Contributor, collaborator or critic? STS and the making of synthetic biology

Jane Calvert and Paul Martin

Note: this is a very early stage draft of the paper that still needs considerably more work. In particular, some further background literature needs reviewing, key arguments elaborating and many more references including. However, we hope it is at a stage where it can be used to provoke debate and discussion at the workshop. We would greatly welcome any comments you have on this draft!

1. Introduction

Synthetic biology has managed to capture a great deal of scientific, public and policy attention in a space of less than five years. It looks like it is set to become the next nanotechnology, both because of the technological revolution it promises, and because of the social and ethical concerns it is likely to provoke. Many column inches have been dedicated to exciting developments in synthetic biology such as Craig Venter's eagerly anticipated announcement that he is going to create a completely new form of bacteria, and poster child applications such as an alternative production route for a drug to treat malaria, as well as promises of biofuels and a greener future.

Where new scientific and technological fields emerge, STS researchers tend to gather, and the aim of this paper is to reflect on how we as social scientists have become involved in synthetic biology, how our role is and should be imagined, and how we have become implicated and complicit in the construction of futures for the field. A motivation for this paper is that we have come across what looks like a new configuration in emerging areas of scientific research, where social scientists are becoming a required component of research programmes, enabling science to become more reflexive at an institution and individual level.

The key questions that this paper will address are: How are particular futures for the development of synthetic biology being constructed in debates about its social and ethical implications? What role do social scientists play in these debates and in the construction of synthetic futures? How is the role of social scientists being imagined by the scientists and policy makers involved? And finally, is there scope for a different role for social scientists through the co-production of new forms of socially robust science?

We place our discussion in the context of the literature on the dynamics of expectations in innovation. This conceptual framework highlights the importance of expectations in emerging scientific fields, and looks at how the future is constructed as a resource to be mobilized in the present. We argue that synthetic biology is a promissory technology and an 'emerging field of hope', and that this enables the field to be constructed ahead of the materialisation of technologies. As social scientists we are becoming increasingly involved in emerging scientific fields and as a result in the 'politics of the future'. In this paper we draw on our own experiences of involvement in synthetic biology, an involvement which has been unexpected and rapid, and which has allowed us to have first-hand experience of some of the key debates and discussions surrounding the emergence of synthetic biology in the UK and continental Europe.

We briefly describe the field of synthetic biology, the major funding initiatives in the area, the debates about its definition and scope, and the way in which it ties into hopes of a progressive, greener future. A distinctive feature of synthetic biology is the early-stage attention to social and ethical concerns, which draws heavily on previous experiences with genetic engineering and genetically modified crops. This has led to a standard list of ethical, legal and social implications of synthetic biology which are repeated in many discussions of the field. The institutional response to these concerns has been to require the involvement of social scientists in synthetic biology, as can be seen in many of the research programmes across Europe and the United States. But what role is being imagined for social scientists in these contexts? Here we introduce our three categories of contributor, collaborator and critic. We show how a 'contributor' is a role that does not threaten the science/society divide, while the 'critic' is the role that we are most familiar with, but one that does not fit easily with relationships of friendship and research collaboration. Being a 'collaborator' involves reciprocal reflexivity, and engaging in the research in a way that could change what is done and the way it is chosen to be done, with the potential for new forms of interdisciplinarity and more socially robust science.

2. Conceptual framework

The dynamics of expectations in innovation

One of the key insights from the sociology of technology is the idea that innovation requires the construction of heterogeneous sociotechnical networks. In this sense, the creation of new technology involves much more than just making something work technically, and instead demands the bringing together of a range of social, economic and political resources into stable alignment. For example, the resolution of ethical debates, the creation of new regulatory regimes, and the formation of dedicated companies all pre-date the introduction of a new product on the market. A number of important processes have been described in the STS literature that enable such network building to occur, one of which is the creation of high expectations.

Recent work on the sociology of expectations (Brown, Rappert, Webster 2000; Borup et al. 2003; Brown and Michael 2003; Martin, Brown and Kraft 2008) has explored the way in which hope, promises and hype help construct 'the future' as a resource to shape innovation and socio-technical change in the present. In particular, attention has been paid to how expectations of an emerging technology are perfomative in mobilising the future into the present through particular cultural metaphors, narrative scripts and promissory agendas (Van Lente 1993; Brown and Michael 2003; Selin 2008). However, expectations are more than just discursive and are also embedded and embodied in a range of socio-technical artefacts, including the design of artefacts, regulatory regimes and firm strategies (Hedgecoe and Martin 2003).

Synthetic biology is an example of a 'promissory technology' that can be thought of as constituting an emerging field of hope (Moreira and Palladino 2005; Brown 2005). At present, relatively little scientific or technical progress has been made in realising the technical promise of re-engineering life, but despite this synthetic biology has already managed to attract significant public and private investment leading to the creation of new research institutes, dedicated companies and major debates about its potential socio-economic impact (Balmer and Martin 2008; Garfinkle et al. 2007). How then are such fields of hope constructed ahead of the materialisation of technologies based on the science of synthetic biology?

A second set of questions also arises from thinking about the role of future-making in the construction of an emerging technology. As others have noted, STS researchers "are becoming more directly implicated in the emergence of these new technologies than in previous epochs of technological change" (Williams 2006, p.341). As social scientists we are increasingly drawn into debates about the promise and potential implications of new fields, such as synthetic biology, and as such are engaged in what might be called the 'politics of the future'. Here competing visions of the potential benefits and social implications of an emerging technology are played out, with the future becoming an object of contention. To what extent can we intervene in these futures and challenge them? What role do social scientists play in the creation of different fields?

Note: we intend to include a short review of the STS literature on reflexivity here

3. Methodology

This paper is based on the direct experience of the authors' involvement in a range of committees, meetings and other activities concerning the ethical, legal and social implications (ELSIs) of synthetic biology. It was conceived after a talk one of the authors (J. C.) gave on the contradictions of being involved as an 'expert' in this field (Calvert 2008a) and was initially developed as a discussion piece. However, it quickly became apparent that we were both becoming heavily (and surprisingly rapidly) involved in a range of activities that could provide valuable experiential and observational data to give greater weight and nuance to any arguments we made. In this sense, the paper is ethnographic, being based on our participation and reflection on our involvement in this emerging area. We have taken notes on our involvement in synthetic biology from the start of this process and have kept a record of our observations, interactions and reflections.

