Chapter 6

Research

Chapter 6 - Research

Chapter overview

In this Chapter we examine the role played by researchers in shaping the emergence of biotechnologies. We examine the influences *of* researchers on biotechnology trajectories and the influences *on* researchers that govern how their influence is brought to bear. We consider two extreme views (that researchers themselves determine the direction of their research and that researchers are merely instruments in society's attempts to achieve goals through science and technology) and ask how the changing relationship between science and society may rebalance the position of researchers between these two extremes. We also discuss the way in which this balance is struck in the UK's current arrangements for funding academic research through the research councils, and how industry visions influence the direction of publicly funded research through road-mapping exercises.

We also consider the influence on researchers of powerful imaginaries encapsulated in 'grand challenges' and argue that in framing these the broadest range of views should be involved in accordance with the principles we set out in Chapter 4, to avoid an over-emphasis on technological solutions to problems with substantial social dimensions. We then consider the effect on research of the need to demonstrate 'impact' to potential funders and conclude that this can encourage a tendency to 'overpromise' in relation to the benefits of emerging biotechnology in a way that is not supported by the science.

Finally, we discuss the role of researchers as public figures, communicating research to a wider audience and informing public decision making and the responsibilities that this entails, including consideration of how others, such as DIYbio practitioners and social scientists might enrich the practices of professional research.

Introduction

6.1 This Chapter focuses on the role of researchers in steering the development of emerging biotechnologies. Researchers do not form a homogenous group but are subject to different motivations, pressures and influences, including the kind of institution in which they work and the sources of their funding. There are perceived tensions between the 'basic research' mission of researchers in academic laboratories and the applied purposes of research carried out in more commercial environments, but simple distinctions between basic and applied research are inadequate to account for the diversity of motivations and external pressures to which researchers are subject.[368]

6.2 We also acknowledge the different roles of researchers both as influencers and as subject to influences coming directly from funders, indirectly from the wider socio-political environment, and from the emerging tendencies of the scientific enterprise as a whole. We recognise a paradox in the lack of agency of individual researchers despite their centrality in the research enterprise.

6.3 The questions that guide this Chapter are: what decisions determine the direction of research in emerging biotechnologies? How does the framing of these decisions about research priorities and trajectories get closed down? How can decisions be opened up to social and ethical values? And how can we steer the research system to maximise the contribution of research on emerging biotechnologies to the public good?

Where is research on emerging biotechnologies done?

6.4 It is extremely difficult to identify where research on emerging biotechnologies is carried out, due to the paucity of data available or its ambiguity. Some information can be gleaned from papers published in journals, from research grants awarded, and from reported information about economic activity surrounding research. However, as is perhaps to be expected in any emerging field, the categorisations are not sufficiently precise and consistent, and not used sufficiently precisely or consistently, to allow meaningful comparison or aggregation.[369]

[368] Calvert J (2006) What's special about basic research? *Science, Technology & Human Values* **31**: 199-220.
[369] The limitations are documented in research commissioned for this project from Dr Michael Hopkins and available via the Council's website. See: www.nuffieldbiothics.org/emerging-biotechnologies-evidence-reviews.

6.5 At an international level the Organisation for Economic Co-operation and Development (OECD) periodically collects statistics according to a two-part definition of biotechnologies it has developed. However, these statistics suffer from an acknowledged variability and incompleteness of responses across countries, as well as differences in methods used.[370] At the UK level, although some research councils and other agencies, such as the Medical Research Council (MRC), and the Technology Strategy Board (TSB), do make information available on grants awarded[371] there is little available analysis on aggregated levels of funding by area or technology focus.[372] For these reasons it is only possible to provide a broad-brush characterisation of institutions and groups that carry out research on emerging biotechnologies. Such institutions and groups include:

- Universities.
- Government/research council institutes, some key examples of which are:
  - Roslin Institute (Biotechnology and Biological Sciences Research Council (BBSRC) and University of Edinburgh: biosciences for livestock applications);
  - John Innes Centre (BBSRC: biosciences for crop science);
  - MRC Laboratory of Molecular Biology (MRC and University of Cambridge: disease research);
  - Francis Crick Institute (MRC, Cancer Research UK, The Wellcome Trust, University College London, Imperial College London and King's College London: interdisciplinary medical research); and
  - Wellcome Trust Sanger Institute (The Wellcome Trust, MRC: genome research).
- Large firms (such as big pharmaceutical firms).
- Small firms (typically start-ups and spin-outs).[373]

6.6 Outside such professionally constituted and recognised settings, there is also is a shifting and indefinite penumbra of research in non-institutional settings such as, for example, the 'Do-It-Yourself Biology' (DIYbio) movement.[374] Although it is difficult to ascertain the real extent and significance of such research, it is important to recognise that not all of those who may be classified as 'researchers' are operating in universities, institutes or firms.

Who funds research on emerging biotechnologies?

Research councils

6.7 It is similarly difficult to determine who funds research into emerging biotechnologies. Very few specific policies regarding 'emerging technologies' (biological or otherwise) can be found in published documents available from the UK research councils, but when they are mentioned,

[370] For OECD data collections, see: http://www.oecd.org/statisticsdata/0,3381,en_2649_34537_1_119656_1_1_1,00.html; for discussion, see: Hopkins M (2012) *Emerging biotechnologies: can we find out who funds R&D and what they support?*, available at: www.nuffieldbiothics.org/emerging-biotechnologies-evidence-reviews.

[371] These data go back to 2000 and 2004 respectively; for MRC, see: http://www.mrc.ac.uk/ResearchPortfolio/SearchPortfolio/search.htm?AdvSearch=1; for TSB, see: http://www.technologyprogramme.org.uk/site/publicRpts/default.cfm?subcat=publicRpt1. These allow searching only by a limited number of factors.

[372] See: Hopkins M (2012) *Emerging biotechnologies: can we find out who funds R&D and what they support?*, available at: www.nuffieldbiothics.org/emerging-biotechnologies-evidence-reviews.

[373] A 'spin-out', also known as a 'spin off', is either a subsidiary of a 'parent' organisation or an entirely new, independent organisation that has split-off from its parent. This may happen for a number of reasons. In this context, it is often the case that a small, independent spin-out firm is formed by splitting off from a larger, parent, academic organisation (such as a university) for the purpose of profitable commercialisation of a technology developed originally in an academic setting.

[374] Bennet G, Gilman N, Stavrianakis A and Rabinow P (2009) From synthetic biology to biohacking: are we prepared? *Nature Biotechnology* **27**: 1109-11.

their multidisciplinary nature is emphasised.[375] For example, the MRC maintains that "Working across disciplines is key to achieving the best results with new and emerging technologies".[376] As we note in Chapter 7 these documents also tend to stress the anticipated economic value of emerging technologies and the issue of exploiting that value.[377] For example, the BBSRC notes that it is "active in identifying emerging technologies where industry can derive real benefit from ideas emerging from the science base".[378] (The idea that emerging technologies lend themselves to commercialisation is arguably linked to their transformative potential, discussed in Chapter 3;[379] we discuss this assumption further in Chapter 9.)

6.8 The interdisciplinary nature of emerging biotechnologies and the uncertainty of their applications may mean that it is often hard to see who is in control of the funding; indeed coordinated control may be lacking. For researchers, this can mean that their projects fall in the gaps between different research councils; more broadly, persistent ambiguities of this kind may limit the potential for achieving social objectives.

