Gov3 and Gov10). These participants constructed the natural/synthetic divide as something that others like publics may identify, classifying synthetic biology as unnatural (like GM) and potentially objecting to its products on these grounds, based on past controversy experiences. Gov10, a UK civil servant, queried "how will consumers take to that [lab-grown meat]? It goes back to the GM discussion of, will people go, 'Well, this is a strange Frankenfood. This is yuck, I don't like it. This isn't natural'? Will there be that sort of reaction?" This was often presented as one of a range of 'emotional' or 'unscientific' public perceptions and assumed to be rooted in the framings of genetic modification put forward by NGOs and the press during GM controversies.

A second framing of unnaturalness discussed by some governance participants (particularly those with first-hand experiences of GM controversies) was that they did not share what they considered to be these common views around synthetic biology and (un)naturalness. These participants emphasised that any natural/synthetic boundary constructed by publics or other stakeholders should be interrogated to identify its influences or could be considered erroneous, particularly if they are attached to an objection towards synthetic biology on the grounds of its perceived unnaturalness. For example, Gov9 states: "I don't share the same ethical issues that some would about creationism, etc., because personally, I don't have any religious views of that sort. I know that's very heavily influenced often with religious beliefs in terms of you're creating a biology rather than letting nature take over". Gov1 describes: "if you're demanding natural vanillin from chopping down a Madagascan tropical rain forest, then I actually think that maybe the obsession with being natural may not actually be necessarily the right outcome". Here, Gov1 presents unnaturalness objections as a barrier to synthetic biology's potential to achieve "the right outcome", or to provide benefits for nature itself. The implication in both Gov9 and Gov1's comments are that perceptions around unnaturalness, whether based in religious beliefs or driven by something else (Gov1 does not give details), are somehow unimportant or may be dismissed. This sentiment is put into words by Gov3, who says that "the assumption that nature is always benign is obviously a bit naïve". This is connected to Governance participants' third framing, that synthetic biology could be useful to nature, either helping nature or helping scientists to learn from nature but stopping short of "reinventing nature" (Gov1, Gov2, Gov5, Gov6 and Gov10). Taken together, these views suggest that some Governance participants did not consider it to be valid to object to synthetic biology on the grounds of unnaturalness, despite imagining that these views are widely held based on their views about GM controversy. These participants tended to construct synthetic biology and nature as distinct, because they perceived that others (like publics) would construct such a

boundary. However, they did not seem to perceive nature as something to be 'protected' from the potential harms that other participants felt might be posed by synthetic biology. Rather, they suggested that synthetic biology could produce things that could have occurred naturally. In short, they sought to challenge what they perceived to be conventional constructions of naturalness as specially 'good' or 'benign' by presenting synthetic biology as non-conflictual with naturalness, and as also a 'good' thing.

Participants not directly involved in governance also expressed a range of views towards (un)naturalness, including, as discussed, instances in which participants juxtaposed the natural to the artificial, synthetic or unnatural. The remainder of this section focusses on other participants' notions of naturalness, what it meant to them, how the concept was deployed and to what end, exploring how they understood the concepts of synthetic biology and (un)naturalness through the lenses of the connections between humans and nature and the superiority/inferiority of the natural versus the synthetic or human-made.

Human-nature connections

Many participants constructed nature by opposing it to the synthetic, human or manmade, or society. For some, this notion was linked to views around the roles of humans in relation to nature, which varied.

For one UK academic scientist, Sci1, the role of humans in relation to nature was to optimise, design and control, because "evolution doesn't do optimisation. It does satisfaction." Sci1 suggested that "[w]hen you introduce an intention in the process, which is what synthetic biology does, then you have optimisation. You are trying to do things better in a radically new way […] it opens up a completely new area *in which nature can go*" (emphasis added). Here, Sci1 conceptualised synthetic biology as a means through which nature could be designed and "optimised" intentionally, through human means for human ends, later making an analogy with computers: "you could say that we are making cells be more like computers, or we are making computers be more like cells […] this boundary is being blurred" (Sci1). For Sci1, humans' use of synthetic biology, like the use of computers, integrates with nature and that the boundary between synthetic/technological and natural is "blurred".

Sci1, among others, also characterised humans as dominant participants in nature, themselves natural, and therefore further situating synthetic biology as natural, human activity. This broke down the distinction between human and nature sometimes presented by other participants. Sci1 described:

> **Natalie**: Is it a good thing, making cells more like computers or computers more like cells?
>
> **Sci1:** […] [T]he question doesn't have much meaning from my perspective […] you could almost see it as an inevitable natural process. […] even the simplest of organisms, they already change their environment, so bacteria are created their own little environment that they try to adapt to, so it's more likely to make bacteria be happy in their environment. Animals also create their own niches and affect their niches and make it more amenable to their own survival. So, in that sense, the only difference with humans is that perhaps we are the only mis-adapting species. We are destroying the planet and making it better for us, but the jury is still out on that one. We need to wait a few more years. Not long, not long, I think within 30 years we will see whether we were smart enough or not.

Sci1 suggests here that humans are capable not only of "destroying the planet" but also design, intention and being "smart enough" to make "it better for us". This alludes to a 'technological solutions' framing of climate-related challenges, coupled with a view that humans have a natural inclination to shape nature for our own needs. By contrast, another non-UK academic scientist, Sci3, expresses a view that nature or the natural is distinct from synthetic biology, but something that can be learned from, and that humans and nature can "[help] each other" to learn and solve "an intricate problem" (Sci3). This is something that the participant refers to as "relational logic […] in many cases engineers benefit from looking at biological systems and get inspiration [which] helps to sort out problems" (Sci3).

Other participants constructed naturalness and nature as distinct from synthetic biology, and perceived this boundary as something that humans (as reliant on the natural world) should maintain, expressing there to be limits to what humans should do with nature. UK academic non-scientist, Org5, discussed:

> I think we need to adopt a prima facie duty to allow nature to be, to respect nature's integrity. Of course, we cannot do this totally because, if we just allowed nature to be, we would not be able to exist. So, this prima facie duty to allow nature to be needs to be put into the balance with other duties that we have, such as making sure that we provide enough food for humanity. The difficulty lies in weighing up those different prima facie duties. […] synthetic biology raises much bigger issues compared to conventional biology because the engineering of the natural world will produce things that will reproduce and may be able to exist for a very long time. […] we may create species that are new and that will forever bear the mark of humanity. Not just bear the mark of humanity by human beings influencing the course of nature, but by us engineering nature. And this is something that makes me very uncomfortable. (Org5, UK academic non-scientist)

This participant suggests that humans cannot "just [allow] nature to be," therefore must make use of nature to human ends but with a sense of duty or stewardship over it, where nature is conceptualised as something to be cared for and respected. For Org5, there were "certain

boundaries that people perhaps shouldn't be crossing, and we might be crossing those boundaries if we manipulate nature to become a product of human design, which I associate with synthetic biology". As such, this participant situates synthetic biology, or "engineering nature" as more distinct from naturalness than conventional biology or unspecified food production processes, "provid[ing] enough food for humanity". Synthetic biology is, for Org5, classified as something that is not only highly unnatural, but "very uncomfortable" and must be controlled. Org5 was keen to explain that they were not "theologically inclined" themselves, but that religious aspects remained important in discussion about naturalness:

> For someone who's theologically inclined, they might say, 'Well, God created nature and we should accept nature as it is,' right? Rather than intervene. And of course, what they might forget is that we intervene in nature all the time. So, they need to then think about how is intervening in one way different from intervening in another way, and where do you draw the line? So, for somebody like me who does not adopt a theological perspective, I understand the 'playing God' objection as the idea that there is something very frightening about living in a world where everything that we see around us bears the mark of humanity. (Org5)

They also spoke at length about the notion of "playing God" in relation to ethics of certain human interactions with nature through synthetic biology, an argument that was often discussed by participants when describing their experiences of GM controversies.

One non-UK academic non-scientist, Org7, discussed synthetic biology as distinct from naturalness, and suggested that its applications (such as to potatoes for blight resistance) could potentially be viewed as "too much power over nature" and "yet another step down a wrong road". Here, Org7 constructs synthetic biology's unnaturalness as something problematic, "wrong". Sometimes synthetic biology was also opposed to food production practices viewed as less problematic by virtue of being constructed as more natural. In Org7's view, like organic farming and "earth to table" approaches (Org7) were more natural and less problematic. Org3 and Org4 felt similarly. Furthermore, animal agriculture presented a conflict with many participants' ideas of naturalness. For example:

> [Well known meat analogue product] is really popular, isn't it? It always puts me off. The only reason I was slightly put off, because I was reading about it once and it was like a chemical company. I think it was the type of company that owned the license I found a bit disturbing, because I linked it with industrial chemicals or something, and I cannot remember what it was. I think it was the link to think… That is just psychological, isn't it? That it is chemicals in your body […] But then equally, if you do talk about meat, it has probably never seen the light of day. Some of those chickens, they've never- So why would you judge that any different from it not being treated like a natural thing? (Org2, UK academic non-scientist)

Org3, a UK foodservice industry worker and researcher, expressed a similar view, recommending the banning of "factory farming", framed as "unnatural and wrong on so many levels, modifying living things. Not nice." That this participant used the phrase "unnatural and wrong" suggests a conflict in their view between practices like "factory farming" and others that might be "natural and right", although it is unclear what they might be.

Elsewhere, discussions of naturalness were also accompanied by discussion of slippery slope-type arguments relating to the roles and powers of humans in the world, including powers over other humans and non-humans. One UK academic non-scientist, Org2, framed (un)naturalness as a difficult concept ("we affect nature all the time in everything we do"), something echoed by others, like Sci1. Nonetheless, Org2 went on to raise the question of (un)naturalness in relation to something that they considered ethically problematic – human cloning and application of synthetic biology in pursuit of the "perfect human":

> I can see why people are thinking, 'No, do not dabble and change nature.' But we affect nature all the time in everything we do. When we start a car, we are affecting nature. When we mine ore out of the earth you are affecting the world, when you heat something up. […] I think when people breed even flowers, don't they, they try and put two types of flowers together or breed dogs. They are all affecting, actually, what nature is intending. So, I do not see why one thing is acceptable and something else is not. If you are accepting of one, I think you are accepting the other. The only ethical thing I have is any decision on what is a perfect human. […] What is the perfect apple? Everything is relevant to each other, some people like green, some people like red, but nobody likes a bruise. Do you know what I mean? So, I think it is easy to say that you like a crunchy carrot or whatever, the size and shape is something you can be more able to predict. The size and shape of a carrot is different to the size and shape of a person. (Org2, UK academic non-scientist)

This raises a question about "what nature is intending" and it is not clear what is meant by this term, or what intention nature might have, if any. However, it does provide a contrast to views like those of Sci1, that intention is a distinctly human attribute, while nature by contrast only does "satisfaction" and "survival". Similarly to Org2, in discussions of naturalness, Sci11 also raised slippery slope-type ethical questions around the use of CRISPR on humans, constructing synthetic biology as something which could be in conflict with human beings' own nature.

Inferior or superior nature

Often notions of the natural were discussed in contrast to perceived "manipulation" by humans, with some applications portrayed as "fake", "artificial", "synthetic", "not real" or "not normal", conveying senses of inferiority and superiority. Org4, a farm worker and researcher, described Michael Pollan's notion of "edible food-like substances," with an implicit sense of inferiority

of these ‘substances’ when compared to food “from the earth and natural and whole foods”. Org2 and Org3 shared this sentiment, often when describing imagined futures of lab-grown meat or other alternatives to animal products. For Org4, “there is part of me that thinks this [application of synthetic biology to food and agriculture] is all really cool. There is also part of me that is a little off-put” (Org4). This participant also mentions that “it’s like so far removed from how food used to be. I also don’t think that we need to be idealising and trying to return to something that is really far gone and could never work in the amount of people and with the societies that we have now. But I do think, like I feel pulled towards more natural foods, actually natural foods and whole foods.” In their use of the phrase “actually natural,” Org4 was referring to a nuance in labelling regulation that allows in some circumstances for a synthetic biology-derived flavouring to be labelled as ‘natural’ based on the use of fermentation in the production process. Org4 implied that such a product was not, in their view, “actually natural”, but when pushed, Org4 explained their understanding of “a natural food”:

> **Natalie:** How would you define a natural food?
>
> **Org4:** Yes, probably something that is grown and then derived from that. Or extracted from that. Yes, probably as close as you can to the growing process. That’s probably how I would describe it. But that’s also how I like to eat. I mean it’s so hard just to make huge claims because yes, cheap food, cheap, processed, unnatural food helps feed a lot of people unfortunately because it’s so cheap.

