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Science and Technology Studies in Policy: The UK Synthetic Biology Roadmap

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Claire Marris¹  and Jane Calvert² 

Abstract

In this paper, we reflect on our experience as science and technology studies (STS) researchers who were members of the working group that produced *A Synthetic Biology Roadmap for the UK* in 2012. We explore how this initiative sought to govern an uncertain future and describe how it was successfully used to mobilize public funds for synthetic biology from the UK government. We discuss our attempts to incorporate the insights and sensibilities of STS into the policy process and why we chose to use the concept of responsible research and innovation to do so. We analyze how the roadmapping process, and the final report, narrowed and transformed our contributions to the roadmap. We show how difficult it is for STS researchers to influence policy when our ideas challenge deeply entrenched pervasive assumptions, framings, and

¹Centre for Food Policy, Department of Sociology, City, University of London, London, United Kingdom

²Science Technology and Innovation Studies, University of Edinburgh, Edinburgh, United Kingdom

Corresponding Author:

Claire Marris, Centre for Food Policy, Department of Sociology, City, University of London, Northampton Square, London EC1V 0HB, United Kingdom.

Email: claire.marris@city.ac.uk

narratives about how technological innovation necessarily leads to economic progress, about public reticence as a roadblock to that progress, and about the supposed separation between science and society. We end by reflecting on the constraints under which we were operating from the outset and on the challenges for STS in policy.

Keywords

responsible research and innovation, futures, public acceptability, governance

Introduction

On July 11 2013, David Willetts, then UK Member of Parliament and Minister of State for Universities and Science, stood at a podium at Imperial College London at the Sixth International Meeting on Synthetic Biology (SB6.0) holding up a copy of a report entitled *A Synthetic Biology Roadmap for the UK* as he announced millions of pounds of government funding for the field. Some members of the audience clapped. A few cheered. Excited delegates tweeted photos of the minister at the podium: “the Government is in the house,” “the Minister is here,” and “Total of £126M invested in synthetic biology by the UK Government!” A few minutes earlier, two young women had silently distributed a pamphlet with an intentionally inflammatory image of Willetts, two high-profile synthetic biologists and the Shell logo,¹ caught in the tentacles of a sinister monster, which was also instantly tweeted (Agapakis 2013). Meanwhile, the two authors of this paper sat in the audience feeling rather uncomfortable; and by the end of that day, after a session on responsible research and innovation (RRI) organized by one of us (J.C.) and chaired by the other (C.M.), we felt despondent.

In this paper, we discuss our involvement in the UK Synthetic Biology Roadmap and explain why we felt downhearted on that hot summer’s day in South Kensington. We start by reviewing science and technology studies (STS) perspectives on how to govern uncertain technological futures and on the increasing use of roadmaps as a tool for doing so. We then review relevant literature on STS in policy and reflect on our methodology in light of this literature. The main body of this paper describes our participation in the roadmapping process. In the conclusions, we reflect on what lessons we can draw from our experience for STS researchers involved in policy-making.

Governing the Future

STS research has drawn attention to three features of attempts to govern the future that are important for our discussion of the UK Synthetic Biology Roadmap. First, the future is always uncertain, so attempts to predict or control the development of any technology are necessarily fraught with difficulties. Collingridge's "dilemma of control" was a pioneering attempt to engage with this unpredictability from an STS perspective. The dilemma arises because, in its early stages, it is hard to predict how a technology is likely to develop, so it is difficult to intervene and shape it, although the power to control and influence its development is high. However, once the consequences of the technology become apparent, the power to control its development is limited because it will have become part of an entangled material, economic, and social fabric (Collingridge 1980). Other authors have built upon Collingridge's dilemma to demonstrate how innovation is an irreversibly branching evolutionary process that is "shaped" by or "coproduced" with society and that choices between alternative technological pathways tend to get closed down over time. As a result, not all that is scientifically realistic, technically practicable, economically feasible, or socially viable will be historically realizable. Technologies are path-dependent and can become "locked-in" (Bijker and Law 1992; David 1985; Jasanoff 2004; Stirling 2008). The (often misunderstood) lesson of the Collingridge dilemma of control is not that we should give up on attempts to govern the future but that it is necessary to act while acknowledging uncertainty. Collingridge (1980, 12) argues that instead of focusing on better predictions, we should develop a "theory of decision making under ignorance". Since prediction and control will not be possible, it becomes necessary to incorporate flexibility, resilience, and diversity into technological developments to avoid lock-in.

Second, as literature on the sociology of expectations demonstrates, discourses about the future are not mere speculation, they are performative: they have real effects in the present because actions in the present are made legitimate through promises about the future (Brown 2003). If a technology is expected to succeed, people will invest (time, energy, political support, finances) into it, meaning it is more likely to succeed. Expectations also attach hopes and concerns to new technologies, in this way embedding specific roles for different actors, and thus influencing what the technology becomes. This leads to our third feature, which is that what may appear to be merely technological projections embody value judgments, since they are visions about a future that is *desirable*. All discussion of the future is therefore normative, yet this is often overlooked in scientific and policy

discourse. Although prediction and control are not possible, it *is* possible to have a discussion of the visions, values, and purposes that drive technological development. These intentions are always in the present, even if their future consequences are not. This is a key justification, from an STS perspective, for encouraging the participation of diverse groups of people in the governance of science and technology. As Wilsdon and Willis (2004, cover page) put it “[t]he task is to make visible the invisible, to expose to public scrutiny the assumptions, values and visions that drive science.”

Technology Roadmaps

Technology roadmaps are one mechanism for governing the future. They were first developed in the 1980s in the private sector and were taken up by the public sector in the 2000s as a tool to foster the competitiveness of specific industries. The International Technology Roadmap for Semiconductors (ITRS) has become an exemplar for technology roadmaps. Reissued every year or two between 2001 and 2015, it has coordinated the actions of competing firms across the semiconductor industry and has enabled Moore’s Law to become a self-fulfilling prophecy by guiding technological and investment decisions (MacKenzie 1996). When roadmaps are developed in other fields, the success of the ITRS is often in the background. As pointed out in a Nuffield Council report on emerging biotechnologies: “having a technology roadmap conveys the impression of purpose and inevitability in the way that a new technology is expected to unfold, and perhaps also seeks to associate the new technology with people’s experience of rapid change in computer technology” (Nuffield Council on Bioethics 2012, 102).