Technology Strategy Board

6.9 The TSB, in partnership with the research councils, funds Innovation and Knowledge Centres in areas of technology that they define as emerging. These are very much orientated towards industrial exploitation. They are described as "centres of excellence with five years' funding to accelerate and promote business exploitation of an emerging research and technology field. Their key feature is a shared space and entrepreneurial environment, in which researchers, potential customers and skilled professionals from both academia and business can work side by side to scope applications, business models and routes to market."[380]

Direct funding from Government departments

6.10 Although a large proportion of UK Government funding for research is channelled through agencies such as research councils and TSB, the Government does provide some direct funding for 'emerging technologies', for example through the Ministry of Defence (MoD). Funding is provided for specific 'areas of interest',[381] although the MoD does note that these areas "will not necessarily receive direct MoD funding. In the UK, the research councils and the TSB support extensive civilian research programmes on Emerging Technologies".[382] In the US, significant funding is made available through the Defense Advanced Research Projects Agency for a very wide variety of technological initiatives.[383]

European Union

6.11 The European Union provides science and technology funding in a number of ways, perhaps the most significant of them being the Framework Programmes system: large, long-term projects with budgets running into the tens of billions of euros.[384] During the previous

[375] We extracted key references to emerging biotechnologies from a range of publications available for download from the BBSRC, MRC and Engineering and Physical Sciences Research Council, as well as carrying out keyword searches of their websites.
[376] MRC (2012) *Strategic aim four – research environment*, available at: http://www.mrc.ac.uk/About/Strategy/StrategicPlan2009-2014/StrategicAim4/Researchenvironment/index.htm.
[377] See paragraphs 7.10 to 7.17.
[378] BBSRC (2008) *Delivering excellence with impact: BBSRC delivery plan 2008-2011*, available at: http://www.bbsrc.ac.uk/web/FILES/Publications/bbsrc_delivery_plan.pdf, at p37.
[379] See paragraphs 3.22 to 3.25.
[380] TSB (2012) *Emerging technologies and industries*, available at: http://www.innovateuk.org/ourstrategy/our-focus-areas/emerging-technologies-and-industries.ashx.
[381] These are: advanced electronic and optical materials; advanced materials; autonomy; bio-inspired technologies; communications; data and information technologies; emerging quantum technologies; energy and power; future computing; high power technologies; human focused technology; medical advances from biological science; micro and nano technologies; micro electronics; system(s) integration. Ministry of Defence (2012) *Emerging technologies*, available at: http://www.science.mod.uk/strategy/dtplan/technologies_default.aspx
[382] Ibid.
[383] See, generally, http://www.darpa.mil/default.aspx.
[384] A detailed breakdown of the funding streams provided by the current Framework Programme can be found here: http://cordis.europa.eu/fp7/budget_en.html.

Framework Program (FP6) there were a number of initiatives relevant to emerging technologies: 'New and Emerging Science and Technologies' (NEST)[385] and 'Future Emerging Technologies' (FET).[386] FP6 ended in 2006; NEST programmes are no longer independently active under FP7, having been "partially incorporated into the thematic priorities of the Co-operation programme rather than operating as a separate cross-thematic activity",[387] as part of the activities of the European Research Council. FET remains active under FP7[388] and will continue, along with the activities of the European Research Council, under the category of 'Excellent Science' during the next Framework Programme ('Horizon 2020').[389]

6.12 Funding for FET has increased consistently since FP5: ~€290m during FP5, ~€325m during FP6 and a predicted ~€840m by the end of FP7. The proposed funding under the Horizon 2020 programme is €3.505 billion.[390] The FET programme now incorporates a large amount of funding for two 'flagship' projects, which are "large-scale, science-driven, research initiatives that aim to achieve a visionary goal" on a scale similar to that of the Human Genome Project. Although FET comes under the Directorate General for Communications Networks, Content and Technology, multidisciplinary pilot projects for this funding involve biotechnology elements through convergence between information and communications technology (ICT) and biology or biomedicine.[391] One of these is the 'IT Future of Medicine' pilot, which aims to realise personalised medicine through the creation of *in silico* virtual models of living patients to aid diagnosis and prescribing.[392] Another is the Human Brain Project which promises similar insights into the human brain, both to advance neuroscience and neuromedicine, and to advance computer science though emulating the brain's computational capabilities.[393]

Commercial firms

6.13 Research into emerging biotechnologies is also funded by a variety of large, small and medium-sized firms, although in many cases, with the exception of dedicated biotechnology firms, it is difficult to disentangle the extent of biotechnology research funding from other research activities. Finance may also be provided, for example, in the case of biotechnology spin-outs, by angel investors[394] and venture capitalists. We return to this sector and its role in shaping emerging biotechnologies in Chapter 9.

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385 See, for example, European Commission (2006) *What is NEST? Opening the frontiers of tomorrow's research*, available at: http://cordis.europa.eu/nest/whatis.htm; European Commission (2006) *New and emerging science and technologies (NEST): Specific activities covering wider field of research under the Integrating and Strengthening the European Research area (2002-2006)*, available at: http://cordis.europa.eu/search/index.cfm?fuseaction=prog.document&PG_RCN=5702828; and European Commission (2006) *Calls for proposals*, available at: http://cordis.europa.eu/fp6/dc/index.cfm?fuseaction=UserSite.NestCallsPage.

386 Described as "an incubator and pathfinder for new ideas and themes for long-term research in the area of information and communication technologies (ICT)... [going] beyond the conventional boundaries of ICT and ventures into uncharted areas, often inspired by, and in close collaboration with, other scientific disciplines, since radical breakthroughs in ICT increasingly rely on fresh synergies, cross-pollination and convergence with different scientific disciplines (e.g. biology, chemistry, nanoscience, neuro- and cognitive science, ethology, social science, economics) and with the arts and humanities." Guy K (2011) *Workshop on future and emerging technologies*, available at: http://cordis.europa.eu/fp7/ict/programme/docs/fp7-fet-02_en.pdf, p1. See also: European Commission (2009) *Future and Emerging Technologies (FET) 2002-2006*, available at: http://cordis.europa.eu/ist/fet/home.html.

387 See: Guy K (2011) *Workshop on future and emerging technologies*, available at: http://cordis.europa.eu/fp7/ict/programme/docs/fp7-fet-02_en.pdf, p2.

388 European Commission (2012) *ICT - Future and emerging technologies*, available at: http://cordis.europa.eu/fp7/ict/programme/fet_en.html.

389 Personal communication, European Commission, 25 May 2012.

390 European Commission (2011) *Proposal for a regulation of the European Parliament and of the Council establishing Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)*, available at: http://ec.europa.eu/research/horizon2020/pdf/proposals/com(2011)_809_final.pdf, p85.

391 For FET flagships, see: European Commission (2012) *Welcome to the FET flagship initiatives*, available at: http://cordis.europa.eu/fp7/ict/programme/fet/flagship/home_en.html.

392 See: http://www.itfom.eu.

393 See: http://www.humanbrainproject.eu/vision.html.

394 Angel investors are wealthy individuals who provide capital to new businesses from their own resources, in return for certain financial rewards. They sometimes operate collectively with other such investors.

Charities and philanthropy

6.14 Emerging biotechnologies are increasingly being funded and shaped by a variety of non-governmental, and non-commercial, organisations. In some cases these have resources available that match or exceed the resources of many governments or major multinational firms. Such organisations introduce a variety of different perspectives to shape the direction of research that come neither from the scientific community nor from industry. These perspectives range from those of very wealthy individuals such as Bill Gates,[395] through to patient groups and the very wide donor bases that underlie many biomedical research charities and disease-specific non-governmental organizations. Charities and philanthropic organisations can be highly focused on the objectives of particular populations or social groups. They have a large degree of independence and are not subject to the same obligations and accountabilities as public funders, such as research councils. Examples include:

- Wellcome Trust (~£640 million on charitable activities, which includes research and public engagement);[396]
- Bill and Melinda Gates Foundation (agricultural biotechnology with a focus on Africa and the developing world, e.g. C4 rice project,[397] anti-malarial drugs using synthetic biology[398]); and
- Other medical charities (e.g. Action on Hearing Loss for stem cell treatments for deafness[399] and auditory brainstem implants[400]).

