

What's the matter with biosecurity?

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Main Point: We need to promote a dialogue between multiple conceptions of security and then build governance mechanisms that are flexible enough to maintain that dialogue through power sharing. Doing this entails connecting work in STS and Responsible Research and Innovation with the biological and security communities, and those communities with others (policy, publics, industry...) as equals, not dominant or subordinate.

“If you don't have security, you don't have society,” might be a good way to describe the general thinking about the role that a perception of security plays in ensuring we can do all the other things that constitute society. Such a simple statement, however, misses two basic points about security: it is multiply constituted, and those that have the power to define the objects, subjects, and governance mechanisms of security are also fundamentally shaping the type of society in which we live.

The biosecurity community is well-versed in the need for security to be a central topic of discourse for states, and biosecurity professionals have argued for broadening the conception of national security beyond traditional state concerns to include things like health, agriculture, and building design. But in doing so, the argument is usually for those other communities to take on a security discourse, rather than for the security community to promote its goals by taking on the discourses of health etc (e.g. Bernard, 2013). In the US, such arguments are based on the assumption that security is the language that Washington listens to, and that it is where to find the money. That these assumptions are often borne out speaks to the power the security discourse has in shaping [at least American] society.

But what type of security are these arguments talking about? Rabinow and Bennett (2012) argue strongly that the pervasive understanding of security is one based on a framing of the ‘dual-use’ problem: that there are bad actors out there who must be prevented from using our knowledge and technology against us. While there are likely many cases where we can know the enemy, know the technology that might harm, and be able to prevent the two coming together with destructive results, there are just as many cases where the subjects, objects, and actions of security concern are not known. Focusing only on the former is tantamount to the old adage of looking for your keys under the streetlamp because that's where the light is. Export controls, Institutional Biosafety Committees, even the newly minted Dual-Use Research of Concern US Government policies fall into this camp. So what would it mean to govern security concerns that are not yet known?

This question should be a central strand of research and action in the coming decade. Answering it means finding meaningful ways past the traditional framing of security as a dual-use concern, where this framing is found to be lacking. It means fully appreciating that potential security concerns may also be health concerns, or concerns about the environment, economy, or morality.

¹ Acknowledgements: This work is funded by the ESRC/AHRC/DSTL Science and Security grant ES/K011308/1, and by Synberc. I'm grateful to Megan Palmer, Emma Frow, and Ken Oye for discussions that helped form the ideas expressed here.

Crucially, this line of research should go against calls to think of everything as a potential security problem. This is not a call for securitization. Rather, it is a call to reassess the ways that we make the subjects and objects of security concern. For example, what assumptions about the innovation process, the role of science in society, and the relationship between science and security are we making when we build governance mechanisms that rely on scientists as the ones who raise potential security concerns about work they are undertaking? How would those assumptions need to change if we instead instituted broader systems of prior research approval?

Security should not be the trump card it is often wielded as today in the US, particularly when threats are contested, unknown, or ambiguous. Instead, it should be a discourse of equal standing to the many others that form our society. In the same vein as the first statement, perhaps we could also say, “As war is politics by other means, talking about security is talking about the economy, health, and environment by other means.” The trouble is, as with war, talking about security tends to prevent, or at least overshadow, these other ways of addressing an issue.

Work within STS, particularly the responsible research and innovation literature, has been promoting alternatives to many ways of understanding, building, and governing innovation systems, but much work still needs to be done, particularly in studying alternatives to traditional ways of framing and governing security concerns.

But this is not just a field of study. STS has a history of being quite poorly integrated into American political thought and governing institutions. The National Nanotechnology Initiative was a preliminary step to change that, and synthetic biology, and perhaps next geoengineering, are areas where STS scholars’ insights have an opportunity to be influential in shaping future governing and thinking. The recent work of Ken Oye and the Wilson Center in the US, and of several scholars in the UK are good examples of reshaping at work (Kuiken et al, 2014; Jefferson et al 2014).

The National Science Foundation has a key role to play reshaping our understanding of what it means to engage in biosecurity governance. If it continues to fund work on societal aspects of emerging technology as an add-on to other research, it can only expect to get back findings that show how the current system works (or more often, doesn’t). Finding ways to put together a process whereby research and development proceed in step with the development of governance and public engagement is a much better use of funds.

Bernard, K. W. (2013). Health and National Security: A Contemporary Collision of Cultures. *Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science*, 11(2), 157–162.

Jefferson, C., Lentzos, F., & Marris, C. (2014). Synthetic biology and biosecurity: challenging the “myths.” *Infectious Diseases*, 2, 115.

Kuiken, T., Dana, G., Oye, K., & Rejeski, D. (2014). Shaping ecological risk research for synthetic biology. *Journal of Environmental Studies and Sciences*, 1–9.

Rabinow, P., & Bennett, G. (2012). *Designing Human Practices: An Experiment with Synthetic Biology*. University of Chicago Press.

The Joint Genome Institute's Synthetic Biology Internal Review Process

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Synthetic biology has the potential to accelerate science and bolster economic growth. However, like any new technology, synthetic biology could be misapplied or result in unintended consequences. Serious concerns have been raised over the possible intentional use of synthetic biology approaches to engineer pathogenic organisms as well as the possible accidental environmental release of genetically engineered organisms. Scientists pursuing synthetic biology research must diligently consider issues such as these.

The U.S. Department of Energy (DOE) Joint Genome Institute's (JGI) Synthetic Biology Internal Review process seeks to assess, beyond technical and scientific merit, certain broader aspects (e.g., environmental, biocontainment, biosafety, or biosecurity) of the research proposals associated with the JGI's DNA synthesis program (<http://jgi.doe.gov/our-science/science-programs/synthetic-biology/>). The purpose of this internal review process is two-fold: 1) to assess the broader aspects of the research, request proposal modifications if issues of concern are not sufficiently addressed in the proposal, reject research proposals where issues of concern are not or can not be satisfactorily addressed, and output a paper-trail audit of the review process; and 2) to encourage and educate researchers to more extensively consider the broader aspects of their research, including beyond the immediate research itself.

All JGI DNA synthesis proposals (including those from the JGI Community Science Program and from the DOE Bioenergy Research Centers) contain a broader implications section dedicated to a brief discussion of these broader aspects. This broader implications statement should address not merely the possible rewards but also a considered statement of the risks associated with the work. These statements serve as a useful tool to protect not only the public, but the Investigators (and their institutions), as well as JGI itself. These statements are proof of consideration and deliberation - proof of the responsible application of science. As members of the research community, we must consider risks, and be able to show our consideration of those risks - even if they are demonstrably small.

After a synthetic biology research proposal has successfully passed technical feasibility and scientific merit review, the proposal enters the JGI's Synthetic Biology Internal Review process. A JGI system administrator uploads the proposal to the Synthetic Biology Internal Review System (SBIRS, <http://jgi-sbirs.jgi-psf.org>) and assigns a minimum of 3 Reviewers to it. Each Reviewer reads the full proposal, makes comments on the proposal in the SBIRS, and votes in the SBIRS to either approve the proposal or to discuss it further with the other assigned Reviewers. If not unanimously approved, the assigned Reviewers discuss the proposal in person or via telephone, and decide to approve or reject the proposal, or to require that modifications be made to the proposal to address the Reviewers' concerns. The Reviewers email the decision to a system administrator, who records the decision in the SBIRS. If the Reviewers decide to approve the proposal after discussion, a JGI Director is required to approve the proposal before work begins. A JGI Director can reject any proposal, and can require that additional modifications be made to any proposal. The entire Synthetic Biology Internal Review process should take three

weeks or less (unless modifications are requested, which could delay the process by an additional three weeks or more).

Investigators are strongly encouraged to use the broader implications section of the proposal to make it clear to the Reviewers that the Investigators are actively thinking about the broader implications (noted above, primarily environmental, biocontainment, biosafety, or biosecurity) of their research, and that they have mitigation strategies in place to address outstanding issues of concern. Note that Investigators are not expected to provide an in-depth analysis (e.g., full socio-economic analysis) of their early-stage research, but Investigators should demonstrate that they are currently considering the implications of their research, and that more in-depth analyses can and will be pursued as their research matures. Investigators should not merely write "None" or "All research will be conducted in a safe manner according to Federal regulations" in the broader implications statement, as this will lead to the Reviewers asking for proposal modifications, incurring three week or longer delays.

Investigators must explicitly state if their proposed research would:

1. Demonstrate how to make a vaccine ineffective
2. Confer resistance to antibiotics or antiviral agents
3. Enhance a pathogen's virulence or make a non-virulent microbe virulent
4. Increase transmissibility of a pathogen
5. Alter the host range of a pathogen
6. Enable a pathogen's ability to evade diagnostic or detection modalities
7. Enable the weaponization of a biological agent or toxin

Investigators are encouraged to think broadly about the aspects of their research. This will make sure that JGI DNA synthesis is not delayed, and it will start to nudge the collective research community's cultural mindset in the right direction. Reviewers should assess whether Investigators are actively thinking about the broader implications of their research, and whether the Investigators have mitigation strategies in place to address outstanding issues of concern. Reviewers should request proposal modifications if issues of concern are not sufficiently addressed in the proposal, and reject research proposals where issues of concern are not or cannot be satisfactorily addressed.

JGI Synthetic Biology Internal Review Process Statistics (as of Oct.7, 2014):

- 22 proposals reviewed
 - 12 from DOE BioEnergy Research Centers
 - 10 from the JGI's Community Science Program
- 74 Reviewer comments
 - General [33], BioSafety [17], BioSecurity [6], Ethical [2], Legal [2], Social [6], Environmental [8]
- 13 proposals unanimously approved by Reviewers
- 6 proposals discussed and approved by Reviewers
- 3 proposals discussed and modifications requested by Reviewers
 - 2 revised proposals unanimously approved by Reviewers
 - 1 proposal pending modification and resubmission
- 21 proposals approved by JGI Director

Synthetic biology and biosecurity: an agenda for social science research
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The dominant narrative permeating scientific and policy discussions on the security threat posed by synthetic biology can be summarized as follows:

- Synthetic biology is making it easier for non-experts to manipulate dangerous pathogens and, therefore, making it easier for terrorists to concoct bioweapons.
- Synthetic biology has led to the growth of a do-it-yourself biology community that could offer dual-use knowledge and equipment to bioterrorists seeking to do harm.
- DNA synthesis has become cheaper and can be out-sourced, making it easier for terrorists to obtain the basic materials to create biological threat agents.
- Non-experts could use synthetic biology to design radically new pathogens.
- Terrorists want to pursue biological weapons for high-consequence, mass-casualty attacks.

This narrative rests on misleading and stubbornly enduring assumptions about both synthetic biology and bioterrorism; yet these five ‘myths’ are challenged by social science research into the realities of scientific research currently being conducted in both professional and do-it-yourself laboratories, and by an analysis of historical cases of bioterrorism (see Jefferson et al 2014; Marris et al 2014). Here, we focus on the first three ‘myths’ and suggest that social science research has significant contributions to make in countering these simplistic assumptions.

1. Synthetic biology is not easy. The assumption that synthetic biology makes it easy for *anybody* to “engineer biology” is not true. The underlying vision holds that well-characterized biological parts can be easily obtained from open-source online registries and then assembled, by people with no specialist training working outside professional scientific institutions, into genetic circuits, devices and systems that will reliably perform desired functions in live organisms. This vision, however, does not even reflect current realities in academic or commercial science laboratories, let alone the situation facing people with no specialist training who work outside professional scientific institutions. Academic and commercial researchers are still struggling with every stage of the standardization and mechanization process. Moreover, even if the engineering approaches proposed by synthetic biology are successful in making processes more systematic and more reproducible, skills will not become irrelevant, and not all aspects of the work become easier. Certainly, advances in synthetic biology do not make it easier for *anybody* to engineer living organisms, including dangerous ones.

2. Do-it-yourself biology is not particularly sophisticated. Developments in synthetic biology are seen to be closely associated with the growth of the do-it-yourself bio-community, and some observers have expressed concerns that do-it-yourself biologists could offer knowledge, tools, and equipment to bioterrorists seeking to do harm. But the link between synthetic biology and DIYbio, and the level of sophistication of the experiments typically being performed, is grossly overstated. Do-it-yourself biologists typically comprise a wide range of participants of varying levels of expertise, ranging from complete novices with no prior background in biology to trained scientists who conduct experiments in their own time. Studies of scientific practice in community labs demonstrate the challenges that amateur biologists face while trying to

successfully conduct even rudimentary biological experiments. In particular, these amateurs lack access to the shared knowledge available to institutional researchers, highlighting the importance of local, specialized knowledge and enculturation in laboratory practices (see Revill & Jefferson, 2014).

3. Building a dangerous virus from scratch is difficult. DNA synthesis is one of the key enabling technologies of synthetic biology. There are now a number of commercial companies that provide DNA synthesis services, so the process can be out-sourced. The price charged by these companies has greatly reduced over the last 20 years and is now around 3 cents a base pair, which puts the cost within reach of a broad range of actors. This has led to routine statements suggesting that it is now cheap and easy to obtain a synthesized version of any desired DNA sequence. However, even specialized DNA synthesis companies cannot easily synthesize, *de novo*, any desired DNA sequence. Several commercial companies provide routine gene synthesis services for sequences of less than 3,000 base pairs, but length is a crucial factor, the process is error prone, and some sequences are resistant to chemical synthesis. A number of synthesized DNA fragments would have to be assembled to produce a full genome, which means that, even if doing so were not already regulated by voluntary guidelines, simply ordering the full-length genome sequence of a small virus online is not possible. Ordering short DNA sequences and assembling them into a genome requires specialist expertise, experience, and equipment available in professional laboratories but not easily accessible to amateurs. For longer sequences, assembly of DNA fragments becomes the crucial step. This was the major technological feat in the work conducted at the J. Craig Venter Institute that produced a “synthetic” bacterial genome, and the Gibson assembly method developed for that project is now widely used. Gibson et al’s own account of that work, however, demonstrates how the assembly of smaller fragments into larger ones and eventually into a functioning genome requires substantial levels of expertise and resources, including those needed to conduct trouble-shooting experiments to identify and correct errors when assembled DNA constructs do not perform as expected. Indeed, constructing a genome-size DNA fragment is not the same as creating a functional genome, and ensuring the desired expression of viral proteins is a well-documented, complex challenge.

An Agenda for Social Science Research. There is an important role for social science research in countering oversimplified understandings of synthetic biology practices and providing more balanced assessments of the security implications. In particular, through in-depth ethnographic work, social science research can play a crucial role in highlighting the importance of the social context of science and technology and characterising the significance of intangible dimensions of research, such as tacit knowledge and community practices. Our analysis of current debates on the potential for the so-called “dual-use” of synthetic biology demonstrates that is crucial for social scientists to question the sociotechnical promises constructed by synthetic biologists. Taking them for granted leads to unhelpful “speculative ethics”, which is evident in much of the current discussions about the “societal issues” related to synthetic biology.

References

- Jefferson C., Lentzos F. and Marris C. (2014) “Synthetic biology and biosecurity: challenging the ‘myths’”. *Frontiers in Public Health* 2:115. doi: 10.3389/fpubh.2014.00115
- Marris, C., Jefferson, C. & Lentzos, F. (2014). “Negotiating the dynamics of uncomfortable knowledge: the case of dual use and synthetic biology”. *BioSocieties*, forthcoming December 2014.
- Revill, J. and C. Jefferson (2014). “Tacit knowledge and the biological weapons regime.” *Science and Public Policy* 41(5): 597-610.

Engaging the public to build a better biosafety and biosecurity culture

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Biosafety and Biosecurity are now topics receiving more public attention due to the recent media coverage of the biosafety and biosecurity cases. Although there are continuous debates on the issues along the development of the research in the field, the recent reports on biosafety and biosecurity lapses indicate that it is necessary to reinforce our biosafety and biosecurity culture [1, 2]. These incidences, ranging from lab staff members potentially exposed to anthrax, shipping samples contaminated with lethal flu strains, to smallpox vial unattended, all violating the existing guidelines, showed the lack of compliance and oversight even in those prestige laboratories. Thus, novel strategies are needed to strengthen a biosafety and biosecurity culture. On the one hand, it is important to initiate a movement dedicated to biosafety and biosecurity among the research community, by means of continuous education on the issues and stringent oversight from the corresponding authorities is the best practice to ensure public trust and support on our research. On the other hand, engaging the public to this movement should help to build a better biosafety and biosecurity culture.

Biosafety encompasses the prevention of unintended negative consequences involving biological material, such as accidents. Biosecurity deals with all the intentional misuse for nefarious purposes. Biosafety wants to keep the pathogens away from people, while biosecurity aims to keep those with malicious intention away from getting access to the pathogens. Recent discussions on the challenges raised by synthetic biology showed that the challenges came from two perspectives- one was the extent of what synthetic biology would have achieved as an engineering discipline, and the other was the extent of de-skilling the tacit knowledge and other socio-technical factors to reproduce experiments based on available scientific knowledge [3]. One of the goals of synthetic biology is making biology easier to engineer. If such a goal can really be achieved, the tangible and intangible barriers to prevent misuse of science will not function any longer. The de-skilling of factors critical to reproduce the technologies would provide outsiders more accesses and increase the biosecurity threat. Meanwhile, the lay people will not only just learn about the technology, but also they are more likely able to apply the technologies to those that of their own interest. Thus, engaging the public in would be an important to build the framework of better biosafety and biosecurity culture.

To engage the public is not easy. The communication skills of the scientists to interact with the public are not sufficient [5]. Switching the scientific communication between scientists and the public from a deficient model to a public debate model and a co-production of knowledge model should be applied to the communication on biosafety and biosecurity issues. Both of the latter two models call for a two-way communication [4]. Such bi-direction communication between the scientists and the public will address a broad range of issues, which is also an important component for the framework of Responsible Research and Innovation.

Besides the traditional approaches to engage the public (such as survey, workshop, and etc), there are new channels for scientific communication. The internet has brought a convenient channel for science communication to engage the public. Studies have shown that more and more laypeople obtain science and technology related information from the web [6]. While online media provide more channels to reach the public, there are also challenges of using them for biosafety and biosecurity communication —the information should not be too complex but still factually correct; while the web should be designed to provide incentives and motivations for the public to engage in a participatory manner. A tailored made documentary film on the topic may probably easily provide

the information. It has been shown repeatedly that audio-visual content is widely preferred over written materials when it comes to information consumption about science and technology. To programme a science game may provide another approach to engage the public, exploiting the benefits of science gamification which is currently one of the new trends in communicating educational content in an entertaining way. Furthermore, organizing a science/culture fair would provide an attractive platform for scientific communication, of which is more likely receiving attention from the interested public and coverage from the media.

Engaging public to build a better biosafety and biosecurity culture is not an easy task, although it is an urgent issue [7]. More research on this topic is needed. Thus new approaches or models can be developed to engage the public in an efficient way.

Reference:

1. Editorial, *Biosafety in the balance*. Nature, 2014. **510**: p. 443.
2. Reardon, S., *Safety lapses in US government labs spark debate*. Nature, 2014.
3. Jefferson, C., F. Lentzos, and C. Marris, *Synthetic Biology and Biosecurity: How Scared Should We Be?*, 2014.
4. Ouborg, J., *Two-way communication between genomics and society*. *Science & Society Series on Convergence Research*. EMBO Rep, 2009. **10**(5): p. 420-3.
5. Pouliot, C. and J. Godbout, *Thinking outside the 'knowledge deficit' box*. EMBO Rep, 2014. **15** (8): p. 833-5
6. Peters, H.P., et al., *Public communication of science 2.0: Is the communication of science via the "new media" online a genuine transformation or old wine in new bottles?* EMBO Rep, 2014. **15** (7): p. 749-53
7. Bulter, D., *Biosafety controls come under fire*. Nature, 2014. **511**: p. 515-6.

More Socio-Technical Assessments of Synthetic Biology to Inform Security Deliberations

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Many are concerned that synthetic biology may prove to be a cheaper and easier way to conduct bioterrorism. Over the past ten years, there have been a number of different government and non-government reports and articles emphasizing the growing security threats from synthetic biology, stemming from the assumptions that as science advances in this field, synthetic biology tools and techniques will be more accessible to those wishing to do harm. Typically these writings focus on the availability of commercial DNA pieces, DNA synthesizers, and open scientific journals, and the fact that different kinds of synthetic genomes have been constructed. These writings and policy discussions, however, rarely interrogate what people, infrastructures, and contexts are required to conduct and replicate synthetic biology work. These are critical factors if we are concerned about malevolent actors (state or non-state) developing and using synthetic biology for harm.

Most current government and non-governments efforts that try to assess synthetic biology and other kinds of emerging technology threats are based on a “Revolutions” framework for thinking about science and technology, based on assumptions about a Biotechnology Revolution and/or an Information Technology Revolution. This “Revolutions” framework typically focuses on material and technical aspects in synthetic biology. For example, it focuses on codified knowledge (i.e., information found in journal articles, scientific textbooks, websites, databases, software, or other written sources), the accessibility of biological materials (e.g., pathogens, oligonucleotides), biological supplies (e.g., reagents, prep kits), infrastructure (e.g., DNA synthesizers, laboratory benches, other kinds of commercially available biotech equipment). Along with this material focus, there follow assumptions about the presumed ease of globalization, diffusion, and technology transfer of synthetic biology end-products. Furthermore, this framework tends to focus on cutting edge developments in synthetic biology and assumptions that these will pose greater security dangers. Finally, those using this Revolutions framework assume technological and threat trajectories that are linear or exponential. However, this “Revolutions” framework provides little exploration of the more complex non-technical factors that can shape and modulate scientific and technological innovation and diffusion. This omission leads to particular kinds of policy conclusions and interventions for synthetic biology that are flawed because they do not consider the broader set of social factors that can shape S&T development.

This position paper argues that a new analytic framework and research agenda is needed that takes the social dimensions of synthetic biology work seriously in security assessments of synthetic biology. We need more in-depth analyses of what is shaping the development, diffusion, and adoption of new synthetic biology techniques and technologies by different actors (including possibly malevolent ones). If we don't do a more comprehensive assessment, we are bound to come up with erroneous assessments that lead to policies that are ineffective and can hinder innovation.

A new framework and research agenda for synthetic biology would be based on social science studies of scientific and technological diffusion. These analyses would go beyond gathering up the material and written information properties of synthetic biology work, and

would also incorporate in-depth, longitudinal, and multi-disciplinary qualitative research of the field's developments. It would focus on the *socio-technical* dimensions of technological development, diffusion, & adoption of synthetic biology techniques and tools that would involve important micro- and macro-level studies of synthetic biology.

For Micro Level studies: There is a need to better elucidate the role of tacit knowledge/know-how and training practices in synthetic biology and *how/to what* extent this is changing over time. Through qualitative social science inquiry, this would involve conducting additional case studies of individual published synthetic biology experiments, commercial/applied synthetic biology developments, and IGEM and DIYBIO teams (national and transnational). All of this information can then be used to discern what implications this has for technological diffusion and adoption that can better inform the development of security policies.

For Macro-level National and Transnational Studies: This would involve answering the questions of who, what, when, where, and *how* for the development and diffusion of new synthetic biology technologies and progress in the larger synthetic biology field. This would involve social science inquiry into the various actors (scientists, engineers, technicians, regulators, citizens, policymakers, etc...) involved in synthetic biology work. In addition, further social science studies of the institutions (corporations, governments), infrastructures (social, legal), public policies, and funding streams would be valuable for understanding what is involved in turning a basic research synthetic biology experiment into a marketplace application. Finally, it would also be important to examine the different cultural and social conditions, and national and international circumstances, shaping synthetic biology developments and diffusion across countries and regions around the world.

In sum, we need for more complex assessments that take into account the socio-technical context of synthetic biology. This would involve examining factors like tacit knowledge, the role of interactional knowledge and knowledge networks, organizational components and dynamics, as well as the larger socio-political-economic-legal context in which synthetic biology activities are situated. Having this depth of knowledge and a more nuanced understanding of various synthetic biology approaches and how they are (or are not) able to travel easily to new settings, would enable the creation of a more refined spectrum of factors shaping threats from state/non-state actors to inform intelligence analysts, policymakers, and the public. This is opportune moment to gather historical and contemporary studies of synthetic biology as the field is developing.

References

Vogel, Kathleen M., "Revolution versus evolution?: Understanding scientific and technological diffusion in synthetic biology and their implications for biosecurity policies," *Biosocieties*, forthcoming.

Vogel, Kathleen M., *Phantom Menace or Looming Danger?: A New Framework for Assessing Bioweapons Threats* (Baltimore: The Johns Hopkins University Press, 2013):

Vogel, Kathleen M., "Framing Biosecurity: An Alternative to the Biotech Revolution Model?" *Science and Public Policy*, vol. 35, no. 1 (February 2008): 45-54.