Like other ways of governing the future of technologies, roadmaps are performative. They aim not just to inform decision-making but also to “weave a picture of the future that attempts to galvanise actions in the present” (McDowall 2012, 531). As McDowall notes, they combine and conflate three ways of engaging with the future: expectations (what is likely to happen?), desires (what is hoped will happen?), and promises (what will be made to happen?). Another important feature of roadmaps is that who is involved has a large influence on the path sketched out for the future and also on the legitimacy of the roadmap. In line with the STS work discussed above, McDowall (2012, 534) argues that “roadmaps that are developed through processes that are broadly inclusive and participatory will have a greater claim to setting out a legitimately desirable future pathway”. However, roadmaps often involve a narrow range of participants from industrial, academic, and policy worlds who are closely associated with current

developments in the field and are seeking to attract resources. McDowall maintains that such actors are likely to offer optimistic, even hyperbolic, accounts of the future of the technology. This problem is exacerbated by the fact that roadmaps usually purport to present a consensus view and identify only one road: a supposedly shared vision of the future. This is arguably essential to inculcate a sense of purpose and to assemble resources as “a confident, prescriptive roadmap developed on the basis of a consensus of relevant (and powerful) actors will have most influence” (McDowall 2012, 533). However, since “actors in the innovation system are unwilling to subscribe to overly diverse, pluralist and contested pathways” (McDowall 2012, 534), this closes down deliberation about technology choice. We discuss below how these features of roadmaps played out in the UK Synthetic Biology Roadmap, but first we address the literature on STS in policy and its implications for our methodology.

STS in Policy and Methodological Implications

This paper builds on ongoing discussions about the role that social scientists, and STS researchers in particular, are expected to play in policy contexts. Since the emergence of STS, there has been an “activist” strand (Sismondo 2010) that has aimed to positively influence interactions between science, technology, and society (Bijker 2003; Rip 1999). There has also been a call for more “socially robust” science (Nowotny, Scott, and Gibbons 2001), one that is “both more *democratically* and more *technically* warranted” (Webster 2007, 460, emphasis in original). Commentators have pointed to a “normative turn” in STS (Lynch and Cole 2005) and many STS scholars have found themselves “in the policy room,” as Webster (2007) put it. The introduction to the 2008 *STS Handbook* noted that the field could, in recent times, be “characterized by its engagement with various publics and decision makers” (Hackett et al. 2008, 1).

However, the terms on which we are allowed entry in the policy room are not always the terms on which we would like to be engaged. In many instances, as Wynne (2007, 493) notes, the situation arises where “social science is required to deliver the Holy Grail of public acceptance for whatever technoscience might throw up.” Webster (2007, 475) suggests that STS analysis can help to challenge what Latour (1993) has labeled “purification:” the attempt to separate the “scientific” from the “political.” Webster (2007, 462) also points to the danger of “cooption and capture” and emphasizes that “STS needs to retain its reflexive and critical edge” in policy contexts. Hackett et al. (2008, 5) recognize that the normative turn

is not an easy one and point out that “the core challenge remains: how to bring the distinctive insights and sensibilities of STS into the analysis of policy and the process of social change.”

The “normative turn” has methodological implications. In particular, as Rip (1999, 76) points out, there is necessarily a “tension between distance and engagement” in policy processes. In our case, in the years leading up to the Synthetic Biology Roadmap, we had both been closely involved in collaborations with synthetic biologists and engaged in diverse policy initiatives in this field and continued to be involved afterward (Balmer et al. 2015). More specifically, we were both members of the UK Synthetic Biology Roadmap Coordination Group (hereafter SBRCG) and thus involved in the processes we discuss in this paper. We are reluctant to call our involvement in the roadmap “participant observation” because we did not attempt to put ourselves in the position of those we were observing: we were not “outsiders” trying to gain an “insider’s” perspective. We were engaged in what Gusterson (1997, 116) calls “polymorphous engagement,” interacting with our research participants across a number of sites and in different configurations. It is important to acknowledge that there are significant power relationships involved in the kinds of cross-disciplinary work we have been involved in, as Rabinow and Bennett (2012) show. This complicates our situation and raises important questions of methodology and research ethics. Anthropologists who call for a “critical repatriated anthropology” have discussed the methodological and epistemological problems involved in investigating the cultures of the powerful and speak of “researching up” when studying populations with more power than the researcher (Gusterson 1997; Nader 1974). This up/down metaphor is however not well suited to our situation because we were in some respects equal partners in the SBRCG. Overall, the diversity of different collaborative arrangements and peer-type relationships we engage in cannot be adequately described by in/out or up/down metaphors, as we are entangled in multifaceted power relationships.

For example, natural scientists and engineers muster much greater financial resources than social scientists in terms of overall research funding; however (at least in the UK during the period studied here), natural scientists in certain fields, notably synthetic biology, are often required to include social scientists in their grants to demonstrate to their funders and wider publics that they are taking “ethical, legal and social implications” seriously (Marris 2015). Issues clearly arise here about our complicity with such research agendas, and some social science researchers, including some within STS, take the position that maintaining critical distance means avoiding any engagement in the processes being researched. Others,

however, encourage STS to engage with the world of action in order to help ensure that society's understanding of science is "driven by the critical stance of the STS movement" (Rip 1999, 78). We embrace the latter approach but also heed Bijker's (2003, 446) warning that "STSers can contribute to making things, to changing the world. In doing so, they inevitably will dirty their hands, for there is no free ride here". We recognize that by actively engaging in research and policy-making in and around synthetic biology we chose to get our hands dirty, but we aimed to do this without losing our critical stance. We are also keen to maintain our long-term collaborative and polymorphous relationships with our synthetic biology colleagues. This adds complication to our attempts, such as this paper itself, to write about our experiences in the field. We are not alone in grappling with these issues. Mosse (2006), for example, talks about how in conventional ethnography a researcher exits from the field in order to write their account. But in those circumstances where we are members of the professional and policy communities we study "[t]he relationships of the field persist, the capacity to exit through writing is in question, and ethnographic representations have become unavoidably part of the world that is studied" (Mosse 2006, 937). Gusterson (1997, 117) similarly notes that when anthropologists "study up," often their research participants "will read and argue with what is written about them" and this threatens to undermine the critical force of the research. One response to this quandary is simply not to write about our experiences and be satisfied to see our attempts to influence policy as an impact of our research. But we believe that analysis of our work in these policy arenas can make important contributions to STS knowledge and scholarly practice. We therefore try to tread a delicate path that simultaneously respects our ongoing participation in scientific, industry, and policy processes around synthetic biology and enables us to draw conclusions that we hope will be helpful to STS researchers as they increasingly find themselves in similar policy rooms.

This leads to difficult issues of confidentiality and research ethics. Confidentiality was never explicitly discussed at the SBRCG meetings, but there was an unarticulated recognition that conversations were confidential, or at least sensitive. We have decided to follow the Chatham House rule in this paper. We do not attribute any specific comment or position to any member of the SBRCG. Furthermore, although we do report on some aspects of the meetings when this is important to our analysis, whenever possible we draw on information that is either publically available or was presented at public meetings. Finally, we have purposely waited several years before publishing this paper. The UK now has a different government,

most of the major policy players have moved on to different roles, and the roadmap itself has been superseded by another document (SBLC 2016). With these caveats in place, we now turn to the UK Synthetic Biology Roadmap itself.