What determines the directions of research in emerging biotechnologies?

6.15 It is clear that research in emerging biotechnologies would make no progress without researchers, so the position of researchers in the process by which the biotechnologies emerge is central. However, it is less clear whether researchers, collectively, have a dominant role in dictating the directions of research or whether, in contrast, it is the effect of various external influences on researchers that is more important. In reality, it is likely that there will be a complex set of feedbacks between the influence *of* researchers and the influences *on* researchers. These issues can be highlighted by considering two contrasting positions:

- Science-led research: the scientific community collectively decides which are the most interesting directions for emerging biotechnologies, and funders, guided by peer review, support the highest quality research. Industry subsequently picks promising leads to develop further, or research is spun-out into new firms.
- Goal-directed research: funders, whether research councils, Government, charities or industry, decide on priorities for emerging biotechnologies, perhaps with reference to national or global challenges such as food security or the ageing population, or with reference to perceived commercial opportunities. Researchers then adjust their approaches to take advantage of funding opportunities that this offers.

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395 The Bill and Melinda Gates Foundation has had a major impact on health research but has been criticised by some for diverting staff and resources from more basic needs and increasing dependency. See, for example, Piller C and Smith D (2007) Unintended victims of Gates Foundation generosity *Los Angeles Times* 16 December, available at: http://www.latimes.com/news/nationworld/nation/la-na-gates16dec16,0,3743924.story.

396 See paragraph 7.18 for more detail.

397 See: International Rice Research Institute (2012) *All about C4 rice*, available at: c4rice.irri.org.

398 See paragraph 2.21.

399 Action on Hearing Loss (12 September 2012) *Human stem cells restore hearing*, available at: http://www.actiononhearingloss.org.uk/news-and-events/all-regions/press-releases/human-stem-cells-restore-hearing.aspx.

400 Action on Hearing Loss (2012) *Improving medical devices*, available at: http://www.actiononhearingloss.org.uk/your-hearing/biomedical-research/projects-and-research/researchers-and-phd-students/researchers/improving-medical-devices/jinsheng-zhang.aspx.

6.16 Clearly neither of these positions wholly reflects what happens in reality. The first position does not provide a complete account of research as the directions scientists take are strongly determined by research for which funding is available to them. The freedom of action of an individual scientist varies: elite university-based researchers with long-term personal funding may have substantial amounts of freedom, although this is dependent on the continuation of outputs that are able to be published by major journals, while industry-based researchers may have little or no individual agency. Although both kinds of researcher will work subject to shared visions of the kind discussed in Chapter 2 (see paragraphs 2.29 to 2.38), most researchers fall somewhere on a continuum between the two extremes.

6.17 Goal-directed research also clearly has limitations. For example, researchers themselves, individually or collectively, must clearly have a role in shaping the priorities of those who fund them, and identifying the scientifically viable technologies. As we discussed in Chapters 3 and 4,[401] this influence may also be modulated by normative frames other than the technical frames generated within a scientific discipline. How strong the influence of researchers is, compared to other influences – such as the interests of industry, the priorities of government, the views of publics expressed directly and indirectly or the effects of more widely-conditioned social imaginations about the future – or how strong it should be, is an issue that it would benefit from explicit debate.

6.18 Both researchers and funders may also be influenced by unintended consequences of prevailing institutions, structures or practices. For example, the way intellectual property tends to drive research may lead to bias towards research directions that produce readily appropriable patentable outputs (namely devices or formulations) rather than research that focuses on new social processes or public knowledge.[402]

6.19 Researchers are also subject to other transnational trends and tensions in science:

- The entry of new disciplinary perspectives into existing fields can lead to new ideas about what constitutes good knowledge or valuable research. For example, with the movement of physicists and engineers into biology we see the aspiration to make biology more quantifiable and predictable.[403] Such an interdisciplinary approach is often a necessity in emerging biotechnologies because many analytical techniques rely heavily on computer science, modelling and quantitative skills.

- In many areas of emerging biotechnology there is a movement from observation to construction and from understanding to producing. This can be seen in synthetic biology where the field has grown considerably through the involvement of those interested in design and engineering possibilities. A shift towards producing devices rather than testing theories may also reflect both the drive to produce protectable intellectual property and the evolution of what high status journals regard as having the widest impact.

- In recent years, reductive approaches to bioscience such as genetics and structural biology have been superseded by more ‘integrative’ perspectives, such as systems biology (which studies the interactions of many individual biological components, and draws heavily on mathematical modelling). Such shifts reflect general changing attitudes to reductionism and holism.

6.20 It is also important to recognise the influence of technological development on science. What is possible in the life sciences is clearly affected by the introduction of new technologies. Sometimes these enabling technologies are consciously developed in response to the

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401 See paragraphs 3.28ff and 4.33ff, above.

402 For a discussion of the affect of patenting on emerging biotechnologies, see Chapter 9 below.

403 Keller EF (2005) The century beyond the gene *Journal of Biosciences* **30**: 3-10; Calvert J and Fujimura JH (2011) Calculating life? Duelling discourses in interdisciplinary systems biology *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* **42**: 155-63.

perceived needs of life sciences researchers but at other times they are developed in other contexts (usually ICT). Having been developed, their commercial availability and improvements to their ease of use allows new techniques to spread rapidly to different laboratories and research settings. Examples of this interpenetration and diffusion of techniques within different research areas include cheaper DNA sequencing and synthesis, large scale databases, robotics and microfluidics to increase the rate at which experiments can be done, and computing power to analyse results.

6.21 Because of these multiple and multi-directional influences, from some perspectives it can seem as if the direction of research in emerging biotechnologies is more an emergent property of the research system than a matter for higher level political (and democratic) control. This gives an ironic twist to our focus on 'emerging' biotechnologies in this Report. While this might be the case it does not mean, of course, that the emerging trajectories do not have socially and ethically important dimensions or that they are not conditioned by a variety of normative forces, including prevailing social and ethical dispositions.

Influences *on* researchers

6.22 The most obvious external influence on the direction of research in emerging biotechnologies is the pressure from funders of that research. When funding derives from commerce and industry, researchers will expect there to be close links between the commercial imperatives of the funding organisation and the direction of the research they are undertaking. For research carried out by start-ups and spin-outs, additional pressure is applied to researchers in situations where venture capitalists are keen to see a healthy return on their investments in relatively short timescales. Funding from charitable and philanthropic sources may also be expected to be closely targeted at meeting the goals of donors though in this case, support for 'basic science' may coexist as an explicit aim along with more focused efforts to alleviate particular conditions such as famine and disease, often through specific strategies.

Public funding

6.23 There is a balance to be struck by government funding agencies[404] when allocating resources between managed projects in support of strategic goals of the funding agency and projects that follow the priorities of individual scientists.[405] Decisions about how this balance should be struck can be contentious. In understanding the way research councils strike this balance and set their priorities, the relative importance of the following factors needs to be considered:

- the priorities of individual scientists as they emerge and are aggregated as the sum of many individual grant proposals;
- the views of elite scientists as they directly inform strategic discussions;
- the views of industrialists and financiers as they inform strategic discussions;
- direct steer from Government; and
- the influence of wider society.