A rose by any other name: On synthetic biology, genetic engineering, and societal control of technology

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Is synthetic biology a more fashionable reincarnation of genetic engineering? Researchers from SYNENERGENE, a European Union project to study societal dimensions of synthetic biology research, were hard pressed to defend against the claim. Increased interdisciplinary depth needed to deal with large outputs of genetic data might set synthetic biology apart, but none argued that the central methods of study have changed. No change, of course, beyond revamping a moniker to circumnavigate the tortuous waters of public opinion over GMOs and genetic engineering.

This troubling position was made clear at the 2014 conference of the Society for the Study of Nanoscience and Emerging Technologies (SNET). The avowed mission of the aforementioned SYNENERGENE project is to “contribute to Responsible Research and Innovation (RRI) in synthetic biology by establishing an open dialogue between stakeholders concerning synbio’s potential benefits and risks, and by exploring possibilities for its collaborative shaping on the basis of public participation” (1). Such a mission presumes *de facto* the continued pursuit of synthetic biology.

If synbio is merely a more politically viable genetic engineering, a disturbing question follows: are science and technology (S&T) scholars complicit abetting the genetics community’s efforts to advance an agenda at odds with societal interests? Often, S&T scholars call for critical reflection on the role of science in society and the paths of technology development. If public outcry over GMOs *was* that critical reflection from society, who are S&T scholars to work with scientists to make more palatable a research agenda for synthetic biology.

Andy Stirling, in his SNET keynote, argued that the perspective of inevitability oversimplifies the complex, co-constructed process of technology development. The linear conversation of inevitability leads to token discussions about “what risks are taken, how many, and for whom?” without second-order reflection on “to what end and in what way, why, says who, and what alternatives are available?” A research agenda for societal aspects of synthetic biology should start by grappling with these latter questions—must ask: to what end is synbio research pursued, why, who decides, how, and can parts of society opt-out. Grappling with these questions must move beyond tokenism and apologetics. If the public is engaged only in a conversation of risks and benefits, of presumed development, then such engagement is simply a public promotion campaign: an effort to build public support by increasing exposure to and comfort with the ideas of synbio. Without an outlet to policy and a legitimate voice, the results of engagement will be relegated to an esoteric corner of academe and, more unconscionable, researchers and publics will burn-out, relinquishing agency to entrenched interests driving technology forward, unquestioned, under the guise of social progress.

With these points in mind, a research agenda on the societal aspects of synbio must question the very pursuit and organization of synthetic biology research. Such an agenda must allow for the structured reflection of whether, how, and to what end synbio research is conducted. The question boils down to one of societal control of technology. As Collingridge argued, society faces persistent tradeoffs in the ability to detect and correct undesirable outcomes of

technological systems (2). Where the time to detection and costs of such outcomes are low, or time to detection is high and costs are low, a technological system may be more controllable. When it takes a short time to fix an undesirable outcome and response costs are low, or when it takes a longer time to fix an outcome but response costs are low, a system may be more flexible. A combination of high controllability and high flexibility correlates with society's ability to correct mistakes in selected development pathways. What kind of sociotechnical system is synthetic biology shaping up to be? Is the landscape of the system homogenous or heterogeneous? Do governance arrangements need to treat different landscapes of synthetic biology differently to allow for alternate avenues of pursuit, or to allow for the exercise of the right not to pursue? Looking backward, looking around today, and looking forward, these and related questions offer a vital entrée to reflecting on societal control of synthetic biology.

By way of a case study, one can look to the hacker community. The idea of a hacker community refers to a polycentric arrangement of bootstrapped research venues that, more often than not, exist outside of a formal research institute. At a given hacker space, anyone with time and an interest can learn more about and practice synthetic biology research. At the SYNENERGENE panel, some argued that the hacker community presents a massive potential risk to human and environmental health. Often this fear is anchored in a centralized command and control approach to risk governance. By contrast, others at the panel viewed the hacker community as a democratically evolved mode of conducting research. A founder of one hacker space claimed that the community creates a unique venue for public engagement and the conduct of research because these spaces a) directly connect to public interests through the interests of those publics who join the community, and b) promote responsibility through a culture of transparency and self-monitoring. The experiential nature of hacker spaces and the way they tangibly render abstract ideas of synthetic biology may make such spaces ideal for hosting public dialogues on potential futures of synthetic biology. Hacker spaces represent one public voice on an alternative way to pursue a future of synthetic biology. The mainstream scientific community has no more right to deny the choice of those wishing to opt-out of synthetic biology (née genetic engineering?) than to shut down a conversation about alternative modes of pursuing synbio.

As currently constructed, the narrative of synthetic biology research seems to reinforce an amplifying feedback loop in which scientists hype the promise of economic growth from a technological pursuit; scientists benefit from greater funding to pursue said technology; scientists subsequently make calls of greater promises of economic growth, if more investment in science is made; and society is left waiting for these benefits to materialize. The scheme should sound familiar, especially since 2008: it's called a Ponzi scheme and it will benefit neither science nor society in the long-run. A research agenda on societal aspects of synbio must allow for multiple lines of inquiry into whether, why, and how to pursue synbio if such a research agenda is to meaningfully inform decisions about futures of the field. Calls to the contrary are simply a lobby for more science regardless of public interest, an untenable path forward.

References Cited

- (1) Synenergene (2014) Synenergene In Brief: What is Synenergene. Available at <http://www.synenergene.eu/brief>; Last accessed 6 October 2014.
- (2) Collingridge, D., 1980, *The social control of technology*, Pinter London, New York.

Perspectives on Engineering Life

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Background

My research involves the design and construction of synthetic living systems, re-engineered organisms, and engineered parts for existing organisms. My group focuses on applications of synthetic biology ranging from cell-based diagnostics to microbial consortia that produce biofuels. Our particular emphasis is on designing gene circuits and cell-cell communication systems that enable novel multicellular behaviors in bacteria or yeast. In recent work^{1,2}, we *ported* an entire signaling pathway from the plant *Arabidopsis* to the yeast *S. cerevisiae* making new parts and pathways available to synthetic biologists. We are currently building on this work to coerce yeast to behave cooperatively in a multicellular manner, with the aim to perform simple distributed computation. In other work³, we developed a method for tuning the spontaneous switching rate of a genetic switch, and are now building that work to develop sequential logic systems in cells⁴ that could control them to divide the labor of digesting complex feedstock among specialized, synthetically differentiated cells.

The Industrialization of Biology

Attempting to build on scientific results in the life sciences, synthetic biologists often find that even when a scientific result is valid, the methods are poorly explained, purposefully not explained, or simply buried in some researcher's head. My lab's Aquarium Project⁵ aims to fix this problem by providing the means to specify, as precisely as possible, how to obtain a result. Researchers encode protocols as computer programs specifying how to manipulate items in the Aquarium inventory. Protocols are scheduled and presented to technicians on touchscreen monitors placed throughout the lab. Every step is logged: who performed the step, which items were used, and so on. The data can be used to debug and improve the experiment. More importantly it provides a complete, executable description of the results obtained -- one that could be used by any lab running Aquarium to reproduce the result. Systems such as Aquarium, for example embodied in companies such as *Emerald Cloud*, *Transcriptic*, and *Synthego*, clearly point toward a future in which the design and construction of new synthetic life is almost as routine as computer programming. The repercussions are staggering. What living programs will we write? Which ones should we avoid writing?

The Ethics of Funding and the Principle of First Use

Coming from an engineering background (I was trained in computer engineering, robotics, and control systems), I have plenty of experience with the usual funding agencies that support engineering such as DARPA, AFOSR, and ONR. In fact, some of my early funding came from them. Since I started working on synthetic biology, however, I have become increasingly wary of DOD funding in this realm⁶. Synthetic biology will someday develop into an incredibly powerful technology that has obvious *dual-use* concerns. A common argument among researchers is that they do not care from whom their funding comes as long as it is out in the open. However, I have seen first hand that the context in which a new technology is first explored often determines its first use. For example, unmanned aerial vehicles were first explored in earnest by DOD programs with intense interest from the military, and their first successful use was in war. It is only later that drone technologies have started to become useful in other fields. The dangers of drones should not be understated, but they pale in comparison to a first use of synthetic biology in a warfare situation. Thus, it makes sense to first explore peaceful (for example therapeutic) applications of synthetic biology so that the discipline has a chance to mature before potentially dangerous applications are explored. I am intensely interested, then, in exploring first uses of synthetic biology in biofuels, diagnostics, global health, therapeutics, and the like.

References

1. E. Pierre-Jerome, S. S. Jang, K. A. Havens, J. L. Nemhauser and E. Klavins, "Recapitulation of the forward nuclear auxin response pathway in yeast", *Proceedings of the National Academy of Science*. 2014.
2. K. Havens*, E. Pierre-Jerome*, S. Jang*, J. Guseman*, N. Bolten, E. Klavins, and J. Nemhauser, "A synthetic approach reveals extensive tunability of auxin perception", *Plant Physiology*. pp. 112.202184. July 2012.
3. R.G. Egbert and E. Klavins, "Fine-tuning gene networks using simple sequence repeats", *Proceedings of the National Academy of Science*. Vol. 109, No. 42. pp. 16817-16822. Oct 2012.
4. K. Oishi and E. Klavins, "A Framework for Implementing Finite State Machines in Gene Regulatory Networks", *ACS Synthetic Biology*. 3 (9), pp 652–665. 2014.
5. Aquarium. <http://klavinslab.org/aquarium.html>.
6. Hayden, E.C., "Bioengineers debate use of military money", *Nature*. Vol. 479. p. 458. Nov. 22, 2011.

Ethics and Policy in Synthetic Biology: The Development and Testing of a Massive Open Online Course

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Introduction

In 2011, Stanford's Sebastian Thrun held an open online version of his popular course, "Introduction to Artificial Intelligence" – 160,000 people, internationally, took that course. Such massive open online courses (MOOCs) quickly became both pervasive and incredibly popularⁱ. To date, only a handful of MOOCs are available on bioethics, and of these, none is directed at scientists, themselves. At the same time, there is increasing interest in training basic scientists not just in research integrity (e.g., do not falsify data), but also in broader social implications of science, driven in the US by recent revisions to NIH and NSF requirements. Even in the context of a US university, opportunities for ethics and policy training for basic scientists related directly to the work they do can be difficult to find and access. Outside an academic setting, for individuals doing science in industry or community labs, it is arguably even more difficult. MOOCs might be a useful way to increase access to high quality training in the US and internationally.

In the case of synthetic biology, in particular, ethics and policy issues are an important and growing area of concern. One of the main concerns raised for many by synbio is dual-use: the development of knowledge and technologies that can be used both for good and nefarious purposes. Dual-use issues are rarely addressed with basic scientists, despite increasing concerns about bioterrorismⁱⁱ. Furthermore, education on this topic is repeatedly cited as an important component to addressing security risks related to advances in the life sciences^{8,iii}. This connection to dual use concerns and the importance of education is further highlighted by the FBI's interest in synthetic biology research, including at universities and in DIY labs. Dual-use and biosafety concerns have been part of the field from its beginnings in recombinant DNA technology in the 1970s^{iv}, though at the time, biohazards were of much greater concern than bioterrorism. Beyond dual-use and biosafety concerns, there are also questions about ownership of modified or new organisms, and less tangible concerns about the meaning of modifying and creating life. Basic scientists rarely in their training and careers have the opportunity to engage with these questions.

A SynBio MOOC

I am currently developing a MOOC on the ethics and policy issues related to synthetic biology, through which I will also test different assessment methods, focused on assessing ethical analysis in the MOOC context. This MOOC will be based in part on lectures I have given over the last six years in the Build-A-Genome (BAG) course, designed by Dr. Jef Boeke, a synthetic biologist formerly at Johns Hopkins, and now at New York University. The course will also draw on ongoing research with Dr. Boeke and others on a set of projects related to the development of a strain of *Saccharomyces cerevisiae* with an entirely synthetic genome. Work with these projects include research on governance structures in academia, industry and DIY labs, and international stakeholder engagement and deliberative meetings about the implications of the Sc2.0 project and synbio more broadly.

The course will begin with an introduction to the science, for those who are not members of the synthetic biology community. The course will then move on to the ethical issues raised by synthetic biology (e.g., dual-use, biosafety and intellectual property issues), and continue to an

overview of current national and international policy relevant to synthetic biology, as well as current and evolving governance structures within synthetic biology.

Course content will be delivered primarily through short (8-12 min) organized into weekly course sessions. Each week will require 2-3 hours of screen and independent work time, but can be completed at the learner's own pace. In addition to watching and working with video and animation modules, learners will also have an opportunity to create content through, for example, participation in online forums on the Coursera platform, and development of their final collaborative project. In these forums, learners are able to ask questions, and vote up or down others' questions, allowing the best questions of the greatest interest to rise to the top. New modules and activities can then be created in response to these questions. Content generation by learners is a strength of MOOCs, allowing for wide-ranging interactions between individuals with very different backgrounds and ways of thinking^{v, vi}. In the synbio context, for example, how a particular culture or government views synbio may not be accessible to the instructor or other learners (e.g., due to language barriers), but will be brought to the course by individual learners. These forums can serve as opportunities for both learning and assessment, wherein learning happens through dialogue, and the initiation of and participation in that dialogue can be captured as metrics of learning¹⁸.

Conclusion

This course would be one of only a handful of bioethics MOOCs, and perhaps the only one aimed at basic science researchers. The dearth of such training generally, combined with the desire for such training, suggests that this course could serve the needs of large numbers of local, national, and international scientists regardless of ability to pay (acknowledging that the need for a computer and broadband access is not an insignificant barrier). Within academic institutions, the course could be used not only in individual science courses under a blended learning model, but also for training of basic scientists more generally, and potentially to fulfill the NIH and NSF training grant requirements. For those working in laboratories without access to bioethics colleagues or in countries lacking bioethics capacity, this could also be tremendously useful. Outside academic institutions, the course could also be used as required or optional training for those working in community and academic molecular and cell biology labs. As this kind of training usually only occurs within academic institutions, this course may be particularly important for the DIYbio community, which largely exists outside any academic institution. This course will bridge that divide and provide access to high quality, important training, which can evolve along with the science. Further, this course would provide not only a valuable learning opportunity, but also a trove of rich content that will live on and can be accessed indefinitely.

ⁱ <http://www.nytimes.com/2012/11/04/education/edlife/massive-open-online-courses-are-multiplying-at-a-rapid-pace.html?pagewanted=all>

ⁱⁱ National Research Council. *Challenges and Opportunities for Education About Dual Use Issues in the Life Sciences*. Washington, DC: The National Academies Press, 2010.

ⁱⁱⁱ E.g., see <http://www.opbw.org>, Final Declaration of Second Review Conference.

^{iv} Berg et al. Summary statement of the Asilomar conference on recombinant DNA molecules. *Proc Natl Acad Sci USA* (1975) vol. 72 (6) pp. 1981-4.

^v Clougherty Jr and Popova. *Crowdsourcing to Assess MOOCs: A Position Paper*. MOOCs FORUM (2013). 1(1): 10-13.

^{vi} Hong and Page. *Groups of diverse problem solvers can outperform groups of high-ability problem solvers*. *Proc Natl Acad Sci USA* (2004) 101(46): 16385-9.

Fabrication of Biofuels With a Multi-Strain System

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This year, the Arizona State University iGEM team has taken on a project that involves creating biodiesel in a new and efficient way using *Escherichia Coli*. Sustainability has become somewhat of a buzzword here at ASU, and the worldwide demand for renewable fuel sources has been growing in response to increasing concerns about dwindling oil reserves. Modern science has succeeded in genetically engineering bacteria that can metabolically synthesize a form of “biofuel” that is structurally similar to the fuel used in jet engines. Despite these revelations, however, bacterially-produced biofuels have not advanced to the point of being a commercially viable fuel source. There is much work that still needs to be done in making the production of biofuels both efficient and cost-effective.

A wax esterase exists that, when produced in bacteria, can react with the naturally produced ethanol and fatty acyl-CoA to produce an energy-dense biofuel. However, *E. coli* uses the same intermediate products to produce both fatty acids and ethanol, which reduces the efficiency of this process. The end goal heading into this project was to improve upon an existing idea by fixing this stoichiometric inefficiency. Our proposed solution is to create colonies of bacteria where multiple strains of bacteria coexist in the same isolated environment.

The basic idea is this: with two strains of bacteria, there will be no need for the cells to delegate resources towards producing both fatty acyl-CoA and ethanol at the same time. One strain of bacteria (hereby known as Strain 1) will focus on producing the ethanol, while the other (Strain 2) can devote its energy to the fatty acyl-CoAs. Ethanol, being the smaller molecule, can then diffuse into the extracellular fluid and into the Strain 2 cells. The Strain 2 bacteria will also be transformed with DNA to produce the wax esterase that is needed to catalyze the final reaction to produce the biodiesel. In this way, the synthetic process can be compartmentalized.

A wide variety of genetic engineering parts is being used to create this bacterial system. *Pdc* and *adhB* are together responsible for the production of the ethanol in Strain 1. We have obtained experimental results confirming that these parts increase natural ethanol production. An *acc* and *TesA* (thioesterase) plasmid has been ligated as well as an attempt to kickstart fatty acyl-CoA production. The first steps that we’ve been taking towards realizing this goal generally involve maximizing the production of the biofuel’s “ingredients”.

In order to be successful in improving the efficiency of the system, we must further analyze the stoichiometry of the equation. The reaction between fatty acyl-CoA and ethanol is 1:1, so ideally we would want to be producing roughly the number of molecules of each. Since they’re very different molecules in a structural sense, a single strain of engineered cells wouldn’t be able to produce equal amounts due to the differences in metabolic cost. In the future, we hope to be able to explore different avenues of controlling the population numbers for the different strains in an attempt at balancing the chemical reaction. Quorum sensing is a promising concept that, with further research, could potentially allow the system regulate itself without any outside interference. There is still a lot of work to do towards making biofuel a successful industry.

Sustainability, substitution and synthetic biology

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In our most recent work we have analysed some of the main contradictions and paradoxes arising within a dominant, inherently modern framing of sustainability (Benessia *et al.* 2012, Benessia and Funtowicz 2013, Benessia and Funtowicz *in print*) relying on technoscientific innovation in order to describe, confront and solve our present human predicaments (environmental, social, economic, cultural and political). We have explored this framing as evolving from the institutional discovery of sustainable development as a global issue in the 1992 Rio Conference, when it was associated with diversity, participation and precaution, to the Rio + 20 Conference when sustainable became merely an adjective of growth (Brand 2012).

Along this narrowing path, the distinction between weak and strong sustainability has been progressively fading and the mainstream economics ideal of replacing the natural with manufactured artefacts is now leading the way towards a sustainable future. More generally, in its intersection and co-evolution with innovation, the notion of sustainability becomes more uncertain and ambiguous, as both influencing and being influenced by the mutable boundaries of technoscience. On the one hand, the modern discourse about sustainability in all its contradictions is functional for preserving the technoscientific path-dependent trajectory on its track despite its ever increasingly socially and politically controversial aspects, while remoulding the very definition of what science is and does. On the other hand, the issues of “What to sustain?” and “For whom?” are deeply modified by the technoscientific enterprise.

The unchallenged economic policy aims of growth, productivity and competitiveness - reinforced during the financial and economic crisis both in Europe and in the US - are fundamental ingredients of this whole scenario. If we keep these goals as givens for improving, extending and even equalizing¹ human welfare on this planet, then we (continue to) face the paradox of sustaining an accelerating increase in our global resource consumption within a complex, closed and finite system, with limited stocks and bio-geo-chemical resilience².

The dominant discourse about a way out of this paradox comes from the grand narrative of technoscientific innovation, which serves a double purpose. As the first line of reasoning reads, we need to take into account an essential hidden variable, which Malthus first proverbially overlooked: natural supplies might be limited, but human creativity is *unlimited*, and so is human potential to: (1) decouple growth from scarcity, improving efficiency in the use of natural resources and ultimately substituting them altogether, with substantially equivalent technological optimised artefacts; (2) tame complexity, uncertainty and the risks of failures through the implementation of effective *ad hoc* technoscientific silver bullets. Secondly, innovation is taken as the mainstream solution in order to keep sustaining growth in a hyper-saturated market, by opening up new pathways of competitiveness and consumption, to be filled with new, constantly upgraded and more seductive, products and services.

Another fundamental element needs to be in place for this whole narrative to be viable: citizens of developing, developed and declining economies have to value and ultimately buy - both metaphorically and

¹ See the internal debate around capital and raising inequality in relation to the publication of “Capital in the XXI Century” by Thomas Piketty (2014).

² Ulanowicz’s notion of hypercycle provides a useful description of this paradoxical dynamics and of its unsustainability (Ulanowicz 1986).

literally – the processes and products of technoscientific innovation. This means that the societal expectations about the goods have to be encouraged and the concerns about the bads to be deflected (EC 2013, ESF 2009).

Synthetic biology has positioned itself within this grand narrative of innovation and sustainability just like any other emergent (and emerged) technology platform (Benessia *in print*). However, its response consists on a unique strategy of demarcation between science and technology, based on a promise and a principle of substitution. The first two lines of argument are addressed by proposing the industrial standardization and optimization of the *bios*, conceived as a Cartesian *res extensa*, an inert substratum to act upon in the most productive and controlled way (STOA 2011, Philip 2014).

Synthetic biology enters into the discourses of biodiversity protection and clean energy production (Wiek *et al.* 2012), by promising to restore to life extinct species (de-extinction) and even expand the canvas of the *bios*³, and by proposing a complete transition from fossil fuel-based economy to bio-based economy, through the development of renewable biofuels (Mackenzie 2013). The scarcity of natural resources and market shares can then be *substituted* with the abundance of synthetic goods and a plethora of new products and marketable possibilities can revitalize struggling economies⁴. In this context, synthetic biology is defined and described in terms of a strictly technological endeavour, emerging from the triad of biotechnology, nanotechnology and ICT.

In response to the third structural element of the narrative of innovation - i.e. the need for public acceptance and endorsement – synthetic biology becomes a tool for scientific enquiry and education, thus needed for the ultimate exploration of the wonders and mechanisms of life. More precisely, and much more radically, it becomes a science by changing what science *is*. Indeed, by intertwining Baconian pragmatism, Cartesian reductionism and Vico's principle of "verum et factum convertuntur"⁵ with a validating reference to Richard Feynman's epigraph on a Caltech blackboard⁶, synthetic biology defines a new principle of demarcation in which knowing and making are identified. As Evelyn Fox Keller points out (2009), this fundamental epistemic move implies the *substitution* of science itself with technology, a development consistent with the process of commoditization of science (Mirowski, 2011).

While some continuity can be traced in the narrative strategies of the contemporary technosciences it springs from⁷, synthetic biology stands out for its awareness and explicit treatment of complexity, both within and outside its own boundaries. In order for knowing and making to be identifiable and technology to *become* science, a fundamental epistemic and normative assumption has been made and implemented: complexity must be recognized and explicitly assessed as a burden to be eliminated. This eradication of complexity seen as an impediment on the way to optimization and complete substitution is the foundation stone of both Craig Venter's creationist approach and Drew Endy's standardizing and democratizing notion of open source BioBricksTM bank (Le Fanu 2009, Mackenzie *et al.* 2013).

References

³ The idea of substituting natural biodiversity with a synthetic one can be seen as a consistent development of the concept of Ecosystem Services, leading to mapping, measuring and counting the goods and services of ecosystems in monetary terms (Turnhout *et al.* 2013).

⁴ The principle of substantial equivalence, already at work within the framework of both bio and nano technologies, provides a scientific and normative base to this ideal of substitution.

⁵ "The true and the made are reciprocal" Vico 1710.

⁶ The (misquoted) version of Feynman's text is: "What I cannot build, I cannot understand".

⁷ Richard Feynman is also evoked as the founding father of nanotechnology ("There is plenty of room at the bottom"). As a Nobel laureate for the formulation of Quantum Electro Dynamics (QED), a well renowned science educator and an acute science investigator at NASA after the Challenger's explosion, his figure can be regarded as the perfect bridge between modern curiosity oriented science and contemporary corporate technoscience, therefore responding to the demands for public acceptance of the technoscientific enterprises after the biotech clashes (Benessia and Funtowicz 2013).

- Benessia A. *in print*. Do we really want, can and need to be smart? Public Understanding of science. Special Issue: Imagining public issues in the technosciences.

- Benessia A. e Funtowicz S. *in print*. Sustainability and technoscience: What do we want to sustain and for Whom? The international Journal of Sustainable Development. Special Issue: In the name of sustainability.

- Benessia A. and Funtowicz S. (2013). Ottimizzare, sostituire e sconfiggere: i proiettili d'argento dell'innovazione In: Jasanoff S., Benessia A. and Funtowicz S. L'innovazione tra utopia e storia. Torino: Codice Edizioni: p. 55-120.