The UK Synthetic Biology Roadmap

Origins of the UK Synthetic Biology Roadmap

The UK Synthetic Biology Roadmap was initiated by the Technology Strategy Board (TSB). The TSB was set up by the UK government in 2007 as its national innovation agency.² It reported to the UK Government's Department for Business, Industry and Skills (BIS) and in 2011 its stated goal was "to accelerate economic growth by stimulating and supporting business-led innovation" (TSB 2011, 2). In 2011, BIS (2011, 10) stated that TSB had identified synthetic biology as "a key emerging technology with the potential to create a billion pound industry within the UK in the next decade". The identification of synthetic biology as a technology with great market potential was central to the motivation for the roadmap. As we shall see, this became something the roadmapping process simultaneously needed to demonstrate and bring into being.

The SBRCG met for the first time in November 2011. The then Science Minister David Willetts explained (Willetts 2012a):

I have asked leading researchers and business experts in a group chaired by Dr Lionel Clarke of Shell to produce a synthetic biology roadmap to set out the timeframe and actions to establish a world leading synthetic biology industry in the UK.

Initial meetings were attended by representatives from two large multinational firms, the two governmental agencies that fund synthetic biology research (Biotechnology and Biological Sciences Research Council [BBSRC] and Engineering and Physical Sciences Research Council [EPSRC]), UK Trade and Investment,³ and prominent scientists in synthetic biology and related fields. In early February 2012, J.C. was invited to join the group, on the basis that ethical, social, and legal areas of expertise were unrepresented. She responded positively, saying she would like C.M. to act as her deputy since she would not be able to attend all the meetings. In practice, we both became members of the SBRCG. Membership involved participating in the constitution of a shared reading list, two stakeholder

workshops, and SBRCG meetings once every two weeks. Four meetings were held between November 2011 and January 2012, before we joined, and we attended the seven meetings held between February and May 2012. Most of the meetings were held at the BIS Headquarters close to the UK Houses of Parliament, where we were met with large publicity posters referencing the Union Jack and proclaiming that “Innovation is Great (Britain).”

The final output was a 34-page report published in July 2012. The first part briefly depicts the emergence of synthetic biology, and UK strengths in related areas. The main body is composed of five themes: foundational science and engineering, continuing RRI, developing technology for commercial use, applications and markets, and international cooperation. A vision of the future of UK synthetic biology is set out at the start, and the report ends with a set of recommendations to realize this vision.

Key Framings

Going back to our first meetings, we found that joining a group when it had already been running for three months meant that key framings had already been set. We soon noticed three clusters of underlying assumptions that structured the discussions: (i) public acceptability was a key problem to be addressed; (ii) understandings of innovation followed a linear model; and (iii) the role of synthetic biology was to promote jobs and economic growth. We describe below how each of these played out in the context of the SBRCG.

First, we immediately and repeatedly noticed how presumed public concerns were a dominant topic in SBRCG discussions and how they were thought of as a roadblock for innovation and business, an obstacle to be surmounted. SBRCG discussions also frequently adopted a deficit-model approach to public understanding of science: “the public” was represented as a homogeneous mass that passively accepts or rejects a technology, and rejection was assumed to be based on irrational fears. These ideas have been challenged by decades of STS scholarship (Gregory and Miller 1998; Wynne 1992). The second set of framing assumptions that dominated the roadmapping process were linear models of innovation that have also been critiqued by STS and innovation studies (Godin 2006; Latour 1987). The innovation process was portrayed as an ineluctable upward progression from “science and engineering” to “technology” to “applications” to “market growth” (as depicted in figure 5 of the Roadmap, p. 15).

This was linked to the third assumption that the primary aim of the roadmap was to promote jobs and economic growth and that this would

be achieved through industrial development of synthetic biology. This focus on economic growth and job creation was not surprising considering the roadmap's origins in BIS and the composition of the group reflected this. Although the SBRCG had members from public funding bodies and universities, it was chaired by someone from Shell, had representation from GlaxoSmithKline and UK Trade and Investment. All the members (ourselves included) were closely associated with current developments in synthetic biology, and there were no members from groups with critical views on these developments. As a result of this shared assumption about the importance of "jobs and growth," economic values were given more weight than public values throughout the roadmapping process. More fundamentally, this precluded any discussion about whether jobs and growth should be the main aim of synthetic biology and there was no perceived need to generate any evidence to support the underlying belief that synthetic biology could indeed generate significant job creation and economic growth. The assumption that synthetic biology had the potential to deliver these benefits even became embedded in the definition of synthetic biology used for the roadmap (SBRCG 2012, 4):

Synthetic biology is the design and engineering of biologically based parts, novel devices and systems as well as the redesign of existing, natural biological systems. It has the potential to deliver important applications and improve industrial processes—resulting in economic growth and job creation.

The first sentence of this definition had been commonly used elsewhere (e.g., Royal Academy of Engineering 2009, 6), but the second was added explicitly for the roadmap. The Chair of the SBRCG put this even more succinctly in his presentation of the roadmap subsequent to its publication: "Synthetic Biology may be defined not only in terms of *what it is* but also in terms of *what benefits it can deliver*" (Clarke 2013, slide 2, emphasis in original). This illustrates how synthetic biology became reified as a technology that will necessarily deliver promised (economic) goods, as long as it is given appropriate support. In line with this economic emphasis, a key justification for the roadmap was the prior TSB/BIS projection that synthetic biology would create a 1 billion-pound market for the UK within a decade. The roadmap cites, three times, a BCC Research (2011) prediction of a US\$10.8 billion global market for synthetic biology by 2016. This report was prohibitively expensive (approximately £3,500) so it was not circulated to SBRCG members, and we were not able to scrutinize the methods used to generate this forecast. The roadmap did acknowledge that

such assessments depend on the definition of synthetic biology and relevant market sectors and that this assessment might not be accurate (SBRCG 2012, 8). But it was decided that the size of the future synthetic biology industry only needed to be credible, since the figure could become a self-fulfilling prophecy.

It is worth noting that this framing of synthetic biology as a driver of economic growth was not the only framing in circulation at the time. The US-based BioBricks Foundation (n.d.), a not-for-profit organization that was influential in the early development of synthetic biology (albeit not in an official capacity like that of the Roadmap), had a strikingly different vision that emphasized their own normative agenda:

Our mission is to ensure that the engineering of biology is conducted in an open and ethical manner to benefit all people and the planet. We envision a world in which scientists and engineers work together using freely available standardized biological parts that are safe, ethical, cost effective and publicly accessible to create solutions to the problems facing humanity. We envision synthetic biology as a force for good in the world.

Our Contribution to the Roadmap

One of our earliest contributions to the roadmap was to introduce some literature into the SBRCG's reading list, including the McDowall (2012) article cited above. Several members took note of his argument that roadmaps are "purposefully performative." We also made small but significant contributions to the definition of the vision used for the roadmap. As noted above, an important component of roadmaps is a shared vision for the hoped-for future development of a technology. For this roadmap, it was decided that the first part of the vision was that synthetic biology should be "economically vibrant." We suggested, on the basis of the two stakeholder workshops we had attended, that synthetic biology should not simply be seen as "economically vibrant" but also "diverse and sustainable." Another key component of an early version of the vision was that synthetic biology should be "widely publicly supported: within an effective and responsive regulatory framework." We argued for the phrase "widely publicly supported" to be changed to "of clear public benefit," to shift the onus from the public to support the technology onto those developing the technology to demonstrate its benefits. Both our suggestions were incorporated into the vision.