6.24 The way in which research council priorities are set and operationalised is clearly important to researchers working on emerging biotechnologies. A key step for the research councils is the negotiation of their budget in the run up to the Government's four-yearly comprehensive spending review. This process begins with each research council preparing a bid document, outlining how they would use funding at various indicative levels. These documents draw on

[404] In the UK, the research councils.
[405] 'Investigator-driven research' or 'responsive mode'.

strategic plans that the research councils have drawn up with input from their advisory panels[406] and respond to societal challenges as understood by the Government. Although each research council aims to maximise the overall size of the science budget that the Treasury sets, they also want to maximise their own share of that budget in comparison to other research councils.

6.25 The research councils collaborate more closely in the choice of cross-council programmes on themes such as: 'global uncertainties' (e.g. energy, food security and proliferation of chemical, biological, radiological, nuclear and explosive weapons and technologies);[407] 'living with environmental change';[408] and 'lifelong health and wellbeing'.[409] These themes are agreed by chief executives of each research council with the expectation that each theme should be sponsored by a Government department.

6.26 Once the budget settlement is agreed, research councils then respond with more detailed delivery plans that set out, in more detail, how they will fulfil the promises made in their bid documents. Strategy and policy in the research councils are drafted by their staff; they are influenced by, and given final approval by, the governing body ('the Council') and informed by the advice of various strategic advisory panels.

Roadmaps and industry visions

6.27 Representatives of industry steer the research directions of scientists directly employed by their firms but also influence the direction of publicly-funded research through their role in providing formal advice regarding policy formation to Government and research councils. A collective view, from a business perspective, of the likely direction in which technology may unfold, and how that might be steered to the advantage both of individual businesses and wider business sectors, will influence the science funding environment and may inform the way individual scientists frame their own research proposals. (We consider the level of this influence further in Chapter 7).[410]

6.28 Firms carry out analyses of the business implications of new technologies that are relevant to the requirements of their own businesses. In some cases firms will regard these analyses as commercially confidential in the hope that the early adoption of new technology will lead to competitive advantage. Very often, however, firms may find it advantageous to act collectively to promote particular public visions of technological futures.[411] This may be motivated partly by the aim of improving public relations and partly by a desire to influence public regulatory policy. Trade associations, either national or supranational,[412] offer one vehicle for exerting such influence collectively. The trend to 'open innovation',[413] whereby firms deliberately share information with their potential competitors and customers to accelerate innovation and develop

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406 The most recent strategic plans for the BBSRC, MRC and EPSRC can be found at the following locations: http://www.bbsrc.ac.uk/web/FILES/Publications/strategic_plan_2010-2015.pdf; http://www.mrc.ac.uk/Newspublications/Publications/Strategicplan/index.htm; and http://www.epsrc.ac.uk/SiteCollectionDocuments/Publications/corporate/EPSRC_strategic_plan_2010.pdf.

407 See: EPSRC (2012) *Global uncertainties*, available at: http://www.epsrc.ac.uk/ourportfolio/themes/globaluncertainties/Pages/default.aspx.

408 See: RCUK (2012) *Living with environmental change (LWEC)*, available at: http://www.rcuk.ac.uk/research/xrcprogrammes/Pages/lwec.aspx.

409 See: MRC (2012) *About LLHW*, available at: http://www.mrc.ac.uk/Ourresearch/ResearchInitiatives/LLHW/about/index.htm.

410 See paragraph 7.44ff.

411 This could be illustrated by almost any industry with a unified (or semi-unified) lobbying approach. Lobbying by the pharmaceutical sector, for example, might promote a collective view of medicine as a primarily biomedical enterprise. The biofuels lobby might argue for a particular understanding of climate change and energy security.

412 For example, the UK BioIndustry Association (http://www.bioindustry.org), Biotechnology Industry Organisation (http://www.bio.org), EuropaBio (http://www.europabio.org) and Association of the British Pharmaceutical Industry (http://www.abpi.org.uk).

413 "Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively. [This paradigm] assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology." Chesbrough H, Vanhaverbeke W and West J (2005) Open innovation: a new paradigm for understanding industrial innovation, in *Open innovation: researching a new paradigm*, Chesbrough H, Vanhaverbeke W, and West J (Editors) (Oxford: Oxford University Press), p1.

anticipatory markets, may provide an increasing motivation for firms to be open about their own technological priorities. Clearly, firms will wish to steer national research policy to the advantage of individual businesses or of wider business sectors, and this tendency may be embraced by governments in the pursuit of economic growth.

6.29 'Roadmapping' exercises, where the requirements for goal-orientated technology development are identified and planned, are often used to articulate and promote collective visions for technology development. These are also influenced or consolidated by related processes such as the UK Government's Foresight[414] programmes and the European Technology Platforms (relevant examples include biofuels, highlighting synthetic biology, plants for the future, and nanomedicine).[415] The approach we set out in Chapter 4 suggests that the identities of those involved in developing these visions – and the extent to which these processes tend to open up or close down discussions of future technological trajectories – are important issues, since it is often the case that only a narrow range of industrial, academic and policy participants are involved in informing the development of roadmaps.[416] In the context of emerging biotechnologies, roadmapping exercises can be potentially problematic, because there is a danger that they could prematurely push research in one direction, towards a single destination, rather than fostering a symmetrical appreciation of a diversity of possible pathways that might be explored, through the creation of what we described above as an anticipatory paradigm.[417]

6.30 Arguably, much of the power of the idea of a technology roadmap originates from one rather successful example, namely the International Technology Roadmap for Semiconductors (ITRS). This has been effective in orchestrating the actions of many independent actors to maintain the continual, exponential growth of technological capability associated with 'Moore's law'.[418] Thus, 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. It is therefore worth reflecting on whether there are particular conditions in the semiconductor industry which make the ITRS particularly powerful, and whether there is any analogy between these conditions and those that might prevail in emerging biotechnologies, particularly considering that the relative controllability of parameters in ICTs is much higher than in complex biological processes.

6.31 The ITRS is based on very well-specified future outcomes attached to definite dates in the future. This allows equipment manufacturers to design and plan the new plant that will be needed to manufacture components to the specifications in the roadmap, it prompts semiconductor firms to design new materials, identifies the research and development challenges that need to be overcome, and, not least, allows firms to identify and develop markets for the new products that will be made possible by the technological advances.

6.32 It is unlikely that emerging biotechnologies such as synthetic biology are anywhere near being able to carry out roadmapping of this sort, given the uncertainty about the reliability of the foundational technology, what it might be used for, and what the barriers are likely to be. Roadmapping-like approaches can be used for technologies at an earlier, more formative stage, but it is important that they are in a form that is appropriate to the maturity of the innovation system. For emerging technologies this may involve, for example, providing a broad framing vision of the path forward rather than setting out precise long-term technical targets.[419]

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[414] See: http://www.bis.gov.uk/foresight.
[415] See: European Commission (2011) *European Technology Platforms*, available at: http://cordis.europa.eu/technology-platforms.
[416] See, for example, McDowall W (2012) Technology roadmaps for transition management: the case of hydrogen energy *Technological Forecasting & Social Change* **79**: 530-42.
[417] See paragraph 3.25, above.
[418] See: http://www.itrs.net; 'Moore's law', first proposed in 1965, refers to the observation that the number of transistors able to be fitted on to an integrated circuit will grow constantly at an exponential rate, approximately doubling every two years.
[419] McDowall W (2012) Technology roadmaps for transition management: the case of hydrogen energy *Technological Forecasting & Social Change* **79**: 530-42.

6.33 At the beginning of 2012, the UK Government established an initiative to produce a synthetic biology roadmap.[420] The roadmap exhibits a forceful linear narrative, supported by suggestive evidence (such as the rate of fall in the cost of gene sequencing), and presents a catalogue of new biotechnology products as virtual *faits accomplis*, despite the admission that "Synthetic biology is still at an early stage of development and relatively unproven".[421] The purpose of the roadmap is, of course, to identify the conditions that will produce this linearity (namely the funding, infrastructure, regulatory conditions, public and political support required) and it duly contains a number of recommendations to this end including building networks and capacity, investing in transfer to industry, and improving leadership and coordination.