The extent of these activities has been considerable, reflecting both the high level of engagement by the scientific community and policy makers in debates about synthetic biology and our unanticipated successes as social scientists in being invited into this process. The fact that we have been invited on the basis of being 'ELSI' practitioners is something that we problematise and discuss below. **Table 1** summarises the various committees, meetings, networks and other activities we have been invited to participate in during the period 2007 to early 2009. In total these constituted a very large percentage of all such events concerned with the implications of synthetic biology in the UK, and to a lesser extent, in Europe, and therefore enable us to have an excellent overview of the way in which the future of synthetic biology has been constructed by scientists, policy makers, ethicists and social scientists.

The written documents produced by funders, scientists, industry and other academic participants in these events have also been collated and analysed to provide another source of discourse and evidence on how the role of social scientists is being imagined in debates about synthetic biology. Finally, it should be noted that both authors have written reviews of the social and ethical issues raised by synthetic biology; one of these (P.M.) was commissioned by the Biotechnology and Biological Sciences Research Council (BBSRC) (Balmer and Martin 20008) and the other (J. C.) by the International Risk Governance Council (IRGC 2008).

Table 1: Authors' involvement in ELSI debates on synthetic biology

Date	Activity	Sponsor	Contribution	Focus	Author
Expert committees					
2007-present	Membership of expert group on issues of concern to the public (4 meetings)	BBSRC	Attended committee meetings and commissioned to write review of the ELSIs raised by SB	Issues of "concern to the public"	PM
2008 – present	Membership of Working Party on Synthetic Biology	Royal Academy of Engineering	Contributing to sections of the report on ethical, legal and social issues	ELSIs	JC
Meetings attended as speakers					
Apr 08	Presentation to BBSRC Council	BBSRC, London	Talk to governing Council	Presented findings of ELSI report	PM
Apr 08	2nd International Forum on Biosecurity	National Academy of Sciences	Talk on 'Systems biology and synthetic biology in context'	ELSIs	JC
Jun 08	Launch of EU strategy for SB (Tessy)	EC, Brussels	Talk as part of launch of EU 'roadmap' in SB	Public awareness	PM
Jun 08	Workshop on the Risk Governance of Synthetic Biology	IRGC, Geneva	Talk on 'Synthetic biology: risks and opportunities of an emerging field'	ELSIs	JC
Nov 08	EMBL/EMBO Science and Society Conference on Systems and synthetic biology: scientific and social implications	EMBL/EMBO, Heidelberg	Talk on 'Calculating life'	Social and epistemic dimensions	JC
Nov 08	Wellcome Trust scoping meeting	Wellcome Trust, London	Led roundtable discussion on ELSIs at scientific meeting	ELSIs	PM
Feb 09	German National Academy of Sciences	German NAS, Berlin	Talk on ethics of Synthetic Biology	Ethics	PM

Meetings attended as workshop organisers					
Nov 08	Synthetic Biology 4.0, Hong Kong	BioBricks Foundation	Discussion-based workshop	ELSIs	JC
Mar 09	BioSysBio, Cambridge	Institution of Engineering & Technology	Discussion-based workshop	ELSIs	JC
Membership of collaborative networks					
2008-2011	Co-investigator in multidisciplinary network with scientists	BBSRC	Workpackage on public engagement/ understanding	Local and national events	PM
2008-2011	Member of multidisciplinary network with scientists	BBSRC	Talks at network meetings, participation in network events	ELSIs, particularly in respect to standards in synthetic biology	JC
Other activities					
Jul 08	Article in Science and Public Affairs	BA	Discussion of how scientists and policy makers might engage the public	Public engagement	PM
Mar 09	Article in EMBO Reports	EMBO	Paper on the role of social scientists in synthetic biology		JC/ PM
Mar 09	Public dialogue in synthetic biology	Royal Academy of Engineering	Talk on ELSIs	Public dialogue	JC
April 09	Week long synthetic biology 'sandpit'	NSF (USA) and EPSRC (UK)	Participation in the sandpit		JC
Jun 09	Science Festival	Cheltenham Science Festival	Presentation on ELSIs	ELSIs	JC
Jun 09	Science Communication conference	British Science Association Communication	Talk on public engagement	Public engagement	PM

4. Synthetic futures: synthetic biology as a new 'field of hope'

Synthetic biology is very much a field in the making that is surrounded by both high expectations and great technical uncertainty. There are major debates about its definition, its potential applications and how it might be best institutionalised, with different disciplinary and national traditions present.

The making of a new multidisciplinary field

In common with many emerging areas of techno-science, synthetic biology covers a broad and disparate set of research activities and there is as yet no consensus of what constitutes the field (see O'Malley et al. 2008). Competing definitions exist, but all stress the application of engineering principles to the (re)design of life. The MIT group, for example, defines synthetic biology as "the design and construction of *new* biological parts, devices, and systems and the re-design of *existing*, natural biological systems for useful purposes" (www.syntheticbiology.org, emphasis added).

Many different activities go on under the heading of synthetic biology, including: the construction of interchangeable biological parts and devices, often called 'BioBricks' (see Endy 2005); work at the level of whole genomes, including both the synthesis of viral genomes from scratch (e.g. Cello et al. 2002) and the reduction of existing bacterial genomes (e.g. Glass et al. 2006); and the attempt to create 'protocells' from simple components (see Deamer 2005; Luisi et al. 2006). Because there is such a range of work that calls itself 'synthetic biology', it is very hard to strictly delimit the boundaries of the discipline at present. In this sense it is best thought of as a 'field in the making' in which the science undertaken, the technologies developed, the institutions being established and the expectations driving these development are co-produced.

Something that all the approaches to synthetic biology share is the hope that they will succeed in making biology into an engineering discipline where so-called genetic engineering failed (Andrianantoandro et al. 2006; Heinemann and Panke 2006). For this reason, synthetic biologists commonly distinguish their work from genetic engineering. There are two ways in which they do this. One is in terms of the methods that are adopted. It is argued that since synthetic biology uses standardised parts and follows a formalised design process, the tools and intellectual approach of engineering are used in a way which makes synthetic biology more authentically an engineering activity (Endy 2005). Another distinction is in terms of the sophistication of the work. In previous genetic engineering one gene at a time is modified or added, whereas in synthetic biology a whole specialised metabolic unit or pathway can be constructed (see for example Martin et al. 2003). So in synthetic biology we see engineering at the systems level rather than at the level of the individual components. It should also be noted that synthetic biologists may be keen to distinguish their field from genetic engineering because of some of its negative perceived social implications.