Other participants also expressed views about how they liked or did not “like to eat”. Several participants suggested that lab-grown meat was something that they would not like to eat. This was not always a “yuck” or unnaturalness-based objection. A non-UK academic non-scientist discussed that they “prefer to eat close to the ground, so to speak, and there are plenty of plants you can eat instead of meat to get your protein” (Org7). This participant also raised economic factors “it's still rather expensive. They have gotten the price down from $300 for a nugget to $30 I think, but that's still a lot for a nugget.” Furthermore, Org7 queried the production process, “it needs to be grown in animal serum, which then defies the purpose”. Indeed, as discussed previously, the “yuck factor” was typically presented as an uninformed reaction based in perceived naturalness, rather than an informed stance against GMOs.

For one UK scientist and government advisor, Sci5, naturalness and natural processes were connected to notions of tradition. Sci5 suggested that these must be understood in order to make “sensible” judgements about how to regulate other products (comments made in reference to DEFRA’s 2021 consultation on genome editing):

> [W]ith genome editing you can end up with a plant […] that's identical to one that could have just arisen naturally or you could have got it in some other way,

> it makes no sense whatsoever to regulate differently when, to all intents and purposes, it is exactly the same. I think there's a need to move away from worrying about how you do something, to looking at what you actually have done, and what that end product is, and what impact that might have when you grow it in the field. What are the risks associated with it? (Sci5)

Another UK scientist, Sci4, echoed this view, problematising "mutation breeding" and using this to advocate for product-focussed governance approaches, rather than process-based ones. This participant felt that scientific evidence suggested that synthetic biology has the capacity to be more precise than mutation breeding, but instead is considered "completely unnatural" because of the involvement of scientists and laboratories in their development. Similarly, Gov3 assumed that while the natural or traditional are not considered problematic, synthetic biology and other scientific methods are viewed as such by virtue of their perceived unnaturalness. By using terms like 'unnatural' and 'traditional', Sci4 and Sci5 among others provide nuanced views that, for them, perhaps, the natural is not superior to, or less problematic than, the product of genetic technologies. This provides an argument in favour of more product-based rather than process-based governance, whereby a product of synthetic biology could be considered based on its individual merits.

In sum, the consumption of food is both necessary and tied to emotional, cultural, social and historical factors, not least of which are personal value-based and belief-based judgements about what should or should not be eaten, as well as situational factors about what can or will be eaten or not. Notions of (un)naturalness are perhaps tied to these judgements ("yuck", "I wouldn't eat it") but also to understandings of the roles of human beings (and their scientific and technological endeavours) in relation to the world.

7.9. Summary

This chapter built on those prior by addressing imagined futures of synthetic biology, focussing on prominent aspects such as potential implications in terms or risk and ethics, as well as naturalness. I introduced contextual factors like participant views about how Brexit and the COVID-19 pandemic combined to create a policy window to allow synthetic biology-relevant governance to be reconsidered. There was also a sense from some participants that these factors have created a squeeze on civil servants' and politicians' time, meaning that synthetic biology might not be high on political and policy agendas.

This chapter also explored some of the particular qualities of synthetic biology that participants considered to have potential food policy implications. This included the fragmented and varied nature of synthetic biology, involving many actors often with many

roles in the field. The perceived responsibilities or domains of these actors (their things to "worry about") were often viewed through the lens of perceived expertise, "that is not my area of expertise at all". There was a sense that current regulatory approaches in the UK were "probably strong enough," with participants occasionally citing the roles of expertise, science and evidence as supporting factors for their view that existing governance is "robust". Overall, there was a sense that policy in this area may be shifting and changing, and participants were keen to discuss ongoing debates and consultations, including for example product-based and process-based governance approaches.

Risk was discussed in all interviews, suggesting that synthetic biology and some of its products were commonly characterised as risky. This perceived risk was often non-specific, likely due to ideas about it being 'downstream' (attached to applications), with participants describing possible widespread, escalating, unforeseen risks to ecosystems, biological systems and intangible aspects like connection to food. Generally, there was a sense of vagueness and lack of specificity in participant responses to questions about the future of synthetic biology, but participants would reach for imagined applications in order to discuss the topic. Further, there was a tendency to catastrophise (imagine an application that "will kill us all"- Sci2) or present a hopeful or utopian vision of what might or should happen, often with a "technological solutions" focus. It also helps to underscore a theme of potential controversy, rooted in memories of, or observations about, GM controversies, which was an important component of participants views on potential approaches to policy and debate.

Participants' responses to questions about ethics often centred on views about power and inequalities and often also touched on experiences of GM controversies as well as perceptions around naturalness. Ideas about (un)naturalness were also connected to beliefs about the roles of humans in the world and in relation to non-humans and broader considerations, including 'playing God', human and non-human wellbeing, economic aspects and the equitable distribution of benefits. However, views around unnaturalness were often dismissed by Governance and Scientist participants, raising a question around the extent to which these would be considered or taken into account under current or future governance. Indeed, through processes of reinforcing and consolidating the importance of technoscientific expertise, it remains likely that in policy contexts, current narrow technical and scientific considerations of risk (e.g., to human health and the environment, just some of the many aspects discussed here) will persist.

The following chapter discusses the findings in relation to the existing literature and my research questions. I summarise my claim to originality, as well as my main arguments. I then discuss my interpretation of the data, including an exploration of the findings around current and potential future governance, the food policy relevance of the topic, GM Trauma and notions of expertise. Finally, in Chapter Nine, I go on to offer some recommendations for policy and further research.

Chapter 8: Discussion

8.1. Introduction

The previous chapters detailed the findings of my research project. The findings were broadly divided into three areas. The first focussed on a concept I identify as 'GM Trauma'. I use the term GM Trauma to evoke a sense that observations about and experiences of GM controversies are sensitive for participants and cast a long shadow over their subsequent reflections on GM and synthetic biology. The second area covered the ways in which GM Trauma influences participants' constructions of synthetic biology as novel, promising, and potentially controversial, and likewise informed participants' views about ways that publics might be engaged with, communicated with or managed. The third area encompassed how participants imagined the future of synthetic biology in food and agriculture and its governance. The three findings chapters provide insights into the views of a unique and varied sample of stakeholders towards synthetic biology applied to food and agriculture in the UK. There is originality in this scope, along with my focus on possible approaches to policy and the unexpectedly turbulent 2021-22 socio-political context. To my knowledge, no other empirical, qualitative research has covered this combination of factors, nor discussed them with a range of participants from policymaking, the research community, industry, funders, and NGOs. Furthermore, while existing literature has somewhat 'taken for granted' that synthetic biologists have internalised a fear of controversies like those around GM, my research provides rich detail of the influence of this 'GM Trauma' on synthetic biology stakeholders' policy-relevant views and actions.

The following sections draw together preceding chapter to answer my research questions and situate the findings amongst the relevant literatures.

8.2. Summary of findings

This research initially took an exploratory approach, guided by two interlinked questions:

1. What are the implications of synthetic biology for UK food policy?
2. What are the implications of relevant UK government policies on the development of food-related synthetic biology in the UK?

These broad questions supported the collection of rich interview data from 30 synthetic biology stakeholders. My data has shown that, for these practitioners in work relevant to synthetic biology's future in food and agriculture, experiences of GM controversies are important. These

experiences and their influences on participants' thinking are something I term 'GM Trauma'. My concept of GM Trauma prompted a need for deeper reflection through three further research questions:

1. What are the ways in which synthetic biology is constructed by this sample of its stakeholders?
2. Why did these stakeholders construct synthetic biology in these ways?
3. What are the implications of these constructions for UK food policy?

GM Trauma has explanatory power when considered through the lens of Finitism as a particular 'background framework' into which participants fit (and from which participants derive) their conceptualisations of synthetic biology. It can help to explain why stakeholders constructed synthetic biology in the ways that they did, which I set out below.

Constructions of synthetic biology

Synthetic biology is constructed as different to GM by all the scientist participants (except Sci9) with first and second-hand experiences of GM controversies. For example, synthetic biology is considered by these participants as more precise, sophisticated, 'constructive', complex or as an umbrella term encompassing a broader range of technologies and techniques (sometimes including GM). This construction of synthetic biology was intended to separate synthetic biology from the perceived negative public opinions associated with GM and its perceived riskiness. These views were shared most commonly by participants working in governance, or with past experiences in similar roles, including those with first-hand experiences of controversy (Gov8, Gov1, Gov5 and Org9) and second-hand GM Trauma (Gov10, Gov2, Gov6). The term, "engineering biology" was used particularly by participants working in governance, regardless of their experiences of the original GM debates, to signal a new phase of synthetic biology and convey its applications and commercialisation as something to be thought of, funded, and regulated distinctly from its supporting technologies, including GM and gene editing. All these participants seek to distinguish synthetic biology from GM in order for it and its products to be considered separately from the controversies and 'problems' attached to GM.

Gov3, Gov4, Gov7 and Gov9 - the remaining participants working in policy contexts with first-hand experience observing GM controversies - constructed synthetic biology and GM as similar to each other, as potentially beneficial, promising, and misunderstood by publics. In the case of Gov3 and Gov9, for example, risks were deemed to be overestimated by publics and regulators for both fields. These two participants hope that synthetic biology and GM will be

considered in parallel, to remedy some of the perceived unfairness and conflict of GM controversies by discussing both anew.

All the remaining participants felt that synthetic biology and GM's risks, ethical implications, likely reception by publics and other stakeholders, and potential to be controversial were indistinguishable. These parallels were deployed in support of these participants' view that policymakers should maintain strict controls on both GM and synthetic biology.

Why synthetic biology was constructed in these ways

I suggest that synthetic biology was constructed in these ways because of GM Trauma, where the experiences of or observations about GM controversies shape the ways that the stakeholders I interviewed think about synthetic biology. This is because stakeholders conceive of synthetic biology as reasonably similar to GM such that it would be received by publics, stakeholders and regulators in the same ways. GM controversies are perceived as having caused problems, such as regulatory hurdles, public opposition, reductive binary arguments, and stakeholder conflicts. They are also understood as having shaped GM's development in ways that are unpalatable to stakeholders in different ways. For example, the scientists (except Sci8, who works for an environmental NGO) and policymaking participants tended to focus on strict controls over GMOs in the UK and EU, conceiving these as a failure contributing to lost opportunities for the field. The two participants involved with NGOs took a more global view, describing GMOs' widespread use in countries like the USA and understanding this as a failure to control the field's development as they might have hoped. The other participants working for other (non-science, non-policy) private and public sector organisations understood GM's development as having had a range of observable, sometimes negative impacts on farmers and publics, with a distribution of benefits in favour of perceived unscrupulous companies like Monsanto.

Synthetic biology is also constructed in these ways because of the context of the coincidence of Brexit and the COVID-19 pandemic. This particular time was conceived of by participants as a chance for scientists and policymakers to review GM regulations, to discuss the UK food system and its weaknesses more broadly, or to 'reframe the argument' on genetic technologies because of their positive roles in vaccine development, virus sequencing, and testing. All participants viewed the current socio-political context as an uncertain period with the potential for synthetic biology (and other relevant genetic technologies) to be discussed or regulated differently in the UK. Often this was framed as pressing or necessary because of the

political and policy importance of climate action, with the complex roles of food systems in relation to the climate both as negatively contributing to climate crises and reliant on the climate for stable production.

Implications for policy

Past GM controversies are viewed as having resulted in a governance framework that many participants perceived critically, while acknowledging that it is probably strong enough to manage risks to food safety and the environment. The current governance approach was variously viewed as stifling, illogical, draconian, and neither rooted in current scientific knowledge nor facilitative of scientific progress and innovation. Several participants across groups viewed governance as reactive or not agile or broad enough to manage an emerging synthetic biology that might produce applications which pose problems for the current comparator approach to governance. For many of the scientists, policymakers and government advisors with first-hand GM controversy experiences, current governance was also perceived as the result of a shift in the authority of science, with policy instead captured or shaped by 'ideology' or 'politics' driven by NGOs and taken up by malleable publics, leading policymakers to react to public opposition to GMOs by imposing an unnecessarily strict regulatory system for many decades. By contrast, the majority of those involved in other private and public sector organisations either defended the regulatory status quo or recommended introducing stricter controls.