6.34 It is very likely that the roadmap's recommendations will contribute, marginally or substantially, to the reinforcement of synthetic biology as a field of practice with its own identity. However, it would probably be a mistake to imagine that the conditions recommended to reinforce the productivity of the field are sufficient to deliver the products described in the report. Similarly, it may also be a mistake to imagine that whatever products are delivered will have required those conditions in order to be delivered. Nevertheless, the anticipatory paradigm is likely (and is indeed designed) to exert a measure of control on the emerging trajectory of synthetic biology research (and on alternative technological and social trajectories). The framing of the animating vision therefore deserves broad interrogation.

6.35 The clear focus of the roadmap is "economic growth and job creation",[422] although to its credit, it also addresses issues of responsible research and innovation, and emphases the importance of involving diverse social groups in the development of synthetic biology.[423] It is also notable that the proposed synthetic biology Leadership Council will incorporate a broader range of stakeholders than is normally the case,[424] and will meet at least once a year in public.[425] This is a development to be welcomed, although it remains to be seen whether the mechanisms designed to promote responsible innovation, such as the cross-domain collaborations and the broad background of the Leadership Council, are capable of addressing questions of public ethics and their associated ambiguities.[426] These include questions such as: are the social objectives the *right* social objectives? Why should we think that synthetic biology is a desirable (or even acceptable) way of fulfilling the social objectives identified? What should 'desirable' mean in this context (for example: 'most effective', 'safest', 'cheapest'[427]) and according to whose standard? What understanding of uncertainties should apply to the prospects of synthetic biology leading to the outcomes in terms of which its desirability is framed? (We return to this in the next Chapter.) More importantly, it is unclear (since this is not contemplated) whether these mechanisms would be able to locate the will or mobilise the power to halt research and innovation trajectories within synthetic biology if it appeared appropriate to do so.

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420 See: Willetts D (2012) *Our hi-tech future*, available at: http://www.bis.gov.uk/news/speeches/david-willetts-policy-exchange-britain-best-place-science-2012.

421 UK Synthetic Biology Roadmap Coordination Group (2012) *A synthetic biology roadmap for the UK*, available at: http://www.innovateuk.org/_assets/tsb_syntheticbiologyroadmap.pdf, p4.

422 Ibid. In fact, the first sentence encountered in the document is "The excellence of the UK research community provides an opportunity for future economic growth." It continues: "Deriving significant benefits also relies on the ability of business to develop products and services and on the expectation of a sizeable global market. The Technology Strategy Board highlighted synthetic biology as an emerging technology meeting all these key criteria and offering particularly strong growth potential in the UK." Ibid.

423 Ibid, p21.

424 Social scientists, non-governmental organisations and other stakeholders are listed as potential members of the Leadership Council in the roadmap report. Ibid, p32.

425 Ibid. pp32-3.

426 Ibid, p32.

427 The Roadmap states that a condition of the broad public acceptability of innovation in synthetic biotechnology will be that it is "demonstrably directed towards ...solutions to compelling problems that are more effective, safer and/or cheaper than existing (or alternative) solutions." (Ibid, p19.)

Societal challenges and 'salvational narratives'

6.36 Over the last decade we have seen the emergence of the idea that research on emerging biotechnologies is needed to address societal challenges,[428] up to and including the notion that they are essential to avoid a global disaster, as can be found in the 'perfect storm' narrative of Sir John Beddington, the UK Government's Chief Scientific Advisor.[429] Such attitudes are embedded in the notion of the 'biotechnology wager' which we discussed in Chapter 1. In the context of research council plans, societal challenges are chosen in the light of broader social goals. For example, the BBSRC has three challenges in its 2011 *Delivery plan*: food security; industrial biotechnology and bioenergy; and enhancing lives and improving wellbeing.[430]

6.37 The use of grand societal challenges in today's policy discussions is heavily influenced by the Gates Foundation's 'Grand challenges in global health' initiative, launched in 2003 in collaboration with the US National Institutes of Health.[431] Following this initiative, such challenges became "a tool for mobilising an international community of scientists towards predefined global goals with socio-political as well as technical dimensions".[432] The challenges potentially allow for a more expansive social debate about funding priorities, and the views of the public are sometimes incorporated into their formulation, such as in the case of the UK nanoscience 'Grand Challenges'.[433] They also allow many different kinds of research (fundamental, strategic and applied) to fit under a single broad heading. Although we do see a familiar agenda of national economic competitiveness and technological leadership in the discussion of societal challenges, they can act to leaven the relentless influence on economic drivers that dominates research policy (see Chapter 7). They may also, however, be promoted by those with a vested interest in particular kinds of technology as a way of securing resources and other forms of support. Furthermore, there is a risk that meeting the challenges in prescribed ways can inadvertently and detrimentally come to define the criteria of 'success' in research (the 'tunnelling' problem we identified in Chapter 2[434]). We see the main bulwark against these dangers as being the cultivation of what we have labelled the 'virtue of enablement'[435] in institutional and procedural contexts and we therefore recommend that, **when framing science policy through societal challenges, a 'public ethics' approach should be taken to avoid an overemphasis on technological rather than social solutions to problems with substantial social dimensions**. Applying a public ethics approach (such as that which we set out in Chapter 4) to the consideration of research priorities can enable detailed scrutiny, rigorous critical analysis and extended peer review, as well as securing greater legitimacy, trust and public confidence in research directions.

The 'impact agenda'

6.38 Funding restrictions and the need for universities to increase revenue streams from elsewhere ('third stream' funding from organisations in the private, public and voluntary sectors, for example) have contributed to increasing demands placed on university researchers in the UK to

[428] See, for example, National Research Council (2009) *A new biology for the 21st century*, available at: http://www.nap.edu/catalog/12764.html.
[429] Beddington J (2009) *Food, energy, water and the climate: a perfect storm of global events?*, available at: http://www.bis.gov.uk/assets/goscience/docs/p/perfect-storm-paper.pdf. This is echoed with even more urgency by a joint paper presented at the UN Environment Programme's Governing Council meeting on 20 February 2012 by the 18 Blue Planet prize laureates, asserting that "humanity's behaviour remains utterly inappropriate for dealing with the potentially lethal fallout from a combination of increasingly rapid technological evolution matched with very slow ethical-social evolution" creating an "absolutely unprecedented emergency". See: Brundtland GH, Ehrlich P, Goldemberg J *et al.* (2012) *Environment and development challenges: the imperative to act*, available at: http://www.af-info.or.jp/en/bpplaureates/doc/2012jp_fp_en.pdf, p7.
[430] BBSRC (2011) *BBSRC delivery plan 2011-2015: maximising economic growth in the age of bioscience*, available at: http://www.bbsrc.ac.uk/web/FILES/Publications/delivery_plan_2011_2015.pdf.
[431] Omenn GS (2006) Grand challenges and great opportunities in science, technology, and public policy *Science* **314**: 1696-704.
[432] Brooks S, Leach M, Lucas H and Millstone E (2009) *Silver bullets, grand challenges and the new philanthropy*, available at: http://www.ids.ac.uk/files/dmfile/STEPSWorkingPaper24.pdf, p8.
[433] Kearnes M (2010) The time of science: deliberation and the 'new governance' of nanotechnology *Governing Future Technologies*: 279-301.
[434] See paragraph 2.33.
[435] See paragraph 4.52.

frame their research, both retrospectively and prospectively, in terms of 'impact'.[436] This reflects broader international trends. In the US, "broader impacts" are an essential criterion for assessing research proposals to the National Science Foundation, as specifically mandated by Congress.[437] In the EU's framework programmes, 'expected impacts' have always been given an explicit weight in proposal review and in successive programmes the types of impacts eligible to be considered has been tightened.[438]

6.39 The focus on impact represents a perfectly proper concern to ensure that research is often appropriately examined for its wider social and economic value, especially when that research is supported by public money, and to maximise the economic and wider public benefits of academic research. In the UK, the search for impact encompasses the encouragement of academic entrepreneurialism (which has been a feature of research policy since the 1980s, especially in the US[439]), the promotion of the importance of the university spin-outs through a series of government reports,[440] and the ascending influence of some successful role models. It also seeks to encourage the many other ways in which academic researchers interact with business, through collaborative research, consultancy and other routes.[441]

6.40 There are, however, several different concepts of impact, which frame the presentation of research in often subtly different ways, although economic value lies behind almost all. The main concepts of relevance to academic researchers in the UK are those implemented by the funding body for the universities, the Higher Education Funding Council for England (HEFCE), and the research councils.