- Benessia A., Funtowicz S., Bradshaw G., Ferri F., Ráez-Luna E.F. and Medina C.P. (2012). Hybridizing sustainability: Towards a new praxis for the present human predicament. Sustainability Science 7 (1): 75-89

- Brand U. (2012). Green Economy – the Next Oxymoron? No Lessons Learned from Failures of Implementing Sustainable Development. GAIA 21/1(2012): 28 – 32.

- European Commission (2013). Science for an informed, sustainable and inclusive knowledge society. Policy paper by President Barroso's Science and Technology Advisory Council, Brussel 29th, 2013.

- European Science Foundation (2009). Synthetic Biology: Engineering Complex Biological Systems (EuroSYNBIO).<http://www.esf.org/coordinating-research/eurocores/running-programmes/eurosynbio.html>

- Fox Keller E. (2009). What does synthetic biology have to do with biology. Biosocieties 4: 291-302.

- Le Fanu J. (2009). Why us?:how science rediscovered the mystery of ourselves. New York: Vintage Books.

- Mackenzie A. (2013). Synthetic biology and the technicity of biofuels. Studies in History and Philosophy of Biological and Biomedical Sciences 44 (2013) 190–198.

- Mackenzie A., Waterton C., Ellis R., Frow E. K., McNally R., Busch L., and Wynne B. (2013). Classifying, Constructing, and Identifying Life: Standards as Transformations of “The Biological”. Science, Technology and Human Values, 38(5), 701-722.

- Mirowski, P. (2011). Science-Mart: Privatizing American Science. Harvard University Press

- Philip J. C. (2014). Emerging policy issues in synthetic biology. Industrial Biotechnology 10(4): 256-258.

- Piketty T. (2014). Capital in the XXI century. Harvard: Harvard University Press.

- STOA Workshop (2011), Making Perfect Life: European governance challenges in 21st century: bio-engineering. Rathenau Instituut, The Hague (NL), printed in Brussel EU: 2012. [http://www.europarl.europa.eu/RegData/etudes/etudes/join/2012/471574/IPOL-JOIN_ET\(2012\)471574_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/etudes/join/2012/471574/IPOL-JOIN_ET(2012)471574_EN.pdf)

- Turnhout E., Waterton C., Neves K. and Buizer M. (2013). Rethinking biodiversity: from goods and services to “living with”. Conservation Letters, 6 (3). pp. 154-161.

- Ulanwicz R.E. (1986). *Growth and Development*. New York : Springer-Verlag
- Vico G. (1710). *On the Most Ancient Wisdom of the Italians, Unearthed from the Origins of the Latin Language*. Including the Disputations with the *Giornale de' Letterati d'Italia*. Translated with an Introduction and Notes by L. M. Palmer. Ithaca and London: Cornell University Press, 1988.
- Wiek A., Guston D., Frow E. and Calvert J. (2012). Sustainability and anticipatory governance in synthetic biology. *International Journal of Social Ecology and Sustainable Development* 3(2), 25-38, April-June 2012.

Transforming Meat for Environmental and Moral Improvement

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In August 2013, at a cost of about \$350,000, the tissue engineer Mark Post unveiled the first synthetic hamburger. Here, we want to suggest that a grand challenge for synthetic biology of enormous potential environmental and moral value could be achieved through a strategic, long-term R&D program aimed at building the foundations for a synthetic meat industry that satisfied and ultimately displaced the nutritional, culinary, gustatory, and cultural values now provided by animal products.

The social science agenda here is rich and complex, and involves (1) effective science policies to guide syn bio R&D through appropriate institutional and innovation system models; (2) socio-technical system analysis, to understand the current meat production system in all its dimensions; (3) political, social and economic transition analysis, to elucidate the possible pathways for that system's transformation; (4) survey work and cultural analysis, to understand attitudes and beliefs about, opportunities for, and obstacles to a social transition from animal to synthetic meat; (4) anticipatory governance of the research enterprise (of course!) to help steer the necessary R&D reflexively and wisely.

The argument for bringing emerging syn bio capacities to bear on creating meat alternatives—either synthetically created meat products (factory or test-tube meat), or non-meat products that have all the qualities of meat—is rather obvious. As a matter of energy and environmental concerns, meat production is enormously costly and inefficient. FAO estimates, for example, that meat production accounts for about 14 percent of global greenhouse gas emissions. The effects of grazing on land quality is often highly deleterious, and growing demand for meat worldwide will continue to cause deforestation, ecological stress, and soil and water quality problems. Industrial meat production, in turn, creates enormous quantities of waste that are difficult to contain and are responsible for significant pollution costs such as widespread eutrophication. The energy inputs to creating animal protein are typically many times that required for equivalent vegetable-based nutritional value, and synthetic meats may also offer significant energy savings for a burgeoning global population. They may also offer health benefits through avoiding many of the contamination problems associated with animal meat.

Moreover, as two appreciative meat-eaters, we nonetheless would like to imagine a time when billions of animals do not need to be killed (often after living lives of great unpleasantness if not suffering) to satisfy our culinary whims. Indeed, for us the moral benefits of this grand challenge are as compelling as the environmental ones. We are well aware that we are hypocrites here, but that comes with the territory of being human. In a wonderful essay by E.B. White from the early 1950s, he describes the great sorrow of losing his pig to a painful disease, a sorrow of empathy and affection for an animal that, had it not so succumbed, would later that same year have been slaughtered for the culinary pleasure of his family. Can syn bio help make us be better people through a process of technological substitution?

Synthetic Biology as Open Science: Sharing tools and Making Communities

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Synthetic biology, and particularly the so-called 'BioBricks' school (also known as 'parts based'), is often referred to as a paradigmatic case of open science. There have been previous instances in which the 'open' circulation of data and tools has been key to the development of research fields and communities. The development of climate change global models and the IPCC research program is but one such instance (Edwards, 2010). Another interesting case was the rapid advancement of developmental biology through the production of knowledge, tools and standards, to characterize the drosophila fly as a model organism. Such cooperative work ended up producing a scientific community (widely known as the drosophila community). In both instances, the exchange and sharing of knowledge was subject to certain internal and external norms, a political and a moral economy of the property and proprietary co - existing (Kelty, 2012).

As for other emerging technosciences such as geoengineering and nanotechnology, in synthetic biology, digital design software and platforms for storing and sharing data are increasingly becoming key research tools and infrastructures. A (relative) technical openness comes together with the use of new digital technologies for research in these emerging fields. However, perhaps a specificity of the parts based synthetic biology is that it repeatedly announces itself as a program to "make biology easy to engineer" (Endy, 2005), and therefore potentially accessible to many. Beyond (and together with) technical openness, the need for sharing and for cooperative work is often invoked. An analogy to the decentralized development of computing science and the Internet is often mobilized to indicate the promise of synthetic biology. Cooperative and horizontally organized work is put forward as key for the production of innovation in biology. In a quite particular way, open designs and tools in synthetic biology are informed by a combination of an engineering ethos of making things and making them easy with a sort of a 'hackers ethics'. Nevertheless, in practice, 'openness' in synthetic biology is articulated in a number of different settings, resulting in not one, but diverse forms of 'openness', such as 1) Institutionalized 'biohacking' in leading institutions such as MIT, 2) Subversive hacking out of the institutions and in the form of citizen science (DIYbio), 3) As 'industrial' hacking in biotech companies such as Ginkgo Bioworks.

Institutionalized biohacking, DIYbio and 'industrial' hacking rely on technical openness –of different sorts; they differ in terms of political and moral economy. This paper aims at providing some clues on how synthetic biology might be articulating itself as 'open' science. It looks at how 'openness' configures itself through practices of sharing and owning (or: property?) in those three different settings. It will do so by reporting on empirical materials from: 1) The 'biostrike' series of workshops organized by DIYbio groups in Europe. This included the recent publication of a 'Biocommons White Paper'; 2) The development of SBOL (Synthetic Biology Open Language), a large technical infrastructure for enhancing data sharing and digital design in synthetic biology (Galdzicki et al., 2014); 3) Introducing Ginkgo Bioworks, an innovative synthetic biology company and its 'open' biological designs. What forms of communities are

being envisioned and enacted through sharing and owning practices in those different settings? This is the question that this paper aims to address.

References:

Endy D, 2005, “Foundations for engineering biology” *Nature* 438(24) 449-453. Edwards, P. N. (2010) *A Vast Machine. Computer Models, Climate Data and the Politics of Global Warming.* Cambridge, Massachusetts: MIT Press.

Galdzicki et al., 2014, “The Synthetic Biology Open Language (SBOL) provides community standards for communicating in synthetic biology” *Nature Biotechnology* 32(6) 545-550.

Kelty, C. M, 2012, “This is not an article: Model organism newsletters and the question of ‘open science’” *Bio Societies* 7(2) 140-168

Evaluating the Benefit of Community Laboratories

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Synthetic biology aims to make living organisms easier to engineer through the use of standardized DNA “parts”. Hiding biological complexity behind abstraction is key, since it allows the practitioner to design new biological circuits quickly and facilitates automation of the process. In computer software, the ones and zeros of the most basic code are hidden behind operating systems and programming languages. Synthetic biology aims to make coding life similarly user-friendly.

One of the unintended consequences of making biology easier to engineer was to facilitate a new class of practitioners known as the DIYbio movement. These citizen scientists practice synthetic biology in unconventional surroundings, outside of traditional venues such as university campuses and biotech startups. Since reading and writing (synthesizing) DNA code has become faster and cheaper, it is now within the reach of the hobbyist or inventor or artist to build biological circuits. The specifications and other information contained within registries such as the iGEM Registry of Standard Biological Parts plus the availability of free software such as that provided by DNA 2.0 has allowed almost anyone to be the designer of DNA code which can then built by a fee-for-service synthesis company. The price of DNA has dropped precipitously in the past few years as companies compete for business; the cost of 1000 basepairs of double-stranded DNA (a modest bacterial gene) is now under \$200. These factors, coupled with the popularity of the Maker movement, fueled the rise of DIYbio.

Early voices in the movement were often strident and inflammatory. In her “Biopunk Manifesto”, Meredith Patterson argued that that we all have the right to explore the world through biological experimentation, and implied that established institutions block this process by withholding information. The anti-authority stance that many early practitioners adopted garnered a lot of publicity (much of it negative) as the perception that practitioners were less concerned with safety than with personal freedom was perpetuated by the press.

The founding of the DIYbio Google Group by Mackenzie Cowell and Jason Bobe, both former iGEM participants, was the key step in establishing the DIYbio movement. It is still vibrant with nearly 4,000 members. The group quickly became a worldwide forum for discussions about community-building and practice by local groups of citizen scientists. By 2009 there were enough local DIYbio groups to meet at iGEM, where coincidentally the FBI was pursuing its mandate to reach out to synthetic biologists both professional and amateur and make them aware of the dual-use potential of their science. This began a relationship between DIYbio and Homeland Security which continues to this day.

In 2010-2011 the first community labs opened to the general public: Genspace in New York and Biocurious in the San Francisco Bay area. The idea was to create a welcoming informal space with a fully-equipped molecular biology lab facility that complied with all biosafety guidelines but was welcoming to the novice. Personal and group projects could be pursued

at a relatively low cost. The spaces would provide safety training and mentorship (both individual and in the form of hands-on classes and workshops), as well as a place for community gathering and discussion around synthetic biology and its implications. Both organizations decided to incorporate as nonprofits pursuing a mission of public benefit. Science literacy in both adults and students, particularly in the new area of synthetic biology, is woefully low. The DIYers felt that hands-on experience in the technology of synthetic biology would help to both educate and demystify it. The mission also helped to allay fears that the citizen scientists were selfishly tinkering with DNA code without thought to the greater community good.

In 2011 Genspace hosted a bridge-building meeting where heads of local DIYbio groups were introduced to the FBI personnel in their home city. A similar event was held at Biocurious the following year, with international participation. This strengthened the relationship between DIYbio and Homeland Security forces, which consider citizen science groups allies in vigilance against bioterrorism.

In the same time period, the Wilson Center in Washington DC received a grant from the Sloan Foundation to study the biosecurity implications of DIYbio. Led by Jason Bobe of DIYbio and Todd Kuiken of the Wilson Center, two meetings (one in the US and one in Europe) were convened to help DIY practitioners develop a formal code of ethics to guide their practice. Both successfully resulted in codes that all participants agreed upon as guiding principles. Thus the DIYbio community showed that they were wholeheartedly committed to safe and secure practice of synthetic biology.

Biocurious and Genspace continue to be models for community labs, and advise people worldwide who want to start one in their area. DIYbio has introduced hundreds of people to the concepts and practices of synthetic biology, and is unique in that we directly interact with the general public on a daily basis to inform and inspire. Our thesis is that the spread of community labs should be encouraged because it communicates synthetic biology to the public in a way that established institutions cannot. Our spaces are informal and make use of recycled and DIY equipment and materials. Many of the volunteer mentors in these labs have advanced degrees in biological sciences, yet they are not in the formal environment of a large laboratory complex or an office. This facilitates a more open and honest dialogue around the social and ethical implications of the technology. In 2012 a poster describing Genspace's groundbreaking program that teaches synthetic biology to the public in a community lab space was awarded the prize for Best Social Study in Synthetic Biology at the International Synthetic Biology meeting SB5.0.

Unfortunately, there is little data that quantify the benefit of community labs, particularly in their ability to communicate synthetic biology to the public. I propose that further research evaluating the impact of community labs will help guide their evolution and help them become even more useful to both the general community and the synthetic biology community in particular.

Beyond the Lab and Far Away: Engagement with the DIYbio Community

Adapted from Beyond the Lab and Far Away: A View from Washington in BioCoder Issue 3, 2014ⁱ

Todd Kuiken, Ph.D. – Woodrow Wilson Center

In the 1970 film *Tora! Tora! Tora!*, Admiral Isoroku Yamamoto exclaims, "I fear all we have done is to awaken a sleeping giant and fill him with a terrible resolve." This was in response to the successful 1941 attack on Pearl Harbor by forces of Imperial Japan. In spring 2013, a small project listed on Kickstarter that was part of the larger DIYbio movement awoke the U.S. regulatory system with a dimly lit glowing plant. On May 7, 2013, *The New York Times* published "[A Dream of Trees Aglow at Night](#)"ⁱⁱ, which exposed those not paying attention to the power of crowd funding and the possibilities, albeit with a novelty product, of biotechnology and the DIYbio movement. As I opened the door to my office that morning, my phone was already blinking, the first message from a U.S. Senator's office wanting to know how this type of product could escape regulatory oversight. As I hopped in a cab on my way up to Capitol Hill to brief the Senator's staff, all I could think about was the quote from Admiral Yamamoto. Glowing Plant's ability to raise half a million dollars in such a short period of time and the perception that there was no oversight of the first release of a genetically engineered seed produced by "amateurs" caught the government off guard. The swift and immediate reaction from the Hill gave me the sense that the "sleeping giant" had been awoken.

Our conversation was based on how a project like Glowing Plant was perceived to have escaped regulatory oversight and whether the [Coordinated Framework](#)ⁱⁱⁱ, a regulation written in the mid-1980s, was capable of dealing with applications that could come out of the DIYbio movement. Established as a formal policy in 1986, the Coordinated Framework for Regulation of Biotechnology describes the federal system for evaluating products developed using modern biotechnology. It established which federal agencies would have jurisdiction over a particular application in order to streamline the process for companies that could potentially fall under the jurisdiction of at least three federal agencies and no less than four federal laws: the Plant Protection Act; the Federal Insecticide, Fungicide, and Rodenticide Act; the Federal Food, Drug, and Cosmetic Act; and the Toxic Substance Control Act. The three main federal agencies responsible for regulating the safe use of genetically engineered organisms are the U.S. Department of Agriculture, the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Health and Human Services' Food and Drug Administration (FDA).

As the ability to manipulate and design new organisms rapidly evolves, debates on whether the coordinated framework is suitable to regulate the changing face of biotechnology should continue. However, the issue around Glowing Plant is not whether the process it is going to use is [regulated or not](#)^{iv}, but whether the government and general public are comfortable with "amateurs" being able to use these techniques. Glowing Plant challenges the status quo in a number of ways. First, it showed how a research project could be funded outside the traditional funding methods, how democratized access to biotechnology techniques could spur a new company with thousands of supporters, and how a project/product could be marketed and sold as an open source application. At the same time, it is challenging whether our governance structures

can deal with fast-paced technologies, particularly when it comes to environmental release from products produced outside the traditional biotechnology industry.

The recent exposure in the popular press and those in academia around DIYbio can be both good and bad, depending on your perspective. It could potentially open the doors to federal funding, increase the ability to acquire surplus or retired laboratory equipment, and enhance access to user facilities and government expertise. However, it also shines a brighter light on the community, which could increase scrutiny from regulatory agencies and exacerbate the [myths](#)^v that surround the DIYbio community. The Woodrow Wilson Center has been actively engaged with the DIYbio community for several years and surveyed the community in order to challenge seven widely held beliefs about DIYbio practitioners, particularly about their labs, capabilities and goals. The survey found that the science they practice is far more benign than described in the popular press. In fact, the report suggests that the DIYbio community offers national education and entrepreneurship opportunities, rather than over-inflated risks. In addition the report documents how the DIYbio community has been actively engaged in addressing the biosafety risks associated with their community by developing codes of conduct and, with the help of the Woodrow Wilson Center, launched the Ask a Biosafety Officer program which gives amateur scientists direct access to professional biosafety officers.

Anyone tinkering with and experimenting with biology raises legitimate biosecurity, biosafety, and environmental concerns. As the movement becomes more sophisticated in its scientific abilities, these concerns will continue to grow and the community should continue to address and adapt to these apprehensions. The movement is going to have to engage with those in the federal government, academia and the general public if it wants to avoid knee-jerk regulatory actions based on misinformation and conjecture from those that believe placing biology in the hands of the public is too dangerous and that the movement has nothing to contribute beyond becoming the next biosecurity threat.

The DIYbio movement, and the larger citizen science movement, presents an interesting dichotomy for the U.S. government. On the one hand, it wants to [support the movement](#)^{vi} in order to promote innovation; on the other hand, there are legitimate biosecurity, biosafety, and environmental concerns that raise public policy and public perception issues. Like it or not, the community has a spotlight on it, and while the movement has its supporters within the government, there are those who are looking for ways to limit its ability to flourish and, in some instances, shut it down completely. By engaging directly with the government and the communities in which they operate, the community can build supporters, adapt to their concerns early, and control the narrative around DIYbio.

ⁱ <http://chimera.labs.oreilly.com/books/1234000002013/index.html>

ⁱⁱ http://www.nytimes.com/2013/05/08/business/energy-environment/a-dream-of-glowing-trees-is-assailed-for-gene-tinkering.html?_r=3&

ⁱⁱⁱ http://www.aphis.usda.gov/brs/fedregister/coordinated_framework.pdf

^{iv} <http://www.nature.com/news/2011/110720/full/475274a.html>

^v http://www.synbioproject.org/site/assets/files/1278/7_myths_final.pdf

^{vi} <http://www.whitehouse.gov/blog/2014/02/03/announcing-first-white-house-maker-faire>

Hacking Life? The Politics and Poetics of DIY Biology

Morgan Meyer, Agro ParisTech

Biohacking, or do-it-yourself (DIY) biology, has rapidly established itself as a distinctive movement over the past 6 years. Numerous media articles have reported on biohacking, and it has even entered the museum world, in an exhibition called *Biohacking: Do-It-Yourself* at the Medical Museum in Copenhagen. Last year, a dedicated web series of documentaries and a quarterly journal called *BioCoder* have been launched. DIY biology is today a rather fashionable phenomenon, attracting an increasing number of practitioners, journalists, academics, scientists, students, citizens, hackers, artists, and potential entrepreneurs. The average DIY biologist is male, educated and young, works 7 hours per week on DIY projects, and values transparency [1]. Out of the long list of activities that DIY biologists do, let us mention the following ones: extracting DNA; “hacking” yoghurt (to alter its taste or produce fluorescent proteins, vitamin C or Prozac); DNA barcoding of plants or sushi; producing bioreactors; developing home-brewing kits for the public; genetic testing; bio-art projects; molecular gastronomy; producing biosensors to detect pollutants in food and the environment; educational activities, courses and workshops.

History

The history of DIY biology is both a recent and an old one. Its recent history can be roughly outlined as follows: in 2005, biologist Rob Carlson predicts that “garage biology is at hand” [2] and stories about home laboratories of people like Carlson, Kay Aull and others gain increasing attention. The association DIYbio is created in Boston in 2008 and among the first community labs established there is *GenSpace* in New York (2010), *BiologiGaragen* in Copenhagen (2010), *BioCurious* in Sunnyvale, California (2011) and *La Paillasse* near Paris (2011). A European DIY biology network, DIY Bio Europe, is launched in 2012. At the time of writing, there are around 50 DIY biology labs across the world. But the history of DIY biology is also much older and more complex. The involvement of amateurs and citizens in science, in particular in biology, has a long tradition. Be it in natural history (ornithology, botany, zoology), in epidemiology, or in astronomy, non-professionals have actively contributed to science for centuries. Thus, DIY biology can be seen as a continuation of this longer tradition of amateurs and professionals co-producing scientific knowledge. At the same time, it also represents a rupture. The amateurization and domestication of molecular biology is also a novel phenomenon and while amateurs in natural history have been observing and describing the natural world, DIY biologists aim at experimenting with, and (re)engineering, the biological world [3].

In addition, the history of DIY biology cannot be told without mentioning at least four related movements. First, do-it-yourself has emerged in the 1950s and 1960s and usually refers to home-improvement and fashion (however, while DIY biologists now also use the expression, the term “do-it-with-others” seems more appropriate). Second, DIY biology can be situated within the broader open science movement, a movement itself inspired by the open source movement that has developed since the 1990s [4]. Third, the proximity between the hacker movement and DIY biology is noteworthy - a proximity that is technical and spatial (the tools and physical spaces of hackerspaces and DIY labs are often shared), semantic (through terms such as “biohacker” or “biohackerspace”) and ethical (i.e. favoring access, sharing, collaboration). Fourth, the

development of synthetic biology over the past decade has also played an important role: its engineering vision has been influential, and many founders of DIY biology labs have met each other at a student competition in synthetic biology called iGEM and collaborations between iGEM teams and DIY biology are on the rise [5].

DIY biology cannot and should not be reduced to either one of these histories. Neither a radically new phenomenon, nor a simple continuation of amateur or DIY practices, nor an extension of hacker and open source ethics to a new domain: DIY biology is best understood as an entanglement of all of these.

The politics and fabric of openness

Increasing “openness”, “accessibility”, or “availability”: these are some of the words commonly used to describe how DIY biology aims to transform science. Biology should not be an activity confined to university researchers, but the broader public – whether called “amateurs”, “citizens” or “everyone” – should also be involved. In a nutshell, the idea is to “democratize” science. As much as such terms sound reasonable, they are also problematic: words such as “openness” and “democratic” are too vague and too widely used to provide a thorough description of DIY biology.

In fact, DIY biology aims at “democratizing” biology in various ways: spatially, technically, socially and economically. In terms of the spaces of biological experimentation, a two-fold effort is visible: some people’s homes are transformed into laboratories (biology is “domesticated”) and new community laboratories are established (like the ones mentioned above). The redesign of scientific and technical equipment is another way in which biology is made more accessible. There are now many examples of alternative equipment: using a webcam instead of a microscope, the *OpenPCR* instead of a conventional PCR machine, the *DremelFuge* instead of a centrifuge, or building one’s own electrophoresis gels, magnetic stirrers, autoclaves, etc. [6]. People from all socio-cultural backgrounds can join DIY laboratories and their mailing lists. Neither diplomas, nor previous expertise is required to become a member (unlike institutional science). Finally, DIY biology aims at making biology more affordable economically: DIY biology labs usually ask for no membership fees, or only modest ones, and one of the motives behind the creation of alternative equipment is to decrease their cost (often 10 to 100 times).

Hence, rather than arguing that DIY biology “opens up” and “democratizes” biology, the concrete processes of this democratization need to be unpacked. Various processes are visible: DIY biology builds new, and reconfigures existing, spaces; develops creative workarounds around technical equipment and protocols; renders the sites and techniques for scientific experimentation more affordable; creates networks and laboratories accessible to various people, motivations, and interests; portrays itself as an alternative to established and “closed” science and a way to “demystify” science. DIY biology not only seeks to foster a “politics” of openness, it also aims to produce the very fabric of this openness. We might even talk of a “cosmopolitical” form of public participation and experimentation, involving “various powers, actors and communities across scales and ontologies” [7].

DIY biology aims to constitute a distinct and political form of self by providing people with access, by enabling them to transform themselves into active producers of science, by making their bodies and ailments more knowable, and by demonstrating that one *can* do it oneself. The “yourself” in DIY is not a passive, individual person, but someone who engages with biology and does things (with others), a self that is active and juxtaposed to other sites and scales of science production: the university, the institution, the enterprise, etc.