Our biggest contribution to the report, however, was in the chapter we were asked to lead on. In an early draft this was called “acceptability,” demonstrating the dominant assumption in the SBRCG that an overriding issue in the development of synthetic biology was to generate public acceptability. To shift the focus away from this assumption, we suggested the chapter should be renamed “Responsible Research and Innovation” (RRI), a term that was just beginning to emerge at that time in UK research funding institutions and at the European Commission. The concept was enthusiastically adopted by the SBRCG and became one of the five themes of the roadmap. It was also incorporated into the final version of the third component of the vision, which reads (SBRCG 2012, 4):

Our vision is of a UK synthetic biology sector that is [...] of clear public benefit: an exemplar of responsible innovation, incorporating the views of a range of stakeholders and addressing global societal and environmental challenges within an effective, appropriate and responsive regulatory framework.

We felt that reframing our contribution to the roadmap in terms of RRI had several advantages. First, we hoped the term would encourage attention to the entire process of innovation, including research at the laboratory bench, rather than being primarily concerned with downstream applications and their impacts, which is where scientific and policy communities often assume that “ethical, legal, and social issues” (ELSI) start to become relevant. Second, we wanted to steer the SBRCG away from issues of “public acceptability” and associated deficit model assumptions. Third, we hoped the concept of RRI would help shift the focus away from concerns about health and environmental risks and their regulation, which were key topics in the chapter outline we were given. Through this intervention, we sought to shift the deliberations away from simply attempting to predict and manage risk to focus instead on the motivations and purposes driving research.

Our proposed chapter title was embraced as a good idea by the rest of the group, and we were given the freedom to draft text for this section. Given our STS-informed belief that all discussions about the future are necessarily normative, we were keen to stress the importance of opening up to diverse groups, purposes, visions, and trajectories. Thus, in the sections of the chapter we wrote, we made the point that (SBRCG 2012, 21):

“engagement” means genuinely giving power to a wide range of diverse social groups, including those who will be the end users or presumed beneficiaries of the technologies, taking their concerns seriously, and enabling

them to participate throughout the whole pathway of technological development.

We also wrote that “it is essential for debates to go beyond the community of experts to open up discussions about the purpose of innovation” (SBRCG 2012, 19).

Approximately half of the text in the final version of Theme 2 in the roadmap is our own (all of page 19 and some of page 21). However, a number of subtle decisions were made in the final stages of the production of the report that had a significant effect on the meaning of our text. Three examples illustrate this.

First, the word “continuing” was added to the title of the chapter (which became “Continuing Responsible Research and Innovation”) because there was a worry that without this additional word there would be an implication that research and innovation in synthetic biology had previously been *irresponsible*, and this would raise public concerns. For similar reasons, two boxes (written by other members of the group) were inserted into the chapter to highlight existing positive practices. The first box (p. 20) described a public consultation exercise organized by UK research funding bodies (BBSRC and EPSRC) in 2010. The second box (p. 21) outlines the “checks and balances” in place at BBSRC to ensure that “the researchers it funds are aware of any ethical and social issues that their research raises, and they respond to them appropriately.” While the initiatives described in these two boxes are relevant, the text in the boxes reveals assumptions that are inconsistent with our framing for the chapter.

Both boxes aim to reassure the reader that UK research institutions are already dealing adequately with any social and ethical issues raised by their research. But the interpretation of what counts as legitimate “issues” is narrower than our own interpretation, based on STS scholarship. The examples of ethical issues given in the second box (the need to use animals in an experiment or the potential for misuse) do not address the issue of the *purpose* of the research.⁴ The box about the Public Dialogue speaks of the “hopes and fears” of members of the public and focuses on the narrow issue of whether participants were supportive of the research—thus bringing the focus back toward public acceptability. And neither of the boxes speak about opening up deliberations on these issues to a broad range of stakeholders, as opposed to unspecific “members of the public.”

A second example of the way in which the meaning of our text was reframed was that in the final layout of the report a prominent “public acceptability” subheading was inserted into our text. The words that follow

this are our own: “Public acceptability is widely recognised as a crucial issue for synthetic biology, but it cannot be adequately dealt with through communication aimed at reassuring the public” (p. 19). We started the sentence with “public acceptability” because the phrase had come up repeatedly in the stakeholder workshops and at SBRCG meetings, and in many other scientific and policy arenas we had participated in, so we thought it had to be acknowledged and addressed. But in our text, we had tried to shift the understanding of “public acceptability” away from a focus on “hopes and fears” of members of the lay public and their supposed concerns about environmental and health risks and ethical issues. We drew on the results from the BBSRC/EPSRC Dialogue mentioned in the box to illustrate how participants were concerned about the *purpose* of the research and *decision-making processes* within research institutions. Changing the chapter title from “Acceptability” to “responsible research and innovation” was intended to signal and enact this shift, but the introduction of the two boxes and the subheading pulled the focus back to a narrower understanding of the societal dimensions of research.

The third example is that, in the summary of the themes, Theme 2 on RRI is described as “the recognition that the ground-breaking opportunities and benefits arising from synthetic biology also come with the potential for unintended consequences, which can be avoided through awareness, training and adherence to prevailing regulatory frameworks” (p. 16). As a result, RRI was essentially reduced to adherence to existing risk regulations, which was exactly what we had been seeking to move away from by introducing the concept in the first place. Indeed, the second part of theme 2, which we did not write, was devoted to risk regulation (pp. 20, 21). In these ways, the report failed to recognize the inescapable uncertainty discussed in the introduction to this paper that is key to our understanding of the governance of technologies.

It is also telling that the word “responsible” occurs only once in the short summary of the five recommendations of the report. This is in the third recommendation, that states the need to “Invest to accelerate technology responsibly to market” (p. 32). Thus, the term is used here within a recommendation that makes it seem as if only commercial outcomes are to be valued, when our aim had been to introduce a broader perspective.

The emphasis on *accelerating* technological and commercial development ties into what Joly, Rip, and Callon (2010) call the “tyranny of urgency,” based on a narrative of global competition, and the fear of lagging behind other nations. Joly, Rip, and Callon (2010) note that in a context where the focus is on future technological developments that are inherently

uncertain “technoscientific promises start to function as a political order, with a tyranny of urgency and naturalisation of technological progress. Civil society is then taken into account only as the final and undifferentiated passive recipient of innovation, and when resisting, labelled the enemy of innovation” (pp. 26, 27). We experienced a similar sense of urgency in the roadmapping process. A key motivation for the roadmap was the belief that if the UK did not act fast to invest in synthetic biology and to deal with its recalcitrant public, other countries would take the lead. This sense of urgency was prevalent at SBRCG meetings, which were held every two weeks. The roadmap was written with tight deadlines, which partially explains why there was no time for collective deliberation about the text for the summary and recommendations and why most members of the SBRCG were not given a chance to review the final draft and proofs. The report had to be published in time to feed into the next Comprehensive Spending Review in the autumn of 2012.