6.41 Although the assessment of research impact is notoriously difficult,[442] particularly given the complexity of technology innovation systems and the range of disciplines to which it is applied, a retrospective assessment of impact underlies the Research Excellence Framework (REF),[443] the results of which will determine future university funding.[444] This provides a direct mechanism to shape institutional choices of public sector research direction in universities.

6.42 The forward-looking aspect of the impact agenda in the UK is implemented through the inclusion in research proposals of a section on 'pathways to impact'. Although interpreted by many as an (arguably futile) attempt to induce researchers to predict the future, it is more accurate to think of this as a way of attempting to modify the behaviour and values of

[436] The history of the Higher Education Funding Council for England or Department of Trade and Industry third stream funding is set out in Public and Corporate Economic Consultants and the Centre for Business Research (2009) *Evaluation of the effectiveness and role of HEFCE/OSI third stream funding*, available at: http://www.hefce.ac.uk/media/hefce1/pubs/hefce/2009/0915/09_15.pdf. At page 22, it is stated that: "The broad aim of all HEFCE/OSI third stream funding to date has been to enhance the direct and indirect economic benefits of HE, through embedding a culture and capacity within institutions that support the transfer and exchange of knowledge between HE, business and the wider community."

[437] National Science Foundation (2011) *National Science Foundation's merit review criteria: review and revisions*, available at: http://www.nsf.gov/nsb/publications/2011/meritreviewcriteria.pdf. The America COMPETES Reauthorization Act of 2010 lists eight goals to be met under this heading: increased economic competitiveness of the United States; development of a globally competitive STEM workforce; increased participation of women and underrepresented minorities in STEM; increased partnerships between academia and industry; improved pre-K–12 STEM education and teacher development; improved undergraduate STEM education; increased public scientific literacy; and increased national security.

[438] Holbrook JB and Frodeman R (2011) Peer review and the ex ante assessment of societal impacts *Research Evaluation* **20**: 239-46; the extension of the impact agenda has drawn equally robust resistance in some quarters; see: Jump P (2012) ERC rejects 'impact agenda' *THE* 8 March, available at: http://www.timeshighereducation.co.uk/story.asp?storycode=419276.

[439] Slaughter S (1993) Beyond basic science: research university presidents' narratives of science policy *Science, Technology & Human Values* **18**: 278-302.

[440] For example: Sainsbury D (2007) *The race to the top: a review of Government's science and innovation policies*, available at: http://www.hm-treasury.gov.uk/d/sainsbury_review051007.pdf.

[441] Abreu M, Grinevich V, Hughes A and Kitson M (2009) *Knowledge exchange between academics and the business, public and third sectors*, available at: http://www.cbr.cam.ac.uk/pdf/AcademicSurveyReport.pdf.

[442] See, for example, Grant J, Brutscher P-B, Kirk SE, Butler L and Wooding S (2010) *Capturing research impacts: a review of international practice*, available at: http://www.rand.org/content/dam/rand/pubs/documented_briefings/2010/RAND_DB578.pdf.

[443] The 'Expert Panels' of the REF will begin assessing submitted research in 2014. The work to be assessed will be that performed from 2008-2009. See: REF2014 (2012) *Timetable*, available at: http://www.ref.ac.uk/timetable.

[444] REF2014 (2012) *Background*, available at: http://www.ref.ac.uk/background.

researchers, by priming them to think about how they might increase the 'utility' of their research in terms of who the onward users of that research might be (and, indeed, to build anticipatory links with them).

6.43 This may have the effect of reinforcing, within the research community, an external notion of utility, albeit one that may be narrower and more elusive than measures of utility found within research itself, as we see in the conspicuous emphasis on economic impact in relevant policy documents. A second consequence, of course, may be not that research becomes better at generating utility (however this is defined), but that researchers become better at manipulating the system, particularly if the endpoints are remote and the pathways unclear, and there is little likelihood of attracting a penalty for doing so. Such a process may therefore produce an *illusion* of administrative control while actually making the process of research more constrained, and less flexible and creative.

6.44 The identification by researchers of the distributaries of wider value for their research provides channels for the appraisal of ethical, legal and social implications of research. It also facilitates policy 'impact assessment' (adapted into a variety of administrative forms). By nature these tend to give concrete form and value to impacts and displace more open social appraisal of biotechnologies. The tendency to simplification and concretisation of the concept of impact may also become exacerbated and consolidated by bioethicists and others, whose modes of argument often involve pointing to exaggerated, absurd or intolerable consequences.[445] This may result, for example, in an undue focus on speculative scientific claims or dystopian scenarios as standard reference points within the discourse surrounding biotechnologies, driving apart scientific practice and the discourse on that practice, and thereby creating opportunities for mistrust and disappointment.[446]

6.45 Some have argued that such discursive interactions instigate a 'promise-requirement cycle', where scientists, funders and others articulate technological possibilities, signal opportunities, that give rise to promises of possible future states of affairs which, if accepted, result in the provision of resources as well as the imposition of additional requirements.[447] This cycle prompts speculation and concerns about future worlds, which in turn trigger further promises and requirements.[448] The dynamics of such institutionalised processes entail a very pertinent danger of escalating expectations driven partly by the competitive nature of research funding.

6.46 The causes of dissonance between the discourses on impact and the prospects of research are not solely or principally the responsibility of researchers, but arise in the encounter with the broader system of research funding, policy and expectant users, critics and beneficiaries on one hand, and the realities and uncertainties of research and innovation systems on the other. The necessity of engaging in competition for funding from various sources nevertheless places researchers in an invidious position. We conclude that there is a need for institutional systems to be designed better to embody and instil the virtues of public reasoning, accountability, candour, and caution and recommend in particular that **public systems for the allocation of research funding should be designed to avoid encouraging researchers to overstep the bounds of their competence when assessing the impacts of their research in non-research contexts**.

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445 The 'slippery slope' argument, for example, is a common trope in bioethics of new technologies. See: Swierstra T and Rip A (2007) Nano-ethics as NEST-ethics: patterns of moral argumentation about new and emerging science and technology *Nanoethics* **1**: 3-20.

446 Nordmann A (2007) If and then: a critique of speculative nanoethics *Nanoethics* **1**: 31-46. In addition, in Borup M, Brown N, Konrad K and van Lente H (2006) The sociology of expectations in science and technology *Technology Analysis & Strategic Management & Organizational History* **18**: 285-98, the authors describe the dynamics of hype and disappointment and the functioning of promising in securing commitment to technological futures.

447 See, for example, van Lente H and Rip A (1998) Expectations in technological developments: an example of prospective structures to be filled in by agency, in *Getting new technologies together*, Disco C, and van der Meulen B (Editors) (Berlin: Walter de Gruyter).