The ethics and economics of DIY biology

The politics of openness of DIY biology is at once celebrated and dreaded. On the one hand, it is praised for empowering citizens, for fostering open innovation, for providing new means for education, and for being inclusive. Optimist accounts often compare DIY biology to the Home Brew Computer Club and Steve Jobs - a promissory comparison that brings side by side a familiar success story and a story-in-the-making, and offers a narrative of change, innovation and revolution. On the other hand, DIY biology also raises concerns about security, safety and regulation. The most negative accounts even refer to bioterrorism - with the figure of the terrorist being used to crystallise the unpredictable danger of biohacking and to represent evilness. It should come as no surprise that this anxiety is mostly voiced in the US.

There have been three kinds of responses from the DIY biology community to such concerns about safety and security. The first response is argumentative: responses by practitioners highlight that DIY biologists do not work with dangerous material and that potential terrorists do not need DIY biology to meet their aims. The second response has been ethical, by collectively establishing a code of ethics. The European code of ethics, first drafted in 2011, states that practitioners should “emphasize transparency”, “adopt safe practices”, “promote citizen science and decentralized access to biotechnology”, “respect humans and all living systems”, etc. The third response has been practical: on DIYbio.org, a portal has been set up through which people can ask questions about safety to a panel of biosafety experts and members of a professional association of biosafety; and DIY Bio Europe has developed “Community Biolab Guidelines”.

Discussions not only concern the ethics of DIY biology, but economics and funding as well. We see both non-market and market rationales at work [8]. In its purest form, there is a logic of “do-it-without”: DIY biology is often portrayed as a reaction against big pharma, standard/expensive equipment, patents and, in general, against everything that keeps knowledge from being freely shared. Yet, DIY biology relies - at least partially - on markets and industries: by buying used equipment from commercial websites, tools and products from supermarkets, or seeking and accepting donations from companies. Also, various sources for funding DIY biology projects have been sought, be it via membership fees, crowdfunding, grant funding, funding from the European Union or from local municipalities [9]. And, there are even entrepreneurial projects that have developed out of DIY biology (like *OpenPCR*, *Pearl Biotech*, *LavaAmp*, *Ginkgo Bioworks*). The potential relationships and co-existence - or, conversely, tensions and ruptures - between non-market and market rationales and projects will be interesting to follow as the movement develops.

DIY biology is an interesting phenomenon and merits academic analysis. Its history and genealogy, its politics of openness, and its ethics and economic logics all need to be carefully

analysed and defy neat categories and simple narratives. The politics of life are complex and multifaceted - and the politics of hacking life are no exception.

References and Notes

1. Woodrow Wilson International Center for Scholars, *Seven Myths & Realities about Do-It-Yourself Biology*, Washington (2013). Of the respondents of this survey 75% are male, and 63% are between 25 and 45 years old.
2. R. Carlson, "Splice it yourself: Who needs a geneticist? Build your own DNA lab," *Wired Magazine* **13**, No. 5 (2005).
3. M. Meyer, "Domesticating and democratizing science: a geography of do-it-yourself biology," *Journal of Material Culture* **18**, No. 2 (2013), pp. 117-134.
4. H. Ledford, "Life hackers," *Nature* **467** (2010), pp. 650-652.
5. Yet, in the past, DIY biology teams have not been allowed to take part in the iGEM competition. From 2014 onwards, this is changing via a new "community labs" track at the competition.
6. T. Landrain, M. Meyer, A. M. Perez, and R. Sussan, "Do-it-yourself biology: Challenges and Promises for an Open Science and Technology Movement," *Systems and Synthetic Biology* **7**, No. 3 (2013), pp. 115-126.
7. D. Kera, "Innovation regimes based on collaborative and global tinkering: Synthetic biology and nanotechnology in the hackerspaces," *Technology in Society* (in press).
8. A. Delfanti, *Biohackers: The Politics of Open Science* (Pluto Books, 2013).
9. Examples include: crowdfunding campaigns on Kickstarter to fund the development of *OpenPCR* and the setting up of *BioCurious*; Wellcome Trust funding for *MadLab* (Manchester) to develop a "citizen science" partnership; the EU COST initiative being tapped into by DIY Bio Europe.

Note: this article has been published in Meta-Life. *Biotechnologies, Synthetic Biology, A Life and the Arts*, Annick Bureaud, Roger Malina, Louise Whiteley (Eds.), Leonardo ebook series, MIT Press, 2014

**The DIYBio network:
What kind of work we are doing now and what kind of work we want to do**

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What kind of work we are doing now: a brief review of the literature on the DIYbio network¹

The formation of the DIYbio network² was first analysed as a biosafety and a biosecurity concern (Schmidt, 2008a; Schmidt *et al.*, 2008b; Bennett *et al.*, 2009). These authors considered DIYbiologists and biohackers as yet another uncertainty attached to the emerging field of synthetic biology. An uncertainty that they propose to address by simply calling more attention to it, including by using alarmists claims based on the analogy between computer viruses and “‘bio-spam, biospyware and bio-*adware*' and other bio-*nuisances*” (Schmidt, 2008a, n.d); or by using the 'ethical tool-kit' known under the name of 'human practices' (Bennett *et al.*, 2010). This first analytical framework, although skewed towards biosafety rather than biosecurity, still marks more recent works, as for instance the one of Catherine Jefferson, who proposes to extend the framework Responsible Research and Innovation in Synthetic Biology to DIYbio members (Jefferson, 2013).³

A first departure from these works focusing on biosafety and biosecurity from a policy-oriented perspective, is produced by the arrival on the field of the science and technology scholars. Their first

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- 1 This review focuses on academic publications and does not cover how the DIYbio network has been described in governmental and think tanks report, nor on the role of STS scholars in the writing of these reports. Additional work on DIYBio and biosecurity has been done by Alex Hamilton, but at this stage his work is not available.
 - 2 I use the term 'DIYbio network' to indicate a loose group of individuals, mainly interconnected by Internet mediated communication and sharing a number of common interests and practices. Other commons terms used are: the DIYbio community, biohackers (and biohacking), and garage biology.
 - 3 This turn also marks governmental reports on the DIYbio network. Early reports considered DIYBio as a biosafety and biosecurity threat while later ones stressed the importance to engage with the network and recognise the practices of its members as positive 'citizen science' and 'science outreach' initiatives.

entrance is marked by the question of ethics and moral values within the DIYbio network. Sara Aguiton proposes that members of the DIYbio network participate in the replacement of *community norms* with what she names 'critical individualism.' This is a type of reflexivity according to which the submission or adaptation to moral or ethical criteria is no longer necessary, and 'difference and divergences are accepted and regarded as a possibility of new and innovative ideas' (2009: 40). Moral norms are also the point of entrance of Alessandro Delfanti's work (2010; 2013). He argues that a 'remix' of the Mertonian's norms and the hacker's ethic are brought into the life sciences, and that biohackers are an example of it. Citing Luc Boltanski and Laurent Thévenot's work on the 'imperative to justify' one's search for a new ethical norm, Delfanti understands such 'remix' as a symptom of a crisis in the proprietary regimes of biotechnology (Boltanski and Thévenot, 2006 cited in Delfanti, 2010:19).⁴

As Aguiton (2010) revisits her work on the DIYbio network, she focuses on 'doing DIY.' She proposes that doing as an amateur, meaning working outside the professional organization of labour, biology becomes a medium to express the pleasure of doing (Aguiton, 2010). The argument of pleasure is also taken up by Delfanti for whom hedonism is evidence that hacker culture is inspiring DIYbio members (Delfanti, 2010). The relation with craft and artisan practices is also central to Sophia Roosth's work. She proposes that after the 'genetic fetishism' of the 1980s and 1990s, we are witnessing the return of the biological as a crafted substance, and that the DIYbio network is an example of this return (Roosth, 2010: 14). While lasting only a chapter, Roosth's work greatly expands the interpretative framework through which to understand the DIYbio network. For her the DIYbio network is in a Foucauldian sense an *undisciplined* offspring of synthetic biology (2010: 113), a 'mode of political action' claiming biology as a right rather than a privilege (ibid.: 105), a tinkering practice as described by Claude Lévi-Strauss (ibid.: 110), a 'recursive public,' as defined by Christopher Kelty in his studies of the Free/Libre/Open Source Software movement (Kelty in Roosth, 2010: 110), but also a 'frontier' where what it means to do science is questioned (Gieryn in Roosth, 2010: 110). Roosth's analysis of the DIYbio network as redefining the contours of scientific practice is endorsed by Kelty, who, in a brief publication, concludes that the type of public composing and being gathered by the DIYbio network and related initiatives are 'aggressively active' and radically different from the 'public of opinion polls and scientific literacy' (2010: 8).

Concerned by similar questions on the relations between science and society, Joel Winston's Master's dissertation specifically describes the types of science communication and knowledge exchange practices taking place within the London Biohacking group (2012). He concludes that

4 In his most recent works, Delfanti proposes an additional interpretative framework by adapting the work on co-option of David Hess to the case of the DIYbio network (Delfanti, forthcoming).

biohacking widens the concept of citizen science and is a site where people with no formal education in science can learn more about biology. The notion of boundary work is also further explored in Morgan Meyer's work (2012), who, by situating the DIYbio network as part of an undistinguished continuity, including popular epidemiology, militant patient groups, patients associations and consumer engagement, concludes that what characterize the DIYbio network is the creative workarounds of tools and places resulting in the production of more permeable boundaries between professional scientists and amateurs. Stacey Kuznetsov and colleagues' work is also focused on practices, and speculates about the creative opportunities that DIYbio offers to the field of Human Computer Interactions (2012). Another scholar particularly interested in the type of objects DIYbio members produce is Ana Delgado, who mobilizes Heidegger's political theory of things, in order to interpret the type of production of the new undertaken by DIYbio member (2013). She concludes that the mundane and immediate doing of DIYbio members illustrate how their doing produces things rather than techno-objects. Lastly, turning away from US and Europe-centred analysis, Denisa Kera (2012) explores the specificities of similar emerging practices in East-Asia. She argues that, rather than simply enabling 'rebellion or utopian wish-fulfillment' the practices she witnesses reconfigure indigenous practices and recent technological transformations. More recently some of these scholars have begun authoring papers in collaboration with DIYbio members. This is the case of Meyer in Landrain *et al.* (2013) and Schmidt *et al.*, (2014) whose works are marked by a supportive discourse where the work of DIYbio members is described as a more participatory strand of citizen science.

If this literature review reads as a fragmented field, it is because these authors often write simultaneously, and only a minority actually cite and engage with each other's works. It seems that therefore, a recognized field of research has yet to be established. Additionally given the diversity of the analytical propositions made by these scholars, I wonder if such interpretative fragmentation mostly reflects scholars matters of concerns and their disciplinary position (as I am sure mine does) or actually also speaks about the DIYbio network as a composite sub-culture. As this literature only emerged during my research period (spanning between 2009 and 2013), my own research is not a radical departure from these interpretations, rather an attempt to locate each of these interpretations in more detailed descriptions based on field work analysis, while at the same time trying to figure out how the DIYbio network became such a composite sub-culture. For instance, in my research, the 'doing DIY' of Aguiton (2009) or the frame of 'craft' as used by Roosth (2010), is located in an analysis of the relationship between DIYbio members and the 'maker movement.' A contemporary 'movement' curated by O'Reilly Media Inc., an influential publisher in the field of computer and software engineering.

Following the tradition of the Whole Earth Catalog, the founders of the 'maker movement' designated itself as the advocate of a 'Modern DIY.' As part of this reconfiguration, I argue that the ideology of a personal technology has come to include biology and biotechnology, and that such ideology which is based on collaborative and creative work, non-hierarchical relations, small-scale technologies, has become a conformable refuge in times of social unrest.⁵

What kind of work we want to do: from a research experience to some propositions

The writing of the first proposition is informed by the Introduction to the edited book 'Dissenting Academy' that Theodor Roszak published in 1969.⁶ A work he begins with

'Dare to know!' So Kant defined the function of intellect in a day which pursued the critical examination of life and society neither as an amusing pastime nor as a lucrative career, but rather as an act of defiance and of risk (1969: 3).

A work that I read from a feminist perspective. One that questions what does it mean to make explicit the relationship between our subjectivities, the questions that we ask and the interpretations we produce as scholars (Haraway, 1991). In this respect therefore, it seems to me that the first **(1)** kind of work that 'we' might want to do is about making explicit the political composition of the 'we.' Roszak argues that one of the problems of the academic 'we' is that it is oriented towards the formation of international network of influence and the politics of academic careers, rather than on the establishment of 'local' alliances (i.e. within a university or a city) focused on matters of concerns. This is of course a much larger issue, but the literature review proposed in the first sector, and my experience as a researcher working in the DIYbio network, reflect this impression. That of a number of scholars who seem more interested in the production of their own interpretations of what is the DIYbio network (if not the endorsement of its practices as participatory 'citizen science'), than on making explicit why the DIYbio network matters to them in the first place. In this sense making explicit the political composition of the 'we' is also about making explicit what type of work does the DIYbio network (or synthetic biology) do for us as scholars. Therefore, in both cases (i.e. DIYbio network and synthetic biology) what is the 'partial perspective'⁷ from which we elaborate our 'concerns'? And how to make collectively explicit our partial perspective? It seems to me that this question remains mostly implicit, while to a certain extent

5 This work is available in the form of a PhD thesis awaiting for examination, if you might be interested please contact me.

6 As the book focuses on the 'American intellectual establishment' I merely respond to the way in which, more than forty years later, the book address me as a female and European ex-biologist not-yet-turned-into a science and technology scholar.

7 For an introduction on the politics of the 'partial perspective' and situated knowledge see Haraway (1991).

'we' are asked to 'work together.' Mine is not a desire for more factions and fragmentation, rather a desire for the establishment of collaborations that are not only meaningful professionally, but also politically.

In what follows I would like to make two additional propositions specifically related to the DIYbio network. A second type of work **(2)** that we might want to do is to better understand how DIYbio, to a certain extent, has become the public outreach arm of synthetic biology, as recent events organized by DIYbio members have been endorsed by national funding bodies and think tank alike. In doing this we might want to ask what type of persuasive work the techno-utopia of a personal and empowering relation to biology and biotechnology is doing for the field of synthetic biology and more generally biotechnology. To do so, we might want to look at what happened since its introduction to the 'human practices' (later 'practices') track and the ideal of 'public engagement' that its practices by iGEM participants, but also at the public outreach practices specifically concerning genetic engineering and synthetic biology as advocated by DIYbio members. This of course is tight to recent programs such as the Symbio4all lab aimed at 'extend[ing] the synthetic biology scientific endeavour to the public by harnessing its potential for identifying key research projects that will then be implemented in a certified research lab.'⁸

A third type of work **(3)** that we might want to do concerns the recent organization of hybrid forums of DIYbio community laboratories and start up incubators and accelerators. This is once more tight to the entrepreneurial track at iGEM and more generally to a tendency toward entrepreneurial discourses and practices among younger and younger post-graduated and graduates.⁹ What we might want to ask in this case is what is the formative role of entrepreneurship in undergraduate and graduate students in the field of synthetic biology and as members of the DIYbio network.

Bibliography

Aguiton, S., 2009. *Synthetics, An Ethical and Sociological analysis on Synthetic Biology*, Report IGEM 2009 (MIT) - Paris, IGEM.

Aguiton, S., 2010. *Un vivant 'sexy' et à peu près faisable. Anthropologie d'un concours d'ingénierie génétique*. Master D. École des Hautes Études en Sciences Sociales.

⁸ Available at <<http://citizencyberlab.eu/portfolio/synthetic-biology/>>. Last accessed 8 October 2014.

⁹ In relation to this aspect see the ongoing fieldwork of Sarah Choukah.

- Bennett, G., Gilman, N., Stavrianakis, A., and Rabinow, P., 2009. From synthetic biology to biohacking: are we prepared? *Nature Biotechnology*, pp. 1109 – 1111. [e-journal] (27). Available through: Nature Biotechnology website <<http://www.nature.com/nbt/journal/v27/n12/full/nbt1209-1109.html>>.
- Delfanti, A., 2010. *Genome hackers, rebel biology, open source and science ethic*. Ph. D. University of Milan.
- Delfanti, A., 2013. Biohackers. *The politics of open science*, Pluto Books.
- Delfanti, A., 2014. Is do-it-yourself biology being co-opted by institutions?», in Bureaud, A. and Whiteley, L. (eds): *Meta life. Biotechnologies, synthetic biology, Alife and the arts*, MIT Press, (forthcoming)
- Delgado, A., 2013. DIYbio: Making things and making futures, *Futures*, 48, April, pp. 65-73.
- Haraway, D. J., 1991. *Simians, Cyborgs, and Women: the Reinvention of Nature*, New York: Routledge.
- Jefferson, C., 2013 *Governing Amateur Biology: Extending Responsible Research and Innovation in Synthetic Biology to New Actors*. University of Bradford.
- Kera, D., 2012. Hackerspaces and DIYbio in Asia: connecting science and community with open data, kits and protocols. *Journal of Peer Production*, Issue 2.
- Kuznetsov, S., Taylor, S. A., Regan T., Villar, N., Paulos E., 2012. At the seams: DIYbio and opportunities for HCI. *ACM Designing Interactive Systems (DIS)*.
- Landrain, T., Meyer, M., Perez, A. M., Sussan, R., 2013. Do-it-yourself biology: challenges and promises for an open science and technology movement. *System and Synthetic Biology*, 7, pp.115–26.
- Meyer, M., 2012a. Bricoler, domestiquer et contourner la science: L'essor de la biologie de garage. *La Découverte I Réseaux*, [e-journal] 4(3), pp. 173-174. Available through: Cairn.info website <<http://www.cairn.info/revue-reseaux-2012-3-p-303.htm>>.
- Roosth, S., 2010. *Crafting life: a sensory ethnography of fabricated biologies*. Ph. D. Massachusetts Institute of Technology.
- Roszak, T., 1969. *The Dissenting Academy – Critical essays on the American intellectual establishment*. London:Chatto and Windus
- Seyfried, G., Pei, L., Schmidt, M., 2014. European Do-it-yourself (DIY) Biology: beyond the hope, hype and horror. *BioEssays*. 36(6), pp. 1-4.
- Schmidt, M., 2008a. Diffusion of synthetic biology: a challenge to biosafety. *System and Synthetic Biology Journal*, [e-journal] 2(1-2). Available through: Pub Med website <<http://www.ncbi.nlm.nih.gov/pubmed/19003431>>.

Schmidt, M., Torgersen, H., Ganguli-Mitra, A., Kelle, A., Deplazes, A., Biller-Andorno, N., 2008b. SYNBIOSAFE e-conference: online community discussion on the societal aspects of synthetic biology. *Systems and Synthetic Biology* Vol. 2(1-2):7-17

Winston, J., 2012. *New Perspective on Biohacking: A study of the London Biohacking Group*. Master Imperial College London.

Nanotechnology Risk Perception and Public Participation Research as a Template for Synthetic Biology

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Synthetic biology has already emerged with a large red flag for potential risk perception amplification and regulatory challenge (e.g., IRGC 2008; FOE 2010). Indeed, the potential for synthetic biology's rapid scale up and commercialization around the globe appears to far exceed that realized thus far for nanotechnology; and yet as with nanotechnologies, this will likely be accompanied by very high levels of lack of knowledge among publics in many countries (cf. Satterfield et al. 2009). In this short piece, I would like to suggest the most salient aspects of nanotech risk perception and public deliberation work that synthetic biology funders should consider and incorporate in building future research initiatives with societal components if their aim is responsible innovation and development.

Risk perception and decision risk research are well-established fields, based on cognitive and affective theories and well-validated methods, approaches, and tools. In particular their ability to theorize and assess the construction of preference and preference reversals is critical to issues of public acceptance that have preoccupied nanotechnology funders and industry. In addition to providing a rigorous approach to understanding public perceptions, the field also has long scrutinized the nature and distribution of points of connection and disconnection between publics and experts, in particular, and between different kinds of 'situated' or 'affiliative' knowledges more broadly. Work based on these approaches at CNS-UCSB has added value to the nano initiative at NSF by helping characterize and disentangle the multiple factors that operate on upstream benefit and risk perception (Pidgeon et al. 2009; Pidgeon, Harthorn & Satterfield 2011).

Government agencies in the US have widely adopted multi-stakeholder approaches to engagement, yet these activities are often conducted without knowledge of or reference to evidence of such perceptions among participants. They also tend to be shaped around incorporation of leading upstream actors at the cost of public involvement, which is viewed as more appropriate downstream (thus removing precaution from dialogue). And they tend to shape participant composition according to intuitive ideas rather than informed evidence-based knowledge of constituents views and preferences. In addition, the skilled analysis of the effects of such power and perspective differentials is a critical and frequently ignored dimension.

Public participation is widely mandated across numerous governmental institutions for input in science and technology policy decision making. Yet methods for its implementation are largely unspecified, ad hoc, and often performed with a 'check the box' approach that limits their impact and violates normative ethics. Engagement in the context of high scientific uncertainty about risks and widespread lack of knowledge as has been the case with nanotechnologies has added yet further complexities. But research in a number of countries has demonstrated that such upstream and anticipatory engagement can indeed be performed, assessed and found to be effective in achieving its goals (Corner & Pidgeon

2012). Our work has also found US participants to be strongly supportive of public deliberation as a vital, though excessively unfamiliar, approach. It has also found pervasive public ambivalence about societal implications of science and engineering development (cf. Harthorn, Shearer & Rogers 2011), particularly around issues of trust, institutional recreancy, and procedural and distributive justice. These seem likely to be yet more extensive in the synthetic biology case.

Responsible risk communication, a widely mandated and ethically requisite element of governance in the US, needs to include a comprehensive approach across agencies that is currently faulty or absent entirely. The science of risk communication also demonstrates the importance of tailoring risk messages to specific audiences, of integrating different levels of risk governance into them, and of basing them on evidence-based rather than intuitive understandings of multi-stakeholder risk and benefit perceptions. Nano has provoked great advances in empirical evidence on diverse stakeholders, yet comprehensive risk communication has not (yet) arisen; synthetic biology could benefit from and extend this evidence base. In the event of likely risk amplification in synthetic biology, this is a vital area of research focus for responsible development. Nanotech has also provided an excellent case study for showing the limits of traditional quantitative risk assessment to resolve safety questions ahead of innovation and development, and hence has demonstrated the limits of regulation based on risk assessment alone.

Finally, both societal nano focused centers in the US at UCSB and ASU have succeeded in producing the requisite social and intellectual chemistry for innovating new modes of integration of science and society of which syn bio should take sharp notice—the large center context that has produced these is not incidental to their development and should be examined as a model for syn bio development.

References

- Corner, A. & N. Pidgeon. 2012. Nanotechnologies and upstream public engagement: Dilemmas, debates, and prospects. In *The Social Life of Nanotechnology*, ed. Harthorn, B.H. & J. Mohr, 169-194. NY and London: Routledge.
- Friends of the Earth (2010). Letter to Dr. Amy Gutmann, Dec 16, re: synthetic biology concerns of 58 organizations. Link available at: <http://www.upenn.edu/president/meet-president/ethics-synthetic-biology-guiding-principles-emerging-technologies>
- Harthorn, B., Shearer, C, Rogers, J. (2011). Exploring ambivalence: Techno-enthusiasm and scepticism in US nanotech deliberations. In *Quantum Engagements: Social Reflections of Nanoscience and Emerging Technologies*, eds. T. Zulsdorf, C. Coenen, A. Ferrari, U. Fiedeler, C. Milburn & M. Wienroth, pp. 75-89. Heidelberg, Germany: IOS/AKA Press.
- International Risk Governance Council (IRGC). 2008. Synthetic Biology: Risks and opportunities of an emerging field. Concept note. Geneva. Available for download at: <http://ec.europa.eu/digital-agenda/futurium/en/content/synthetic-biology-risks-and-opportunities-emerging-field>
- Pidgeon, N., Harthorn, B., & Satterfield, T. (2011). Nanotechnology risk perceptions and communication: Emerging technologies, emerging challenges. *Risk Analysis (special issue)*, 31(11), 1694–1700. doi: 10.1111/j.1539-6924.2011.01738.x
- Pidgeon, N., Harthorn, B., Bryant, K. & Rogers-Hayden, T. (2009). Deliberating the risks of nanotechnologies for energy and health applications in the United States & United Kingdom. *Nature Nanotechnology* 4(2): 95-98.
- Satterfield, T., Kandlikar, M., Beaudrie, C., Conti, J, and Harthorn, B.H. (2009.) Anticipating the perceived risk of nanotechnologies. *Nature Nanotechnology* 4:752-758.

The Role of NPOs/NGOs in Building Science and Technology Social Capital within Underrepresented Communities

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People of color and women, especially those living below the poverty line, are less likely to have social capital than their counterparts. Lack of social capital negatively correlates with job promotion, owning homes, financial stability, and inherited social networks. They also have less influence on policy, and are less likely to create social mobility for themselves. One of the areas where this gap becomes evident is in the development and utilization of technological and scientific advances. Specifically, a gap lies between populations that have access to scientific and technological advancements, including but not limited to medical treatments, decision makers, and information surrounding scientific principles and emerging technology. The development and use of genetically engineered food, synthetic biology, and other emerging technologies are areas of science and technology where this gap can be seen.