In summary, despite our efforts, the overall impression given in the final report is that risk regulation is the most desirable and useful form of governance for the future of synthetic biology (with appropriate regulation already in place), and public acceptability remains the key roadblock for the commercialization of synthetic biology. We had explicitly sought to challenge these notions in our discussions within the SBRCG and our text for the report, but our meaning was reoriented through subtle decisions, such as the insertion of boxes and a subheading, and the formulation of text used in the executive summary and recommendations. These significantly altered or obscured the intended meaning of our contributions. The end result is that the concept of RRI is narrowed, diluted, and even turned into something that undermines the points we were trying to introduce. Overall, the final report is permeated with a traditionally dominant understanding of the relationship (or rather separation) between science, technology, and society that we explicitly sought to challenge.

We want to stress that we do not believe these decisions about the final wording and layout of the report were deliberately devised to subvert our arguments. We are aware that it is common practice for the Chair and/or a subgroup of a committee to draft executive summaries and final recommendations from reports drafted by expert groups. Moreover, we assume that the SBRCG members who made the final decisions about the text and layout of the report were unaware they were reframing RRI away from our intended meaning. But the fact that this was probably inadvertent further reveals the pervasiveness of dominant frames and underscores the difficulty of challenging them effectively.

More Diffuse Effects on Policy Spaces

There are some indications that our contributions to the roadmap may have had some effects that are more aligned with our intentions. For example, in a talk in July 2012, the BIS representative on the SBRCG maintained that the involvement of social scientists had challenged and reshaped his department's thinking. He explained that, previously, they had only considered the scientific risks to human health and the environment in their work but now they were considering incorporating broader social concerns. He added: “[t]hat would be a cultural change for us, moving away from our comfort zone of looking at scientific considerations only, to looking at much wider societal issues. We call this responsible innovation.” He then went on to say of the SBRCG (Uffindel 2012⁵):

[s]omething we've done that is perhaps slightly different from what we've done in the past is to be more involved with social scientists in the process right from the outset. That's made a real difference to actually how we're thinking as a group, and how we've begun to think within government itself.

This suggests we may have had some positive influence on the way some participants in the roadmapping process felt about the involvement of social scientists in policy, although it clearly differs from our own perception of our limited influence.

Repercussions of the Roadmap

A Successful Roadmap with Limited Legitimacy

The roadmap led to substantial investment in synthetic biology. In 2013, the UK government announced £126M funding for a “Synthetic Biology for Growth Programme” which it described as an implementation of the Roadmap recommendations (BBSRC 2013); and synthetic biology was identified by the UK Government as one the “Eight Great Technologies in which Great Britain is set to be a world leader” (BIS 2013a). Many of the funding announcements were made by Willetts himself, culminating in his speech at SB6.0 in July 2013 mentioned at the start of this paper, where he declared that “the roadmap has been an invaluable guide to public policy since it was produced.”

Thus, the roadmap was a success, in that it has served to legitimate further funding and visible political support for synthetic biology. It was published at an important moment for the development of synthetic biology

in the UK, enabling it to establish itself as an independent field. The roadmap became a reference point around the world, a demonstration of the UK's leadership in synthetic biology and of the government's support (see, e.g., Joyce, Mazza, and Kendall 2013).

But the legitimacy of the roadmap and of the vision for the future it embodies is limited to actors who share a particular, dominant, vision of the relationship between science, innovation, and society that we sought to challenge in our work on the SBRCG. The fact that others do not share this vision was illustrated by leaflets distributed by protestors within and outside the SB6.0 auditorium in July 2013, including the image of the tentacled monster described in the Introduction. So this roadmap is an example of what McDowall (2012, 535) describes as a "confident, prescriptive roadmap developed on the basis of a subset of relevant (and powerful) actors [that] will have most influence." A more inclusive and participatory process that was more open to diverse and contested pathways may have had a greater claim to setting out a legitimately desirable future pathway. The future of synthetic biology may have looked different, but it may also have been more viable and socially robust.

The Synthetic Biology Roadmap as a Catalyst for UK RRI

The roadmap can be seen a significant marker in the emergence of a discourse around the concept of RRI in the UK, with the concept heavily influenced by STS scholarship. In his Forward to the Roadmap, Lionel Clarke, Chair of the SBRCG, stated: "Synthetic biology has the potential to increase prosperity and address some of the major challenges facing our planet—but much work needs to be done, and it has to be done responsibly" (p. 3). And in his official written response to the roadmap, Willetts stated (2012b) "the Roadmap rightly defines the development of responsible innovation in this field as a key component." RRI became, by 2013, a central part of the discourse of UK research councils and was incorporated into funding calls for synthetic biology in the following years. The roadmap was mentioned as the justification for this (e.g., BBSRC 2013), although it is important to recognize the reciprocal influences between our work on the SBRCG and other parallel discussions at the EPSRC and the European Commission, which included other STS scholars (Stilgoe, Owen, and Macnaghten 2013; Owen, Macnaghten, and Stilgoe 2012). The EPSRC (2013) published its "framework for responsible innovation" in October 2013. This framework is derived from the work of Owen, Stilgoe, and Macnaghten, but the acknowledgments also

mention the Synthetic Biology Roadmap and refer specifically to page 19 of the Roadmap, which is the page containing our most significant contribution.

At the same time, however, we observed how easily STS insights were erased when it came to investment decision-making that was justified through promissory discourses. The word “responsible” did not appear in Willetts’ speech at SB6.0, nor in the BIS (2013b) press release that accompanied it. Instead, we heard the eminently quotable and tweetable catchphrase about synthetic biology’s potential to “heal us, heat us and feed us,” which had previously been used by then UK Chancellor George Osborne (2012). Indeed, despite Willetts’s identification of RRI as “a key component” in the development of synthetic biology in his official response to the roadmap, the word “responsible” did not appear at all in the series of BIS press releases announcing further funding for synthetic biology in 2012–2015. The roadmap is predominantly used in these press releases as a basis to confirm the promissory nature of synthetic biology as a field that “could provide solutions to the global challenges we face and offers significant growth opportunities in a range of important sectors from health to energy” (BIS 2012). In the end and despite our efforts, the roadmap contributed to solidifying existing framings of synthetic biology as a driver of jobs and economic growth for “UK Plc” (a term that was routinely used in SBRCG discussions and is mentioned in the report, p. 27) and RRI was interpreted as a means to smooth this path.

Discussion: Challenges for STS in Policy

Reflecting on our experiences with the Synthetic Biology Roadmap, we now return to Hackett et al.’s question of how to bring the distinctive insights and sensibilities of STS into policy. In the Introduction, we identified three STS insights we believed were relevant for our work on the Synthetic Biology Roadmap: (1) the future of technological development is unpredictable, making it necessary to act while acknowledging uncertainty, (2) discourses about the future of technology are performative, and (3) technological visions of the future embody value judgments, meaning that it is important to have discussions of visions, values, and purposes in the present. Did our involvement in the SBRCG help embed these insights into the Roadmap?