Participant perceptions of past controversy and conflict also seem to manifest as an expectation of future controversy. This is described in conflictual terms, with proponents of synthetic biology sensing themselves to be under attack from opponents, and vice versa, contributing to a sense of insularity among stakeholder groups. Taken together with differing interests and power to influence policy (which could be described as a scientised policy space), and the perceived policy window of Brexit/COVID-19, a picture emerges of a struggle by the scientists and participants working in governance-related roles, primarily, to shift towards a more deregulatory or self-regulatory policy regime, and to retain scientific advisory committee oversight of case-by-case risk assessments of individual products. This perhaps has its roots in the sentiment that GM regulations have an 'ideological' basis rather than a 'scientific' one. If successful, a new policy approach like this could signal the allocation of greater responsibility for synthetic biology's governance to the scientific community itself.

These ideas about which kinds of policy approach might be desirable were informed in part by perceptions of synthetic biology's potential risks and benefits, and of what counts as

evidence for riskiness, safety, and ethical acceptability, which varied significantly across participants. The interests, values and beliefs also driving these differing imagined synthetic biology futures, often glorifying or vilifying the roles of technoscience in food and agriculture, might be challenging to bridge. However, participants across groups and backgrounds routinely advocated communication with publics and stakeholders to this end, although often to drive their own visions of synthetic biology forward (such as toward public acceptance, for proponents). Conversely, my participants did not typically perceive the food policy implications of synthetic biology to be something that was their individual responsibility to discuss or address.

8.3. Interpretation

The previous section summarised my key findings in relation to my research questions. In the following sections, I discuss the findings alongside the existing research. I also explore the implications, strengths, and limitations of the findings.

8.3.1. Worldviews underpinning GM Trauma

Consistent with the main finding of SSK, Finitism, the first phase of this research found that stakeholders' constructions of 'synthetic biology' could be explained by exploring their individual past experiences (their 'background framework') and the social and political context in which they sit (e.g., Bloor, 1991 & 1999; Bloor *et al*., 1996; Li *et al*., 2010). This takes the form of GM Trauma, an original concept which describes the way that stakeholders draw on their experiences of GM controversies, or observations about their results, in order to frame their conceptualisations of synthetic biology in food and agriculture, and their discussions of its governance.

Importantly, GM Trauma can be said to be underpinned by a number of limiting and problematic worldviews and can in turn help to explain why these viewpoints persist. For example, participants across groups and backgrounds routinely made assumptions about others' lack of knowledge, indicating an application of deficit model-type thinking to other stakeholders, as well as publics. In this case I suggest that there is (a) an unwillingness to accommodate or recognise varied knowledges as equally important, and (b) an assumption that disagreements over what might be considered 'known' or 'important' about synthetic biology can be resolved through addressing knowledge deficits. This is consistent with the observations

of a number of STS scholars across a range of science policy considerations, including Wynne (2001), Jasanoff (2005) and Marris and Calvert (2020).

Accompanying this was a tendency for primarily scientists and those working in governance to devalue or dismiss views that they considered 'unscientific', or perhaps not 'scientific' enough to inform policymaking. These participants blamed the publics and stakeholders who have these 'unscientific' views for stoking controversy about GM and contributing to the production of a policy regime that is viewed negatively, whether as too restrictive (or for Sci8 too facilitative) of GM development. This way of thinking lends itself to an overreliance on scientific expertise to inform decision-making - ultimately politically driven - which can limit the range of types of voices that influence policy.

Finitism offers a useful lens through which to explain how participants arrived at their constructions of synthetic biology via the background of GM Trauma, and to situate these conceptualisations within the rich fabric of their experiences, learnings, worldviews and social-political context. In particular, participants' GM Trauma leads many to advocate for more science and less of what they perceive to be 'non-science'. Both NGO participants advocate for 'different' science which may be more critical of genetic technologies and their implications for broader ecosystems. The participants that were not involved in science or governance typically felt that a wider range of groups (including ethicists, social scientists, farmers, publics etc.) need to be involved in discussions about synthetic biology because their views are perceived as likely different to those held by scientists and NGOs. Although not interviewed for this research, politicians could perhaps play a role in voicing the views of their constituents to this end. These understandings and their explanations in turn point to policy implications, from who is around the policymaking table, to the types of policy frameworks that stakeholders advocated for, and the policy considerations that they felt were important.

8.3.2. A shifting policy landscape

Despite challenges defining the term 'synthetic biology', most of my interviewees felt that the scope of existing UK GM regulation captures activities within the field. In terms of current activities, my research found very little to suggest that synthetic biology applications will present cause for concern regarding food safety in the near future. Despite this, participants often focussed on perceived human health risks and food safety as the highest priorities for policymakers and practitioners in synthetic biology-related roles, although it was broadly considered that current policy frameworks are "probably strong enough" in this respect.

There was some sense of dissatisfaction from participants relating to aspects of current policy frameworks, perceived as originating in the GM controversy, retained following the UK's departure from EU membership. Proponents of GM or synthetic biology in food and agriculture viewed current control measures based on the assumption of future risk as "onerous", "draconian" or "excessive". The existing framework is based on the precautionary principle, and a source of frustration for some appeared to be the perceived lack of manifestation of the assumed future risks that provide the foundation for the precautionary high levels of control over present scientific endeavours.

That said, over the course of this project, policy in this area began to shift and change. Several high-profile food policy initiatives, including the Obesity Strategy (2020), Environmental Land Management Schemes (2021), and Food Strategy (2022), have been unveiled only to be deployed partially, shelved, reformulated or abandoned. In 2022, amidst economic uncertainty, short-lived Prime Minister Liz Truss hinted towards a focus on deregulation, with the food sector a prominent target. Her replacement, Rishi Sunak, (perhaps rightly) now instead states that he prioritises addressing the present economic crisis. While it is unclear which form future food policy might take, a deregulatory trend may build upon prior tentative steps taken in synthetic biology-relevant spaces. For example, early-2022 saw an amendment to GM regulations to permit the release of gene edited crop plants in research contexts without formal risk assessment and authorisation, opening the door for more discussion about how synthetic biology might be governed going forward. This was viewed positively by many participants, although the two participants from NGOs broadly felt that this was an unacceptable step towards scientists' self-regulation. In parallel, one (perhaps cynical) indication from participants was that the "government wants" policy change to enable the eventual entry of GM or synthetic biology applications onto the UK market, and that public consultation has been deployed as something of a rubber-stamping exercise on this pathway.

A direction of travel towards a UK governance approach that may eventually be more facilitative of the commercialisation of synthetic biology-related applications seemed acceptable to some participants particularly those who expressed aversion to "noise" or conflict with publics, NGOs, and other interest groups like organic farmers. However, the scope of current risk assessments (human health and environmental risks) is narrow. Consistent with ideas described elsewhere in the literature, participants often felt that publics perceived synthetic biology to present intangible risks and infringements of values like connection to food and rights to informed choice, as well as views on "playing God" and (un)naturalness (Liu & Stewart, 2015; Jin *et al*., 2019; Robaey *et al*., 2018; Meckin & Balmer, 2019; Frewer, 2013;

FSA & Collingwood Environmental, 2020:21; and Kamrath *et al.*, 2019). Governance participants' discussions, and dismissals, of perceived common views about (un)naturalness in particular suggest that policymakers are conscious that publics might potentially hold such ideas about synthetic biology and are seeking to reframe the relevant notions in policy spaces. Today, in England, some genetically modified plants are now regulated based on whether they "could have occurred naturally". This approach might blur any boundaries between technoscience and nature, a distinction that participants described (or imagined) as important to some publics.

While likely to be unpalatable to its opponents, any loosening of restrictions on synthetic biology was viewed as enabling of scientific progress, something that many participants viewed as important. In turn, this must be understood within the decision-making contexts discussed throughout this thesis, which are influenced by notions of expertise and dominant discourses around the roles of science and scientists. This provides a normative and performative space in which scientific progress is more likely to be viewed as inherently desirable and something to be supported, in turn making it more likely to be supported (Marris & Calvert, 2020).

8.3.3. Expertise and insularity in policymaking

The incorporation of scientists and their scientific expertise into policymaking spaces (like those relevant to synthetic biology) builds particular, often fraught, relationships between science and society (e.g., Jasanoff, 2005 & 2016; Yearley, 2005; Collingridge & Reeve, 1986; Marris & Calvert, 2020). In their discussions of policymaking around synthetic biology, Marris and Calvert (2020) refer to "assumptions about relationships between science and society that reinforce one another in a cumulative manner like the layers of an onion". They describe the roles of four particular layers of dominant assumptions that they believe are 'taken for granted' by those involved in synthetic biology policymaking:

> These layers are (1) the ELSI model of social scientific engagement, (2) the technocratic model of risk, (3) the deficit model of public understanding of science, and (4) the linear model of innovation. Each of these layers of assumptions acts to push the "social" outside of the realm of the "scientific", and all of them were at work in the Synthetic Biology Roadmap. Addressing one set of assumptions alone can only scratch the surface because each layer builds on the others. (Marris and Calvert, 2020:53)

My research finds all these points to be evident a decade after Marris and Calvert's experiences. My findings include the embeddedness and (likely quite deliberate) re-entrenching of several of these traditionally dominant layers of assumptions around technoscientific developments.

Marris and Calvert consequently ask (2020:53) "why are these framings so entrenched? Even when alternative arguments are put forward and appear to be heard, why do they seem to have no lasting effects?"

In answer, I suggest that, arising from GM Trauma-related perceptions about (and sensitivity towards) conflict between scientific communities and those considered 'outside' them, it might be strategic for some groups to frame their own expertise and activities as separate to the consequences or implications of scientific research, restricting their focus to a technocratic risk model. This may have a threefold effect:

(1) Reconstructing (and seeking to protect) the view that scientific progress is an inherently good thing promotes continued investment and development without inconvenient deliberations about purposes, trajectories, and goals. In turn, this allows scientific communities and funders to self-determine synthetic biology's trajectory and goals according to purposes, beliefs and values, many of which are assumed to be in the public interest, but which may or may not be articulated or debated. For some, describing synthetic biology as novel, emerging, or simply an approach or mindset was a way of reinforcing its status as fundamental science and, therefore, not concerning but rather something to be supported.

(2) Closing down the scope of deliberations to downstream risk and safety discussions cements the role of expertise and experts in governance through a reliance on technocratic assessments of risk. The two NGO participants in this study, framed by others as opponents of GM and synthetic biology, also used language of technocratic models of risk, reaching for more research, more evidence and broader risk assessment, but were more accommodating of public debate. This scope again seeks to frame the time for concern as downstream, attached to applications that might arise sometime in the future. Synthetic biology and its applications, as well as imagined applications, were perceived by all in various ways as potentially risky for the environment, human health and animal welfare. Synthetic biology was also thought to pose intangible risks, such as to people's connections to food. It was deemed potentially ethically questionable in terms of applications to animals, or because it may result in unequal distribution of benefits and negative impacts on farmer livelihoods. Indeed, discussions around GM's risks also encompassed such a range of objections, including those that were technical and non-technical, tangible and intangible. For participants who were proponents of synthetic biology, controversy around these aspects of GM was viewed as traumatic, conflictual, "irrational" and, broadly, to be avoided going forward, mitigated instead through strategic communication with publics.

(3) Scientists and participants involved primarily in governance tended to 'other' non-scientific actors and views (publics, social scientists, NGOs, broad stakeholders), shaping assumptions about their legitimacy and potential roles in deliberations about governance. To take a Finitist view, it is reasonable to suggest that this is informed by assumptions rooted in experiences of GM controversies, namely a sentiment that scientific authority is under attack from those with opposing views and is something to be protected. My research also finds that many assumptions about others' views on risks, benefits, ethics and potential (un)acceptability are drawn from experiences of GM controversies. For my participants, these appeared to inform views about publics and how they might be communicated with or managed, including a range of notions about (mis-)understandings of science, and is captured in my concept of GM Trauma.