As NPOs/NGOs increasingly provide civic goods and services for underrepresented communities, including addressing hunger and food security, questions arise for social scientists and practitioners as to how NPO/NGO management can be more conducive for building technology and science social capital within these communities on an international stage. An appropriate research topic for social scientists involved with emerging technology may be to explore how NPOs/NGOs can actually create or build social capital for underrepresented populations with regard to the development and utilization of emerging technology and its applications.

There are two reasons why this kind of study would be important for non-profit management. First, NPOs/NGOs are increasingly becoming organizations that provide civic goods and services that are necessary for many people to function in today's society, especially women, people of color and the poor. Often times, these civic organizations are increasingly being associated with the degradation of social capital for underrepresented communities (Wacquant, 1998; Bourdieu, 1985; 1986). Second, because these types of organizations represent civic goods and services, NPOs/NGOs have a unique position in society. Their perpetual interactions with these populations may prove to be a source of social capital for these underrepresented communities. As our society's population grows, and governmental programs become obsolete, like social security benefits, NPOs/NGOs serve more and more of the population; more NPOs/NGOs are being contracted to provide governmental services; more NPOs/NGOs are operating globally (Cross & Lin 2008; Leana & van Buren 1999). These face to face interactions that serve to be a possible source of social capital, can also, be adapted to strategically and continuously meet the needs of these underrepresented groups, with regard to emerging technology being utilized in their neighborhoods, which are in constant change as well.

Focusing on social capital for the underrepresented communities also ensures that the NPO/NGO is meeting the needs of the population they serve, in real time. Adequately meeting the needs of a NPOs/NGOs' target population is a big debate in the academic-practitioner community. The growing critique of service organizations are that they are in the business of repeat customers. Service organizational goals are not geared toward serving the consumer in such a way that they gain social mobility or social capital, it is to ensure that the populations have just enough to get by with their current circumstances. This model of service delivery allows for a recurring circle of continued care instead of providing a means where skills are built and utilized to acquire and maintain social capital, and therefore social mobility. This model of service delivery also denies other consumers assistance because of the dependence factor the model builds. The literature calls this support capital, a type of social capital that attempts to help individuals deal with their current circumstances versus leverage capital, which allows individuals to "change their life circumstances and take advantage of opportunities" (Hepworth & Stitt 2007, pg. 898).

Since there are several types of individual social capital as defined by the literature, the following is a sample of social capital constructs that can be associated with science and technology: 1) Network capital, specifically, the power dynamics that result from networks in the form of information sharing and decision making power; 2) Human capital or legitimacy i.e. education level, technical and industrial certifications or licenses, experience with scientific applications and processes, acquisition of new skills; 3) Economic capital which i.e. access to funding, access to information about what is being funded, and for what purpose.

Not only do NPOs/NGOs need to build social capital for those they serve, but research has found that the NPOs/NGOs that obtain and maintain organizational high social capital have a better opportunity to meet the needs of the populations they serve. Organizations high in social capital are allowed flexibility, attain more legitimacy and funding, which in turn leads to more survivability, therefore allowing for more individuals of underrepresented communities to be served, increasing NPO/NGO and individual effect on the societal forces. Organizational social capital also has several definitions and may have several connections to science and technology. The following types of organizational social capital can be associated with science and technology; 1) structural capital, which are the patterns of linkages in its networks with other organizations that produce new knowledge concerning leveraging of public money, the ability to harness emerging technology, the ability to adapt the workforce; 2) relational capital: a) trust and b) norms associated with the legitimacy of the organization; and 3) cognitive capital: the organization's ability to create and sustain ongoing relationships through collaboration and/or cooperation processes.

Being that social capital is defined as resources and norms embedded in the social structure that are accessed by purposive action, the question arises as to how to access these embedded resources or how to change the norms and rules surrounding these resources so that they can be more easily accessed. Essentially, NPOs/NGOs shape societal structures by building social capital for the underrepresented groups that they serve, who in turn, act as individual actors shaping the society's rules about who gets access to the resources. Schneider (2006) stated that "social relationships and patterns of trust (social capital) that enable people to gain access to resources like government services, organization funding, and jobs are crucial..." (pg. 243). Society is simultaneously, shaping and influencing NPOs/NGOs and individuals of underrepresented communities. These connections can be utilized to ensure that the voices of underrepresented communities not only can be heard, but can be used to design the technological and scientific contributions to the society they live in.

References

- Bourdieu, P. (1985). Social Space and the Genesis of Groups. *Theory and Society*, 14, 723-744.
- Bourdieu, P. (1986). "The Forms of Capital", in Richardson, John G. (ed.), *Handbook of Theory and Research for the Sociology of Education*, 241-258, New York: Greenwood Press.
- Cross, J.L.M. & Lin, N. (2008). Access to Social Capital and Status Attainment Outcomes in the United States: Racial/Ethnic and Gender Differences. In Lin, N. & Erickson, B. (Eds.), *Social Capital: An International Research Program* (364-381). Oxford, United Kingdom: Oxford University Press.
- Hepworth, C. & Stitt, S. (2007). Social Capital and Faith-Based Organizations. *Healthcare Journal*, 48, 895-910.
- Leana, C. & van Buren, H. (1999). Organizational Social Capital and Employment Practices. *Academy of Management Review*, 24, 538-555.
- Schneider, J.A. (2006). *Social capital and welfare reform: organizations, congregations, and communities*. New York, NY: Columbia University Press.
- Wacquant, L. (1998). Negative Social Capital: State Breakdown and Social Destitution in America's Urban Core. *Netherlands Journal of Housing and the Built Environment*, 13, 25-40.

Framing Responsible Innovation in Synthetic Biology: the need for a critical discourse analysis approach

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The terms ‘responsible innovation’, ‘responsible research and innovation’ and ‘responsible development’ are interpretively-flexible umbrella terms (Rip and Voss, 2014) that evoke notions of responsibility (Richardson, 1999; Pellizzoni, 2004), science and innovation (Grinbaum and Groves, 2013). Various framings of responsible innovation and responsible development have been proposed over the last few years, some specific to synthetic biology (e.g. PCSBI, 2010; UK Synthetic Biology Roadmap, 2012) and others more general to technovisionary science, emerging technologies, and innovation (e.g. von Schomberg, 2011; Owen et al, 2014; Stilgoe et al, 2013). Simultaneously, the last few years has seen the rise of ‘responsible research and innovation (or RRI)’ as a policy driver in Europe, where it has become a cross cutting theme for Horizon 2020, the European Commission’s key research and innovation funding instrument (Owen et al, 2012; Owen, ERIAB report 2014) and where it is increasingly being adopted by funding institutions in member states (Owen, 2014). The RRI turn has shifted emphasis from risk to innovation governance, and from a pre-occupation with impacts to those of science and innovations’ purposes (agendas) and processes, seeking to empower social agency in technological choices (Stirling, 2008), making these more participatory, inclusive and publicly accountable (Jasanoff, 2003), while enlarging the role responsibilities of researchers and research funders (Mitcham, 2003; Douglas, 2003). RI / RRI has emerged from historical foundations well known in science and technology studies, from technology assessment in its various forms (e.g. Schott and Rip, 1996; Guston and Sarewitz, 2002) to ‘upstream public engagement’, values sensitive design and socio-technical integration, placing a premium on future-oriented dimensions of responsibility that include care (sometimes translated as a desire to align innovation to societal values) and responsiveness (to different perspectives and emerging information). The desire for social alignment has been transcribed by von Schomberg (2011) into a quest for the ‘right impacts’ of science and innovation, which in turn question extant models of representative and deliberative democracy and the role of various modes of participation in agenda setting (e.g. Jones, 2008; Voices for Innovation). Most recently questions have also been raised concerning RRI’s potential expansionism as a Northern political artefact into the so-called developing world, where assumptions concerning science – innovation and society relationships cannot be made, where cultural representations of genetic modification have been highly resonant and where other formulations of innovation and responsibility abound (Pansera and Owen, in press), for example around ideas of ‘inclusive’, ‘grassroots’ or ‘empathetic’ innovation (e.g. Gupta, 2012), set within broader contested discourses of post colonial development and post development thinking. In total RI / RRI presents as a set of emerging, pluralistic, sometimes hybridising narratives that, in a Foucauldian sense, have far from stabilized and which are the subject of debate and contestation. Our key research question is how are discourses of responsible (research and) innovation emerging and what dynamics (Fisher and Rip, 2013) are influencing these discourses?

A critical discourse analysis approach

We are beginning to take a critical discourse analysis (CDA) approach to understand, and critically reflect on, emerging discourses of RI. In doing so we adopt a CDA framework based on an integration of the ‘ten steps for discourse analysis’ proposed by Hajer (2006) and a combined tool of the ‘building tasks of language’ and ‘context’ by Gee (2011). This initial analysis represents two steps of Hajer’s approach: desk research and document analysis (UK Synthetic Biology Roadmap, 2012 and PCSBI report, 2010).

Originating from linguistics, DA allows analysis of both written and oral forms of language-in-use and reveals power relations of different parties, uncovering the significance, practices (activities), identities, relationships, dynamics and politics (including the distribution of social goods) (Gee, 2011), which a certain piece of discourse is used. There has to date been limited reflection on the ‘politics of RI’ (Owen et al, 2012; van Oudheusden 2014) and we aim to critically evaluate this using a CDA approach.

Responsible Innovation in synthetic biology: emerging themes

We are yet to conduct a thorough DA of RI in synthetic biology, but an initial analysis reveals several themes that emerge as these are discourses related to RI.

Social Alignment: as mentioned above, this theme has been transcribed into a quest for the ‘right’ impacts of research and innovation based on the normative anchor points in the Treaty on the EU, which, to name but a few, include social justice, equality, and sustainable development (von Schomberg, 2011). In the context of synthetic biology, the PCSBI report points out two similar principles: (1) public beneficence and (2) justice and fairness (PCSBI, 2010).

Responsiveness: this theme is perceived as setting the direction, affecting the trajectory and pace of innovation through effective mechanisms of governance (Owen et al. 2013). In this regard, the UK Synthetic Biology Roadmap (2012) calls for an effective risk regulatory framework, whereas the PCSBI report (2010) requests for responsible stewardship.

Collective Responsibility: modern innovation is often a collective action, so there is a collective responsibility for the right impacts and negative consequences of innovation (von Schomberg, 2013). It also refers to the political considerations of a group’s conduct regardless of the level of personal involvement of each individual (Grinbaum and Groves, 2013). In the UK Synthetic Biology Roadmap (2012), responsibility is taken as a culture that needs to be built. While the PCSBI report (2010) looks responsibility as an individual and institutional notion which, to some extent, bears a collective sense.

Anticipation: one perception of this theme is about describing and analysing intended and unintended impacts (Owen et al., 2013), by means of technology assessment and foresight (von Schomberg, 2013), which build up a prior capacity to time, position or order (Guston, 2013). Both documents have covered anticipation in different ways which are yet to be discussed.

The above themes form an initial list of potential research topics to be explored in greater depth and detail to understand how RI is framed in the context of synthetic biology. A CDA approach would serve such a purpose well as it provides insights of the meaning of language-in-use and its implications in the societal aspects.

Synthetic Biology as Post-Normal Science: Lessons from Empirical Social Science

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NBIC technologies as postnormal science

Scientific debates in modern societies – including the U.S. – often blur the lines between the science that is being debated and the political, moral and legal implications that come with its societal applications. As a result, the answers that science can provide do not match the questions that different publics want or need answers to.

Science can tell citizens how vaccines work, what their likely side effects are, and what the risks are for individuals and society if a certain percentage of the population ends up not getting vaccinated for various reasons. The vaccination issue, however, also raises a series of ethical and political questions: Should vaccinations be mandated? If yes, should there be exceptions based on religious concerns? What kinds of trade-offs should societies allow between a person's individual choice to not get vaccinated and the increased risks for all members of society if fewer people get vaccinated? And how can we harmonize regulatory frameworks across different political systems with different underlying value systems in order to minimize the likelihood of global epidemics? None of these questions have scientific answers, i.e., answers that are based on scientific facts or even accurate judgments of risks and benefits. Instead, the answers to these questions are moral, philosophical and political in nature.

These challenges are exacerbated by the nature of modern science. Science is in the midst of a rapid emergence of interdisciplinary fields that some have called a Nano-Bio-Info-Cogno (NBIC) revolution, i.e., a convergence (Roco & Bainbridge, 2003) of new interdisciplinary fields at various interfaces of nanotechnology, biotechnology, cognitive science and information technology. NBIC technologies exacerbate a host of existing challenges when it comes to communicating about science with lay audiences. As discussed elsewhere (Scheufele, 2013), these include (a) the scientific complexity of emerging interdisciplinary fields of research, such as synthetic biology or neurobiology, (b) the pace of innovation in some of those fields, and (c) the nature of public (policy) debates that accompany different applications of NBIC technologies (Scheufele, 2013).

Public interfaces for synthetic biology

As a result, public communication about modern science is inherently political, if we like it or not. Many research areas, such as the ones that developed out of the NBIC convergence discussed earlier (e.g. tissue engineering, nanomedicine, and synthetic biology), raise significant ethical, legal and social questions with answers that are both scientific and political in nature. How can we ensure the privacy and safety of human genetic information and weigh commercial interests against the rights of individuals? Is it possible to ensure equal access to medical treatments or applications developed from this research, based on race, ethnicity, and socioeconomic factors? And how can society come to an agreement about the right balance between the scientific importance of research on synthetic biology, for instance, and the ethical, moral and religious concerns that might arise from that research among different public stakeholders?

The tension between what science can do and what might be ethically, legally or socially acceptable, has become particularly visible for NBIC technologies. When J. Craig Venter and his team transplanted a chemically synthesized genome into a bacterial cell in 2010 (Gibson et al., 2010), the potential of their findings for creating “synthetic life” was immediately apparent. In fact, Venter himself referred to the team’s work as an “important step ... both scientifically and philosophically” and described their work as “the first incidence in science where the extensive bioethical review took place before the experiments were done. It’s part of an ongoing process that we’ve been driving, trying to make sure that the science proceeds in an ethical fashion, that we’re being thoughtful about what we do and looking forward to the implications to the future.” (Wren, 2010).

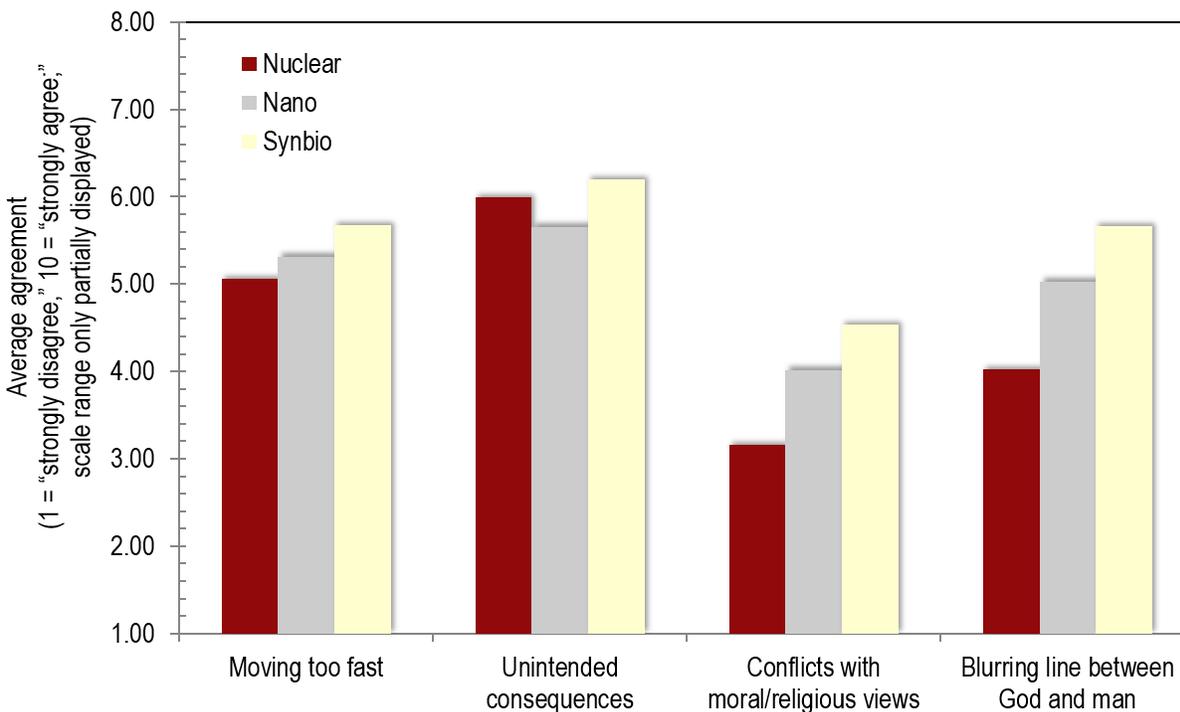
Mapping the landscape

Public opinion data nicely illustrate many of the complexities. Nationally-representative surveys conducted by the Public Opinion and Values Research Team of CNS-ASU show that non-expert audiences have a murky grasp of synthetic biology at best, with a vast majority of respondents indicating little or no familiarity with the technology. Their understanding of the policy landscape is equally tenuous. When asked if they thought that it was true or false that the Obama administration had recently banned all research on synthetic biology, only about one third of respondents were able to identify that statement as false.

A lack of scientific or policy knowledge does not mean, of course, that non-expert audiences will not form judgments about NBIC technologies when they encounter them as consumers, voters or citizens. In fact, research has long documented how mental shortcuts and heuristics become important replacements for information about science (Scheufele, 2006). For post-normal science, i.e., technologies that are characterized by high levels of uncertainty and decision stakes (Funtowicz & Ravetz, 1992), heuristics, such as elite framing or personal value systems, play a particularly important role. Findings about (religious) value systems among different countries and their connection to public attitudes about the use and moral acceptability of nanotechnology, for instance, nicely highlight this phenomenon (Scheufele, Corley, Shih, Dalrymple, & Ho, 2009).

Survey results also suggest that the political, moral and legal aspects will float to the surface even more so for synthetic biology than they did for nanotechnology and other scientific issues. Figure 1, for example, shows public attitudes compared across nuclear energy, nanotechnology and synthetic biology, based on split-ballot national survey designs. Results suggest that as synthetic biology and its various applications emerge on the public agenda, concerns about encountering unintended consequences and overstepping moral and religious boundaries will likely move to the forefront of public (policy) debates. In fact, data from the same surveys also show that non-expert publics are already significantly divided in their views on potential risks of synthetic biology, based on partisanship and levels of religiosity.

Figure 1: Agreement with various concerns about nuclear energy, nanotechnology and synthetic biology



Sustainable social/science collaborations for emerging NBIC technologies

For synthetic biology and related NBIC technologies, we will see highly polarized public debates emerge in real time as new breakthroughs are being announced or new applications are being developed. Should synthetic biologists create life in the lab, for example, as J. Craig Venter infamously claimed he had done in 2010? Is it a good idea to create materials that do not exist in nature? And what are the moral considerations surrounding de-extinction, i.e., the process of restoring extinct species of plants or animals by using genetic engineering or related techniques? None of these questions have exclusively scientific answers, but will require careful societal debates about the amalgam of scientific, political, moral, ethical and religious questions they raise.

Unfortunately, the normative desire to build better public-science interfaces for these debates has not led to the degree of intellectual cross-fertilization between the bench and social sciences that is necessary to get us closer to that goal. This is a direct outcome of two related factors: First, many STEM scientists are not aware of the growing body of work in the social sciences that provides empirical insights into the mechanisms and outcomes of various communication efforts. Second, social scientists often continue to examine science controversies as outside observers, i.e., in a retrospective and narrow disciplinary fashion. Neither phenomenon is particularly surprising, given the inherently disciplinary focus of academia. But they partly explain why there have not been widespread systematic efforts – either from within the social sciences or the bench sciences – to develop on-going working relationships among social and natural scientists to jointly explore the interplay between the scientific promise behind emerging technologies and the social debates surrounding them in democratic societies.

These ongoing collaborations are crucially important in a time where highly diverse sets of NBIC technologies constantly produce new challenges with respect to the types of technologies we are dealing with, the ethical, legal and social concerns that surround them, and the political and communication environments they are embedded in. As a result, academic institutions, funding agencies, and the federal government will have to prioritize institutional capacity building and infrastructure at the science-society interface, including (a) sustained social science efforts surrounding emerging technologies and (b) formalized interfaces between social and natural sciences.

Building these sustainable collaborative infrastructures is not a luxury. It is a necessity for informing public debates, enabling better and more responsible tech transfer, and helping to maintain a robust R&D enterprise in the U.S. (Scheufele, 2014).

References:

- Funtowicz, S. O., & Ravetz, J. R. (1992). Three types of risk assessment and the emergence of post-normal science. In S. Krimsky & D. Golding (Eds.), *Social theories of risk* (pp. 251-274). Westport, CT: Praeger.
- Gibson, D. G., Glass, J. I., Lartigue, C., Noskov, V. N., Chuang, R.-Y., Algire, M. A., . . . Venter, J. C. (2010). Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome. *Science*, 329(5987), 52-56. doi: 10.1126/science.1190719
- Roco, M. C., & Bainbridge, W. S. (2003). *Converging technologies for improving human performance*. Dordrecht, Netherlands: Kluwer Academic Publishers.
- Scheufele, D. A. (2006). Messages and heuristics: How audiences form attitudes about emerging technologies. In J. Turney (Ed.), *Engaging science: Thoughts, deeds, analysis and action* (pp. 20-25). London: The Wellcome Trust.
- Scheufele, D. A. (2013). Communicating science in social settings. *Proceedings of the National Academy of Sciences*, 110(Supplement 3), 14040-14047. doi: 10.1073/pnas.1213275110
- Scheufele, D. A. (2014). Science communication as political communication. *Proceedings of the National Academy of Sciences*, 111(Supplement 4), 13585- 13592. doi: 10.1073/pnas.1317516111
- Scheufele, D. A., Corley, E. A., Shih, T.-j., Dalrymple, K. E., & Ho, S. S. (2009). Religious beliefs and public attitudes to nanotechnology in Europe and the US. *Nature Nanotechnology*, 4(2), 91 - 94. doi: 10.1038/NNANO.2008.361
- Wren, K. (2010). Science: Researchers are the first to “boot up” a bacterial cell with a synthetic genome. *AAAS News*. Retrieved April 20, 2014, from <http://www.aaas.org/news/science-researchers-are-first-%E2%80%9Cbootup%E2%80%9D-bacterial-cell-synthetic-genome>

**Constructing a “futurology from below”:
A civil society contribution towards a research agenda**
Jim Thomas, Programme Director, ETC Group

Almost fifty years ago, British social historian EP Thompson led a revolution in the study of history. He memorably termed it “history from below”. Addressing the social tumult that accompanied the first industrial revolution in England, he exhorted his academic colleagues to turn away from the standard history of great men and big events and to instead assess the lived impacts of social and economic forces on the lives of ordinary folk (craftworkers, agricultural labourers, etc).

Today, the study of new technologies—particularly Syn Bio—could benefit from something very similar. A parallel “futurology from below”—a people’s assessment of new technologies—could be beneficial as we hurtle into the next industrial revolution. The standard story “from above” of the technological and economic transformation around us is well rehearsed in popular science magazines and TED-style edutainment gatherings. It foregrounds stunning technical abilities, great men (Craig Venter!, George Church!) heroic good intentions (biofuels!, anti-malarial drugs! de-extinction!) and a dazzling new industry promising to deliver prosperity through progress. Embroidering that standard story is arguably the intellectually lazy option for public scholars.

Meanwhile Civil Society and some social scientists have been trying to tell a different story “from below”. Instead of accepting the claims of a northern scientist synthesizing artemisinin, this approach asks for the voices of existing artemisia growers in East Africa. Instead of accepting the claims of biofuel companies, futurology from below prefers the experience of Brazilian landless peasants. Since both publicly-funded research and civil society properly take the public interest as their starting point, there should be (and indeed there is) fruitful collaboration between them. Elements of such a collaboration could be:

Case Studies, deliberative processes and fieldwork “from below”: The first commercial products of Synthetic Biology are no longer imaginary. They are already creating real-world social, cultural, political and economic changes along commodity supply chains. It is not enough to speculate or pronounce from afar about whether or not the introduction of Syn Bio vanillin will impact livelihoods of Madagascan vanilla farmers or Syn Bio opiates impact regional security in south asia. Sustained studies are urgently needed, where researchers travel to affected communities, collaborate with in-country researchers, engage communities in conversation and critically analyze trends.