Promising a greener future?

Synthetic biology pioneers, such as Craig Venter and Jay Keasling, have been very active in constructing what might be called progressive futures for synthetic biology, which provide a very attractive way of re-imagining genetic engineering. One of the key features of this re-imagining is the specific framing of the future applications of synthetic biology within dominant discourses about climate change and the need for a sustainable post-carbon future (e.g. Keasling and Chou 2008). This area of alternative energy production and the possibility of carbon capture have attracted considerable media attention (e.g. Highfield 2007; Service 2008).

Other areas of application in synthetic biology include bioremediation, biosensors, *in vivo* health applications, new drug development pathways, synthetic vaccines, and biobased manufacturing (ITI Life Sciences 2007). Already there are some claims of success in realising the vision of reengineering life. Most notably, synthetic biology has successfully been used to produce a precursor for the antimalarial drug artemisinin (Martin et al. 2003; Ro et al. 2006).

In many discussions of this emerging field, there is an embedded rhetoric about the future benefits of synthetic biology which is repeated so often that it becomes a mantra, with comparisons made to previous technological 'revolutions'. For example, leading advocates repeat tropes about how synthetic biology today bears resemblance to the 19th century industrial revolution (a similar point has been made about nanotechnology, see Rip 2006) and the nascent computer industry (see NEST 2005). This latter analogy is further emphasised by the use of a powerful metaphor to describe engineered biological parts in terms of formal circuit diagrams. In fact, one of the main research objectives in synthetic biology has been to build analogues of electronic engineering, such as oscillators, amplifiers and logic gates, in biological systems (Ferber 2004)

Building new communities of promise

Policy makers have readily bought into talk of these potential applications – as they have previously bought into the promises of other new fields such as gene therapy and stem cells – and a number of significant public research programmes in synthetic biology have been announced in the last couple of years. Most of the activity is seen on the East and West coasts of the USA. Notably, the US National Science Foundation (NSF) has invested 16 million dollars into the multi-institutional Synthetic Biology Engineering Research Centre (SynBerc). The Gates foundation has invested 43 million dollars into medical applications in the field, and the 500 million dollar Energy Biosciences Institute at Berkeley (funded by BP and the US Department of Energy) has a substantial synthetic biology component (Royal Academy of Engineering 2009). There is also scientific activity in Europe and Asia. For example, a European Union New and Emerging Science and Technology (NEST) pathfinder initiative has funded 18 projects for approximately 25 million Euros (NEST 2007). The UK research councils have funded seven UK networks, to bring together researchers interested in synthetic biology from different disciplines (BBSRC 2008).

Unusually for an emerging scientific field, one of the most important areas of activity in synthetic biology is an annual undergraduate competition, the international Genetically Engineered Machines competition, known as iGEM (see www.igem.org). This started as an event that was internal to MIT in 2003 but has since expanded to include students from other universities around the world. In 2008 there were 84 teams competing from 21 countries. The iGEM team was the spark that initiated many of the synthetic biology activities in the UK that we have been involved in as social scientists. The competition is a deliberate attempt to build a synthetic biology community from the 'bottom up'.

5. Constructing the social and ethical concerns

Anticipating areas of concern

One thing that is distinctive about this emerging community is the conviction that there are important ethical, legal and social issues raised by this emerging field, and that these issues should be explicitly addressed. This anticipation of the ELSIs is being purposely built into the developing field by research funders and leading researchers. In this way, particular futures for synthetic biology are being constructed in debates about its social and ethical implications.

Although its proponents make considerable efforts to distinguish their work from the genetic engineering of the past, it is undeniable that synthetic biology evokes many of the same fears that were associated with the early development of recombinant DNA. This means that there is already a well established set of anxieties which frame the emergence of synthetic biology. In particular, the idea that scientists are 'playing God' is perhaps even stronger in this field, where a central project is the creation of new life forms 'from scratch'. However, almost all concern about synthetic biology is anticipatory. Most of the work currently taking place in this field is far from being translated into working technology or being commercially exploited, as indicated by the fact that the majority of it is funded by public institutions, rather than companies (De Vriend 2006). The field has yet to deliver any large scale applications, and it is estimated that no commercially important products will be seen for at least a decade (Garfinkel et al. 2007).

At present the main technological driver of synthetic biology is the dramatically increasing capacity and speed, and decreasing cost, of commercial custom DNA synthesis, which will enable researchers to order very large sections of DNA, containing many genes, over the internet in the near future. The hope is that in the longer term, this will enable wholesale genetic engineering of simple organisms to become a mundane process and will further transform the progress of experimental research in the biological sciences (Endy 2005).

As a consequence of the field still being at an early and emergent stage, the discussion of applications is promissory, with synthetic biologists keen to highlight anticipated applications to demonstrate the power and potential of their work and to help justify its continued funding. But this discussion of applications is a double-edged sword. In making claims for the potential of synthetic biology as a revolutionary technology that can transform science and industry, advocates also acknowledge that these very achievements may give rise to broader public concerns about future developments. In this sense, both utopian visions of a synthetic future and dystopian fears about technology out of control are produced at the same time, each based on a shared assumption about the power of the technology.

The awareness of the scientific community

The synthetic biology is aware that their research has the potential to be extremely contentious, and many scientists regularly write about and publicly discuss regulatory, social and ethical issues. In this way we may be seeing new forms of reflexivity among scientists. This is part of an ongoing process that was institutionalised within the ELSI stream of the Human Genome Project. Our argument here is that this reflexivity is being institutionalised through the embedding of social scientists and ethicists in the field at this early stage.

The awareness of synthetic biologists about the potential impact of their work was demonstrated at the Second International Meeting on Synthetic Biology in 2006, where the participants put forward a declaration on the governance of the field, which focused on biosecurity issues and emphasized self-regulation. However, this call for self-regulation met with a strongly negative response from civil society organisations and NGOs. A global coalition of international organizations wrote an open letter saying "we believe that this potentially powerful technology is being developed without proper societal debate concerning socio-economic, security, health, environmental and human rights implications" (ETC Group 2006). It emphasised the necessity for broad and inclusive public debate on the implications of the field. Public statements such as these demonstrate that pressure to acknowledge the ELSIs raised by synthetic biology is coming not only from within the scientific field, but from external sources as well. In synthetic biology we can see these internal and external pressures reinforcing each other in a way which could fundamentally change the way in which the science is undertaken, because, as we will see below, ELSIs are becoming something that have to be taken into account in routine research programmes.