Taken together, these three aspects, as well as well-studied and debated power dynamics entrenched in policymaking and scientific communities (e.g., Collingridge & Reeve, 1896; Yearley, 2005) provide a picture of some of the assumptions, "visions, values and purposes," that may performatively and normatively drive synthetic biology forward (Marris & Calvert, 2020:37). While "alternative arguments" are sometimes heard against technocratic risk models, ELSI-type engagements with society, the Deficit Model and linear models of innovation and scientific progress, these have no lasting results. My research suggests that the views of 'others' (including publics, NGOs and social scientists) that have been pushed "outside of the realm of the 'scientific'" are routinely discounted by participants I interviewed. Perhaps the 'trauma' of past experiences of public controversies means that, for my participants, they have felt under attack from those 'outside' and so are defensive rather than conciliatory and open-minded when considering the views of others. When this defensiveness is coupled with unchanging views about the primacy of science and the technoscientific approach to assessing risks which dominates existing policy processes, there seems to be little motivation for these participants to reconsider the relationships between the realms of the scientific and the social.

Perhaps the main implications of synthetic biology for food policy, then, relate to the questions of who might be involved in decision-making, to what end, and how synthetic biology-related policy might fit in with other food policy priorities relating to integrating environmental, social, health, and livelihoods goals. It also begs the question, alluded to by Tait (2009), to what extent is this synthetic biology landscape itself conducive to controversy?

8.3.4. Past, present, future controversy

Nelkin states: "Conflict persists. Even as individual disputes are closed, the same tensions recur in other contexts" (Nelkin, 1987:293). My empirical research finds that this assertion holds water in the case of views towards synthetic biology's food and agriculture applications, with these recurring tensions stemming from experiences of, and observations about the results of, GM controversies: GM Trauma.

In the case of synthetic biology, participants seem to have "internalised" past GM controversy (Molyneux-Hodgson & Meyer, 2009:137). Many perceived injustice or unfairness in how GM was publicly received or regulated. Almost all shared a sentiment of something having gone wrong during GM controversies, with those involved first-hand roundly feeling that they had 'lost' the arguments, failed to assert their positions, engage in collaboration or dialogue, or achieve what they had wanted for GM. Those with second-hand experiences also tended to perceive GM controversies as something complex to be learned from, and, like those with first-hand experiences, believed that similar objections might reoccur in the case of synthetic biology. This is exacerbated by uncertainties about publics' views towards the field[23], meaning participants relied on perceptions about how GM food is or was viewed by others, as the closest similar example. GM Trauma therefore informed many participants' consideration of the potential for controversies when describing imagined synthetic biology futures.

Underlying visions of synthetic biology's futures, and feelings that controversy of the type around GMOs might reoccur, was a focus on public acceptance or rejection. This often had an economic theme, conceptualising synthetic biology as something to be commercialised, and in turn to be accepted (many hoped) by publics as consumers (Von Schomberg and Blok, 2019; Marris & Calvert, 2020). Controversy, leading to public rejection, was considered a central feature of participant views on whether synthetic biology would have economic success or not. Attaching notions of synthetic biology's trajectory to its market potential is a rather narrow focus, unconducive to the interrogation of its actors' purposes, goals, hopes, expectations and any perceived directions of travel (Von Schomberg and Blok, 2019; Marris & Calvert, 2020). For many participants, with differing experiences of past GM debates, the

[23] Prior research in this area instead finds that attitudes towards GM (and indeed, towards synthetic biology) are varied and nuanced at the individual level, and highly context-specific (Frewer, 2013 & 2017; Marris 2001; FSA & Collingwood Environmental, 2020:21; Kamrath *et al*., 2019; Jin *et al*., 2019; Bauer & Bogner, 2020; Dragojlovic and Einsiedel 2013).

direction of travel of synthetic biology towards commercialisation was considered as inherently a 'good thing' (as was scientific progress in general). Participants felt that publics 'thwarting' this commercialisation would be an inherently 'bad thing'. Similar attitudes have been observed elsewhere in the literature, with Marris & Calvert (2020) describing how synthetic biology can sometimes be represented by its stakeholders as a 'juggernaut' ploughing on despite any opposition.

One alternative to a view of synthetic biology as a 'juggernaut' is presented in the RI work of Owen *et al.* (2012). It focusses on considering what the trajectory of synthetic biology could, or should, look like. For my participants, this imagined trajectory of synthetic biology took a number of forms. Many participants spoke of the ways in which synthetic biology could be desirable, such as its potential to offer environmental or animal welfare benefits. However, those working in other public and private sector organisations were most likely to view these same environmental and animal welfare goals as achievable without synthetic biology, indeed viewing synthetic biology applications as potentially problematic due to unintended environmental consequences and a lack of informed consent of communities. Furthermore, synthetic biology approaches were even described as highly unnatural, "another step down a wrong road" in terms of peoples' disconnect from their food, and a cause of discomfort around a perceived increasing role of technoscience in food systems. Many of the scientists and policymakers I interviewed dismissed views of such scope (linked to unnaturalness) as unscientific and unimportant.

Participants more often discussed the potential for synthetic biology to be controversial through a narrow lens of perceived future risks and what publics will think about these. Based on restrictive, technocratic, risk-focussed framings, there was tendency to problematise synthetic biology or to assume others would problematise it, as GM was perceived to have been problematised. Some participants involved in scientific or governance work also sought to distinguish synthetic biology from GM in order to frame its risks and benefits in certain ways. For example, they suggested that synthetic biology is "more sophisticated" than GM and its risks more controllable. Many constructed synthetic biology as novel, with potential to offer more or different benefits than GM, and with its risks conceived of as 'downstream'. These are possibly attempts to avoid negative public opinions associated with GM. Such dynamics are noted by Tait (2009:150), who describes:

> [T]wo agendas are being played out here. There is the desire to encourage investment by claiming novelty and also to differentiate synthetic biology, at least in Europe, from the stigma that has become associated with GM crops.

> However, playing with words and definitions has not in the past been able to divert public concerns away from specific areas of development and is unlikely to do so now.

These views and agendas appear as relevant now as over a decade ago, and as several decades earlier during the height of debates around GM crop development. That makes Tait's next point all the more potent: "what are we learning from this earlier experience that is useful for the development of synthetic biology[?]" (2009:150-151).

Tait (2009:151) goes on to suggest that "stakeholder engagement […] may be important but it will not guarantee a smoother ride for synthetic biology compared to GM crops." Here, Tait (2009) raises the same question that Marris and Calvert (2020) return to almost two decades later. My analysis, using a Finitist lens and my concept of GM Trauma, suggests that Tait may be correct that stakeholder engagement will not be enough to avoid controversy and "guarantee a smoother ride for synthetic biology compared to GM crops". This is not least because the feelings of conflict and threat between stakeholder groups arising from GM controversies, and a resulting defensiveness, still endure. A picture then emerges of an inside/outside distinction, similar to that identified by Jasanoff (2003) and others, where policymaking 'insiders' include scientists and policymakers, operating in spaces dominated by science authority and where the GM controversy experience and assumptions about publics are internalised. It is difficult to envisage how fruitful stakeholder engagement can take place in such a context.

Nonetheless, it was very common for participants to advocate for discussion, transparency, and debate on potential synthetic biology futures. However, when starting from an assumption that disagreement and controversy are likely unless debates are carefully managed, these activities might sometimes be tinged with more of a sense of educating or persuading, alongside "listening and learning". This may be exclusionary to the visions, values, and priorities of groups and individuals seen as on the 'outside', whose views are seen as something to find out, react to, or shape, as synthetic biology progresses.

Perhaps a form of deliberative politics the likes of which were constructed in the UK to debate GM foods (see Jasanoff, 2005) could be one approach to mitigate this. Clearly there is deliberation to be had around the "kind of future [that] we want innovation to bring into the world" (Owen *et al*., 2012:758). In particular, the subject of synthetic biology's role in potential food and agriculture-related environmental strategies, raised spontaneously by most participants, might be a fruitful anchoring point for these discussions. However, participants were broadly uncritical about the extent to which any deliberative activities might be undermined by assumptions about who ought to be involved in them, belied by value

judgements about expertise, suggestions about how publics might be communicated with and to what end. Further, perceived fragmentation of stakeholder actors and groups across both governance and practice may pose challenges for any collaborations.

In short, the legacies of GM controversies appear to remain alive as kinds of historical memories for participants, of conflict, and of confrontations between proponents' ambitions of forwarding genetic technoscientific developments as a public good, and publics receiving them as inequitable, undesirable, or an affront to the natural. GM Trauma likely endures because of a sentiment that something went wrong during GM controversies, or that something was 'lost'. The majority participants were promissory about synthetic biology, and their GM Trauma influences how they conceptualised others and how to treat them, with a view towards remedying or avoiding repeating controversy. For many, from this comes an insularity based on characterisations of publics, NGOs, and the press, for example, as threatening, which has relevance for policymaking. Can these differences between stakeholder groups be bridged? If so, how?

8.3.5. Policymaking table

Questions of bridging differing stakeholder values, interests and beliefs in policy contexts are linked to who might be involved in decision-making, or around the policymaking table. Finitism provides that human understandings and uses of concepts are informed by processes of comparing and evaluating new ideas against a finite catalogue of previous ones. While each of us has only a finite range of perspectives and experiences on which to draw, the range of ways in which humans *can* perceive and experience is potentially infinite. These conceptual understandings are then shared and negotiated socially until a communitarian understanding is reached, which in turn can be refined and revised continually through such social processes. Humans socially develop and share a vast range of perspectives, shaped by the trajectories of their lives, influences, interests, biases, values, social and historical contexts, and so on. In short, just as we can understand something one way, so too can these understandings come to change.

It follows, then, that incorporating a range of individuals from varied backgrounds into, for example, policy spaces can promote new ways of thinking, and can challenge and adjust established ideas and concepts. While not every scientific advisor in this policy space was interviewed as part of my research, all those that were had first-hand experiences of GM controversies. This is perhaps unsurprising, as with a longer period spent working in this field comes seniority, experience and these can help consolidate a person's position as an expert. My

research also suggests that those with first-hand experiences of GM controversies had the clearest view of these events as a 'failure' or a 'loss'. These participants often deployed unhelpful binaries. They also tended to characterise other stakeholders as untrustworthy, unknowledgeable opponents, and conceive of publics as a problem to be managed.

By contrast, those without first-hand GM controversy experiences were the most likely to have nuanced understandings of the relevant debates, were the least likely to draw on binaries, or to appeal to limiting notions of 'opponents' and 'sides'. This group perceived GMOs' relationships to our food and agriculture as profound and complex, and felt that synthetic biology would be considered in similarly rich ways. They were likely to conceive of synthetic biology's risks, ethical implications and perceived (un)naturalness as similar to those associated with GM, in turn multifaceted and context-dependent. Rather than obstacles to be overcome through technoscientific risk assessment, these were thought of as subjects that needed to be exposed to broad public questioning, such as about "how they will impact both positively and negatively on our experience as consumers of food".

It is worth adding that many of those I interviewed with second-hand experiences of GM controversies displayed similar worldviews. These participants held broadly scientistic, technocratic, anthropocentric understandings of the world, except for Org1 and Org4. All but three of them were STEM trained to degree level. This likely suggests that access to roles in this area is limited to those with scientific training and perhaps most appealing to, or fulfilling for, those who have these worldviews. I also only interviewed one individual working in a scientific role who did not have first-hand experiences of GM controversies. Despite these limitations, my findings might bring hope that this group of stakeholders have taken something different from GM controversies than those who experienced them first-hand. The result seems to be a tendency towards more thoughtful and accommodating consideration of others' reactions to GMOs and synthetic biology. I suggest that this might make these stakeholders well-placed to play prominent roles in the governance of this area.

For the moment, though, those with first-hand GM controversy experiences dominate the policy space and advisory roles, bringing with them a number of challenging viewpoints which supported their understandings of synthetic biology and how it might be governed. However, their GM Trauma itself could also be viewed as encouraging. Participant views about conflict and controversy suggest that there are ways in which scientific and policy communities absorb and internalise public expressions of disagreement with developments within emerging technoscientific fields. There is sometimes an imaginary that scientists and their endeavours

inhabit separate, exclusive spaces in universities and laboratories, and that these spaces are inaccessible to commentators and opponents. As such, scientists and science (or Org6's 'technical world') may be conceptualised as something to be protected from, or defended against, the political, cultural and social dynamics and debates in which they exist (Org6's 'political world'). However, clearly, past public debates, commentary on and opposition to scientific activities like GM do have a (lasting) impact on those involved. Not only were my participants conscious of and sensitive to GM-related debates, but the sense of GM Trauma also had a focus on futures, as participants expected comparable future controversy around arguably similar technologies. Therefore, controversial topics might be conceived as points of contact between those developing a technology and those expected to 'receive' or 'accept' it – publics - rather than solely a frontier of conflict.