Challenging “solutionism” and technofix thinking: Evgeny Morozov defines solutionism as an unhealthy preoccupation with sexy, monumental and narrow-minded solutions ... to problems that are extremely complex, fluid and contentious... Solutionism presumes rather than investigates the problem it is trying to solve, reaching for the answer before the questions have been fully asked.

The field of Syn Bio is awash with solutionism- speculative technological fixes are casually cast as saviour “solutions” to public health, climate change and biodiversity collapse. Through the lens of simplistic technofixes these complex issues are reduced to simple “puzzles to be solved”. Public research should seek to test both very particular claims—“will switching to algae oil really save forests?”—as well as finding ways to challenge and articulate the bigger problems with solutionism itself. According to Benjamin Bratton, that means engaging complexity: “If we really want transformation, we have to slog through the hard stuff (history, economics, philosophy, art, ambiguities, contradictions).”

Addressing the revolution, not the apps: While there is real value in digging into the claims and societal impacts associated with specific applications, there is also a danger that case by case technology assessments alone obscure the cumulative and platform-level impacts of synthetic biology as a whole, especially over medium- to long-term time scales. Larger changes in the economy, cultural and cognitive changes or new social and economic vulnerabilities may only be detectable when synthetic biology is considered as a platform. Even more importantly, the development of synthetic biology appears to be embedded in the emergence of a new flexible manufacturing platform which encompasses other mechanization tools such as robotics, 3D printing, ubiquitous sensors, big data and drones. It may be tremendously valuable for a number of groups to collaborate on a big piece of work that undertakes a wide ranging assessment of the “new revolution in manufacturing” (spanning from Syn Bio and big data to sensor networks, drones, 3D printing and flexible robotics). Such a study could assess how these technologies synergistically transform supply chains, livelihoods, human rights, health and the environment. Civil Society could contribute fully to such an assessment.

Getting out of “bed”: In the last few years government funding arrangements for work to assess societal impact of new technologies may have fostered an unhealthy and unequal dependence between those developing a technology and those meant be critically assessing it. In genomics ELSI (Ethical Legal and Societal Implications) studies were folded into a far larger funding package for applied work that was already committed to moving ahead the field. In the field of assessing nanotechnology, social scientists became “embedded” in nanotechnology centers. While there are advantages, this nonetheless could have a tendency to cast social scientists and ethicists as potential PR advisors. They may be expected to help shape Syn Bio's social acceptability in lieu of developing deeper platform-level critiques. The extent to which power relationships within such institutions muzzle social scientists is unclear, but at least one high profile breakdown of the relationship between an embedded social scientist/anthropologist and SynBERC should raise warning flags. Having synthetic biologists (some with commercial interests) as day-to-day colleagues may also informally serve to soften critiques. Sending researchers to assess Syn Bio while embedded in ecology, environmental management or developmental biology faculties could lead to far more interesting outcomes.

Partnering with Social Movements and Civil Society: Civil society groups have already had useful and constructive partnerships (both formal and informal) with social scientists, geographers, anthropologists, artists and ethicists tracking the field. ETC Group is part of two formal collaborations with academic partners concerned with societal impacts of Synthetic Biology: the SYNENERGENE project housed at Karlsruhe Institute of Technology and funded by the European Commission, and the Bioeconomies Media Project housed at The University of Victoria, British Columbia and funded by Canada's Social Sciences and Humanities Research Council. In both cases, we play a formal role in assisting knowledge mobilization efforts as well as convening discussions between civil society, policymakers and the public that inform assessment of the field. We have also had informal collaborations (such as developing a patent landscape study and mentoring doctoral and masters students as interns). Civil society groups and social movements are becoming increasingly organized and reflective on the topic of Synthetic Biology and also are repositories of knowledge and novel perspectives. We connect with some of the most impacted communities (e.g. vanilla communities, stevia producers, coconut growers, natural products developers) as well as international policy communities and are working with them to understand real world impacts of synthetic biology “on the ground” as well as in the sphere of governance.

Genetically modified medicine; research questions related to new possibilities for treatment and prevention

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Until now, there has been an interesting discrepancy in Europe between the public distrust of biotechnology used for the genetic modification of plants and crops which are used for food of human beings and animals, as opposed to the use for the production of genetically modified medicine. Genetically modified medicine may take the form of genetic modification, but also of GM pharmaceuticals such as insulin. This discrepancy may elicit surprise, since the use of GM crops for food is used for the nourishment of human bodies, and GM pharmaceuticals are also inserted into human bodies in the form of pills or vaccines. Both types of GM products could therefore raise similar concerns with respect to health, safety and (future) wellbeing of human beings.

Since the 1970s, recombinant DNA (rDNA) technology arose and became known as the technology to perform genetic modification (Mora & Torres, 2010). The debate about the desirability of GMOs was first initiated by scientists who expressed concerns and identified possible risks with regard to GMOs. But some GMOs attracted also a lot of public debate: such as agricultural GMOs used to produce food for human beings or animals.

In Europe, the public opinion with regard to GMOs in the agricultural sector remain mainly sceptical and/or ambivalent (Legge et al. 2010; Gaskell et al., 2010; Devos et al., 2007). While many different issues are raised - such as concerns about the usefulness of GMOs, socioeconomic impacts, (loss of) freedom of choice, unnaturalness of genetic modification, inequalities between industrialized and poor countries, fallibility of experts, and sustainability of agriculture- the most important topic of public concern remains the safety of GMO food, and the consequences it may have for individual and public health. (Schuttelaer et al 2006; Legge et al 2010; Devos et al., 2007; Stol & Nelis, 2010). Most prominent among the risks mentioned for human beings are that GM food could disrupt or silence some existing genes, or modify their expression, or it could alter patterns of metabolites. It supposedly could lead to the development of new allergies, harmful toxins that the body cannot handle, or antibiotic resistance. (Legge et al 2010) Based on such considerations, consumers indicated in 2010 that safety was their main reason to object to GM food, even though the European Union (EU) declared the GM products safe for human use (Stol & Nelis, 2010).

It is interesting that genetic modification in the agricultural sector receives so much public attention, while the application of genetic modification in medicine is hardly objected to at all. In fact, the public has even expressed positive expectations with regard to the development of GM medicine. (Stol & Nelis, 2010) This is especially surprising because specific health-related concerns are raised with respect to GM food -including concerns about future resistance against antibiotics- which are not raised with respect to medicine. How can this discrepancy be explained?

It may be hypothesized, of course, that the public may be more appreciative of GM medicine as opposed to GM food because its risk-benefit balance differs when treatment of a diseased body is

concerned, while food is in principle consumed by healthy bodies. But GM medicine does not only solve a health problem. There are also new GM vaccines being produced (for example against influenza), which are supposed to protect the public against outbreaks of infectious disease. This raises the question whether present public acceptance of GM medicine will persist in the future, and also whether it vaccines will be accepted as well, which are in principle used on healthy bodies to prevent disease-outbreaks at a population level.

Simone van der Burg

Empirical questions

- How can this discrepancy between the hot debate about GM food, and the lack of debate about GM medicine be explained?
- Are members of the public aware of the GM nature of some medicines?
- What kind of expectations do members of the public have with regard to GM medicine and to GM food?
- What hard and soft impacts play a role in the public's considerations about (the future of) GM food and GM medicine?
- What are the different values and norms that play a role in the public's considerations about GM medicine as opposed to GM food?
- What is the role of 'trust' in people's expectations?
- What do people consider risks and benefits related to GM food and medicine? (And how do they perform the risk-benefit analysis?)
- How does the public assessment of GM medicine for treatment purposes compare to the public assessment of GM vaccines used for prevention of infectious diseases?

Ethical questions

- How should risks be communicated to patients/members of the public to whom GM medicine/vaccines are proposed? (How much information is sufficient/ justified to make an informed choice possible)
- How can we strike a balance between protection of autonomy (informed choice) and protection of the health of the public? (Is 'nudging' allowed when GM medicine/vaccines are proposed?)
- What is the responsibility of individual members of the public, of professionals, of health care institutes (such as hospitals), insurance companies regarding GM medicine/vaccines?
- What is the responsibility of researchers and pharmaceutical companies with regard to the public acceptance of GM medicine/vaccines?
- Should there be a division of roles with regard to care for safety, health, public trust and autonomy?

Policy questions

- Are there reasons to expect more controversy in the future regarding GM medicine or GM vaccines for prevention?
- What consequences can this have for the future public acceptance of medicine/vaccines, and for the protection of the health of the public? (Can it lead, for example, to lesser acceptance of vaccines, inefficient herd immunity, outbreaks of infectious diseases)

- How can policy-makers prepare for this future?
- Should the public have a role in decision making about future policy regarding disease management with GM medicine/vaccines? (If yes, what role?)

References

- Devos, Y., Maesele, P., Reheul, D., Speybroeck, L. & Waele, D. (2007). Ethics in the Societal Debate on Genetically Modified Organisms: A (Re)Quest for Sense and Sensibility. *Journal of Agricultural and Environmental Ethics*, 21(1), 29–61.
- Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Castro, P., Esmer, Y., Fischler, C., Jackson, J., Kronberger, N., Hampel, J., Mejlgaard, N., Quintanilha, A., Rammer, A., Revuelta, G., Stoneman, P., Torgersen, H. & Wagner, W. (2010). *Eurobarometer 73.1 - Europeans and Biotechnology in 2010: winds of change?* Luxembourg. Retrieved from http://ec.europa.eu/research/science-society/document_library/pdf_06/europeans-biotechnology-in-2010_en.pdf.
- Legge Jr, J. S., & Durant, R. F. (2010). Public opinion, risk assessment, and biotechnology: lessons from attitudes toward genetically modified foods in the European Union. *Review of Policy Research*, 27(1), 59-76.
- Schuttelaar & Partners, *Moet alles kunnen wat technisch mogelijk is? Een inventarisatie van standpunten en argumenten over genetische modificatie van religieuze, levensbeschouwelijke en lifestyle groepen*, Den Haag, 2006.
- Stol, Y. & Nelis, A. (2010). *De maatschappelijke relevantie van biotechnologische trends*. Centre for Society and Genomics, report nr. 3.

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Learning from interdisciplinarity and making it public

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This paper is an attempt to open up discussion about how science communication in public media forums can take seriously the difficult and productive lessons that are being learned in the social sciences of synthetic biology, and use that knowledge towards innovative and experimental media outcomes. It draws on my experience as a public radio producer and host who tells stories about science for a living to general audiences, and as a scholar tracing the communication of the societal dimensions of synthetic biology. My attempt to make these worlds collide in constructive ways inspires my line of thought.

A common narrative has emerged in policy and media concerning synthetic biology that views advances in the biosciences as “de-skilling” science, making biology easier to engineer, of greater access to non-trained professionals, and therefore susceptible to potential “dual use.”¹ At a time when the (at least ideological if not always practical) “de-skilling” of biological engineering is being brought to bear in synthetic biology, individuals are claiming more participation and openness in communities and systems that are changing the natural and life sciences. This ethos can be traced in synthetic biology through the discourses of a cultural phenomenon like DIYbio,² the increasing participation of artist and other non-scientist researchers at events like iGEM,³ and the growth of bioart activities in the field, to name a few. This increasingly polyphonous “ecology of practices”⁴ in synthetic biology intersects with the imaginaries of *what the field means* that bubble over into public consciousness through their representational circulation on blogs, in galleries, on the airwaves, and more. In effect, it is not only science communication that recognizes itself as such that is crafting and telling public stories of synthetic biology to diverse non-expert audiences.

At the same time, internal to expert meetings, synthetic biology’s proactive ‘post-ELSI’ attempts towards interdisciplinary collaboration as a modern science and engineering field has underlined the importance of having ethicists, anthropologists and other social researchers participate in its unfolding.⁵ Yet these attempts don’t always function as planned. Anthropologists have given concerned accounts of their own experiences embedded in a synthetic biology research centre, where they felt that their perspectives were met with dismissal, disinterest, and sometimes hostility.⁶ A social scientist who works with synthetic biologists has said that she has at times felt that what she has to offer has been snubbed by the scientific community, and that non-scientists attached to the field should embrace an “ethics of discomfort.”⁷ At the University of Copenhagen, philosophers and communication scholars embedded in an interdisciplinary synthetic biology project have said that their experiences echo what Fitzgerald has said: that they can be “messy, emotional, and full of unexpected contingencies.”⁸ A manifesto was even written by a group of social scientists actively working in synthetic biology that urges new experimental forms of collaboration with synthetic biologists so that more fruitful outcomes might be discovered for all parties involved.⁹ What, then, is holding these experts back from seeing eye-to-eye? How can we take the communication forum or mode of engagement seriously to try and improve communication and make all parties feel seen, heard, and to the best of everyone’s ability, understood? I am interested in looking at communication experiments that can circulate in the broader public but may influence how experts approach their next interdisciplinary interactions, through forms that non-experts can get involved with and be witness to, i.e. popular media.

In my current research I am developing and analyzing new media for experimental forms of science communication that aim to work with and through people’s polarized perceptions, nourish critical thinking, and encourage empathy across different individuals who may have different or even contradictory goals in working with synthetic biology. This research asks how alternative forms of science communication can bring synthetic biology and various critical discourses concerning it into a more productive relationship than is sometimes experienced through uncomfortable interdisciplinary collaborations by learning from how they go “wrong.” This line of questioning is in no way meant to lead

to a path that can “smooth things over” or homogenize discussion into some form of consensus. It is meant to enlighten and entertain and perhaps inject some surprise into how we discuss and deal with our biotechnological futures in a “post-genomic era” through public media formats. When compared to discourses on climate change, vaccinations, or other topics of interest to risk perception studies, the public discussion on synthetic biology is still young and I argue well positioned to benefit from experimental and innovative approaches to communication that raise it in the public imagination, and can then circulate back into spaces of expert work.

Both Stengers and Latour suggest that a potentially useful way to explore alternative functionalities of being and thinking in Modernist science start with slowing down the speed at which we think.¹⁰ This is done in order to alter our perspective on issues of progress by shifting the automatic associations they carry which bind speed to concepts like efficiency, innovation and growth. It functions as a thinking tool in the public discourse on synthetic biology, allowing (a perhaps esoteric and at least metaphorical) moment of pause, reflection, and careful choosing of how to construct one’s own concerns and questions towards the science itself. By slowing down the claims in public-facing science stories and allowing for personal inquiries and feelings to shape their surface through experimental productions, can we foster productively sensitive (although always subject to failure) dynamics between communicators and publics? Can this process be helped by lessons that are being learned in the social sciences about what it means to collaborate and communicate *well* across the disciplines?¹¹ And could it then circulate back into spaces of interdisciplinary labour as a communication tool? How can creative communicators of science encourage a *slowing down of thinking in public* when crafting stories of synthetic biology for people to ponder? I would like to discuss the possibilities brought forth here with the participants in Arizona.

As Sarah Davies has written, when science communication scholarship focuses too much on the content and discursive elements of public engagement work it misses a rich opportunity to dive into the affective ability of that content to make people literally *feel* differently about science.¹² Science communication projects ranging from lectures to workshops, gallery exhibits, films, radio documentaries and more play on our sensory dimensions. However as Davies has shown, science communication research has sorely overlooked the affective qualities of these sensory elements to the craft.

Professional scientists and their publics are used to interacting in formalized engagement events and through normalized media opportunities (the public radio show, a television appearance, etc), but what room is there here to allow the subjects’ feelings towards science to become a bit more personal? Would the affects of communication change if interactions were not face to face in a room full of colleagues, or constrained by the awareness of a camera crew? What if individuals could discuss what they know and how they feel into a tape recorder in the privacy of their own home, with no one to witness, for example? And how can these personalized interactions be made public once again? What affective power could such an engagement hold? I will present some experimental methods from my own broadcasting work that inch towards answering these questions.

Perhaps by focusing on how science engagement can make one *feel*, creative communicators can find a route towards Latour and Stengers’ recommendation of *slowing down* how we think about technoscientific forces like synthetic biology in the first place. By focusing sincerely on the affective qualities of the communication experience, we might be able to embody sites and experiences that challenge our biased responses, and consider multiple potentials of how to feel about synthetic biology rather than how our professional or cultural positions automatically guide us to.¹³ ; ¹⁴.

References

- ¹ Jefferson, Catherine, Lentzos, Filippa, Marris, Claire (2014) *Synthetic Biology and Biosecurity: How scared should we be?* Kings College, London
- ² DIYbiologists are individuals interested in the non-institutional practice of biotech. They were founded as a cultural brand in 2008. [Diybio.org](http://diybio.org)
- ³ http://2014.igem.org/Tracks/Art_Design
- ⁴ Stengers, Isabelle. 2005. Introductory notes on an ecology of practices. *Cultural Studies Review*. 11 (1): 183-196.
- ⁵ Rabinow, Paul, and Gaymon Bennett. *Designing Human Practices: An Experiment with Synthetic Biology*. University of Chicago Press, 2012.
- ⁶ Ibid.
- ⁷ Calvert, Jane. "Collaboration as a Research Method? Navigating Social Scientific Involvement in Synthetic Biology." In *Early Engagement and New Technologies: Opening up the Laboratory*, edited by Neelke Doorn, Daan Schuurbijs, Ibo van de Poel, and Michael E. Gorman, 16:175–94. Dordrecht: Springer Netherlands, 2013. http://link.springer.com/10.1007/978-94-007-7844-3_9.
- ⁸ Fitzgerald, Des, and Felicity Callard. "Social Science and Neuroscience beyond Interdisciplinarity: Experimental Entanglements." *Theory, Culture & Society*, June 30, 2014, 0263276414537319. doi:10.1177/0263276414537319.
- ⁹ "Towards a Manifesto for Experimental Collaborations between Social and Natural Scientists." *Experimental Collaborations*. Accessed October 5, 2014. <http://experimentalcollaborations.wordpress.com/2012/07/03/towards-a-manifesto-for-experimental-collaborations-between-social-and-natural-scientists/>.
- ¹⁰ Stengers, Isabelle. 2005. The cosmopolitical proposal, in: B. Latour and P. Weibel (Eds) *Making Things Public: Atmospheres of Democracy*, pp. 994–1003. MIT Press: Cambridge.
- ¹¹ Balmer, Andrew S., and Kate J. Bulpin. "Left to Their Own Devices: Post-ELSI, Ethical Equipment and the International Genetically Engineered Machine (iGEM) Competition." *BioSocieties* 8, no. 3 (September 2013): 311–35. doi:10.1057/biosoc.2013.13.
- ¹² Davies, Sarah Knowing and loving: Public engagement beyond discourse. *Science and Technology Studies*. Forthcoming.
- ¹³ Kahan, Dan M., Donald Braman, and Gregory N. Mandel. *Risk and Culture: Is Synthetic Biology Different?*. SSRN Scholarly Paper. Rochester, NY: Social Science Research Network, February 20, 2009. <http://papers.ssrn.com/abstract=1347165>.
- ¹⁴ Meyer A, Cserer A, Schmidt M (2013) *Frankenstein 2.0: Identifying and characterising synthetic biology engineers in science fiction films*. *Life Sciences Society and Policy* 9:9. doi: 10.1186/2195-7819-9-9

The Moral Economies of Biotechnical Facilities: A Working Paper on Venues and Responsible Innovation

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A defining feature of the early synthetic biology manifestos, and the diffuse imaginaries that grew up around them, was the proposition that the near future of biotechnology, and the hoped-for instrumental goods connected to biotechnology, required the invention of a new style of facility for research and production. The proposition was part of the encompassing diagnostic claim that the eventual success of synthetic biology would turn less on growth in scientific knowledge, and more on the ability and willingness of biologists to comport themselves like real engineers. The *imago* of the real engineer in these manifestos is, of course, the computer engineer. The computer engineer, in turn, is portrayed alternately as the student formed by the ethos of MIT's AI lab, capable of designing programs and circuits on the logic of abstraction hierarchies; the Silicon Valley hardware designer, capable of decoupling design and construction through regimes of standardization; and the American high-tech entrepreneur whose freedom-of-operation allows for a style of life and practice characterized, simultaneously, by increases in technical capacity, wealth, social responsibility, and techno-political secession.

At the heart of all of this is the idea of facility, taken in the double sense of (i) an organization designed to provide a service or fulfill a need; and (ii) an increase in capabilities leading to the ability to do something in an effortless manner. If (in the first place), the near future of synthetic biology will only be realized when biologists comport themselves like computer engineers, then (in the second place) it is vital to create the facilities needed for that comportment to be actualized. To put it more plainly and specifically, the early manifestos proposed that biologists will not be able to comport themselves like computer engineers unless and until: (a) they have access to fabrication facilities, which will allow them to decouple the work of designing and building novel living systems; (b) they have standardized practices and materials by way of which they can organize work across time and space, allowing them to share and build on one another's work through black-boxing, abstraction, and inter-articulated composition; and (c) they have mature CAD tools that will allow them to shift from the use of databases and registries to suites of design tools for—as one player puts it—“programming matter across domains and scales.”

Ten years on from these early manifestos, it seems worth returning to the question of what facilities have actually been put into play as part of the maturing of synthetic biology—or at least the maturing of the careers and projects of the biologists and engineers who (sometimes) refer to their work as synthetic biology. The goal would not be to test the extent to which the early manifestos have provided a road-map, nor would it be to assess whether or not synthetic biologists have been able to make good on the analogies to computer engineering and the high-tech industry. The goal, rather, is to investigate and assess how it is that synthetic biologists have designed their work spaces—material, digital, and conceptual—as part of the work of increasing biotechnical capabilities. At stake in this investigation and assessment is the question of how it is that the design of new facilities for advanced bioengineering have inflected (or not) the

economies of life, power, and ethics within which synthetic biology has been imagined, talked about, and animated; how they have contributed to shifting regimes of governance (including self-governance); and the extent to which these inflections can be said to have increased capacities without also intensifying unjust power relations.

The Need for Bioeconomy Data and Metrics

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In 2012, I estimate that U.S. domestic revenues from genetically modified systems were greater than \$353 billion, or the equivalent of ~2.2% of GDP, and grew at an overall annual rate of 10%¹. This is intended to be a conservative estimate, and the actual revenues could easily be 10% larger. Moreover, biotechnology now contributes somewhere between 5% and 8% of annual GDP growth in the U.S. (R. Carlson, Unpublished). While these figures are impressive, the associated uncertainty is unacceptably large and undermines critically important assessments of investment, employment, and physical and economic security. Improved data collection, classification, and analysis are required to understand the scope and impact of biotechnology in the U.S. and around the globe. The NSF should support efforts to better quantify the U.S. bioeconomy.

Biotechnology continues to emerge as a significant contributor to the U.S. economy. Discussions of funding and policy, of benefit and risk, and of opportunity and threat must be informed by a more detailed understanding of where biotech is and where it is headed. Here I summarize data collected from a variety of public and private sources to assemble an initial picture quantitative estimate of the economic value of biotechnology, which I define as science and industry related to the manipulation of genes, genomes, and metabolism. To that end, I construct a metric, the Genetically Modified Domestic Product (GMDP), composed of revenues from genetically modified systems and the technology used to manipulate those systems. The GMDP enables a comparison of biotechnology with the economy as a whole. This analysis reveals that the U.S. economy, and in particular annual U.S. GDP growth, is becoming increasingly dependent upon biotechnology².

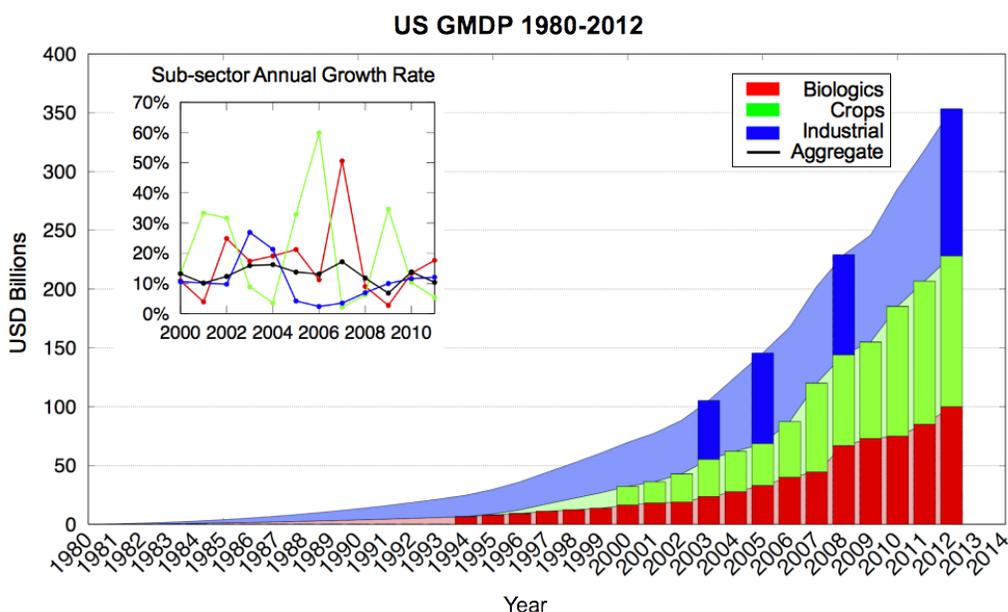


Figure 1. Estimate of annual U.S. Genetically Modified Domestic Product (GMDP) from 1980 to 2012. *Bars*: biologics revenue data and GM crop and industrial revenue estimates. *Shaded areas*: stacked plot of cubic spline interpolation of individual sub-sectors. It is likely that the interpolation overestimates early industrial biotechnology revenues – which were probably no larger than biologics revenues – and thereby underestimates later growth. *Inset*: Sub-sector annual growth rates between 2000 and 2012, calculated from year-on-year data and interpolations.