Making the ELSIs of Synthetic Biology

There is a standard list of ELSIs raised by synthetic biology, which are rehearsed by most of the reports on the field. These include concerns about biosafety, biosecurity, intellectual property and the creation of life. In drawing attention to these issues, social scientists are inadvertently involved in creating expectations about the future of synthetic biology, but within the scope of a narrow range of concerns. ELSI work draws on established tropes, many of which were developed in the 1970s and 80s, to co-produce with the scientists ideas about particular futures for the field. We could be seeing an example here of what Williams (2006) calls 'compressed foresight': an attempt to "map the technical and social outcomes in greater detail than previously, which can make these futures appear as largely determinate and imminent" (p.328). In the context of these caveats and concerns, we will briefly rehearse some of the standard discussions of the ELSIs found in the field.

Biosecurity

As we have seen, the ELSIs raised by synthetic biology resonate with anxieties that already exist in respect to genetic engineering. An important resemblance that synthetic biology has to genetic engineering is that it involves the production of living organisms, which, by definition, are self-propagating. But synthetic biology adds new issues because with the development of the internet and the routinisation of many biotechnological procedures, the tools for doing synthetic biology are set to become readily accessible (Garfinkel et al. 2007). In fact, one of the aims of some proponents of synthetic biology is to make genetic engineering techniques mundane and ubiquitous. This is demonstrated by the involvement of undergraduates (and even high school students) in synthetic biology in the iGEM competition. We also see it in grass roots movements like DIY bio (diybio.org), where home hobbyists aspire to utilise the tools of biotechnology to produce synthetic biological creations beyond the confines of academic institutions. Here we see the potential domestication or deskilling of biotechnology, and this leads to concerns about 'garage biology', 'biohackers', and biosecurity more broadly. Biosecurity concerns have also been exacerbated by the synthesis of several pathogenic viruses. In 2002 an infectious poliovirus was synthesised using only published DNA sequence information and mail-ordered raw materials (Cello et al. 2002). In 2003 a virus that infects bacteria (phiX174) was synthesised in only two weeks, and in 2005 the virus that was responsible for the 1918 influenza pandemic was constructed from scratch (Tumpey et al. 2005). The worry is that biohackers could recreate known pathogens and perhaps even make them more virulent (Tucker and Zilinskas 2006).

Biosafety

It is argued that the major biosafety risk of synthetic biology is the accidental release of synthetic organisms, which could have unintended detrimental effects on the environmental or on human health (De Vriend 2006). Not only are microorganisms living and self-propagating, but they also evolve rapidly, and they can exchange genetic material with each other across species boundaries. Additionally, the flexibility of synthetic biology means that microorganisms could be created which are radically different from those that now exist, and these microorganisms might have unpredictable and emergent properties (Tucker and Zilinskas 2006), making the risks of accidental release very difficult to assess in advance (De Vriend 2006).

Intellectual property
Intellectual property issues are complicated by the fact that synthetic biology operates at the intersection of biotechnology, software and electronics (Rai and Boyle 2007). The objective behind much of the discussion of intellectual property is to develop some form of protection "without stifling the openness that is so necessary to progress" (NEST 2007:15). But patents already exist that could inhibit research in synthetic biology. For example, there are broad patents on foundational technologies, narrower patents on the biological functions encoded by synthetic BioBricks, and patents on software and computer simulations. Worries about these potentially restrictive patents in synthetic biology are closely linked to concerns about the monopolisation of the field by large companies (ETC Group 2007). In response to these concerns, the synthetic biologists working on BioBricks have set up the BioBricks Foundation in an attempt to ensure that their creations are freely available in the public domain. This 'open source' ethos links in interesting ways to the iGEM competition and the attempt to build a new synthetic biology community.

Nature and life
Commentators predict that the perceived unnaturalness of synthetic biology is likely to give rise to ethical alarm, and to questions about where we should draw the line between what is 'natural' and what is not (De Vriend 2006). Statements to the effect that the next 50 years of DNA evolution will take place "not in Nature but in the laboratory and clinic" (Benner 2004:785), accompanied by inventions such as bacteria that produce spider silk, challenge everyday understandings of nature and our place within it. This is exacerbated by the fact that one of the main objectives of synthetic biology is to remove the detritus that organisms have accumulated by evolutionary processes to produce more streamlined and efficient biological constructions (Calvert 2008b). Suggestions have been made that a measure of 'artificialness' of synthetic systems should be introduced, which will involve developing guidelines about how to make distinctions between artificial systems and natural systems (De Vriend 2006). There are also a host of related concerns about synthetic biologists 'playing god' (NEST 2005) by creating new life forms. However, the issue of creating synthetic life has to be understood in the context of centuries of debate on the definition of life and on the distinction between life and non-life (for an interesting recent discussion see O'Malley and Dupré forthcoming 2009).

<u>The institutional response – call in the social scientists and ethicists!</u>
The prominence given to ELSIs, the awareness of the scientists in the field, and the pressures from external actors has led to a situation where social scientists seem to have become a required component in the development of the field. This move is of course not unique to synthetic biology, and there is a long history of engagement of social scientists in emerging technologies, a key example being the ELSI strand of the Human Genome Project. However, what we see in the synthetic biology context is a series of initiatives where ELSIs have become an almost mandatory component, purposely incorporated into research and discussion at the very early stages.

In the UK, for example, four of the UK's research councils have funded seven synthetic biology scientific networks which require an 'ELSI' component (BBSRC 2008). Their justification for this is that

> "It is very important that ethical and other social issues are identified at this early stage in the development of Synthetic Biology, before new products and processes are made, so that research funders and researchers can take these into consideration" (BBSRC 2008, p.5).

What 'taking these into consideration' will actually involve is a key issue here. The BBSRC's aspirations for the influence of the ELSI component are high; they hope that a report they commissioned on the ELSIs of synthetic biology (co-authored by P.M.) will "inform our policy and funding decisions". They also say an aim of this report is to "raise public awareness and stimulate constructive public debate" (p.5). (We perhaps see the implication here that the GM debate was not 'constructive'). On a regulatory level, their aim is "to ensure that the UK's regulatory framework can provide robust safeguards for taking Synthetic Biology forward safely and responsibly" (p.5). This statement, characteristically, assumes that synthetic biology *should* be taken forward. As well as the networks they have funded, the BBSRC also has a 'Synthetic biology working group', established in 2006, comprising natural scientists, social scientists (P.M.) and independent members, to examine public attitudes.