448 Rip A (1997) A cognitive approach to relevance of science *Social Science Information* **36**: 615-40.

Public expectations and responses

6.47 Although the global scientific enterprise as a whole has a certain amount of self-sufficiency and a great deal of self-confidence, it is not isolated from or uninfluenced by the views of wider society. In emerging biotechnologies, opposition to forms of agricultural biotechnology (in Europe), stem cell research (in the US), and the use of animals for experiments, have all had a significant effect on the direction of research. In some cases researchers' perceptions of what the public think may be as important as what those views actually are. In the context of nanotechnology, for example, the name "nanophobia-phobia" has been given to exaggerated concerns amongst the research community about public reactions to nanotechnology.[449] On the other hand, the exposure of researchers to positive views from the public about the importance of their research, for example in biomedical research through the influence of patient groups and research charities, can shape research agendas and contribute to a sense of the value and urgency of biomedical research.

Global context

6.48 The culture of science is strongly transnational, but nonetheless scientists work in distinct locations subject to differing national environments. Different countries have different funding climates and funding priorities, though these inevitably influence each other. Public attitudes to different aspects of emerging biotechnologies have strong national differences, reflecting the divergent cultural and political histories of different nations.[450] Formal legal and regulatory structures necessarily have a territorial basis. Researchers, on the other hand, are often in a position to relocate to a different country if that environment is more congenial to their research. This leads to the very real possibility of a kind of regulatory arbitrage, which can be perceived to limit the ability of an individual nation to maintain a policy or regulatory stance that diverges strongly from world norms.

Influence *of* researchers

6.49 Researchers are undoubtedly subject to many external pressures and influences but they nevertheless play a very important role in setting the agenda for emerging biotechnologies. They not only create new knowledge but, by communicating the results of their research and their aspirations for where it might lead, they create the expectations that inform the decisions of policy makers and investors, among others. Subpopulations of researchers control, through peer review, what research is published and where, and, through the status hierarchy of scientific journals, the level of importance attached to particular pieces of research and particular fields and sub-fields. Through the peer review of research proposals, researchers also control funding at the micro-level of individual research projects; however, they also influence the strategic directions of funders through advisory committees and other forms of formal and informal consultation, advice and participation.

Researchers as communicators

6.50 Researchers devote a significant amount of their time communicating their research to a number of different audiences, such as their peers and funders, and the media.[451] These various communications have different aims. When we consider how knowledge of emerging biotechnologies is presented in the domain of biotechnology and the way these representations feed back into the science and policy domains, we should begin by attending to these different ways that researchers communicate. To the extent that discourse around emerging biotechnologies constitutes an economy of promises, where visionary and speculative claims

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[449] Rip A (2006) Folk theories of nanotechnologists *Science as Culture* **15**: 349-65.
[450] Jasanoff S (2005) *Designs on nature: science and democracy in Europe and the United States* (Princeton, New Jersey: Princeton University Press).
[451] See: Peters HP, Brossard D, de Cheveigné S *et al.* (2008) Interactions with the mass media *Science* **321**: 204-5.

are necessary to attract interest and investment, researchers provide most of the raw materials for that economy.[452]

6.51 The messages that researchers communicate are not invariable and are often tailored to the capacities and requirements of those with whom they communicate. Nevertheless, despite the involvement of scientists in the public understanding of science movement and, more latterly, in public engagement,[453] There is evidence that scientists who communicate with the public may still be failing to attend adequately to the needs of their audiences or to tailor their messages to them.[454] Either way, whether the messages are adapted by the scientists or not, the communication of technical information outside its native technical discourse involves a reframing, either of the message that is sent (by the earnest scientist-communicator who tailors their message to the audience), or of the information that is received (by the lay person struggling to find a way of making sense of the uncompromising technical information in terms with which they are more familiar). It is therefore worth considering the complex network of communication about biotechnologies in which researchers participate in order to appreciate the difficulties of maintaining the consistency and integrity of message about their research. Furthermore, because researchers' communications about biotechnologies are often intended to secure an effect rather than merely to express the truth of a proposition, these are likely to vary depending on the audience or the effect sought.

6.52 Researchers communicate with each other (i.e. to people in the same field) to report results, debate interpretations and establish priority. They communicate with policy makers and funders to make the case for the continued funding of their area or to establish the importance of new disciplinary formations (such as systems biology or synthetic biology). Researchers also communicate with the general public, both directly and through the press offices of universities and journals. Sometimes they are involved in 'public science education' or even as expert witnesses in deliberative engagement activities. More often their communications are further filtered and propagated by journalists and broadcasters, including both science specialists and generalists (see Chapter 5).

6.53 Some of the communication researchers engage in is concerned with reporting the immediate results of their research groups, but this is often set in the context of grander narratives or references to popular images, as we discussed in Chapter 2. A balance clearly has to be struck here between using familiar concepts to get across difficult points and distorting complex messages, particularly when these communications may take on an independent life and may be recycled almost indefinitely in a variety of different contexts. Researchers in biotechnology must acknowledge the public nature of their work and the public interest in it. The virtue of public reasoning goes beyond openness and candour because it entails researchers assuming a responsibility, having carried out research in which there is a public interest (and which furthermore may have relied on public funding) to account for it in public discourse. Therefore **those engaging in public discourse should not only accept responsibility for the factual accuracy and completeness of information they present but also use their best endeavours to ensure, through their continued participation in this discourse, that it is appropriately qualified and interpreted when represented by others**. There are two implications of this: firstly, that those relying on research evidence in other contexts should provide opportunities for ongoing participation of the researchers whose findings they use; second that researchers themselves should not only present complete relevant data (not only data favourable to one side of the argument) but, in doing so, be prepared to engage in discourse about science with the objective of developing understanding of science and the ambitions of scientists (their own as well as their interlocutors') rather than merely communicating scientific findings.

[452] Brown N (2003) Hope against hype: accountability in biopasts, presents and futures *Science Studies* **16**: 3-21; Hedgecoe A and Martin P (2003) The drugs don't work: expectations and the shaping of pharmacogenetics *Social Studies of Science* **33**: 327-64.

[453] For example, initiatives such as those of the Cafés Scientifiques, the British Science Association (formerly the British Association for the Advancement of Science), the RCUK Beacons for Public Engagement or the Royal Institution's Science Media Centre.

[454] Corley E and Scheufele D (2010) Outreach gone wrong? When we talk nano to the public, we are leaving behind key audiences *The Scientist* **24**: 22-9.

6.54 Alongside the communication activities of professional researchers, one group of 'unofficial', or amateur, scientists that has received a large amount of attention in the press is the DIYbio movement.[455] Related to this is the 'bioart' movement, in which artworks are created from, amongst other things, genetically modified organisms and artefacts.[456] It is difficult to assess the full extent of the activities of amateur scientists, and their levels of expertise. However, the symbolic importance of these interventions is likely to be as great as their actual potential to create new developments in biotechnology, insofar as they add to the impression of emerging biotechnologies growing in power and accessibility at the same time as they evade the conventional controls and constraints on the development of high technology.