It might be more useful, therefore, rather than conceiving of controversy as a barrier to scientific progress, to recognise it as one avenue for publics to encourage scientific communities to question their work, or to offer messages that can be carried forward into future work. In short, those developing synthetic biology and relevant policy could reflect on which messages publics, NGOs, and other perceived 'opponents' were conveying in their debates around GM controversies. In parallel, they could consider why this controversy remains so sensitive and salient in the minds of synthetic biology stakeholders (i.e., why is it unresolved?) and how this might be limiting the field's opportunities to find new directions or positions within society, particularly in today's socio-political context, viewed by some as opportune for new policy development. Existing bodies like the Engineering Biology Leadership Council (EBLC) could instigate stakeholder engagement activities with the focus of fostering actively more nuanced views of one another's positions. Similar activities could be promoted through existing funding mechanisms. If such activities are to be incorporated into current funder-provided Responsible Research and Innovation training at the individual synthetic biology project level, then funding could be increased for these strands of work.

Looking ahead to the future of policymaking in this area, it is valuable to consider how a broad range of stakeholders might be embedded into formal decision-making processes, validating views and countering the dominance of scientific expertise. Spaces like scientific advisory committees are potential sites where formal participation opportunities for a range of stakeholders could be built into regulatory decision-making today (i.e., novel product approvals). One suggestion for a "new, more integrated approach to stakeholder interactions" has already been made in a June 2022 policy brief produced by the Regulatory Horizons Council (2022:4). This brief recommends the creation of a Stakeholder

Advisory Panel in addition to existing scientific advisory committees[24], as well as explorations of public attitudes and a requirement for companies to work in demonstrable compliance with a responsible innovation standard (Regulatory Horizons Council, 2022:4). The role of this proposed Stakeholder Advisory Panel alongside other parties, such as DEFRA and BEIS, is framed by the Regulatory Horizons Council's (2022) view that governance should feature "product/sector-based scrutiny," rather than process-based approaches as at present (visualised in Figure 4 on the following page).

However, there is no explanation in the Regulatory Horizon Council's policy brief (2022) of who would be involved in judging whether there "are classes of product emerging that lead to societal or other stakeholder concerns" (the green diamond in the diagram in Figure 4). In short, who would be the gatekeeper in this scenario and on what basis would gatekeepers be making a judgement about the potential concerns of others? Furthermore it is unclear how stakeholder panels might be convened beyond the statement that they could be "potentially sponsored by the Department for Business, Energy and Industrial Strategy (BEIS), representing all stakeholders involved in the development, production and use of products of new genetic technologies along with public/lay representation" (Regulatory Horizons Council, 2022:4). Given the complexity and international nature of food supply chains discussed by participants, it might be challenging to represent all stakeholders, and may result in large, heterogenous panels.

Alternatively, scholars like Tim Lang and others (e.g., Lang & Heasman, 2004; Lang *et al*., 2009) have long called for a cross-departmental food policy organisation within government, to draw together food policy-focussed academics with actors across environmental, health, social and economic dimensions. This hypothetical solution would be radically different to the present policymaking set-up around GM and synthetic

[24] However, the Regulatory Horizons Council policy brief (2022:6) also contains a proviso about the potential disadvantages of embedding stakeholder deliberation into product authorisation procedures:

> **[E]ngagement with stakeholders should relate to the products, their qualities and how they will be regulated, rather than to the technologies themselves.** Making the change to a product-based regulatory system could enable more equitable engagement with a wider range of stakeholders, taking account of the development stage of a product, its benefits and risks and the degree of certainty about its future properties, and considering how products should be developed and regulated. Our proposed regulatory pathway includes a new Stakeholder Advisory Panel to manage this new approach to dialogue.
>
> Where a stakeholder concern relates to a broader societal issue, such as the nature of farming systems or animal welfare, these may be better addressed through other areas of public policy and regulation, such as the Animal Welfare (Sentience) Act, 2022. There are no benefits, and potentially considerable losses, if a safe and useful product is rejected because it might have an impact on a broader societal issue, particularly where that is already addressed by other policy or regulatory regimes. (Regulatory Horizons Council, 2022:6, emphasis in the original)

biology, situating its governance alongside a broad range of other competing food policy priorities, but may promote a less scientised approach

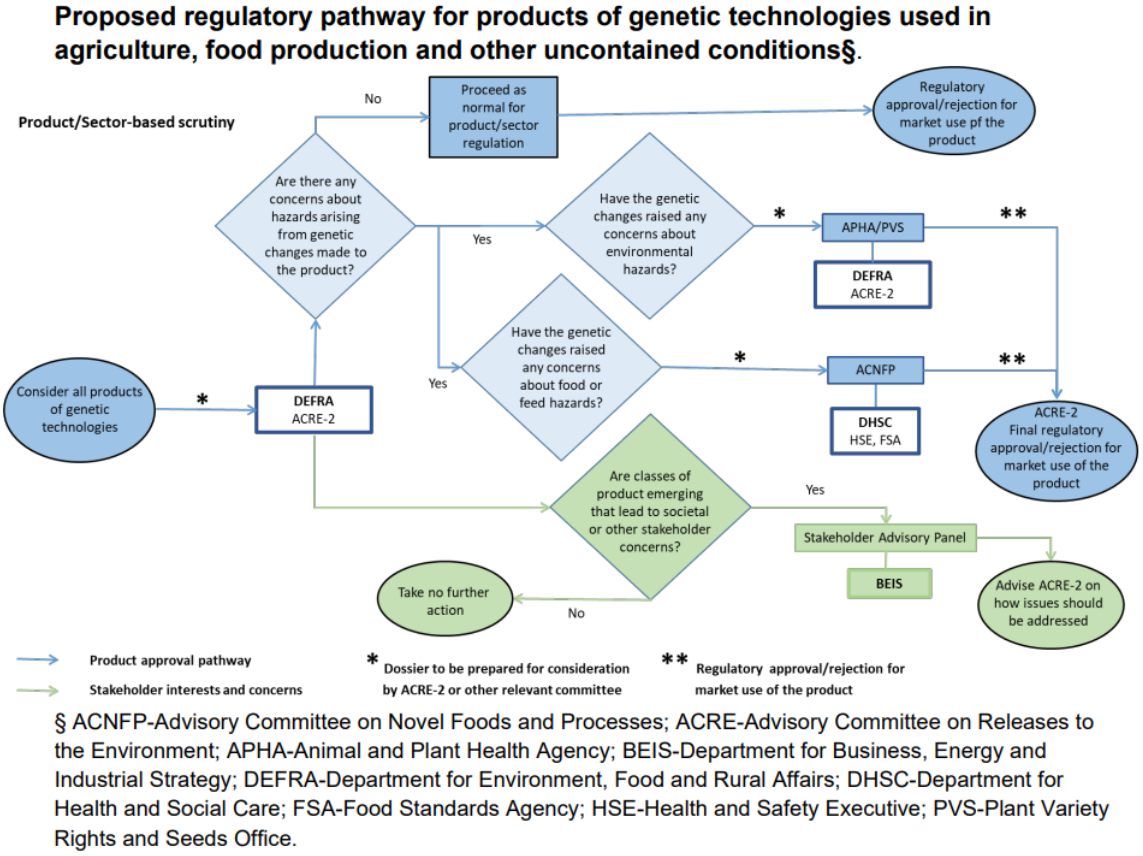


Figure 4 - Proposed regulatory pathway for products of genetic technologies used in agriculture, food production and other uncontained conditions (Source: Regulatory Horizons Council, 2022)

8.3.6. Synthetic biology's relationship to food policy priorities for health, environment and livelihoods

Earlier in this discussion, I asked: How might synthetic biology-related policy fit in with other food policy priorities relating to integrating environmental, social, health, and livelihoods goals? Participants indicated that synthetic biology could have implications for each of those factors, as well as animal welfare, but discussions of the implications of synthetic biology for human health and nutrition were limited. Typically, participants either framed synthetic biology vaguely as a potential solution to perceived food sector challenges, or as a source of potential risk. For example, many discussed how releasing engineered organisms may present a challenge for human (as well as environmental) health (Jefferson *et al.*, 2014; Wimmer, 2018).

During the process of reviewing the literature on synthetic biology's implications for human health, it was sometimes difficult to distinguish promises from achievements. For example, several papers demonstrate overstatements about the achievements of synthetic

biology across various themes. However, some possibilities for synthetic biology's implications for human health (based on scientific research papers) include engineering foods to have improved nutrient contents, engineering microorganisms in packaging to monitor and supplement nutrients of on-shelf foods (Tyagi *et al*., 2016). Tyagi *et al*. (2016) also outline possibilities for synthetic biology biosensors in packaging to change colour or supplement nutrients if these are degraded in the product. Tyagi *et al*. (2016) go on to describe ways in which synthetic biology could be useful in altering the micronutrient content of foods but go further to suggest reductions in energy content and macronutrients. In a medical context, Tyagi *et al*. (2016) describe the engineering of microbial communities, such as probiotics. This application would entail the distribution and consumption of live, engineered microbes designed to improve digestive health or to change colour of faeces to alert consumers to health concerns (Tyagi *et al*., 2016). Elsewhere in the literature, functional foods are repeatedly nominated as a target area for synthetic biology applications, which authors claim would be both commercially viable and publicly acceptable (Liu & Stewart, 2015; Jin *et al*., 2019; Goold *et al*., 2018). None of these examples were discussed, and instead my participants focussed on food safety as a narrow health priority, or offered passing comments that food produced through synthetic biology should be 'healthy' and might contain more vitamins.

By contrast, notions of environmental sustainability, and the impacts of food systems on the environment, were raised spontaneously by all participants. They were discussed in various levels of detail by 29 participants, and briefly acknowledged by the remaining one, who felt they did not have the expertise to discuss them. Participants clearly associated food policy and synthetic biology with environmental implications. Often, participants expressed that food policymakers should focus on the climate crisis as a priority, discussing plastic waste pollution, greenhouse gas emissions, and land use, sometimes linked with rewilding and biodiversity. Participants suggested that this could present co-benefits for both the environment and the economy. For example, through generation of a bioeconomy focussed on environmentally-driven innovation, jobs and training might be generated for skilled workers.

On the environmentally-focussed applications of synthetic biology to microorganisms, participants described how plastics or other environmental pollutants might be broken down, or alternative packaging materials might be produced. In crop plants, it was viewed that some applications (such as nitrogen fixation) might offer improvements in on-farm efficiency, resilience to climate challenges, and productivity, or contribute to reduced need for agricultural inputs like fertilisers, possibly leading to economic benefits for farmers and improvements in soil health and biodiversity. However, participants also felt that engineered plants would likely

be farmed through standard agricultural practices like monocropping, as has been the case with genetically modified soya and corn, rather than supporting any shift away from these methods. Synthetic biology in crop plants was also sometimes envisaged as a potential risk to the environment. Its riskiness was particularly conceptualised as a lack of controllability of synthetic biology organisms when planted, given the possibility of unintended or unexpected consequences or persistence of applications (like "weediness" in plants, or gene drives designed to be passed down to an organism's offspring).

When discussing synthetic biology's environmental applications, participants also discussed how animal product analogues might lead to reduced meat consumption, offering co-benefits for human health, the environment and animal health and welfare. Participants described example animal product analogues (products designed to replace or replicate animal products) such as cow's milk and hen's eggs derived from microorganisms, and products including lab-grown meat. According to Froggatt and Wellesley (2019:4), meat analogues, like those that might be derived from synthetic biology, are distinct from meat alternatives (e.g., tofu, soya-based meat-like products) because they are "aimed at meat-eaters rather than vegetarians or vegans". While this definition is debatable (and, arguably, too limited) the market for alternatives to many animal products, including meat, had been until recently growing (Froggatt and Wellesley, 2019). Froggatt and Wellesley (2019) suggest that there might be arguments for the expansion of analogue products, including for animal welfare and environmental sustainability reasons, and the trend is linked to growing understanding of the impact of animal agriculture on the environment and public health, and an increasingly 'conscious consumer' opting for plant-based products.