With respect to the first STS insight on the unpredictability of technological futures, there was no adoption of what Jasanoff calls “technologies

of humility,” which she defines as “institutionalized habits of thought, that try to come to grips with the ragged fringes of human understanding—the unknown, the uncertain, the ambiguous, and the uncontrollable” (Jasanoff, 2003, 227). Or, to put it in Collingridge’s (1980) terms, no move toward a “theory of decision making under ignorance.” Instead, uncertainty was essentially reduced to risk, and risk was in turn assumed to be quantifiable and manageable, and already adequately dealt with through existing risk-based regulatory frameworks.

With respect to the second STS insight, the roadmapping process we were engaged in illustrated the conflation of expectations, desires, and promises that McDowall (2012) notes is a general feature of roadmaps. We have shown how the SBRCG took on board the performative nature of the roadmapping process, but only in a strategic sense. We saw how a particular vision of the future solidified and how this then had material consequences, in the form of government investment in synthetic biology. This was a classic example of promissory work, whereby discourse shapes material circumstances, and actions in the present are made legitimate through promises about the future (Brown 2003).

The third STS insight, the notion that visions of the future embody value judgments, was not acknowledged during the roadmapping process. The technological vision expressed through the roadmap embodies a narrow set of values; and there was no space for consideration of alternative visions for the future of synthetic biology. Although we inserted text in the report that argued for stakeholder engagement to open up visions and decisions to diverse social groups, the only groups involved in the roadmapping process were from science, industry, and policy. The need for wider stakeholder engagement, openness, and transparency as part of a proposed Synthetic Biology Leadership Council was mentioned in the recommendations, but the Leadership Council that was established subsequent to the roadmap included only a narrow range of actors. Overall, we had hoped, like Stilgoe, Owen, and Macnaghten (2013, 1570), that RRI could “extend the governance discussion to encompass questions of uncertainty (in its multiple forms), purposes, motivations, social and political constitutions, trajectories and directions of innovation” and thus enable a new form of governance more in line with STS insights. But these hopes were not fulfilled and our overriding experience was that of dominant framings persistently reasserting themselves. This explains our despondency at the SB6.0 conference described at the start of this paper.

Interlocked Layers of Entrenched Framings

Our experiences were similar to Wynne's (2007) in a food policy context. He explains (p. 497):

I was utterly unable to diversify existing entrenched ideas about innovation and future expectations. My attempts in this case woefully failed to have the policy team involved step backwards and reflexively question some key taken-for-granted as a precondition for more robust (and perhaps substantively different) advancement.

Challenging such "taken-for-granted" is, in our experience, much harder than taking part in a controversy with diverse but explicit points of view; and this is the greatest challenge faced by STS in policy. A similar conclusion was reached by an expert report on emerging technologies from the Nuffield Council on Bioethics (2012, 66), which argues that dominant framings "are rendered so invisible and unaccountable that the idea of questioning them does not suggest itself and might even appear absurd. Alternatives are deleted not by argument or by force but by the circumscribing of imagination itself."

But 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? We think this resistance to change is built upon four interlocked layers of assumptions about relationships between science and society that reinforce one another in a cumulative manner like the layers of an onion. 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.

The outer layer of the onion is the ELSI model assumption that social science contributions to natural or physical science programs focus only on "consequences" or "implications" of the research, which are thought of as separate from the scientific and technical work. It is also assumed that concerns of the public focus on such downstream issues. This leads to the conclusion that ELSI work can be conducted in isolation from scientific research and that it is primarily focused on public acceptability. The next layer is the technocratic model of risk, where all concerns about a

technology are subsumed to concerns about health and environmental risks, and it is assumed that risks can only be legitimately addressed through scientific methods and institutions. From this perspective, it becomes necessary to rectify mistaken understandings of science, or of risk, present among an amorphous group conceived of as “the public,” through better communication. Underlying this is the pipeline model of innovation, which assumes that scientific research progresses in a linear fashion from “basic” to “applied” research and then “development,” until a “product” is ready to be deployed in the social world, often reduced to “the market” (apparent in figure 5 of the Roadmap, p. 15). This model places scientists at the center of the process and assumes that other actors in innovation systems play no significant role in the development of products. End users are seen only as consumers who can either adopt or reject particular technologies. At the core of the onion is the conception of “science” as separate from “society,” with “impacts,” “consequences,” “applications,” or “products” generated by science and moving out into society. This is a version of Latour’s (1993) notion of “purification”—the ongoing attempt to separate the “scientific” from the “social/political.”

Open-ended STS Involvement in Policy?

This diagnosis leads us to agree with Wynne (2007, 499) that in our policy engagements we are facing a “deeply entrenched cultural condition” and not “a deliberately and rationally decided response to counter-evidence.” Wynne concludes that “[i]t is hard to see how anything but a long-term, open-ended involvement by STS can address this”. But can STS researchers really commit to such an open-ended involvement? And what would this mean in practice? How many STS researchers need to engage with policy? And for how long? Do we have to fight the same battles repeatedly, and if so, how can we do so without feeling ineffective, burning out, or neglecting other work? Our involvement in the roadmap was time-consuming, frustrating, and is not well recognized by traditional academic reward structures. Given such terms of engagement, why participate in such ventures?

Also, what constitutes success in STS engagements with policy? Should we be happy with getting a few paragraphs into a policy report? Should we reconcile ourselves to incremental steps? Perhaps the fact that we were invited to be part of the SBRCG and that we introduced RRI into the roadmap should be regarded as a success—a reflection of the progress STS has made. But are such incremental steps enough if they are simply subsumed into dominant framings? Should we expect more radical change? For

example, in our involvement in the roadmap, should we have been more forceful about presenting alternative visions for synthetic biology, such as the one put forward by the BioBricks Foundation? Should we have insisted on participation from a broader range of stakeholders? Should we have even joined the SBRCG at all? We are aware that because we did join and attempted to influence policy from within, we are implicated, and even complicit, in the whole process. What does this mean for our responsibility toward the roadmap and the ways in which it has subsequently been interpreted and implemented? Should we even have written this paper and how much are we entitled to say? We do not have easy answers to any of these questions, but we raise them because they are live issues for STS researchers who engage with policy.

It is also important to recognize that not all policy rooms are the same. The roadmap is one of the most high-profile policy initiatives in UK synthetic biology to date, but we feel that our engagements in other policy rooms have been more productive. These engagements have been sustained over the longer-term and they have not been driven by such a politicized agenda or demanded predefined deliverables. We have also had a diverse range of experiences in synthetic biology beyond the policy room in research projects, teaching, and experimental art/science collaborations, many of which have been marked by productive interactions between STS researchers and other groups (Balmer et al. 2015; Calvert and Schyfter 2017). But what we have learnt from our involvement in the SBRCG is that the initial conditions of STS involvement matter, and in this policy room, the conditions were particularly constraining. We were brought in late, after the framings had already been set, to write a document in a very short time scale, the purpose of which was to legitimize the funding of synthetic biology within the commercialization-oriented context of the Department for Business, Innovation, and Skills. Our involvement was very much downstream; we had no influence on broader structures and normative frameworks.