The UK's Royal Society on their web page on synthetic biology do recognise that the field "raises a number of uncertainties including its possible impact on society" (http://royalsociety.org/landing.asp?id=1230), and they are undertaking a range of work to address these issues. They have a 'Synthetic biology policy coordination group', which includes researchers, funders, and those "with a stake or interest in the direction and development of the technology" (http://royalsociety.org/page.asp?id=7388). One of the areas of focus of this group is 'Stakeholder and public engagement', and they maintain that "A wide-ranging, international dialogue is needed on the social and ethical issues surrounding synthetic biology, the general direction of the research and ownership and control of the technology". They also emphasise that "Mechanisms need to be developed to encourage the responsible development of synthetic biology and a range of stakeholders (including publics) should be involved in discussing developments from an early stage" (http://royalsociety.org/page.asp?id=5532). The Royal Academy of Engineering has also established a working group on synthetic biology, involving natural scientists, research council representatives, and one social scientist (J.C.). The working group is currently writing a report on the field. The Royal Academy of Engineering has also funded a small-scale Public Dialogue on Synthetic Biology.

The institutionalisation of the anticipated ELSIs raised by synthetic biology is not just a UK phenomenon. In Europe there is a FP7-funded project called SYNBIOSAFE which "aims to proactively stimulate a debate on these issues" (http://www.synbiosafe.eu/). A clear objective of SYNBIOSAFE is to promote synthetic biology. The introduction to the project says that "In order to ensure a vital and successful development of this new scientific field – in addition to describ[ing] the potential benefits – it is absolutely necessary to gather information also about the risks and to devise possible biosafety strategies to minimize them" (http://www.synbiosafe.eu/index.php?page=Introduction). It also states that the aim of SYBNIOSAFE is to "to facilitate socially acceptable development" of the science, and that the role of the project is to create "the framework within which Europe's fledgling synthetic biology industry can flourish". GM crops are drawn upon as a previous failure: "Past experiences, especially in the field of GM-crops, have shown the importance of an early bio-safety and ethics debate" (http://www.synbiosafe.eu/index.php?page=Introduction). This demonstrates Rip's (2006) point that GMOs are a forceful repertoire in Europe when discussing potentially contentious emerging technologies. Another European project, called TESSY (http://www.synbiosafe.eu/index.php?page=tessy), is unambiguously positive in its promotion of the technology, but also acknowledges the need to consider ELSIs.

In contrast, Paul Rabinow's strand of the 'Human Practices' branch of in the US's Synberc programme (http://www.synberc.org/), adopts a much more reflexive and critical approach. The new institutional arrangements forming around synthetic biology – particularly the collaborations between the natural and human sciences – are an explicit object of analysis for the research. This project has resulted in the publication of interesting reflexive material, which will be discussed below. Here the question that is relevant is why has this 'post-ELSI' strand of research been built into the scientific programme? Unlike in Europe, the GM crops experience is not relevant in the US. Instead, the ELSI component here seems to be mirroring the ELSI component of nanotechnology, which received a large amount of funding in the US and has been considered to be a successful example of 'upstream' ELSI.

Other US activity includes funding from the Alfred P. Sloan Foundation on regulatory and governance issues associated with synthetic biology, which resulted in the production of the report *Synthetic Genomics: Options for Governance* (Garfinkle et al. 2007). In 2008 the Sloan foundation announced the funding of three further projects studying various aspects of the social dimensions of synthetic biology: one focussing on ethical issues, one on potential societal concerns and one on public perceptions of the new field (www.sloan.org).

There is also interest in the ELSIs of synthetic biology in the US in the National Academies of Science, which is conducting ongoing work on biosecurity concerns, and which is also involved in organising "an international symposium on the opportunities and challenges of synthetic biology" in collaboration with the Royal Society and the Organisation for Economic Cooperation and Development (OECD), planned to take place in 2009.

Unusually for a scientific conference, the annual synthetic biology meeting in 2008 (Synthetic Biology 4.0) included sessions on biosecurity, future scenarios, intellectual property and commercialization in the programme. Also, in his closing comments to the conference, one of the organisers, Drew Endy, explicitly acknowledged that "we have new colleagues from social sciences, civil society organisations and industry". At this event there was also a session on 'Global social impact' run by the ETC group, one of the most outspoken critics of the technology, and funded by the Sloan Foundation. Although it is notable that a key NGO was given a platform at this event, few synthetic biologists attended this session.

To summarise, what we see here is the construction of what is becoming a standard repertoire of social and ethical concerns in synthetic biology by scientists, funders, external actors such as NGOs, and social scientists, based partially on previous perceived anxieties about genetic engineering and GM crops. A response to these concerns has been to embed social scientists, lawyers and bioethicists in the emerging field, and to give them a voice at conferences and other events (as is evidenced by our own involvement in synthetic biology outlined in Table 1). However, exactly what the role of social scientists is, or should be, in helping address these issues is the subject we wish to explore in the rest of this paper.

6. The imagined role of social science in the making of synthetic biology

<u>The imagined role of social science</u>

We have described various initiatives where the anticipated ELSIs arising from synthetic biology are built into the institutions set up to do research in the field. The questions that arise are: why has this happened? Why have we been invited in? And how is our role as social scientists being constructed and imagined by the institutions and groups who have invited us to become engaged? When the 'why?' question is asked of the BBSRC, the quick response is "we don't want another GM" – a response echoed in many of the meetings we have attended. The assumption appears to be that the involvement of social scientists will in some way prevent such catastrophes happening again.

There are other reasons why we may have been invited to participate. The scientific and policy communities may genuinely think that there are important issues being raised here which are beyond the scope of their expertise. There may be a hope that the involvement of social scientists will give research projects legitimacy, or that this involvement will somehow make the science more democratic. We may be seeing an attempt to shift the responsibility to the social scientist for all the non-scientific consequences of the technology, and the public reactions to these consequences. More cynically, such engagement can be seen as "good for PR".

Contributor in the making of the field

We have developed a tentative analytical framework for understanding the imagined role of social scientists in the making of synthetic biology, which involves distinguishing the three different roles of contributor, critic and collaborator. Each will be discussed in turn. We are using 'contributor' here to stand for the dominant way in which the role of the social scientist is imagined by scientific and policy actors, i.e. as someone who contributes to and facilitates the progress of the field. In this way the social scientist can be seen as a kind of 'social lubricant', greasing the wheels of synthetic biology through the public approval process (Newby 1992; Macnaghten et al. 2005).