One of the most well-known and commercially successful of these products is Impossible Foods' range of Impossible™ products, including the Impossible™ burger. Several participants described the Impossible™ burger, which contains a compound called Soy Leghaemoglobin, derived through the fermentation of genetically engineered yeast (Impossible Foods, 2020a). This compound is designed to give the products a bloody, meaty taste. Some participants described the Impossible™ burger positively, feeling that it would contribute to reduced meat consumption. One participant with first-hand GM controversy experiences felt that the burger had been too loosely regulated under the current US system and that more evidence on the safety of the synthetic biology-derived Soy Leghaemoglobin might be beneficial. They understood synthetic biology products to be risky, and their producers to be untrustworthy, perceiving the GM industry in similar ways. The participant did not provide evidence to support their suggestion that the burger may be unsafe, but questions could be asked

around the benefit of the product. It is a highly processed burger product designed either to be prepared at fast-food chain outlets, or at home. There is also little evidence to suggest that plant-based products such as burgers are displacing meat products or contributing to a reduction in meat consumption.

Questions also remain around another animal product analogue, perhaps the most experimental in research and development: lab-grown meat, sometimes also called cultured meat or cellular agriculture (Froggatt and Wellesley, 2019). The trajectory of upscaling lab-grown meat is unclear, due to several inhibiting factors such as cost and the possibility of a lengthy regulatory approval process (in the EU, for example). Questions also remain about whether the cells used to culture lab-grown meat will need to be genetically modified, as mentioned by Sci10, and what this might mean for the field's acceptability, regulation, and labelling. Furthermore, Sci10 mentioned that there is some uncertainty around the growth serum used for culturing lab-grown meat, which remains typically of animal origin, although work is ongoing to engineer this as well. Overall, participants felt that lab-grown meat might contribute to reduced animal-meat consumption, but is currently prohibitively expensive, unlikely to offer added benefit for human health over animal meat, and may be controversial, challenging, or resource intensive to scale up, not least regarding the use of materials to build production facilities, raising questions about its sustainability.

The term 'sustainability' has been repeated several times in this thesis so far, without definition. This is in part because the parties cited either make reference to the UN's Sustainable Development Goals 2030 (SDGs), or do not offer a definition of the term. 'Sustainability' or 'sustainable development' have become buzzwords signifying an interwoven picture of several concepts, but which themselves remain defined only in general, vague terms, such as:

> In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." (UNAI, 2020)

This definition of sustainability was designed to refer to concepts of economic and environmental sustainability. Economic sustainability is often framed in the sense of sustainable development or sustainable intensification, both of which are underpinned by the assumption that productivity and yields across all sectors must increase to satisfy the needs of an increasing global population, and that poverty can be eradicated through this. Environmental sustainability is often packaged together with the idea that sustainable development should be achieved without increasing use of the earth's resources (land, water, fossil fuels). This is

further complicated by interrelated health and social arguments that for development to be sustainable, it must not be to the detriment of human, animal, and planetary wellbeing.

Perhaps due to the breadth and ambition of the UN SDGs, the most prominent international strategy on environmental sustainability, (also noting the use of absolute language – e.g., 'all', 'everywhere', echoed in Newcastle University's definition of sustainability "enough, for all, forever"), it is plausible that synthetic biology could play a role in achieving some of these goals. However, this is not well characterised. Most company websites viewed in the production of this thesis do not articulate in concrete terms their contribution to sustainability in the present day. Example academic papers on the subject, like French (2019), are forward-looking, promising opportunities for synthetic biology, as well as possible trade-offs between environmental health, social and economic priorities. As Benessia and Funtowicz (2015) put it, in many cases, this begs the question "what do we want to sustain, and for whom?" The answer to this question varies by context and according to understandings of sustainability at the individual, organisational, national, and international level, and is something that participants did not illuminate.

In a food policy context, there is much discussion of how to marry environmental sustainability with improvements in human health, for example, but almost no discussion of how synthetic biology might fit in to this picture. Within such a complex picture, synthetic biology's current contribution to sustainable food systems or sustainable diets is arguably negligible, and policy does not appear to be designed to facilitate steps in this direction. There is a need for critical reflection on the value of promises of future achievement within synthetic biology, and for a focus on grounding (and evidencing) sustainability ambitions in the present instead (Benessia & Funtowicz, 2015), asking: What does sustainability look like in any given synthetic biology context, and is this something of which policy (e.g., funding or product regulations) is supportive?

Many of my participants appeared to view policy through a set of narrow priorities around economic drivers (funding, investment, commercialisation), scientific progress, and risks or benefits. Participants did discuss interests like environmental and animal welfare benefits, but there was little discussion of human health and nutrition beyond potential adverse effects on food safety of the technology, and there was only scant focus on the livelihoods of those involved with food supply chains. Interestingly, participants did not typically consider food policy considerations to be their responsibility, despite widely acknowledging potential (and current) application of synthetic biology to food and agriculture. This contributed to a sense of

“that isn’t something that I do” or shifting responsibility to others in the array of the field’s actors. This may point to a need for further research discussing synthetic biology with food policymakers more specifically.

What interviews with my participants did more clearly illuminate, when analysed through a Finitist lens, is that participants’ past experiences of, or observations about, GM controversies shape their views about synthetic biology. This, their GM Trauma, is in turn of food policy relevance because it has implications for relationships between stakeholders, their involvement in policy spaces, their interactions with publics, and their understandings of which types of policy approaches they consider to be desirable.

Chapter 9: Conclusion

9.1. Introduction

As I am making the final edits to this thesis, I am reminded that, over the course of this PhD, I have spent a lot of time exploring with ideas of how synthetic biology might shape the future of food and agriculture. All the while, synthetic biology stakeholders have been striving to do just that.

For many, synthetic biology offers hope and opportunities to address some of the more alarming questions for food policy today. Considering the climate emergency, pollution of all forms, myriad inequalities and humanitarian and economic crises, today's food system challenges are vast and global, and a few of them may indeed require technological solutions. As one interviewee, Sci4, told me: "if we had three really hot summers and crop failures in a row, you can imagine lots of people just looking at all the plant scientists and saying, 'But are you working on stress tolerance? Why haven't you come up with anything?'" Sci3 also summarised: "If things could be done with bread and butter, that would be wonderful but, in many cases, you can't do things unless you bring in super sexy technologies for reaching that objective." Perhaps, to paraphrase someone else's more dystopian view, we might not even have bread and butter if we do not consider a range of approaches, including technoscientific ones.

Food, necessarily, is the fuel of human survival. But it is also about much more than that. There is tradition, culture, creativity, alongside passion, obsession and graft. In my previous job, I saw sardines cleaned and packed individually, by hand, by Moroccan women into cans that were then sold for 34 pence each in British supermarkets. This is just one example of a product many consume in seconds without a thought of the time and effort it takes to produce. And, I would add, without a thought of the skills passed down through generations, many of which have long since muddled together with science, technology, mechanisation, and automation.

During my three years researching this topic, I have often paused to think about what it would mean for food and food producers if synthetic biology's applications do reach the stratospheric heights sometimes promised of them. In my research, this question inspired a range of reactions. For one interviewee, this would represent another step down a path of ever increasing disconnect from our food and its producers. For others, it could be a means to a greener, utopian end, a better future. I suppose, images of industrial bio-fermenters might one day communicate strong, even beautiful, messages of human inventiveness and, perhaps,

progress, depending on the viewer's position. Maybe we will come to regard them like we might a whisky still today. On the one hand, spectacularly fit for purpose. On the other, representative of the dragging of industries that were once artisanal into the expansiveness, abundance and challenges of the 21st century.

Until then, there are questions to consider around synthetic biology's potential futures, who and what is directing them, and to what end. The previous chapter discussed my research findings in relation to the literature and answered the research questions on synthetic biology's potential implications for food policy, and food policy's implications for the field. It also set out the main findings of this thesis– that GM Trauma is an important factor underpinning stakeholder views on what synthetic biology is, how it might be perceived, how it can be governed, who should be at the policymaking 'table', and why. GM Trauma also contributes to a sense of expected controversy and conflict, which plays out in policy spaces as assumptions about publics and their views, as well as fragmentation of responsibilities across the field's actors and the exclusion of stakeholders like publics and NGOs from policy discussions.

This chapter concludes my thesis with a summary of the recommendations for food policy, as well as synthetic biology-related research and funding policies. I go on to offer recommendations for further research, some of which derive from a policy brief I wrote during my fieldwork period. Finally, I give some concluding remarks about how my research makes an original contribution to this area of research.

9.2. Policy recommendations

Recommendation one: Embed a range of stakeholders in decision-making spaces like Scientific Advisory Committees and funding boards.

Based on my findings that participants routinely highlighted the dominance of scientific expertise in policy spaces, current processes might be restrictive of wider debate and opportunities for publics to shape synthetic biology's trajectory might be missed. These aspects might also contribute to siloed approaches to governance, not taking a systems view of food policy or considering trade-offs and co-benefits for environment, human health, livelihoods and animal welfare, for example. Building on the Regulatory Horizons Council's (2022) recent policy brief, in order to take some steps towards balancing the roles of science authority with stakeholder advice, a straightforward approach might be taken wherein a stakeholder advisory panel *always* reviews and comments on decisions taken by a scientific advisory panel. An accompanying time limit on decision-making might go some way towards addressing views

that current regulatory processes are time consuming, ensuring that advisory committees take authorisation decisions in as timely a way as possible.

Recommendation two: Audit current governance processes with a range of stakeholders regularly, for example, every three years.

Participants viewed synthetic biology as novel, growing and expanding, with potential for unforeseen risks and implications for policy. Participants also described a policy process that was reactive to applications emerging. Both points suggest that routine audits of governance processes might be useful. Such audits could be accompanied by horizon-scanning work on synthetic biology's ongoing developments, by civil servants (e.g., researchers in POST) or obtained via reviews funded through existing funding mechanisms. Reviews should be based in part upon emerging applications and the developments of funded research projects, and their potential implications. They should also consider the effectiveness of procedures for monitoring and evaluation, particularly in cases where formal risk assessment is no longer required under amended GM regulations.

9.3. Suggestions for future research

I recommend the use of existing research funding mechanisms to incentivise and support future research in the following areas.

Area one: UK attitudes towards synthetic biology's development and trajectory

Participants often made assumptions about the attitudes of publics, based on experiences of GM controversies. These assumptions have long been shown by STS scholars to be unrepresentative of the nuanced views of publics (e.g., Marris, 2001; Wynne, 2001). Making assumptions about public views of synthetic biology based on past attitudes towards GM crops also does not take into account the importance of contextual factors and framings in attitude formation.

Quantitative, qualitative and creative methodologies could be combined to research these attitudes, with an aim of elucidating some ideas about where synthetic biology might go, which futures might be desirable, and which might not. The contextual importance of social, cultural, political, historical and economic factors should also be explored.

Further, a review of UK news media coverage of synthetic biology and its applications in the UK would also be useful to contextualise any findings on the topic's salience and interest that might be uncovered through public attitudes research.

Area two: Synthetic biology research in areas aligning with UK & global food policy priorities

Participants often made statements about synthetic biology's potential to provide solutions to food production-related environmental challenges. It was suggested that synthetic biology could play a role in, for example, climate change mitigation and adaptation. Participants also alluded to synthetic biology's promise for providing 'healthy food' (perhaps, preventing diet-related ill health, such as forms of malnutrition like obesity and hunger), but it is unclear which forms this might take, and participant views on this were vague. Funding could attract research to these areas. Further, research on the *implications*, positive and negative, of synthetic biology for the environment, nutrition and farmer livelihoods in food and agriculture would also be of benefit.

Area three: If or how regulators, advisory committee members and other stakeholders distinguish between GM foods and synthetic biology food products or ingredients

The synthetic biology stakeholders involved in my research tended to assume that others would compare GM and synthetic biology and themselves constructed boundaries, similarities and differences between the two fields and their products. As synthetic biology progresses, policy shifts and changes, and products potentially undergo processes of authorisation and regulation, it would be useful to research the ways in which those involved in regulation understand specific synthetic biology food products and ingredients (or categories of these) in relation to GM foods, and the implications of this for governance.