Due to differences in regulatory structure, financing, and, consequently, pace across the industry, the GMDP naturally breaks down into the sub-sectors of biotech drugs (biologics), agricultural biotech (GM crops), and industrial biotech.

Biologics. In 2012 domestic U.S. revenues from biologics reached nearly \$100 billion³. Beyond drugs that are produced biologically, the development and testing of virtually all small molecule prescription drugs are highly

dependent upon biotechnology. Of the approximately \$337 billion in total 2012 U.S. pharmaceutical sales, a large fraction of the small molecule revenues were clearly reliant upon biotechnology⁴. Accounting for this contribution could add tens of billions of additional revenues to the biotechnology tally. Here, however, in the name of simplicity and of sticking to data that are relatively easy to come by, I have chosen to only include “nameplate” biologics revenues that are directly attributable to biological production.

GM Crops. By combining the fractions of crops planted in GM seed with average crop revenue figures compiled by the USDA, I estimate that the sum of farm-level domestic U.S. revenues, seeds, and licensing revenues reached \$128 billion.

Industrial Biotechnology. U.S. revenues from industrial biotech (fuels, enzymes, and materials) reached at least \$125 billion in 2012. The accuracy of this estimate continues to suffer in comparison to revenues from biologics and GM crops due to the quantity and quality of available data. My previous estimates have involved reverse engineering reports from private consulting firms, who rarely describe data sources and methods⁵. For the 2012 datum, here I rely on an estimate provided by Agilent Technologies in late 2013⁶. The internal breakdown of the \$125 billion in these *business-to-business sales* is transformative for understanding the state of the bioeconomy: \$66 billion in chemicals, \$30 billion in biofuels, \$16 billion in biologics feedstocks, \$12 billion in food and ag, and \$1 billion in emerging markets. (Agilent did not provide any greater specificity regarding how these areas were defined or how the data were gathered.) Notably, it appears that chemicals have eclipsed fuels as the largest component of industrial biotech revenues. Finally, the ultimate consumer level economic impact of industrial biotechnology is larger by an unknown factor of somewhere between 10% and 30%, depending on the actual retail margin over business-to-business transactions. The total 2012 consumer-level impact on the U.S. economy could therefore easily have been in the neighborhood of \$160 billion, bringing the total 2012 GMDP to as much as \$390 billion.

The overall paucity of relevant data is due largely to the lack of national reporting mechanisms that capture biotech revenues. While the North American Industrial Classification System (NAICS) includes an optional secondary code for biotech R&D, the vast majority of biotech product and service revenues fall into generic categories such as chemicals, agriculture, and pharmaceuticals. This is particularly problematic when biotech can be used to produce a molecule identical to one derived from petroleum; the biological product may displace the petroleum product from the market on the basis of price or preference, yet revenues are still attributed to a category including petrochemicals. More generally, this misattribution obscures the raw economic contribution of biotechnology and impedes quantitative assessment of key features of sector growth and health such as firm number, firm creation, employment, and the overall impact of federal research dollars. A more aggressively optimistic interpretation of biologics and industrial revenues could easily bring the total 2012 GMDP to more than \$400 billion, or more than 2.5% of GDP. And yet there is no official measurement of this sector. This voluntary ignorance has subsequent impacts, for example confounding an understanding of national security that surely must include the economic role of biotechnology. It is my hope that, by calling attention to these shortcomings, this analysis will encourage both private and public sector efforts to gather and share data that supports a more detailed understanding of the biotechnology sector and its contributions to employment, innovation, and physical and economic security.

Notes:

¹ Initially reported in a Congressional briefing on 5 November, 2013, I have revised 2012 GDMP slightly upward, and its contribution to GDP slightly downward, as a consequence of updated data from the U.S. Department of Agriculture the U.S. Department of Commerce. See <http://www.synthesis.cc/2014/01/the-us-bioeconomy-in-2012.html>

² To be published in full in *Nature Biotechnology* in late 2014.

³ Computed from “Blockbuster Biologics 2012”, *R&D Pipeline News*, La Merie Business Intelligence, 7 May 2013.

⁴ “The Pharmaceutical Industry and Global Health: Facts and Figures 2012”, International Federation of Pharmaceutical Manufacturers & Associations.

⁵ Robert Carlson, *Biology is Technology: The Promise, Peril, and New Business of Engineering Life*, Harvard University Press, 2010, Cambridge, MA.

⁶ Darlene Solomon, “Tooling the Bioeconomy”, U.S. Congressional Briefing, 5 November 2013.

⁷ Robert Carlson, “The Pace and Proliferation of Biological Technologies”, *Biosec Bioterr*, 2003; Carlson (2010); Robert Carlson, “The Causes and Consequences of Bioeconomic Proliferation: Implications for U.S. Physical and Economic Security”, *Biodefense Net Assessment*, Homeland Security Institute, 2012.

Differentiating the discussion on synthetic biology

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Synthetic biology is not a monolithic bloc, it is diverse and on the move. The general subfields are well described. However the large diversity of the disciplinary backgrounds of the scientists contributes not only to the structuring of the field but is also framing the individual research agendas to a great extent. On a closer look even the described subfields (engineering approach, synthetic genomic, protocell research and so on) are not eligible to reflect the realities of the research field. Also regional differences in research agendas and cultures between for example Europe and the US add up to the diversity of the field. That makes societal evaluation of synthetic biology a challenging task and prone to misunderstandings. Confusions arise not only on the level of what part of synthetic biology the discussion is on, but also on the level of the underlying concepts in use. Here some readjustments to do more justice to the heterogeneity of synthetic biology are suggested. Instead of directly reviewing the field as a whole, it is suggested to focus on characteristic *features* of synthetic biology that are relevant for the societal discussion. An important example of these features is the enlarged depth of intervention. Some of these features apply only to parts of synthetic biology, where others might be relevant for synthetic biology as a whole. In the next step this refined view can be utilized for ethical evaluation, risk assessment, analysis of public perception and legal evaluation. This approach will help to differentiate the discussion on synthetic biology and to facilitate and support a problem oriented and sound evaluation of synthetic biology.

To bring this approach to a wider scope a future research agenda could be envisioned in three steps:

- In a first step the actual status of the field could be monitored on the basis of qualitative interviews. Here it would be important to appreciate regional differences as well as the diversity of the disciplinary backgrounds of the scientists that frame the field. On the basis of this work, the specific features that come along with different spaces of synthetic biology should be further characterized. The characterized features should be in addition set into proportion with their relevance to the whole field.
- Once the specific features are characterized, they should be analyzed with respect to the risk assessment and ethical and legal ethical evaluation. What should be for example the level of intervention? At which level of uncertainty?
- In a last step it is important to develop strategies to voice this diversity in the public space and also back to the field of synthetic biology.

Biology Meets Engineering

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Synthetic biology promises to make biology easier to engineer. More broadly, the idea of applying engineering ideas to biological systems may have significant impacts on the natural and social world. To date, we suggest that the study of engineering practice has been relatively neglected by Science & Technology Studies researchers, and the engineering of biology even more so.¹ In this note we draw attention to social, epistemological and ontological questions about engineering biology that we believe merit investment and sustained empirical inquiry.

Building on our previous work, the *Engineering Life* project² aims to provide insights into the engineering imagination, how it is applied to living things, and how it is challenged and expanded in interdisciplinary interactions. We propose to examine how ideas, practices and promises from engineering are being brought into the life sciences. What is meant by ‘engineering’ in a biological context? What relationships between making and knowing are being configured? And what implications are there for the design, building and control of our natural and social worlds? A focus on engineering ideas, practices and promises in biology is arguably of interest whether or not synthetic biology as a field retains its currently high visibility.

Engineering ideas: standardization, abstraction, decoupling, control

Key proponents of synthetic biology suggest that the import of engineering principles and work practices into molecular biology will facilitate the design of organisms with specified properties. Engineering metaphors are being adopted to describe and classify biological systems (e.g. as ‘parts’, ‘devices’, ‘chassis’), and principles such as standardization, abstraction and decoupling are being transposed from engineering to create synthetic biology workflows. The imposition of engineering metaphors and practices might shape the types of things that are brought into the world – for example, is biology naturally modular, or can engineering create organisms that are more modular than their ‘natural’ counterparts?³ Engineering ideals of standardization and decoupling are also inextricably coupled to imaginations of the social world, and systems of ownership, reward, labour and exchange. The objects and tools that synthetic biologists are building incorporate not just particular understandings of the nature of biological systems, but ambitions about the organization of scientific practice and the future of biomanufacturing.⁴ We suggest that studies aimed at better understanding the connections across micro- and macro-scales of bioengineering can inform the development of effective governance strategies.

Designing biological systems

Importantly, biology as a substrate is quite different from common engineering materials. Biological systems are notoriously complex, and evolve and respond to their environment over a range of timescales. Does this complicate attempts to design with biology? Could bioengineering require the development of new engineering principles and practices, to take into account biological properties like self-replication, mutation and evolution? What kinds of expertise might be needed to engineer ‘well’ with biology, and how might different epistemic cultures come together around bioengineering? We see opportunities for interdisciplinary dialogue around questions like: what is the place of rational design and/or evolution in synthetic biology?⁵

Discussions of engineering draw our attention to practices of design. When something is designed, this raises a series of questions such as: is it designed well or not? For what purpose is it designed? Who is it designed for? Engineering is a social activity with a strongly ameliorative impulse; it is intimately bound up with economic, military, social, personal, and environmental needs. From this perspective it is not a criticism of engineering to say that it is instrumental: knowledge is a means to an end, not an end in itself. Important questions arise about what this implies when biology is the thing being engineered. How will we configure the relationships between knowing and making across bioengineering, given the aspiration to re-make natural systems for human purposes, according to our design choices and values? In what ways might synthetic biology challenge current distinctions between ‘natural’ objects and technical artefacts, between nature and culture?⁶ How might governance regimes respond to such challenges?

Methods

We suggest that the topics and questions outlined above are best addressed through detailed empirical studies involving qualitative, mixed-methods approaches. Our project work will span three continents, and involves analysing policy documents and scientific literature, undertaking participant-observation at bioengineering meetings and conferences, performing semi-structured interviews with practitioners and policy stakeholders, and conducting ethnographic research in synthetic biology laboratories that are attempting to make biology easier to engineer. Reflections and ideas will be fed back to the practitioners involved in the project, with the aim of not just studying them but beginning to think *with* them. We also plan to engage in more experimental forms of collaboration, with the aim of creatively exploring the nature and contours of the engineering imagination.

Connections with funding and policy

Government bodies in the US and Europe have been eager to promote synthetic biology as an engine for growth, job creation, and an increasingly sustainable bio-based economy.⁷ They hope and suggest that bioengineering will herald long-term benefits for our natural and social worlds. To what extent does synthetic biology represent a new way of doing biology? In what respects and with what inflections is an engineering ethos infusing the commitments and practices of bioengineers? How might this play out in terms of labour relations, distributions of responsibility, and social justice? When engineering meets biology, is ‘better’ design a result? We suggest that detailed empirical studies focused on understanding bioengineering ideas, practices and promises are key to tracking the evolution of 21st-century engineering imaginations. These grounded studies may be able to offer insights that bridge the technical and social dimensions of bioengineering, and could help to inform interdisciplinary training initiatives, research investments, and governance strategies.

Notes and references

¹ We have recently sought to open a dialogue with engineering studies researchers through a special issue of *Engineering Studies* on synthetic biology (February 2013).

² [Engineering Life project](#), European Research Council Consolidator Grant to Jane Calvert (2014-2019)

³ Calvert, J. (2010) *Sociological Review* 58 (s1): 95-112

⁴ Frow, E.K. (2013) *BioSocieties* 8: 432-448

⁵ *Induced Evolution of Yeast Synthetic Genomes* project, FP7 ERASynBio Grant to Cai, Calvert, Frow (2015-2018)

⁶ Schyfter, P. (2013) *Studies in History & Philosophy of Biological & Biomedical Sciences* 44(4B): 632-640

⁷ See for example the White House (2012) *National Bioeconomy Blueprint* (2012); the UK Technology Strategy Board (2012) *A Synthetic Biology Roadmap for the UK*.

Synthetic Biology: A Whole Bunch of Balancing Acts

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Synthetic Biology, a balance between the compartmentalization methodologies of engineering and the reproductive efficiency of biology, is a field reliant on balance. This need for balance is particularly evident in the area of intellectual property.

The multitude of papers suggesting that synthetic biology be protected via copyright laws instead of patent laws notwithstanding,¹ inventions within the field of synthetic biology tend to be covered by patent law under the current intellectual property regime in the United States.²

However, while statutory patent law in the United States is technology agnostic, the courts and the United States Patent and Trademark Office treat different technologies differently for a host of different patentability criteria, for example, the distinction between predictable arts such as electrical and mechanical related arts and unpredicable art such as biology and chemistry.³ These distinctions have political repercussions as well, as most recently shown by the longstanding concern over the appointment of the next patent commissioner.⁴

Relatively clear cut examples of this discrimination are the related but separate enablement and written description requirements wherein biological inventions are read with an eye to different standards than hi-tech innovations. The differences in enforcement of these criteria not only reflect different properties of the technologies, but also reflect the efforts of the courts and the USPTO to promote innovation through manipulation of these criteria as policy levers.⁵

Synthetic Biology presents a rather unique application of these discriminatory efforts by the courts and the USPTO, particularly since the component fields of synthetic biology, biology and engineering, are often treated differently. Synthetic biology's wide ranging applications across multiple different fields and technologies including health, environment, nanotechnology, materials science, and energy might also cause confusion as to how best approach the patenting of the technologies.⁶ Moreover, synthetic biology is not simply just the insertion of genes or the construction of novel genomes, it incorporates a whole host of enabling technologies⁷ that will innovate alongside innovations in synthetic biology itself.

As such, synthetic biology necessitates a more novel approach; an effort to balance competing concerns and factors to optimally promote further innovation. In lieu of a sui generis system, the courts and the patent office might look toward treating synthetic biology innovations differently depending on whether they lean more toward the predictable or unpredictable, albeit at the risk of predictability for the inventor. For example, basic biological parts might be relatively predictable by nature, particularly in vitro, whereas larger machines, and particularly in vivo machines may be highly unpredictable.

Another area where balancing is required relates to competing efforts within the synthetic biology community to establish open source like protection regimes and proprietary regimes, the two opposing efforts somewhat representative of the engineering and biology aspects respectively,⁸ and not, as some may think, representative of public universities vs. private industry.⁹

Here too, rather than a blanket response for the entire field, it might be better to apply an open source ideology to the protection of say basic parts, and a proprietary philosophy to protection of larger and/or complicated systems that use multiple basic and not-so-basic parts.

Similarly, further distinctions could also be made between general workhorse-like parts necessary for use in many different types of machines versus very specialized parts that might be useful in only a handful of applications.

Additionally, as the US patent regime evolves to tighten up patentable subject matter, even eviscerating the statute and mashing up unrelated parts (e.g., subject matter and non-obviousness), synthetic biology could fall prey to the dragnets designed to rope in software patenting in particular. For example, the current law has become very restrictive on the patenting of methods intended to be implemented via one or a million processors, but conceivably possible to be implemented by a hypothetical human, similarly, a process intended to be implemented via one or a million manipulated genomes but conceivably possible to be implemented by a hypothetical mechanical machine must also become unpatentable.

Whether its practitioners and the courts can find an optimal balance in the intellectual property aspects of synthetic biology is not simply an academic quandary. The courts and the USPTO, which, when captured by an industry tend to work towards the benefit of that industry,¹⁰ need to appreciate the necessary balances in synthetic biology: when patents promote and when patents hinder innovation in this field and to apply the law accordingly. At minimum this requires the non-trivial effort of those in the field to tease out when to apply what type of intellectual property regime and then help the courts and the USPTO learn more about applying those regimes to synthetic biology.

¹ Rai A, Boyle J (2007) Synthetic Biology: Caught between Property Rights, the Public Domain, and the Commons. *PLoS Biol* 5(3): e58.

² Dov Greenbaum, *Legal Concerns in Emerging Science: Synthetic Biology and Intellectual Property*, Intellectual Property Law: Interdisciplinary Analysis (Miriam Bitton & Lior Zemer eds.) (Forthcoming 2014)

³ *In re Fisher*, 427 F.2d 833,839 (C.C.P.A. 1970).

⁴ Klint Finley, Silicon Valley Wins! Obama Picks Ex-Google Lawyer to Head Patent Office, *WIRED* 10.17.14, available at <http://www.wired.com/2014/10/michelle-lee-uspto/>

⁵ Greenbaum, Dov. "An Analysis of Federal Circuit Discrimination: The Evolution of the Written Description Requirement Vis-a-Vis DNA and Biotechnological Inventions Concerns for Synthetic Biology." *Recent patents on DNA & gene sequences* 5.3 (2011): 153-165.

⁶ van Doren, Davy, Stefan Koenigstein, and Thomas Reiss. "The development of synthetic biology: a patent analysis." *Systems and synthetic biology* 7.4 (2013): 209-220.

⁷ Kahl, Linda J., and Drew Endy. "A survey of enabling technologies in synthetic biology." *Journal of biological engineering* 7.1 (2013): 1-19.

⁸ Nelson B. Synthetic biology: Cultural divide. *Nature*. 509(2014):152-4.

⁹ Marks and Clerk, New report reveals trends in genomic research, 24 June 2014. Available at <http://www.marks-clerk.com/Home/Knowledge-News/News/New-report-reveals-trends-in-genomic-research.aspx#.VEL1tBZQF1E>

¹⁰ Greenbaum, Dov. "An Analysis of the Evolution of the Written Description Requirement vis-a-vis DNA and Biotechnological Inventions." *Recent patents on DNA & gene sequences* 1.2 (2007): 138-144.

Realizing Positive Network Effects in Synthetic Biology

Linda J. Kahl, Director, Legal Program, BioBricks Foundation

The emerging field of synthetic biology holds great promise for generating biological solutions to address many of society’s most pressing needs. Advances in DNA synthesis and assembly technologies, innovations in computer-aided design, and the creation of automated strain engineering platforms and associated technical standards are improving efficiencies in the design, construction and testing of biological systems. As such, the tools of synthetic biology can help address unmet grand challenges in health, energy, environment, and agriculture.

Despite remarkable achievements in recent years and the creation of a vibrant, global synthetic biology community, research and development efforts in synthetic biology remain disconnected, duplicative, and delayed in the face of difficult common challenges. It is problematic that the infrastructure within which synthetic biology research is being conducted operates as a closed, guild-like system. Individual researchers, academic institutions, and companies typically are not rewarded for sharing, and instead are rewarded by sequestering information and materials until a paper is published or a patent issued. Career advancement for individual researchers, at least in academia, depends on first-author publications and the ability to competitively secure grant funding. Many academic institutions hold tight to any discovery or technology development that could potentially bring in revenue. And companies rely on the exclusivity provided by patents and trade secret protection to secure investment and obtain market advantage.

The silo mentality created by the current infrastructure impairs the ability of researchers to collaborate with one another and discourages cooperation between organizations, thereby losing the benefits of positive network effects. As a specific example, synthetic biology researchers in both academia and industry are often unable to freely share the biological parts they develop. When sharing biological parts with others outside their own laboratories (Figure 1, left side), most academics need to have a manuscript submitted or accepted for publication, while most industry researchers need to have an agreement in place. On the other end, when requesting biological parts created by others (Figure 1, right side), researchers or their institutions often

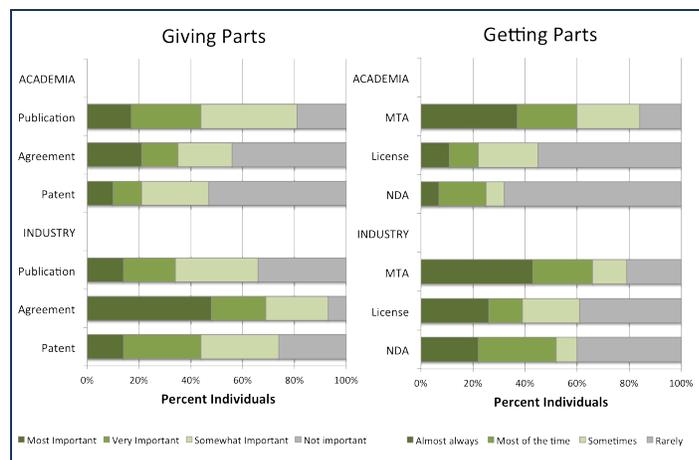


Figure 1. Considerations for sharing and accessing biological parts among synthetic biology researchers in academia and industry. Data from the SB6-State-of-The-Art survey, Kahl et al., manuscript in preparation.

are asked to sign material transfer, licensing or non-disclosure agreements. Importantly, researchers do not always receive the parts they request. When requesting parts as tangible materials, 26% of academics and 57% of industry researchers report having been denied access due to concerns about property rights. Property rights are not the only barrier to access, however, since 32% of academics and 50% of industry researchers reported having been denied access due to other concerns (e.g., competition, failure to fill requests, inability to clear customs).

The inability of academic and industry researchers to freely share biological parts has had a negative impact on synthetic biology research. Among academic researchers (Figure 2, left side), 50% believe their research has not been affected by difficulties in obtaining agreements. However 37% reported their research had been delayed, 26% chose alternate technologies, 6% abandoned ongoing research projects, and 11% chose not to pursue a new research project due to difficulties in obtaining agreements. Among respondents from industry, the impact on research is far greater (Figure 2, right side). Only 14% of industry researchers reported their work had not been affected by difficulties in obtaining agreements, 49% reported their research had been delayed, 54% chose alternate technologies, 9% abandoned ongoing research projects, and 17% chose not to pursue a new research project due to difficulties in obtaining agreements.

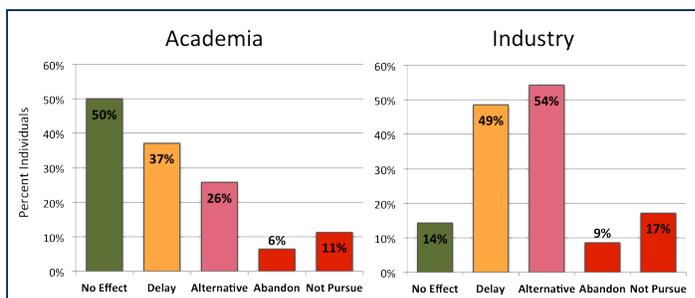


Figure 2. Synthetic biology researchers in academia and industry are impacted by difficulties obtaining licensing or material transfer agreements. Data from the SB6-State-of-The-Art survey, Kahl et al., manuscript in preparation.

It is critical that researchers, together with academic and industry leaders, funders, investors, and policy makers, fundamentally rethink how synthetic biology tools and knowledge are shared and disseminated. Realizing the full potential of synthetic biology will require an infrastructure that enables researchers to share and access information and materials that reside outside the boundaries of any one organization. To benefit from the positive network effects inherent in the engineering of biology, new collaborative platforms and policy initiatives are needed that will reward the sharing and dissemination of data, materials, methods, and practices across institutional and international boundaries.

The types of collaborative platforms and policy initiatives – e.g., convening forums, funding streams, publication venues, and associated rewards systems – that could help ensure social benefit from positive network effects in synthetic biology is a topic for discussion at this Workshop on Research Agendas in the Societal Aspects of Synthetic Biology.

Synthetic Biology in Global Health: Lessons from History and Anthropology

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The term global health “implies consideration of the health needs of the people of the whole planet above the concerns of particular nations,” and is associated with the emergence of important nongovernmental actors.¹ Synthetic biology as a field of research and practice, and those working with SynBio, may constitute such actors. Last year, Douglas and Stemerding convened a special issue of *Systems and Synthetic Biology* to address select SynBio applications, processes, and governance as they relate to global health. They suggest that “SynBio is positioned to address major global health issues through advanced vaccine development, diagnostics, drug synthesis, and the detection and remediation of environmental toxins.”

SynBio holds potential value for the remediation of various health problems, including designing out cold chain requirements, simplifying certain (e.g. vaccine) administration procedures thus facilitating local capacity and uptake, rapid production of preventive and therapeutic agents, and environmental monitoring, etc. The authors in the special issue address a number of important considerations including IPR and patent regimes. In this short piece, I suggest that we would do well to take some lessons from history and anthropology as we consider the application of SynBio in global health contexts.