ELSI expert

The ELSI expert can be seen as someone who plays a merely 'contributory' role because they focus primarily on the consequences and implications of novel science and technology. Linked to this is the assumption that an ELSI expert is someone who can be easily 'plugged-in' to ongoing debates. Both of us have been put in positions where the expectation has been that we should play this particular role. For example, in being invited to join a working party on synthetic biology one of us was asked to single-handedly represent the social, legal, philosophical and ethical perspectives on the field. Here we can see the assumption that studying the 'social' dimensions of a scientific field automatically gives a researcher the competence to cover all the other non-scientific aspects, so that other expert inputs are not needed. (The remit given to the 'Human Practices' thrust of Synberc from the NSF was similarly large, and demanded that attention be given to "ethics, social consequences, public perception, legal considerations, risk assessment, policy implications" (Rabinow and Bennet 2008:7)). The working party (which originally only had members from science, engineering, and the research councils) had already been running for several months before ELSI input was requested. The ELSI contributions where not expected in respect to any issues to do with the novelty of science or the scope of the definition of the field (arguably areas in which STS researchers do have expertise). Conversely, the ethical, legal and social issues were considered to be outside the remit of the scientists on the committee, but were allocated for the social scientist to deal with alone. It was even assumed that the section of the report on social implications could be written in a vacuum without reference to the more technical material. Here we see an enforced separation between science and society, between the technical and the political (Haraway 1997), a distinction that decades of research in STS has challenged.

All this rests on the assumption embedded in the way that much ELSI research has been framed in the past, that scientists first do their research and then the social scientists arrive afterwards to decide what the implications, effects or consequences of this work are for society more broadly (Wynne 2006). As well as being a *post hoc* add-on to the technology, this division of labour also implicates social scientists in the construction of certain kinds of imagined futures. Our role is seen as predicting what the consequences of the technology will be, perhaps by drawing analogies with the impacts of similar technologies in the past. The hope is that if we can predict the negative implications of the technologies we can perhaps prevent or ameliorate them through different forms of social engagement (Williams 2006). In the standard ways in which ELSI is framed, we do not see the idea that knowledge production itself could be changed, and perhaps even conducted in collaboration with non-scientists. This reinforces a strict division between the scientific and the social.

Despite these problems with the framing of ELSI, we have increasingly found ourselves regularly self-describing as ELSI practitioners. This is because adopting this identity in scientific contexts means that our role is not questioned, and there is a shared understanding than our presence is legitimate. It also creates multiple entry points into scientific discussions, as can be seen by the scope of our involvement in synthetic biology summarised in Table 1. More problematic is the fact that we are regularly introduced at conferences and workshops by synthetic biologists as 'ethicists', probably because, from the scientists' perspective, this is a catch-all term for 'non-scientist'.

Another way in which social science can be a 'contributor' to synthetic biology is to somehow represent 'the public'. One of us (J. C.) was surprised that at the first synthetic biology conference she attended her disciplinary affiliation was given as 'member of society' in the programme. It was assumed that as a social scientist she somehow represented society more than the other scientists and engineers at the conference, and perhaps that her presence somehow democratised the proceedings. There is a belief here that as social scientists we somehow represent 'the public's' views, even if we do not have specific expertise on public attitudes or engagement.

Similar attitudes towards social scientists have been found in the nanotechnology field, and Macnaghten et al. (2005) argue that this relies on "The appeal to social scientists as experts in the study of public opinion and political mobilization processes" with the aspiration that "such socially sensitive intelligence may help avoid future disruptive public controversy" (p.4). Although it is problematic to be labelled as a representative of the public in this way, this does at least show that there is a recognition that the 'public' voice needs to be taken into account.

A closely related imagined role for the social scientist is one of a 'broker', 'translator', 'mediator' or 'facilitator', between different groups of actors, particularly between scientists and publics. Social scientists have played this role in the nanotech debate where their knowledge of the field has allowed them to "better elaborate assessment of societal impacts and interact with publics accordingly" (Barden et al. 2008:984). The assumption is that the public do not know enough to have a meaningful discussion, so the social scientist can transmit knowledge to the public and thereby adopt a translational role. For example, on several occasion we have been invited to meetings to advise on public engagement, and it is telling that the subtitle of the BBSRC group on synthetic biology is 'working group on issues of concern to the public'. This is perhaps a more nuanced spin on the role of 'representative of the public' since it inevitably involves "interpreting and reporting (thus, representing) public concerns and questions, which have not been recognised by policy experts" (Wynne 2006, p.74). By translating or brokering between different communities it is perhaps inevitable that STS researchers will become spokespeople for the 'outside' (Rip 2006), and for under-represented groups (Hamlin 1992).

A final way of being a contributor is becoming an evangelist for the field, or becoming part of a broader public relations exercise. This draws on the idea of social scientists as public communicators and disseminators who perform an 'outreach' function (Macnaghten et al. 2005). For example, in several projects, social scientists are expected to organise public meetings and specific events around the scientific programmes. Although this is not a role that most social scientists would willingly adopt, it is to some extent unavoidable. We are aware that every time we talk about our work on synthetic biology we are inadvertently spreading knowledge of and awareness about the field, and at times it is difficult not to be swept along by the vision of reengineering life itself.

The imagined role of social scientists as 'contributors' can be characterised in summary as a particular division of labour that does not threaten the science/society divide. This is the case if the social scientist focuses on the downstream implications of the technological developments or represents and translates the views of the public. The assumption here seems to be that social scientists deal with broader 'social issues', leaving scientists to get on with their research in peace.

7. Critic or collaborator: alternative ways of imagining the role of the social scientist in synthetic biology

The 'contributor' is only one way to think about the role of the social scientist in the making of synthetic biology. Rather than buying into how our role is being constructed by dominant social groups, we perhaps should think about alternative ways of imaging the input of social science that are driven by our own disciplinary norms and goals. In this section we will explore these roles under the headings of 'critic' and 'collaborator'.

Criticising the making of a new field

The role of a critic is a traditional and important one in science and technology studies. The introduction to the first handbook on *Science, Technology and Society*, published in 1977, states that "the most elusive, complicated and controversial" task of science studies is to "criticize the role of science in society" (Spiegel-Rosing and de Solla Price 1977, p.35). Arguably scientific and technological societies need trained critics and this kind of wide-ranging critical reflective faculty is central to STS. Woolgar (2004), for example, says that the point of STS is to "challenge our taken-for-granted assumptions, and to unsettle and disturb our inclination to depend on safe formulae and on comfortable analytic perspectives" (p.347). In this context, to be a critic is to retain "academic integrity and credibility" (Barden et al. 2008:994), and to be responsible to our professional community. Clearly, what it means exactly to be a critic is the crucial question here.