In our experiences with this roadmap and with the field of synthetic biology more generally, we 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 (Shukman 2013). 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?". This question challenges us to acknowledge the multiplicity of possible futures in the development of any technology and underlines the point we tried and failed to convey in our involvement in the SBRCG: that there is more than the one road that this particular juggernaut is set on taking. It is possible to ride in a different vehicle, perhaps take a bike, or even walk instead, and leave the main road for less-trodden paths.

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ORCID iD

Claire Marris  <https://orcid.org/0000-0002-9366-5567>

Jane Calvert  <https://orcid.org/0000-0001-7204-9805>

Notes

1. The Shell logo presumably represented Lionel Clarke, Chair of the SBRCG, who was employed by Shell at that time.
2. The Technology Strategy Board was renamed Innovate UK in 2014.

3. UK Trade and Investment is a government department (renamed Department for International Trade in 2016) whose aim is to “drive the government’s policy of increasing the number of exporters and inward investors to the UK” (UK Government n.d.).
4. Claire Marris has written elsewhere about how the focus on the “misuse” of the so-called dual use research such as synthetic biology is misplaced and fails “to take into account broader institutional, political and societal dimensions of ‘responsible innovation’ that come to the fore from an STS perspective” (Marris, Jefferson, and Lentzos 2014, 408).
5. Transcribed by authors from video recording.

References

- Agapakis, C. 2013. [Twitter] July 11. Accessed September 24, 2018. <https://twitter.com/thisischristina/status/355239108907524096>.
- Balmer, A., J. Calvert, C. Marris, S. Molyneux-Hodgson, E. Frow, M. Kearnes, K. Bulpin, P. Schyfter, A. Mackenzie, and P. Martin. 2015. “Taking Roles in Interdisciplinary Collaborations: Reflections on Working in Post-ELSI Spaces in the UK Synthetic Biology Community.” *Science and Technology Studies* 28 (3): 3-25.
- BBSRC (Biotechnology and Biological Sciences Research Council). 2013. *Multi-disciplinary Synthetic Biology Research Centres. Call for Proposals*. Swindon: Biotechnology & Biological Sciences Research Council. Accessed December 15, 2013. http://www.bbsrc.ac.uk/web/FILES/Guidelines/sbrc_full_call_text.pdf.
- BCC Research. 2011. *Synthetic Biology: Emerging Global Markets*. Lyon, France: ReportLinker. Accessed September 24, 2018. <https://www.reportlinker.com/p05246309/Synthetic-Biology-Market-by-Tool-Technology-Application-Industrial-Global-Forecast-to.html>.
- Bijker, Wiebe E. 2003. “The Need for Public Intellectuals: A Space for STS: Presidential Address, Annual Meeting 2001, Cambridge, MA.” *Science, Technology, & Human Values* 28 (4): 443-50. doi: 10.2307/1557995.
- Bijker, W. E., and J. Law. 1992. *Shaping Technology/Building Society: Studies in Sociotechnical Change*. Cambridge: MIT Press.
- BioBricks Foundation. n.d. “About.” Accessed September 6, 2015. <http://biobricks.org/about-foundation/>.
- BIS (Business, Industry, and Skills). 2011. *Strategy for UK Life Sciences*. London, UK: Department for Business, Innovation and Skills. Accessed September 24, 2018. <http://www.bis.gov.uk/assets/biscore/innovation/docs/s/11-1429-strategy-for-uk-life-sciences>.

- BIS (Business, Industry, and Skills). 2012. *Government to Invest £20 Million in Synthetic Biology*. Press Release November 9. London, UK: UK Government Department for Business, Innovation and Skills. Accessed September 24, 2018. <https://www.gov.uk/government/news/government-to-invest-20-million-in-synthetic-biology>.
- BIS (Business, Industry, and Skills). 2013a. "Eight Great Technologies: Infographics." UK Government Department for Business, Innovation and Skills. Accessed September 24, 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/249255/eight_great_technologies_overall_infographic.pdf.
- BIS (Business, Industry, and Skills). 2013b. *Over £60 Million for Synthetic Biology*. Press Release July 11, 2013. London, UK: Department for Business, Innovation and Skills. Accessed September 24, 2018. <https://www.gov.uk/government/news/over-60-million-for-synthetic-biology>.
- Brown, N. 2003. "Hope Against Hype—Accountability in Biopasts, Presents and Futures." *Science Studies* 16 (2): 3-21.
- Calvert, J., and P. Schyfter. 2017. "What Can Science and Technology Studies Learn from Art and Design? Reflections on 'Synthetic Aesthetics'." *Social Studies of Science* 47 (2): 195-215.
- Clarke, L. 2013. "Slides from Talk 'Synthetic Biology: The UK Roadmap'." In Multidisciplinary Synthetic biology Research Centres Information Workshop, 6th June, Swindon. Accessed December 15, 2013. <http://www.bbsrc.ac.uk/web/FILES/Workshops/1306-sbrc-information-workshop.pdf>.
- Collingridge, D. 1980. *The Social Control of Technology*. London, UK: Frances Pinter.
- David, P. A. 1985. "Clio and the Economics of QWERTY." *American Economic Review* 75 (2): 332-37.
- EPSRC. 2013. "Framework for Responsible Innovation." Accessed September 24, 2018. <https://www.epsrc.ac.uk/research/framework/>.
- Godin, B. 2006. "The Linear Model of Innovation: The Historical Construction of an Analytical Framework." *Science, Technology & Human Values* 31 (6): 639-67.
- Gregory, J., and S. A. Miller. 1998. *Science in Public: Communication, Culture and Credibility*. New York: Basic Books.
- Gusterson, H. 1997. "Studying Up Revisited." *PoLAR: Political and Legal Anthropology Review* 20 (1): 114-19.
- Hackett, E. J., O. Amsterdamska, M. E. Lynch, and J. Wajcman, Eds. 2008. *The Handbook of Science and Technology Studies*, 3rd ed. London, UK: MIT Press.
- Jasanoff, S. 2003. "Technologies of Humility: Citizen Participation in Governing Science." *Minerva* 41 (3): 223-44.