9.4. Conclusion

To conclude, this research finds that experiences of GM controversies, or GM Trauma, shape views on synthetic biology's definitions, boundaries and status as potentially controversial or risky or not. GM Trauma also frames discussions about how publics might be engaged with, communicated with or managed. It supported views about the status and value of scientists and science in policy arenas, sometimes to the exclusion of other stakeholders. Participants felt that past controversies have resulted in a governance framework perceived as reactive, stifling and draconian. However, participants also conveyed a view that current governance is "probably strong enough", particularly to manage risks to food safety and the environment. Nonetheless, participants supported a shift towards product-based governance approaches, instead of the process-based ones at present.

GM Trauma has practical implications. Perceptions of past controversy and conflict also seem to manifest as an expectation of future controversy and conflict. This contributes to a sense of defensiveness, driving stakeholder insularity because of a sensitivity to controversy,

and supported by views about their own roles and about the attitudes and roles of others. Fragmentation across stakeholders, the insularity of scientific and policy communities, over-reliance on scientific expertise in synthetic biology-related policymaking spaces and exclusion of other viewpoints promotes siloed thinking and a narrow focus on technoscientific notions of risk, safety, and economic priorities.

In short, synthetic biology's present risks are likely to be covered by the scope of current food policy, but the field's potential to play a part in food policy priorities around, for example, environmental sustainability, human health and nutrition, livelihoods, and social and ethical considerations, remains unclear. Open debate across society, and with a range of stakeholders, on the potential roles that synthetic biology might occupy in addressing these questions remains a vital priority for all involved in its development.

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Appendix 1 – UN SDGs

No.	UN's topic name	UN's Description
1	No Poverty	End poverty in all its forms everywhere
2	Zero Hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3	Good Health and Well-being	Ensure healthy lives and promote well-being for all at all ages
4	Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5	Gender Equality	Achieve gender equality and empower all woman and girls
6	Clean Water and Sanitation	Ensure availability and sustainable management of water and sanitation for all
7	Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable and modern energy for all
8	Decent Work and Economic Growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9	Industry, Innovation and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10	Reduced Inequalities	Reduce inequality within and among countries
11	Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient and sustainable

12	Responsible Consumption and Production	Ensure sustainable consumption and production patterns
13	Climate Action	Take urgent action to combat climate change and its impacts
14	Life Below Water	Conserve and sustainably use the oceans, sea and marine resources for sustainable development
15	Life on Land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16	Peace, Justice and Strong Institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17	Partnerships for the goals	Strengthen the means of implementation and revitalize the global partnership for sustainable development

Table 7 - United Nations Sustainable Development Goals (Source: UN, 2018)

Appendix 2– Interview Aide Memoire

Project Title: Governing Synthetic Biology: A food policy approach

Part of: Synthetic Portabolomics: Leading the way at the crossroads of the Digital and the Bio Economies.

Interview / focus group aide memoire.

Participant(s):_____ **Code:-**

_____

Notes to self are in italics and provide a reminder of points to cover, rather than a script to follow.

- Confirm consent to record

Start recorder!

Introduction

Start with thanks for their time and then a description of the structure of the discussion and a rough outline of the content.

- *The questions in the discussion are grouped into 4 sections that begin with you and your views then consider wider issues of governance.*
- *The questions cover areas such as your background and your impression of the field of synthetic biology, as well as governance of the field.*

Give a short description of what the aim of the discussion is and what will be done with the data gathered.

- *The discussion is aimed at building a picture of the views of stakeholders such as yourself about the governance of synthetic biology in food.*
- *It is about beginning the process of building a knowledge base for this topic, and generating a conversation about synthetic biology generally, and its possible trajectory.*

Remind participant that only Natalie Partridge, Dr Taylor and Dr Woods will have access to the recording of this discussion.

Consent & formalities

Go back through consent form detailing,

- *Consent to record the discussion.*
- *Consent to sharing the recording and transcript with supervisors.*

- *Consent to use quotes (anonymised and unidentifiable)*
- *Recommend having the Zoom call as the primary window open on PC*

Thinking in general about you–

Section 1. Basic information/preamble.

- Tell me a bit about yourself
- What is your area of work?

Listen out for areas that might require familiarity with regulation, e.g., GMOs.

Thinking about synthetic biology-

Section 2. The field.

Participants may vary in their consideration of what the field of synthetic biology is about and what it 'means'. Try to find out views on intentions within the field, and expectations for the field.

If participant(s) are researchers or experts in the field, begin here:

- (How would you define synthetic biology?) – *not generalists*
- What is going on in synthetic biology research at the moment that you know about?
- Are you aware of anything you think is good or important that's going on in the field?
- What are you aware of that is perhaps not so good?
- Have you come across any interesting applications or research?

If participant(s) are not synthetic biology researchers/industry experts, begin here:

- What do you know (if anything) about synthetic biology in general?
- When I say the term "synthetic biology" what springs to mind for you?
- What are your thoughts (if anything) on the future of synthetic biology? Where do you see the field going in the near future?
    - Benefits, risks, trajectory
- What about further along, in say 15-20 years' time?

Thinking about food –

Section 3. Synthetic biology and food

- Do you know of any uses of synthetic biology in particular food products?
- Can you think of any (other) areas where synthetic biology might be useful in food and agriculture? What do you think synthetic biology can do for the food industry in general, in terms of food production, manufacturing, distribution, product improvement

If GMOs raised, probe about attitudes towards GM compared to SB.

- What do you think synthetic biology-derived foods and ingredients will look like in the near future?
- What about later on – in say 20 years' time?
- Where do the priorities lie do you think, for those applying or seeking to apply synthetic biology to food and agriculture?
- Where should the priorities lie?

Thinking more now about the subject of governance –

Section 4: Governance

- (Turning to food policy - what is the horizon for food policy in the UK? How does synthetic biology fit in?) – *Food policy experts*
- What ethical/societal questions does synthetic biology raise for you?
    - Positive and negative. Benefits and risks.
- Turning to the governance of synthetic biology in UK food and agriculture specifically – do you know anything about current regulation in this area?
- Do you have any thoughts on how you might want synthetic biology-derived food to be governed, regulated?
    - In the UK.
    - Globally.
    - And by whom?

Listen out for thoughts on GM regs, over-regulation, labelling, risk, Brexit

- In your view, what should food policymakers focus on in the near future, in terms of synthetic biology?
    - In the UK.
    - Globally.
- *If not raised:* What about labelling?

Finally… Closing down interview.

- Anything important we haven't covered? Who else should I be talking to about this?
- CONSENT – if anything has made you uncomfortable, or if you're happy to be named in the thesis, let me know via email.
- Outline next steps – may contact again with follow-up questions, thesis to be complete c. 2023.

Close with thanks and the offer to recontact me if anything else occurs to the participant that they think we should know or think about.

Table 8 - Example aide memoire (Source: Author)

Appendix 3 - Recruitment materials

Interview invitation email text

Invitation email text

Dear (Participant),

I'm Natalie, a PhD student at Newcastle University. I came across your (work / name / organisation) during my research into synthetic biology's agri-food applications. I would love to (have a discussion with you / invite you to a group discussion) as part of my project, if you'd be interested.

My research aims to build a picture of what is on the horizon for synthetic biology and explore how the field might be governed in the UK. A key part of this is understanding (industry / academic / your NGO's / policymakers' / food producers' / consumers') views and ideas. As you are (working in this field / involved in researching this field / involved in policymaking / involved in the food industry), your help would be of great benefit to my study.

If you choose to take part: our conversation would last around an hour, at a time convenient for you. We would meet online via Zoom.

Our discussion would cover topics such as:

1. Your thoughts about synthetic biology in general
2. What is on the horizon for the field
3. What the future might hold for the field in a food context
4. Your views on possible approaches to governance.

Please find an information sheet attached for reference. This document contains details about how I will preserve your anonymity and confidentiality, and about the use and protection of data.

If you have any questions, please get in touch with me (details in my signature) or my supervisors Simon and Ken:

Lead supervisor: Professor Simon Woods - simon.woods@ncl.ac.uk
Co-supervisor: Dr Ken Taylor - kenneth.taylor@ncl.ac.uk

I look forward to hearing from you!

Kind regards,
Natalie
Natalie Partridge
PhD Researcher
Newcastle University
Room 2.19 Henry Daysh Building
Newcastle upon Tyne
NE1 7RX
+447707218919
N.Partridge2@newcastle.ac.uk

Table 9 - Participant recruitment; email invitation (Source: Author)

Project Title: Governing Synthetic Biology: A food policy approach

Part of: Synthetic Portabolomics: Leading the way at the crossroads of the Digital and the Bio Economies.

Dear (Participant),

Thank you very much for your interest in my PhD project!

In order to ensure the best use of the information I can obtain from our discussion, I would like to record it. Please complete the consent form overleaf, keeping one for yourself and I will keep one copy on record.

If you have any questions about the interview before we begin, please feel free to raise them with myself or my supervisor Professor Simon Woods.

Interviewer
Natalie Partridge
PEALS Research Centre,
18-20 Windsor Terrace,
Newcastle University,
Newcastle upon Tyne NE1 7RU
Tel: 07707218919
E-mail: n.partridge2@ncl.ac.uk

Lead Supervisor
Prof. Simon Woods
PEALS Research Centre,
18-20 Windsor Terrace,
Newcastle University,
Newcastle upon Tyne NE1 7RU
Tel: 0191 208 3254
E-mail: simon.woods@ncl.ac.uk

Should you have any concerns about this interview that you cannot resolve through discussion with myself or Prof. Woods, please contact the University Ethics Committee in confidence at the following address:

Chair of the Faculty of Humanities and Social Sciences Ethics Committee
Newcastle University, Newcastle upon Tyne NE1 7RU

Thank you very much,
Natalie Partridge

CONSENT FORM

Please tick or initial the box beside each of the statements to which you agree.

I confirm that I have been told about the aims of the research and have had the opportunity to consider this, ask questions, and have had these answered satisfactorily.	☐
I understand that my participation is voluntary and that I am free to withdraw at any time up until the point at which the thesis is in its final draft, without providing any reason.	☐
I understand that anonymised quotes taken from this interview will be used in the production of a PhD thesis, in publications, presentations, public engagement, or other public-facing activities.	☐
I consent to my anonymised research data being retained for a maximum period of 10 years, as specified in Newcastle University's **Research Data Management Policy Principles & Code of Good Practice**.	☐
I understand that my anonymised research data will be retained and stored securely, both digitally and in hard copy, in line with Newcastle University's **GDPR policy** and **Code of Good Practice in Research Data Management**.	☐
I agree to be contacted again if follow-up questions arise after this conversation. ***If you agree,*** *please complete one or both of the below options with your details:* Email address: _____ Telephone: _____	☐
I agree to our conversation being recorded and the transcript will be confidential to Natalie Partridge, Prof. Woods and Dr Taylor.	☐
I agree to take part in this study	☐

Name: _____
Signature: _____
Date: _____

PLEASE KEEP A COPY OF THIS FORM FOR YOUR RECORDS

Table 10 - Consent form (Source: Author)

Governing Synthetic Biology: A Food Policy Approach

Natalie Partridge, PhD Researcher in Sociology
Policy, Ethics and Life Sciences Research Centre, Newcastle University

Introduction

I am Natalie Partridge, a researcher at Newcastle University. I would like to invite you to be interviewed as part of my PhD project investigating the application of synthetic biology to food and agriculture, and the implications this may have for UK policy.

There has been little research on views towards the governance of synthetic biology as applied to the agri-food sector in the UK. My project takes an exploratory approach to addressing this knowledge gap.

My research is funded by Newcastle University and the EPSRC as part of a synthetic biology project called **Synthetic Portabolomics**.

Purpose of the study

The aim of my research is to understand views towards synthetic biology in food and to explore approaches towards regulating the field. I aim to consult widely with stakeholders to discuss the future of the food industry and how synthetic biology might fit in to this picture.

Why have I been contacted?

You have been contacted because your background or current employment suggests that you will have knowledge and views that are relevant to my research. Discussions with people like yourself will help me to better understand a wide range of views on policy in this area.

If I decide to take part, what do I need to do?