It is helpful to distinguish between two different definitions of 'critic'. According to the Oxford English Dictionary, one can be a critic in the negative sense of judging something severely or finding fault with it (as in a critic of the Bush government), or a critic in the sense of a judging the qualities or merits of the work (as in theatre critic). In the latter case we fall into the realms of criticism as connoisseurship, as discussed by Collins and Evans (2002) in respect to art. Being a critic in this sense requires knowledge of and embedding in the field of study (Webster 2007), an embedding which allows alternative forms of socio-technical development to be compared (Hamlin 1992). This constructive form of criticism "stands back from the urgencies of actual research to reflect on the strengths and weaknesses of current approaches" (Stotz and Griffiths 2008, p.3).

But being a critic of science can also involve 'unmasking' scientific developments by highlighting the interests at play and revealing power relationships. From a scientific perspective, this could be perceived as "a politics of judging, achieved through an ethic of critique based on the superior knowledge of the 'social' analyst" (Fortun 2005, p.160). It could be interpreted as negative criticism, denunciation or even resentment (Rabinow 2008). By putting ourselves in the position of a fault-finding critic, we can be seen as being opposed to the knowledge that is being produced.

This role is closer to the politics of science and technology that was prominent in the 1960s and 70s and led to the formation of groups such as the British Society for Social Responsibility in Science (BSSRS) in the UK and Science for the People in the US. These groups were often led by scientists who were committed to a democratic and egalitarian society. Here the role of critic was to demonstrate the way in which science was being used instrumentally by capitalism and the state to impose a particular social order.

This may not be a position it is still possible or desirable to occupy. On purely instrumental grounds, in order to get access to the synthetic biology community it is necessary to be perceived as a 'safe' social scientist, and not to be unduly negative about the field. But the issue is not merely one of access. As researchers in science and technology studies, we are usually interested in new scientific developments, which is why we have chosen to study them. We often have sympathy with scientists who need to get funded to do their research so that they can find out more about their subject. We often become friends – and sometimes even co-investigators – with the scientists that we study.

Collaborating in the making of a new field

An alternative to both contributor or critic is to see our role as a 'collaborator'. Here the input of social science is defined by the kind of involvement that can potentially result in the co-production of new forms of socially robust science; in other words, an involvement in the process of knowledge production itself.

From the position of collaborator we could perhaps see the demand for social scientific input into debates about synthetic biology as a unique opportunity. The UK's research councils now require social scientists to be involved in synthetic biology networks, and although this could end up as a merely token contribution, it has the potential to become a more genuinely collaborative exercise. There could be an opportunity here for authentically interdisciplinary work, which does not just follow science but interacts with it. This is made more likely because social scientists are being involved in synthetic biology at the 'upstream' end, when the research is in its early stages. In this way, social scientists could contribute to the shaping of future research directions, which could change the relationships between life scientists and those who study them.

This opportunity is one that was initially embraced by the 'Human Practices' Thrust of Synberc, who were excited at the start of their project by the prospect of "a co-production among disciplines and perspectives from the outset" (p.132). They describe this mode of interaction as 'post-ELSI' (Rabinow and Bennet p.10), because it is conducted alongside the science, rather than after the research has been done. Rabinow and Bennet (2008) hoped that that an advantage of working alongside the science was that perhaps some pressure would be removed from the social scientists to be continually anticipating and constructing the future 'implications' of the technology; meaning that the focus of the social science could be on the research in progress rather than directed towards some as yet unknown future.

Literature from other areas of disruptive technology, such as GM crops and nanotechnology, maintains that the authentic role of the social scientist in these 'upstream' situations is to explore the normative assumptions that lie behind the choices that are made, or to engage in 'opening up', as Stirling (2005) puts it. Such 'opening up' may give rise to broader questions that go beyond the specific technology which is under scrutiny, such as questions about the aims of scientific research, and what is meant by 'good science' (Wilsdon et al. 2005). This is far from just talking about the 'implications' of a technology on society or criticising its applications.

Other commentators talk about the importance of attempting to institutionalise reflexivity (Barden et al. 2008). The aim here is to make scientists "more self-aware of their own taken-for-granted expectations, visions, and imaginations of the ultimate ends of knowledge" (Macnaghten et al. 2005:11). The objective is that such processes will create 'citizen scientists' who become "sensitised through engagement to wider social imaginations" (Wilsdon et al. 2005 p.34), and who reflect on the social and ethical dimensions of their work. According to Macnaghten et al. (2005) "This implies a potential role for social scientist ethnographers as a new kind of actor-participant in those scientific knowledge communities" (p.13).

However, reflexivity can go further than facilitating social and ethical reflection amongst scientists. It could potentially enable both scientists and social scientists to imagine their work differently, in ways which are not habitual and familiar. This "development of capacities for imagining different futures" (Rabinow and Bennet 2008, p.161), could allow novel areas to be opened up and potentially changed. As social scientists, we can help contribute to a different set of expectations about the future of synthetic biology from the ones that are currently and repeatedly mobilised, and we could break away from the current list of familiar ELSIs associated with the field. In collaboration with the scientists, we could try to articulate which notions of 'social good' are being prioritised by the research (Stengel et al. 2009) and who would benefit from such developments. This 'reciprocal' reflexivity could even come to influence the science that is chosen to be done, and the way it is carried out.

Here it might be useful to draw on ideas from Constructive Technology Assessment (CTA). CTA aims to actively engage in shaping new innovations, particularly when there is uncertainty about future technological directions. It brings different actors together in a deliberative fashion, combing socio-technical mapping with stakeholder dialogue. The aspiration is to influence the direction of scientific and technological innovation so that it becomes more socially robust, i.e. both more democratically and more technically warranted (Nowotny et al. 2000; Webster 2007). We could perhaps think of our involvement in various working groups and committees in synthetic biology (as illustrated in Table 1) as CTA "in the wild".