Researchers as gatekeepers of knowledge

6.55 The most important mechanism through which researchers control the production of knowledge is the peer review process. This has built-in limitations, since scientific and technical considerations necessarily dominate: its weakness in assessing interdisciplinary proposals has been shown in an analysis of the UK's research assessment exercises.[457] It is also difficult to judge potential impact outside of academia, both positive and negative.[458]

6.56 In the design of research approaches (such as universities, institutes, firms, competitions, open source, biotechnology clusters) and their connections with developers, innovators and users, researchers authorise and legitimise certain types of knowledge and not others. They also control who counts as a credible contributor to the scientific work (for example, DIYBio groups are excluded from synthetic biology events such as the International Genetically Engineered Machine (iGEM) competition, unless they are affiliated with an academic institution, on the grounds that iGEM participants must work under the safety rules of an institutional laboratory).[459] This puts researchers in a powerful but, in effect, unaccountable, or self-regulating, position. To cultivate accountability here is not to establish a disciplinary consensus but precisely to engage with wider society about these questions of legitimacy.[460]

Researchers as advisors

6.57 Finally, the most obvious way in which scientists influence the development of emerging biotechnologies is through their roles as policy makers and policy advisors to government and government agencies. In an environment in which policy may be driven excessively by unsupported claims of economic impact, business and industry voices may have disproportionate influence. The involvement of scientists in policy making may yield benefits in terms of their tenure, expertise and appreciation of the methodological value of scepticism. Balanced against this, however, are risks of over-reliance on particular types of expertise and a greater danger of reinforcing perspectives or framings in wholly technical terms.

6.58 Privileging technical expertise in advisory contexts may mean that greater weight is given to 'harder' scientific evidence in evidence-based policy making, i.e. there may be confusion between the idea of evidence that is scientifically more robust and evidence that is more important to the decision to be made ('counting what can be counted rather than what counts').

455 Alper J (2009) Biotech in the basement *Nature Biotechnology* **27**: 1077-8; Ledford H (2010) Life hackers *Nature* **467**: 650-2.

456 Kac E (Editor) (2007) *Signs of life: bio art and beyond* (Cambridge, Massachusetts: MIT Press).

457 Martin B and Whitley R (2010) The UK research assessment exercise, in *Reconfiguring knowledge production: changing authority relationships in the sciences and their consequences for intellectual innovation*, Whitley R, Gläser J, and Engwall L (Editors) (Oxford: Oxford University Press).

458 Rip A (2003) Societal challenges for R&D evaluation, in *Learning from science and technology policy evaluation: experiences from the United States and Europe*, Shapira P, and Kuhlmann S (Editors) (Cheltenham: Edward Elgar Publishers).

459 See: Anonymous (2009) iGEM closes doors to amateurs, on *DIYBio* [internet blog] 10 April, available at: http://diybio.org/2009/04/10/igem-closes-doors-to-amateurs and http://igem.org/Main_Page.

460 See, for example, the sensitivity of the question of legitimate science in the case of 'climategate' in which, despite broad scientific consensus, there was still intense public suspicion about the internal machinations of science. See: Carrington D (2011) Q&A: 'Climategate' *The Guardian* 22 November, available at: http://www.guardian.co.uk/environment/2010/jul/07/climate-emails-question-answer.

There is also a danger of entrenchment of scientific advice, with a narrow range of expertise repeatedly drawn upon in policy contexts (partly because officials who seek scientific advice have to turn to experts to find out who the appropriate experts are, but they need an expert to tell them which expert to ask, and so on, so that they are caught in a pernicious regress of dependence on a potentially limited range of expertise). Where these processes occur in established networks or behind closed doors, any judgment can become self-reinforcing. To avoid this problem, or the appearance of this problem, we recommend that **in all cases in which technical advice is sought by policy makers there should be a demonstrable attempt to avoid sole reliance on a limited range of established experts in particular fields**. This balance should be achieved through a broadening of participation in discourse (rather than through the more earnest selection of unimpeachably authoritative individuals).

6.59 Scientists involved in policy advice may be required to contribute to discussion of issues, such as implementation and scale-up that fall outside their direct area of expertise. In these situations there may be ambiguity over whether they are speaking as scientists, as policy makers, or, indeed, as citizens. Additionally, scientific advice is important to policy making but it is not all that policy makers have to consider. The emphasis on evidence-based policy making can sometimes place a premium on scientific advice and especially on the interpretation of quantitative data, and such data are, as we have seen, subject to selectiveness and interpretive ambiguity. On the other hand, the expectation that policy is framed in terms of scientific evidence can also lead to misunderstanding when broader social responsibilities of policy makers figure strongly, which is not helped by the mission creep of scientific advisory committees within government into giving political and ethical advice.[461]

6.60 While scientists are not exempted from conflicts of interest and partisanship, there is no reason to think they are more prone to this than other groups such as industrialists or financiers.[462] But the privilege granted to scientific evidence in policy making means that scientists involved in giving policy advice have a particular responsibility to exercise self-restraint and vigilance to avoid projecting a false sense of 'scientific certainty'.[463] Nevertheless, they will clearly have an interest in their own work and its value, although this need not betoken a deliberate, instrumental distortion of priorities but instead simply reflect their greater insight into and commitment to their own research. Equally, therefore, there should be more licence for researchers candidly to assert their own convictions that their work promotes public good beyond simple economic benefit.

Extending the boundaries of research

6.61 As well as researchers participating in different discourses of, and also as, policy makers and policy advisors, we see groups such as social scientists, lawyers, patients, and even artists and designers, becoming involved in scientific research. In recent years, these 'others' have become associated with many new fields, such as nanotechnology, stem cell research, and neuroscience, and social scientists are becoming a required component of synthetic biology research programmes around the world.[464] Because of such initiatives, new relations between science, technology and society are being created, which provide new spaces for intervention.[465] In certain cases, and owing to the interdisciplinary nature of biotechnologies, these have been formalised in institutes,[466] although the advantages of flexibility can be found in the *ad hoc* 'situatedness' of 'cooperative research'.[467] It is consistent with the virtue of

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[461] We discuss this issue further in Chapter 7. Experiences in policy making concerning GMOs and drug classification present examples of the contrasting expectations about the role of scientific evidence in policy making.
[462] On scientists' role as policy makers and the influence of their own ideologies, see: Jasanoff S (1994) *The fifth branch: science advisers as policymakers* (Cambridge, Massachusetts: Harvard University Press).
[463] John S and Lewens T (2010) *The universal ethical code for scientists and the 'crisis of trust in science': report to the Science and Trust Working Group*, available at: http://interactive.bis.gov.uk/scienceandsociety/site/trust/files/2010/03/Ethical-Codes-and-Trust-16-Feb-20101.pdf.
[464] Calvert J and Martin P (2009) The role of social scientists in synthetic biology *EMBO Reports* **10**: 201-4.
[465] Webster A (2007) Crossing boundaries social science in the policy room *Science, Technology & Human Values* **32**: 458-78.
[466] Such as the collaboration that existed between the Imperial College London and the BIOS Centre, King's College London in the Centre for Synthetic Biology and Innovation, see: http://www3.imperial.ac.uk/syntheticbiology.
[467] For example, the Co-operative Research on Environmental Problems in Europe (CREPE) project; see: http://crepeweb.net.

enablement and public reasoning that, particularly given the influence of researchers outside the research context, the boundaries of this context should be broadened to enable technical framings and sources of normativity to be counterbalanced within the research context rather than externally to it, where they might already circumscribe decision making. This should not be left to the integrity of individuals but should be supported by systems.

Conclusion

6.62 In this Chapter we have considered the influences *on* researchers that inform how their influence may be co-opted or directed and the role *of* researchers in shaping emerging biotechnologies. We have suggested that, both among individual researchers as well for researchers in general, there is a 'function creep' from research into policy making that heightens the influence of technical framings in setting the conditions for biotechnologies generally. Perhaps the most characteristic feature of researchers' involvement, arising from the 20th Century specialisation and professionalisation of scientific research, is their commitment to individual technologies: consulting any researcher is unlikely to produce a balanced reflection on a range of alternative technologies that might potentially address a given social objective. In the next Chapter we consider the questions that arise for policy makers in contemplating selective support for biotechnologies in relation to social objectives, and the influence of research policy on emerging biotechnologies.