- Jasanoff, S., Ed. 2004. *States of Knowledge: The Co-production of Science and the Social Order*. London, UK: Routledge.
- Joly, P.-B., A. Rip, and M. Callon. 2010. "Reinventing Innovation." In *The Governance of Innovation: Firms, Clusters and Institutions in a Changing Setting*, edited by M. Arentsen, W. van Rossum, and B. Steenge, 19-32. Cheltenham, UK: Elgar.
- Joyce, S., A.-M. Mazza, and S. Kendall. 2013. *Positioning Synthetic Biology to Meet the Challenges of the 21st Century: Summary Report of a Six Academies Symposium Series*. Washington, DC: The National Academies Press. Accessed September 24, 2018. <https://www.nap.edu/catalog/13316/positioning-synthetic-biology-to-meet-the-challenges-of-the-21st-century>.
- Latour, B. 1987. *Science in Action*. Cambridge, MA: Harvard University Press.
- Latour, B. 1993. *We Have Never Been Modern*. Cambridge, MA: Harvard University Press.
- Lynch, M., and S. Cole. 2005. "Science and Technology Studies on Trial: Dilemmas of Expertise." *Social Studies of Science* 35 (2): 269-311.
- MacKenzie, D. 1996. *Knowing Machines: Essays on Technological Change*. Cambridge: MIT Press.
- Marris, C. 2015. "The Construction of Imaginaries of the Public as a Threat to Synthetic Biology." *Science as Culture* 24 (1): 83-98.
- Marris, C., C. Jefferson, and F. Lentzos. 2014. "Negotiating the Dynamics of Uncomfortable Knowledge: The Case of Dual Use and Synthetic Biology." *BioSocieties* 9 (4): 393-420.
- McDowall, W. 2012. "Technology Roadmaps for Transition Management: The Case of Hydrogen Energy." *Technological Forecasting and Social Change* 79 (3): 530-42.
- Mosse, D. 2006. "Anti-social Anthropology? Objectivity, Objection, and the Ethnography of Public Policy and Professional Communities." *Journal of the Royal Anthropological Institute* 12 (4): 935-56.
- Nader, L. 1974. "Up the Anthropologist—Perspectives Gained from Studying Up." In *Reinventing Anthropology*, edited by D. Hymes, 284-311. New York: Vintage Books.
- Nowotny, H., P. Scott, and M. Gibbons. 2001. *Rethinking Science: Knowledge in an Age of Uncertainty*. Cambridge, MA: Polity.
- Nuffield Council on Bioethics. 2012. *Emerging Biotechnologies: Technology, Choice and the Public Good*. London, UK: Nuffield Council on Bioethics. Accessed September 24, 2018. http://nuffieldbioethics.org/wp-content/uploads/2014/07/Emerging_biotechnologies_full_report_web_0.pdf.
- Osborne, G. 2012. "Speech by the Chancellor of the Exchequer, Rt Hon George Osborne MP, to the Royal Society, 9 Nov." Royal Society, London, November 9.

- Accessed September 24, 2018. <https://www.gov.uk/government/speeches/speech-by-the-chancellor-of-the-exchequer-rt-hon-george-osborne-mp-to-the-royal-society>.
- Owen, R., P. Macnaghten, and J. Stilgoe. 2012. "Responsible Research and Innovation: From Science in Society to Science for Society, with Society." *Science and Public Policy* 39 (6): 751-60.
- Rabinow, P., and G. Bennett. 2012. *Designing Human Practices: An Experiment with Synthetic Biology*. Chicago, IL: University of Chicago Press.
- Rip, A. 1999. "STS in Europe." *Science, Technology and Society* 4 (1): 73-80.
- Royal Academy of Engineering. 2009. *Synthetic Biology: Scope, Applications and Implications*. London, UK: Royal Academy of Engineering. Accessed September 24, 2018. <https://www.raeng.org.uk/publications/reports/synthetic-biology-report>.
- SBLC. 2016. *BioDesign for the Bioeconomy: UK Synthetic Biology Strategic Plan 2016*. London, UK: Synthetic Biology Leadership Council. Accessed September 24, 2018. <https://admin.ktn-uk.co.uk/app/uploads/2017/10/UKSyntheticBiologyStrategicPlan16.pdf>.
- SBRCG (Synthetic Biology Roadmap Coordination Group). 2012. *A Synthetic Biology Roadmap for the UK*. Swindon. Accessed September 24, 2018. http://web.archive.nationalarchives.gov.uk/20130302042701/http://www.innovateuk.org/_assets/tsb_syntheticbiologyroadmap.pdf.
- Shukman, D. 2013. "Will Synthetic Biology become a GM-style Battleground?" *BBC News July 12*. Accessed September 24, 2018. <http://www.bbc.co.uk/news/science-environment-23274175>.
- Sismondo, S. 2010. *An Introduction to Science and Technology Studies*, 2nd ed. Chichester, UK: Wiley-Blackwell.
- Stilgoe, J., R. Owen, and P. Macnaghten. 2013. "Developing a Framework for Responsible Innovation." *Research Policy* 42 (9): 1568-80.
- Stirling, A. 2008. "'Opening Up' and 'Closing Down': Power, Participation and Pluralism in the Social Appraisal of Technology." *Science, Technology & Human Values* 33 (2): 262-94.
- TSB (Technology Strategy Board). 2011. *Concept to Commercialisation: A Strategy for Business Innovation, 2011-2015*. Swindon: Technology Strategy Board. Accessed September 24, 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/360620/Concept_to_Commercialisation_-_A_Strategy_for_Business_Innovation_2011-2015.pdf.
- Uffindel, D. 2012. "Perspectives on Synthetic Biology from within the Political System." Talk given at: "Synthetic Biology for the Next Generation: The Six Academies Symposium." Washington, DC, June 12-13. Accessed September 24,

2018. http://events.tvworldwide.com/Events/IOM/NAS120612.aspx?%20VID=events/nas/120612_NAS_SyntheticBiology_1415.flv.
- Webster, A. 2007. "Crossing Boundaries: STS in the Policy Room." *Science, Technology, and Human Values* 32 (4): 458-78.
- Willetts, D. 2012a. "Our Hi-tech Future. Oral Statement to Parliament." Oral Statement to Parliament, January 4. Accessed September 24, 2018. <https://www.gov.uk/government/speeches/our-hi-tech-future-2>.
- Willetts, D. 2012b. "Response to 'A Synthetic Biology Roadmap for the UK': Letter from David Willetts MP to Dr Lionel Clarke." November 2. London, UK: Department for Business, Innovation & Skills. Accessed September 24, 2018. <https://www.gov.uk/government/publications/response-to-a-synthetic-biology-roadmap-for-the-uk-letter-from-david-willetts-mp-to-dr-lionel-clarke>.
- Wildson, J., and R. Willis. 2004. *See-through Science. Why Public Engagement Needs to Move Upstream*. London, UK: DEMOS. Accessed September 24, 2018. <http://sro.sussex.ac.uk/47855>.
- Wynne, B. 1992. "Public Understanding of Science Research: New Horizons or Hall of Mirrors?" *Public Understanding of Science* 1 (1): 37-43.
- Wynne, B. 2007. "Dazzled by the Mirage of Influence?—STS-SSK in Multivalent Registers of Relevance." *Science Technology & Human Values* 32 (4): 491-503.

Author Biographies

Claire Marris is a reader in the Centre for Food Policy at City, University of London. From 2009 to 2015, she played a leading role in the social science component of the Centre for Synthetic Biology and Innovation, which was a collaboration between synthetic biologists at Imperial College London and social scientists at King's College London (initially at the London School of Economics).

Jane Calvert is based in Science, Technology, and Innovation Studies at the University of Edinburgh. Her current research, funded by a European Research Council Consolidator grant, focuses on the field of synthetic biology. She investigates the movement of ideas, practices, policies, and promises from engineering into the life sciences and, more reflexively, examines the ways in which social scientists have been mobilized as part of this endeavor.