There are positive indications that such attempts to challenge existing imaginaries and introduce reflexivity may work. The synthetic biology community is remarkably open to collaboration with people from outside the field, and keen to initiate discussions of the broader implications of their work. To a large extent this multidisciplinary is a key element of the scientific identity of such an emerging field, where novel alliances between different forms of knowledge are being institutionalised in new forms of funding and working practices. In our involvement in synthetic biology we have already come across some possibilities for genuine collaboration. For example, in the BBSRC networks that we are part of, co-authorship between social scientists and engineers has already been discussed, and we are becoming involved in assisting the iGEM teams that will carry out new research.

Barriers and obstacles
It is not necessarily easy to introduce reflexivity, however. In the nanotech debate Doubleday (2007) found that social scientific input did not challenge existing visions of the future, and that "Rather than opening up space for re-imagining innovation, an emergent global policy discourse is reducing deliberation to questions of the risks posed by engineered nanoparticles" (p.225).

It is also sobering to reflect on Rabinow and Bennet's (2008) experience of working within SynBERC. As we noted above, they started with optimism about creating new ways of 'collaborating' with the natural scientists. (They use this word much the same way as we do here, opposing it to merely 'cooperating'.) However, what happened instead was that either an 'ELSI' or an 'Asilomar' frame was steadfastly adopted. In the ELSI frame, the assumption was that 'ethics' would be discussed from time to time, in a broadly moralistic manner, along the lines of "is science good or bad?" (p.182). In the 'Asilomar' frame, all questions became 'reduced' to questions of safety (questions which could be cast in technical terms). Both of these frames deal with the 'implications' or 'consequences' of the science. The only other activity that was approved of by the scientists was educational outreach, or what Rabinow and Bennet (2008) call 'vulgarization' (p.189). For these reasons they conclude that the Human Practices Thrust was unsuccessful, although they note, along with the philosopher John Dewey, that "a discordant situation is one ripe for inquiry and thinking" (p.199).

These are warning signs that we should not become overly-idealistic about the opportunities for reciprocal reflexivity, and we should be aware of the difficulties of this approach. But there are examples of more positive experiences as well. For example, Rip (2006) thinks that "recent developments indicate that coevolution of nanoscience/technology and society is becoming more reflexive, and that sociological enlightenment may play a role" (p.362).

We will end this section by giving two examples of areas where social scientists could be involved in synthetic biology, in a manner which is collaborative but retains the ability to critical.

Reimagining the shape, identity and future of the field
The analysis of how the field of synthetic biology is defined can show the epistemic and political distinctions that are made in separating synthetic biology from other activities. Looking at how synthetic biology is distinguished from fields like genetic engineering shows how 'newness' is negotiated, which has implications for regulatory regimes (because regulation may not be considered necessary unless a technology is considered to be 'new'). The definition of a field can have knock-on consequences, and we can learn from nanotechnology in this respect. Nanotechnology has been defined in a way where the focus is on the environmental, health and safety risks of the impact of the technology "rather than addressing questions of how particular conceptions of health and the human body are reproduced by nanotechnology research programmes" (Doubleday 2007: 213). By critically engaging with the goals of research we may also try to reimagine alternative futures for synthetic biology that serve wider goals than those of a field dominated by the industrial tradition within biotechnology.

Making explicit the social and economic shaping of synthetic biology
An important feature of synthetic biology is that the open source aspirations of the field are particularly strong and well-articulated. These tie into a set of aims more closely associated with the fields of computer science and engineering than with biology (which is traditionally more proprietary), and reveals interesting epistemic tensions within the field. A key issue here is whether these aspirations will lead to 'life' being (re)shaped so it fits better with ideas about open source. Social scientific work could therefore unpack this bundle of IP norms, open source aspirations, epistemic tensions and ontological consequences to make more explicit the economic

shaping of early stage research and help steer it in ways that might maximise public rather than private gains.

Further work will be needed to elaborate the role of collaborator, but the field of synthetic biology offers an excellent opportunity to explore new ways of thinking about the relationship between the production of scientific and social scientific knowledge.

8. Conclusions: reflexive practices in the making of a new field

In this paper we have shown how the emerging 'field of hope' of synthetic biology is enrolling social science in the search for legitimacy and because of a genuine concern about public fears. In this way the anticipation of the ethical, legal and social implications of synthetic biology has become institutionalised in the work of research funders and in the organisation of scientific programmes.

We looked at the promises of greener and more progressive futures that are becoming incorporated into the fabric of synthetic biology, and also at the attendant social and ethical concerns that have been raised. We explored scientists' awareness of these concerns, and pressures from external organisations, both of which have both led to social scientists being invited to participate in the construction of the field. But there are various different ways in which our role can be imagined. The dominant way in which scientific and policy communities imagine our role is as that of a 'contributor'; an easily plugged-in ELSI expert, with no scope to influence the knowledge that is produced. As a contributor we can also be seen as a representative of the public, a translator between science and the public, or an evangelist for the field. But this is not the only way in which the role of social scientists can be imagined. The role of the 'critic' is the one that is most familiar to us as STS researchers, but becoming a critic brings with it its own contradictions and ambivalences, which are not easy to resolve, particularly if we want to retain access to and good relations with the scientists we are studying. Instead we argued that a 'collaborator' may be a more positive way in which to understand social scientific involvement in synthetic biology, because it is one where there is a genuine opportunity for the co-production of new knowledge. This involves 'opening up' the science to scrutiny about the normative assumptions underlying the research, promoting reciprocal reflexivity, challenging habitual ways of thinking and imagining different futures for the field.

We think that this integration of ELSIs in synthetic biology may provide the opportunity for a new form of reciprocally reflexive science that learns from previous problems and tries to construct the field as responsible. The constructive critical engagement of social scientists in synthetic biology could change the type of practices, institutions and even knowledge produced. This could also go beyond the established divisions between science and society to help co-produce new forms of scientific *and* social scientific knowledge in a manner that "transcends the two cultures" (Newby 1992). In this way, we could see STS researchers becoming part of the making of synthetic biology.

It is too early to say if this will happen and there are many structural and institutional barriers that may prevent it, but the idea that we might be seeing the tentative emergence of new modes of scientific knowledge production that are socially reflexive deserves our attention. Further research will be needed to see if this is a more widespread phenomenon in which social scientific knowledge contributes to the making of new multidisciplinary fields and scientists engage more fully with the normative issues that surround their work. Perhaps the most challenging aspect of this transition to a socially reflexive science and new modes of multidisciplinarity will be to define our role as social scientists in such a way that avoids reproducing the science/society divide whilst enabling critical reflection from all involved. The intellectual framing and practical development of such reflexive practices represents a major challenge to STS scholars.

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