If you choose to take part, please respond to me by email. Taking part in this research means agreeing to be interviewed online, via Zoom, to discuss your views on synthetic biology and its governance. Interviews will last around one hour. You will be able to choose whether you have your video on or not. After our discussion, I may contact you again for a follow-up conversation if you agree, and you will be able to contact me via email or telephone. You will need to return a signed consent form prior to our discussion.

Do I have to take part?

No – participation is voluntary. You can withdraw from the research at any time without giving any reason, until the point that the thesis is in its final draft. You may feel that you have little to say, particularly if you do not work directly with synthetic biology, but I am keen to talk with as many people as possible about their views on this topic. Exploring many different perspectives will help future debates around the governance of emerging technologies in food.

Are there any disadvantages or risks involved in taking part?

No, I do not believe that this research poses risk to yourself or your organisation. Please note that to maximise the benefit of our discussion, I would like to record it. All research data will be stored securely, adhering to current data protection regulations and the requirements of Newcastle University (see here and here). Recordings will only be available to me (Natalie Partridge), my supervisors Prof. Simon Woods and Dr Ken Taylor, and an experienced transcriptionist, under a confidentiality agreement. Recordings will be destroyed after verbatim transcription. Transcripts will be anonymised and deidentified, for analysis by me, only. Any quotations I use will be anonymous and unidentifiable, unless you specifically agree to be named. Your participation will be kept strictly confidential.

What will happen to the results of the study?

All participants will be given a website address for this project during their interview. The website will be updated with progress on the research and participants may choose to read this. A summary of the conclusions of the research will be published on the website and an email address provided for any comments participants might want to make.

Contact and further information

Thank you very much for your time. If you have any questions about the study or this leaflet, please do not hesitate to contact me or my supervisors, Simon and Ken:

Lead researcher	Lead supervisor	Co-supervisor
Natalie Partridge	Prof. Simon Woods	Dr Ken Taylor
n.partridge2@ncl.ac.uk	simon.woods@ncl.ac.uk	Kenneth.taylor@ncl.ac.uk

If you have any concerns about this study that you cannot resolve directly with us, or if you would like to discuss it with someone else, then you may contact, in confidence, either: The Dean of Research, Faculty of Humanities and Social Sciences, Newcastle University, Newcastle upon Tyne NE1 7RU or The Chair, Faculty of Humanities and Social Sciences Ethics Committee, Newcastle University, Newcastle upon Tyne NE1 7RU. If your query relates to data protection, please contact our data protection officer at: Executive Office, Newcastle University, Newcastle upon Tyne, NE1 7RU. Email: rec-man@ncl.ac.uk

Newcastle University

Policy Ethics And Life Sciences

PORTABOLOMICS

Figure 5 - Participant information document (Source: Author)

Appendix 4 – Code Book

Code name
(Un)natural
(Not) Normal
(Not) real
Commercialisation
Advertising
Alternative agricultural inputs
Alternative packaging
Animal diseases
Animal feed
Benefit to economy
Capitalism
Cheaper sequencing
Chemicals
Economic challenges for synthetic biology
Efficiency
Food additives
Intellectual property
Lab-grown human organs
Lab-grown meat
Marketing
Meat alternatives
Organics
'Perfect quality'
Plant synthetic biology
Production proximity
Scale-up
Spinout companies
Synthetic biology eggs
Synthetic biology milk
Taste
Textiles
Vegan, plant-based
Current governance
(Un)familiar with policy
Advantageous contamination
Brain drain
Bureaucracy
Comparators
Current institutional set-up
Current regulation
Deciding policy objectives
DEFRA as weak
Detection
Devolved matters

	Evidence-based policy
	Food crime
	Imports
	Informed decision-making
	Interrelationship between regulation and innovation
	Large amounts of sequencing data
	Leadership Council
	Overlapping areas of policy oversight
	Over-regulation
	Policy as reactive
	Policy research, POST
	Policymakers as untrustworthy
	Politicians are busy
	Precautionary principle
	Regulators as hostile
	Regulatory processes are probably strong enough
	Resistance to regulatory change
	Responsible research and innovation
	Subsidies
	Trade
Ethical considerations	
	Choice
	Cloning
	Compassion, empathy, intentionality
	Create life in the laboratory
	Democratising approach
	Distribution of benefits
	Ethical consumerism
	Exploitation, harm
	Extension of technology to humans
	Human intervention
	Impact on farmers
	Knowing what is in foods
	Mark of humanity
	Mosquitos
	Not everything that's useful is ethical
	Origin of cell types
	Playing God
	Profit
	Sovereignty
	Whether it's a goat or pig or bacteria
	Why did you do it to start with
Food policy priority areas	
	Animal Agriculture
	Animal welfare
	Deforestation
	Distribution

	Environment
	Human health
	Industrial agriculture
	Plastics (reduction, alternatives)
	Policy priorities
	Reduce food waste
GMOs	
	Acknowledgement of attitudes
	Common anti-GMO arguments
	Criticism of current EU and UK governance
	Deployment of technical specifics
	Environment argument
	False dichotomies
	Mad scientist
	Things being different from GMOs
	Things being similar to GMOs
	Tradition, nature
	What purpose
Imagined synthetic biology futures	
	Bioeconomy
	Control
	Creating completely new things
	Ensuring the potential of engineering biology
	Financial viability
	Food security
	Fork to farm
	Green utopia
	Hype
	Imagined futures
	Inputs (feedstock)
	'it's just growing at such a huge extent'
	Personalisation
	Precision agriculture
	Replacing the oil industry
	Technological 'solutions'
	Time
People & roles	
	Disconnected
	Funders' responsibilities
	Industry 'doesn't care'
	Interests
	Power
	Role of civil servants
	Role of NGOs
	Role of social scientists
	Role of supermarkets
	Scientific knowledge changes & regulation

Scientists' responsibilities
Separation of science from business
That isn't what I do
Potential future governance
Changing policy
DEFRA consultation
Deregulation
Funding
Funding priorities
It needs to not hamper science
Kind of regulatory structure... decide(s) what comes out
Labelling
Preparedness (strategy)
Product or process regulation
Self-regulation
Shifting from technology push to market pull
Risks
Bioterrorism
Differences between novel and familiar foods
DIY-bio
Gene drive
In its nascency
Interconnected
Lesser evil
Meddling with things we don't understand
Mutation
Release
Risk, safety
The genie is out of the bottle
Unexpected consequences
Synthetic biology-society interface
Are scientists right and publics wrong
Bizarre, weird, crazy
Dialogue (with publics)
Distrust of labelling
Distrust of scientists
Education
'I wouldn't eat it'
Industry as untrustworthy
Language
Medical vs Agri-food
Othering (of publics)
Participate in a democratic food system
Public perception, acceptance
'smokescreen' around industry motivations
Societal effect
Stakeholder engagement

Tradition
Transparency
We were told a lot of myths
What synthetic biology is
(R)evolution
Analogy with formaldehyde in wood processing
Analogy with nuclear
Analogy with tobacco industry
Chemistry
Connection between synthetic biology and ICT
Definition of synthetic biology
Design
Engineering
Models
Optimisation
Rebranding
Uncertainty about technology
Unfamiliar with synthetic biology
Participant information
Participant introductions
Covid
Brexit
Why is this worthy of a PhD
Things I should know

Table 11 - Code book (Source: Author)

Appendix 5 – Early coding example

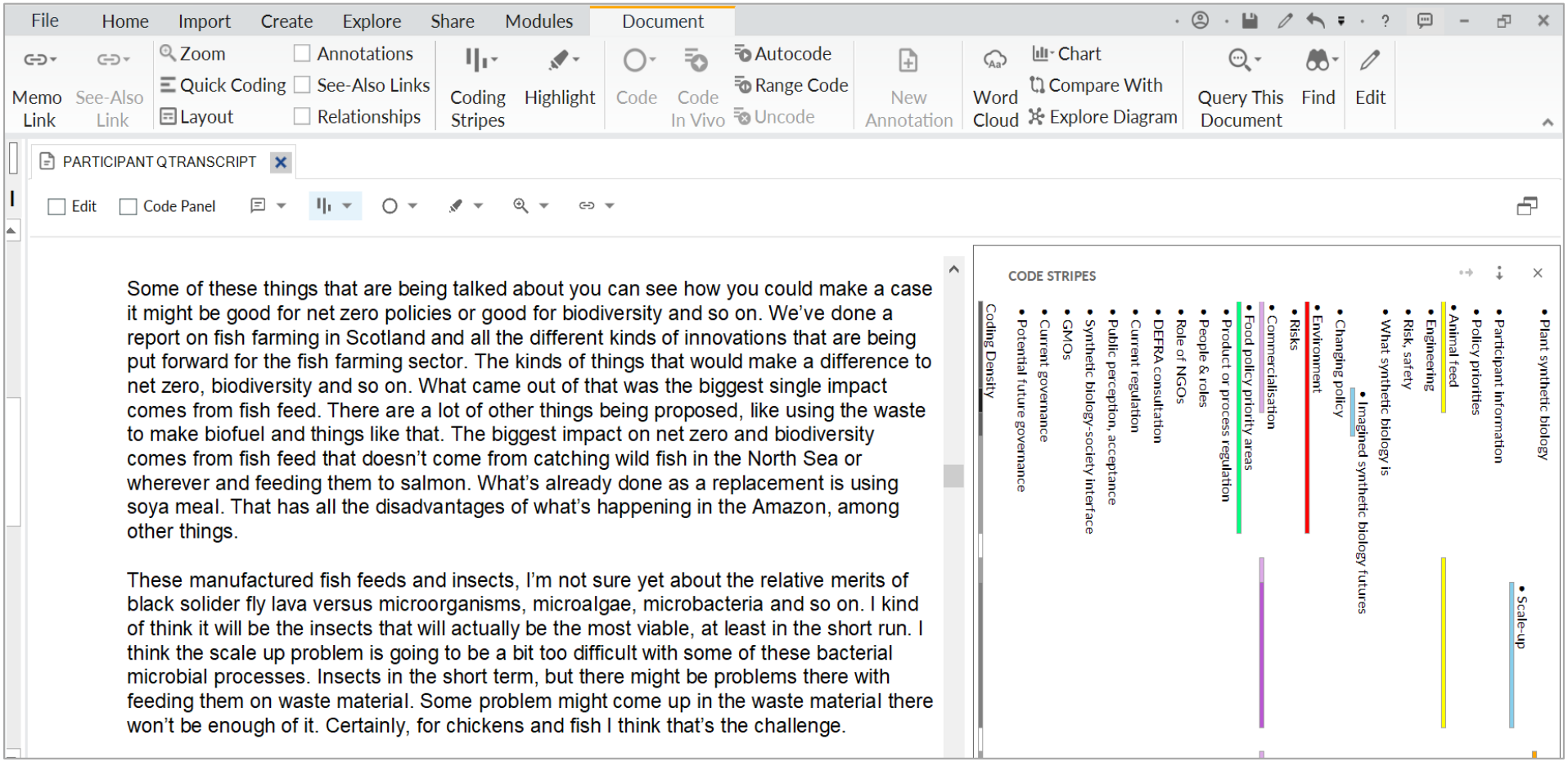

Figure 6 - Example coding stripes (Source: Author)

Appendix 6 – Analysis Step Two

Participant Alias	*Job description*	*Other work details*	*Education level*	*STEM trained*	*Interests*	*Values*	*Beliefs/worldview*	*Working/ studying during GM controversies?*	*Experience of GM controversies*	*GM trauma indicator/examples*	*GM trauma type*	*Constructions of synthetic biology*	*Notes*
Gov8	Advisor to UK government	[redacted]	HE	Yes	Economic success of the field; Positively impacting the world	Western capitalist neoliberal values relating to freedoms, property and wealth; Rule of law; Right to make informed food choices	Technocratic / scientistic	Yes	Conflict with NGOs and other groups Research and government work experience	Feels that GM was wanted but industry was stifled by angry opponents like NGOs making it commercially unviable	1st Hand (Conflict experienced)	On a continuum with GM, but synthetic biology is more of a constructive, controlled, precise approach, GM is more of a destructive approach Both are useful, so their risks should be weighed against their benefits Promising in food, agriculture and medicine	Feels that attitudes towards GM are shifting in favour because of positive COVID-19 vaccine experiences, and that NGOs are not as powerful as they once were in swaying public opinions.

Figure 7 - Sample of table used in analysis (step 2) (Source: Author)