By global health contexts I mean both the local peoples and sites that are most often the targets or recipients of global health interventions (typically in the global ‘South’ and marked by relative underdevelopment and poor health metrics) and the global health partnerships that most often occur between institutions in the global ‘North’ and ‘South.’ I use global health *contexts* to remind us that global health is not a singular thing. “You cannot dwell in the global.”²

Thus, if SynBio is to be meaningful in global health contexts, I suggest that we pay serious attention to various social issues, three of which I foreground here. Histories of global and international health are riddled with stories of failure. Often institutional goals, priorities, and logics do not align with those of targeted groups. Against a backdrop of attending seriously to local contexts, I suggest that we also give serious attention to the following three related areas:

- 1) Public inclusion: including local and multiple publics in design of research, technologies, and programs at every step.
- 2) Placing the technological potential of SynBio in social contexts: locating the broader social, political, economic, etc. aspects of the health problems to be addressed by SynBio.
- 3) Studying SynBio institutions: assess and analyse the underlying priorities, assumptions, and logics of those practicing and applying SynBio.

1. Public Inclusion: Most international health programs have been designed in a top-down manner. The subsequent move to global health initially seemed to include a recognition of the failure of the vertical approach, however many recent programs appear to have resuscitated it. Jenny Reardon’s account of the failure of the Human Genome Diversity Project (HGDP) shows that considerations of varied public values cannot simply be tacked on to existing project design, but rather must be built-in every step of the way.

Especially in projects of controversial science, Science and Technology (STS) scholars have shown that the early inclusion of multiple publics not only produces better public

¹ TM. Brown, M. Cueto, and E. Fee, *AJPH* 2006: 62.

² B.Latour quoted in W. Anderson, *SocHistMed* 2014: 378

acceptance of downstream programs and products, but also better science. Far from the earlier ideal of value-free science, science is shot through with social values and human interests. Thus, Heather Douglas advocates for value-laden sciences; good science requires the acknowledgement of values. Charis Thompson shows how good stem cell science comes out of an ongoing and iterative relationship between science and ethics. This is a relationship in which scientists become one of a set of multiple publics. These scholars, and others, show that good science is expressive of social values and that the inclusion of broad publics is necessary for the production of good science as well as the uptake of its outputs.

2. Placing technology in context: A ‘magic-bullet’ approach has long been favored in biomedicine with its high-tech focus and cultural logic of eradication. If we take seriously the substantial research that suggests that health problems reflect social problems, and that poverty strongly shapes health vulnerability, then technological approaches that ignore the specific social contexts are unlikely to provide much relief and, in fact, risk to make things worse.

Many scholars attribute the failure of the 1950s WHO Malaria Eradication Programme (MEP) to an overreliance on technological fixes.³ One unfortunate consequence was the development of DDT and artemisinin resistance. Even the successful smallpox eradication campaign has been criticized for its violence and social rupture which has left, in some areas, resistance to subsequent vaccination efforts. SynBio technologies applied in global health contexts should not be stand-alone solutions but components of broader socio-political projects.

3. Studying SynBio institutions: Barriers to technological and medical interventions in developing countries have most often been framed as located in the recipient cultural groups. That is, cultural, social or psychological attributes in local communities act as barriers to appropriate uptake. As early as 1976, George Foster recognized the importance of attending to the cultures of bureaucracies as well; global health institutions and personnel have cultures, too, which may serve as barriers to implementation.

Even as the designers of the failed HGDP, for instance, saw the project as an anti-racist corrective to the limited scope of the HGP, those targeted by the project had their own epistemic approaches and political concerns that proved irreconcilable. The failed MEP was reshaped in response to institutional, as much as malarial, pressures along the way.⁴ We must, therefore, critically analyze our own SynBio-related institutions and projects in order to understand the internal underlying logics, assumptions, and interests that underpin SynBio work.

In sum, while some working in SynBio and global health explain public resistance to their projects by recourse to a deficit model of public understanding, this is neither an accurate nor productive framing. Often the deficit is located in our own understandings of other public values. By taking seriously local contexts, including diverse publics, using SynBio innovations in tandem with broader social projects, and scrutinizing our own practices and assumptions, we enhance the possibilities for meaningful engagements of SynBio in global health. Finally, by now, most working definitions of global health include a statement about equity. Equity is not only about the distribution of benefits, but also risks. We should exercise extra caution to ensure those already most vulnerable -- for this is precisely what constitutes them as populations in need of intervention -- do not bear an undue burden of risk related to SynBio.

³ e.g. Marcus Cueto 2013, Randall Packard 2007, Jeremy Greene et al. 2013

⁴ M. Cueto 2013 (full references available upon request)

Governing and Debating an Emerging Science: The Rise of Synthetic Biology in France

Morgan Meyer, Agro ParisTech

In France, the development of synthetic biology has been slow but steady. Over the past few years we have witnessed: the establishment of a national network of synthetic biologists in 2005, the first participation of a French team at the iGEM competition in 2007, the creation in 2009 of a Master's and an institute dedicated to synthetic and systems biology, an increasing number of conferences and debates, and there are plans to set up platforms for fostering collaborations between public and private actors.

Governing

Yet, the governance of synthetic biology has become an official matter much more recently. The National Research and Innovation Strategy (SNRI) defined synthetic biology as a “priority” challenge in 2009 and created a working group in 2010 with the mission to assess its developments, potentialities and challenges - the report of the group was published in 2011. At the same time, the French Parliamentary Office for the Evaluation of Scientific and Technological Choices (OPECST) has embarked on a review of the field in order “to establish a worldwide state of the art and the position of our country in terms of training, research and technology transfer”. The report, titled *The challenges of synthetic biology* and published in 2012, assesses the main ethical, legal, economic, and social challenges of the field. The report contains several recommendations for a “controlled” and “transparent” development of synthetic biology – not much of a surprise, considering that in France the development of GMOs has often been criticised for being the opposite and that controversies are now to be avoided. Both reports stress the necessity of a “real” and “transparent” dialogue between science and society and call for a “serene”, “peaceful and constructive” public discussion. The strategy is now to **follow 3 steps: to establish an observatory, to create a permanent forum for discussion, and to enlarge the debate to include citizens.**

France's self-perception and goals in synthetic biology are high. We are told about a “new generation of products, industries and markets”, “a substantial jump for biotechnology”, an “industrial revolution”. We read that “France disposes of strong competences” and “all the assets needed”. We see a country that wants to position itself globally, with the US, the UK, Europe, and Germany serving as the main reference points for comparison. France could “aim for a world position of second or third”. Yet many structural and organisational challenges persist: public-private partnerships are rare in France, boundaries between disciplines and academic territories impede interdisciplinary work, synthetic biology is in general included in larger biotechnology programs. And while both the SNRI and the OPECST reports do make recommendations for future developments (i.e. setting up funding policies and platforms), it remains to be seen if these will materialise and when and where investments will be made.

Debating

The Observatory was set up at the French National Conservatory of Arts and Crafts (CNAM), a higher-education institution funded by the French government and dedicated to education and research and the dissemination of scientific and technical culture. The Observatoire was created

at the CNAM for essentially two reasons: The CNAM is seen as a privileged and neutral place, and it already has experience in science–society dialogues through NanoForum. The Observatoire is coordinated by an intentionally pluralistic council that is designed to reflect the different stakeholders and positions of the field. It aims to “be the nodal point for the circulation of information, reflections, discussions about synthetic biology” and to be a “place of experimentation... for a science–society dialogue”. Its roles are to collect information, to mobilize actors, to follow debates, to analyze the various positions, to reflect...

The Observatoire launched a Forum of Synthetic Biology, conceived as a “*space of open and pluralistic debate to permit the exchange of information, the sharing of knowledge and the expression of disagreements about the multiple challenges of this emerging domain*” in order to favour an “*enlightened and constructive discussion*”. But during the first forum, held in april 2013, nothing went as planned. A few minutes into the debate, it is interrupted by some 15 persons wearing monkey masks (a group of protesters called PMO).

These debates are not only a place for raising critiques regarding the socio-economic and political aspects of synthetic biology. To understand the different critiques made by the actors who intervene in the debates on the form of the debate itself, the distinction between “divisible” and “indivisible” conflicts is useful (see Hirschman, Barthe, Meyer). On the one hand, the Observatory and the Forum consider themselves as spaces of dialogue and debate where people can deliberate and negotiate. Meant to anticipate conflicts, these spaces of negotiation can nonetheless lead to a proliferation of conflicts – on the substance and the form. On the other extreme, there is PMO, an “indivisible” actor who does not want to negotiate nor discuss: “*We have no question to ask you, no uncertainty to lift. Our position is already fixed: we do not accept*” (pamphlet). The criticisms made by PMO can be qualified as radical and “total”, since they condemn the practices, objectives, products, institutions, debates (considered as “*pseudo-forum*”, “*hollow debate*”, “*masquerade*”) and sociologists involved (qualified as “*sociologists of acceptability*”). Between these two positions, there are actors who negotiate while formulating critiques – actors we might call “inversible”: the *Fondation des Sciences Citoyennes* who is involved in the Forum and the Observatory, but who defines its collaboration as a “*vigilant, critical and non unconditional participation*”; *VivAgora* who has criticised the “*analytically and academically overhanging posture*” of the Observatory and stressed that “*discords*” need to be taken into account. Such an analysis of actors’ criticisms and positioning forces us to problematize terms like debate and participation and renders these terms *divisible* too.

Problematizing

In Foucauldian terms, apart from the construction of synthetic biology as an *object*, we also see the making of synthetic biology as a *problem* and a set of questions. Although we observe efforts to assemble synthetic biology as an (inter)discipline within scientific institutions, we also see efforts to converse, observe, and reflect about the practices and objects of synthetic biology—in other words, to *problematize* synthetic biology. The ways in which all of these objectifications, politicizations, problematizations, and publicizations of synthetic biology interact with, influence, and coproduce one another are a fruitful topic for analyses.

An idea developed by biologist Antoine Danchin can help us further theorize these kinds of interactions. Danchin coined the concept of symplectic biology, a kind of biology that weaves

together objects and disciplines. In his words, “under this scheme, the roadmap to engineering biological systems is determined not by the biological parts but rather by how they interact... The relationships between the objects—and not necessarily the objects themselves— are crucial to any attempt to construct a synthetic cell with nonnatural properties”. Such a “symplectic” vision—which we might also call relational or integrative—can be productive for thinking about synthetic biology. Besides referring to relations between objects, the notion could be generalized and broadened to include the politics and the publics concerned with those objects. This could, then, serve as a potent reminder that synthetic biology should not and cannot be discussed in isolation. On the contrary, synthetic biology needs to be conceived in an integrated way, as an assemblage of scientific objects, policies, problems, and publics. As much as natural scientists should not reduce their vision of synthetic biology to objects alone, social scientists should not reduce their analysis to categories such as *social*, *legal*, or *ethical* as if the socioeconomic, political, and moral dimensions of synthetic biology could be broken down into such neat parts. What social scientists can offer, instead, are relational accounts on how the history, governance, geopolitics, and debates of synthetic biology are woven together and why synthetic life needs to be discussed together with social life.

This text has been compiled based on the following publications: Meyer, M. (2013) ‘Assembling, Governing, and Debating an Emerging Science: The Rise of Synthetic Biology in France’ in *BioScience*, Vol. 63, No. 5, pp. 373-379; Meyer, M.(2013) ‘Aiming high, but investing little’ in *EMBO reports*, Vol. 14, No. 1, p. 2; Meyer, M. (2013) ‘Debating synthetic biology: a necessity or a masquerade?’ in *Carnet de Recherche du CSI*, Juillet 2013

From Contribution to Co-Evolution: A way to promote responsible innovation in synthetic biology?

Eleonore Pauwels, WWICS

Characteristics of the synthetic biology innovation ecosystem

Changes in our research and innovation ecosystems have started re-shaping the role and practices of researchers in life sciences (Pauwels, 2010). As analyzed by Steven Shapin (2008), the scientific persona itself is progressively evolving into one of entrepreneurship. Unlike traditional biotechnologists, most synthetic biology researchers operate simultaneously in several spheres: as academic researchers receiving government funding for research, inventors seeking patentable discoveries, company founders receiving investment capital from the private sector to finance product development and members of advisory boards for groups engaged in similar activities. There are key questions about how these interrelations can be a positive or negative element in developing a culture of responsibility across research and innovation systems.

Adding complexity, the synthetic biology innovation ecosystem also crosses boundaries within the natural sciences. Synthetic biology's practitioners are not, as a rule, biologists or even molecular biologists. Many are computer scientists or come from disciplines that do not study or work with whole organisms, but instead apply an even more mechanistic perspective to living systems than do traditional genetic engineers. The synthetic biology innovation ecosystem is further fragmented among sectors. Synthetic biology represents an amalgam of public and private funding, public and private institutions, experts and amateurs and, in some cases, new approaches to intellectual property protection. To some extent, the fragmentation and complexity of such an innovation ecosystem plays to the strengths of "responsible innovation," in that the systems-based and adaptive premises of this governance approach provide a more comprehensive and flexible framework for dealing with complexity.

End-points for oversight within the synthetic biology ecosystem

Synthetic biology has advanced to the point where more complex organisms are being developed and the inventory of interchangeable biological parts continues to expand, rapidly enabling more combinatorial designs (the number of new biobricks generated annually could exceed 3,500). Looking ahead, it is worth considering what has not been resolved in the field and the likely changes that could affect research, development and commercialization efforts, creating both challenges and opportunities:

- 1) The capacity of our regulations, and more generally, the Coordinated Framework for Biotechnology, to deal with synthetically engineered organisms has been barely tested so far.
- 2) There is almost no funding focused on emerging environmental risks, though the complexity of those risks has become more apparent.
- 3) Public awareness in the US on synthetic biology remains low. According to a national survey conducted by Hart Research Associates for the Synthetic Biology Project (Hart, 2013), only one in four Americans has heard something about synthetic biology and initial impressions are often negative. The results of the 2010 Eurobarometer survey by the European Commission reveal similar lack of awareness and knowledge gaps in Europe on synthetic biology (EC, 2010).
- 4) The field does not have a coherent public message, and current messaging and media reporting often provoke public anxieties.

An effective science-policy interface and mechanisms to support productive public engagement surrounding the science, its long-term benefits for society and scientifically grounded appraisals of the risks are needed. This science-policy interface was, in part, the role endorsed by PCSBI in its 2010 report.

However, there has been little to no action on these recommendations. The difficulty for PCSBI to jump-start a learning strategy around the notion of “responsible stewardship” and “prudent vigilance” leaves us with an array of questions: How can responsible innovation help towards improving our oversight culture? How is the synthetic biology innovation ecosystem both a challenge and an opportunity for implementing devices of responsibility?

The research system

RRI plays an insignificant role in the enterprise of academic research and innovation. Structural changes are needed to sufficiently incorporate the ethical and societal aspects into research and innovation. In A 2011 report, the Royal Society of London states that individual researchers are often not cognizant of the societal and ecological impacts or the ethical dimension that their research might have in the future (Mackintosh, 2011). The extent to which societal demands or ecological aspects are taken into account varies significantly, often depending on the awareness of individual researchers. In the career system of academic researchers, there are hardly any incentive for considering ethics and responsible innovation. For instance, with a few exceptions, there is much less funding for problem-oriented, trans-disciplinary research than is needed. Further, very few high-impact journals publish interdisciplinary studies.

The innovation system

Similar to the research system, the innovation system has systemic constraints resulting in a failure to anticipate RRI or future societal needs, especially when it comes to inter-generational problems or issues faced by less empowered and fragmented groups. It is not only challenging for the public sector to foresee future issues and recommend appropriate solutions, but also unattractive for the private sector due to a longer time frame of a return on investment. Although many companies have introduced environmental and/or sustainability management systems (ESMS) and Corporate Social Responsibility strategies, most companies follow procedures in the R&D process that do not explicitly take all these dimensions into account. Most companies comply with the minimum regulatory requirements for environmental and social responsibility, which are quite basic, and do not exceed this baseline. So far, there is no coherent approach for integrating RRI (or aspects of RRI) into the innovation system of companies or research organizations.

Towards Co-Evolution in Research and Innovation Ecosystems

Ideally, the collaborative practices described by von Schomberg (2011) would require continual conversations with those outside of the lab, including policymakers and non-institutional networks, such as DIYbio practitioners. Knowledge sharing between researchers and policymakers, for example, would help identify safety or regulatory uncertainties in synthetic biology so designs could be adapted for more desirable outcomes. Rejeski (2011) explains how this might be a challenge for the legacy institutions: “the old policies and programs, based largely on an ‘assessment and regulation’ paradigm, need a new operating system, one that moves from Newtonian mechanics to evolutionary biology and shifts the modus operandi from the interminably long process of issue identification, analysis, recommendations and implementation to an emphasis on learning, adaptation and co-evolution (p. 50).” Indeed, policymaking communities need a clear perspective on the challenges posed by synthetic biology to ethics and society, but must also promote deeper thinking inside public policy communities about how to develop and implement learning strategies. If we consider emerging technologies to be complex adaptive systems, then policymakers need to be part of that co-evolving system. Before we try to implement the concept of co-evolution, we still have to confront the challenges posed by our legacy institutions – policy and regulatory.

Social Science Contributions Compared in Synthetic Biology and Nanotechnology

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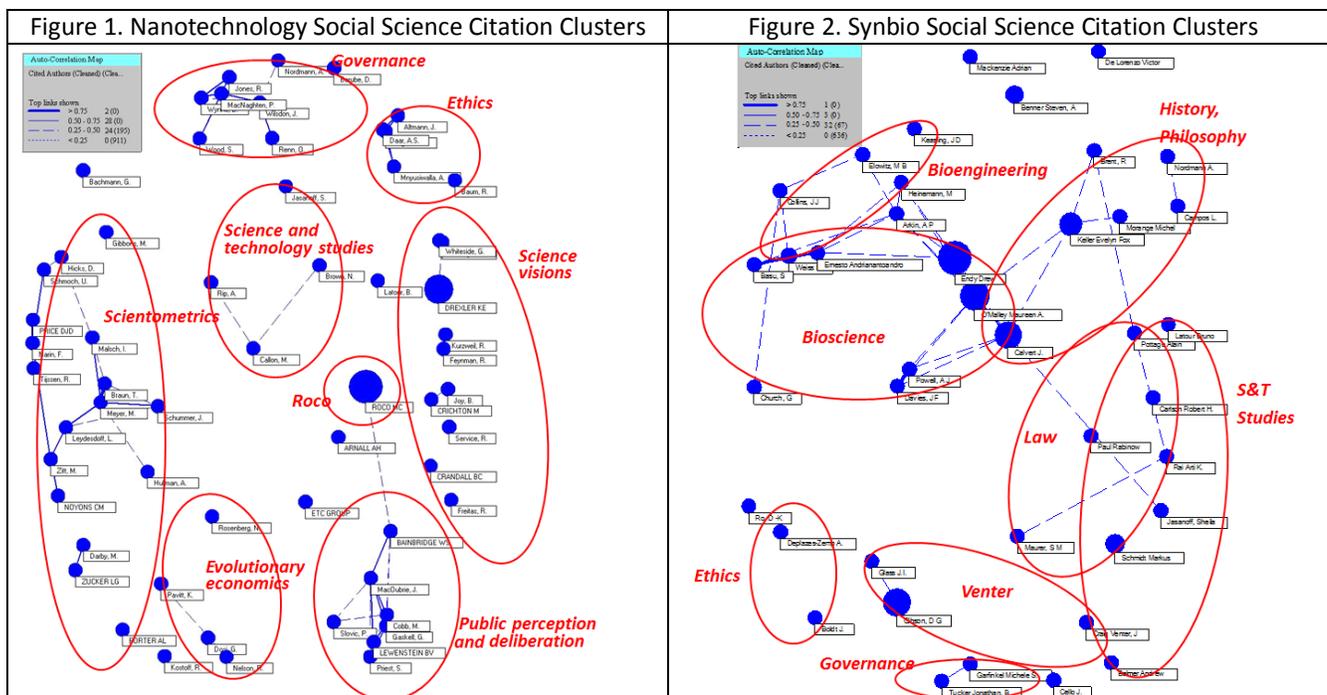
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Researchers in the social sciences (including humanities, law, ethics, and business) are increasingly involved in analyzing and reflecting upon societal aspects of emerging technologies. The late 1980s and 1990s saw growth in ethical, legal, and social implication (ELSI) work via the Human Genome Project. In the 2000s, research on the societal implications of nanotechnology developed in the US, Europe, and other countries. For example, beginning in the mid-2000s, the US National Nanotechnology Initiative (NNI) supported a range of nanotechnology in society research activities including two national centers. (2.7% of the NNI budget was assigned to societal and educational concerns by 2009, although subsequently declining.) Most recently, attention has been given to issues of responsible research and innovation in a range of emerging technologies. As consideration focuses on societal concerns and social science research agendas in synthetic biology (synbio), we probe what might be learned by comparison with social science research outputs from earlier rounds of emerging technologies, particularly nanotechnology. Societal research in nanotechnology and synbio both occur in what might be called a post-GMO (genetically-modified organism) setting in which science comes under greater public scrutiny, and expectations are heightened related to accountability, deliberation, and responsibility and to the societal relevance of research and innovation. At the same time, any comparisons need to take account of contextual differences: whereas there was relatively little dedicated research capability in place prior to the ramp-up of societal research in nanotechnology, societal research in synbio today draws upon a well-established infrastructure of ELSI life science research in biotechnology, human genome, and health domains with many ELSI investigators co-located in transdisciplinary centers comprised of medical researchers, bioethicists, and legal investigators.

We can see that societal research outputs in synthetic biology are already burgeoning. A Google Scholar analysis (by the authors) for the period 2004 to 10/10/2014) finds more than 500 publications (including journal articles, policy reports, books, and working papers) that consider societal aspects of synbio; of these, about three-fifths were published since 2010 (“societal aspects” here includes publications oriented towards social science, humanities, philosophical, business, legal, intellectual property, regulatory, governance or policy). Google Scholar offers broad indications of output scale and picks up a wide range of publications; however, to more finely analyze the characteristics of research outputs, we need to use analytical approaches applied to other structured publication databases. We are particularly interested to explore the underlying knowledge sources and clusters underlying societal research in synbio bio and do so by making a comparison with an earlier study we undertook in the nanotechnology social science subdomain. We compare these two subdomains at similar developmental points, in the initial period of social science investment – through to 2007 for nanotechnology social science research and through to May 2014 for synbio social science research. These two periods encompass roughly the same number of social science articles (approximately 300) extracted from the Web of Science Social Science and Arts and Humanities Index and the Scopus Social Science and Humanities category. Our focus is on the knowledge clusters used in these social science studies (for this analysis, the multidisciplinary journals *Science*, *Nature*, and *Proceedings of the National Academy of Sciences* are excluded as they also include natural science papers). We use a methodology based on analysis of cited references (also known as “backward citations”). One common interpretation of cited references is that they reflect knowledge bases and flows used in a research article. The method used

focuses on highly cited authors (cited by a threshold number of articles); using a Person name fuzzy list cleanup algorithm to obtain this list, applying multi-dimensional scaling to co-citations of authors; and taking the results down to two-dimensional space to produce a network map of the results in which the nodes represented the number of papers citing the work and the links represent the degree of association between the nodes (after applying a path-erasing algorithm to focus on the strongest links).

Our earlier study [1] of cited references found eight social science areas represented in the nanotechnology social science subdomain (Figure 1). These were: science visions (including science fiction), scientometrics, public perception and deliberation, governance, ethics, science and technology, and a hub represented by citations to M. Roco of the National Science Foundation and a highly recognized public entrepreneur. The relative use of citations in these areas changed over time, with science visions articles being cited more in the early years, then other central social science areas being cited more in the later years. Applying the same method to synbio [2], we find a different set of disciplines represented in the peer-reviewed societal research literature to date (Figure 2). Synbio social science knowledge citations focus on a large cluster of bioscientists and bioengineers; an overlapping cluster of history and philosophy researchers; an overlapping cluster comprised of science and technology studies, law, governance, ethics; and a cluster citing the private entrepreneurial scientist Craig Venter. These results surely reflect the differences in pre-contexts between nanotechnology and synbio. The prior ELSI research legacy is providing an important pathway for current synbio societal research, but comparison suggests that gaps are also present. Relatively less influential in synbio social science are papers by scientists with visionary perspectives. Also, several social science knowledge bases evident in the nanotechnology map are not yet widely present in synbio research, particularly public perception and deliberation, scientometrics (including quantitative analyses of research and innovation trajectories), and economics. We should discuss whether and how synbio social science research can incorporate greater outward-looking, engagement, anticipatory, and downstream perspectives.



Source: Analysis of Web of Science & Scopus, 308 nanotechnology social science articles (7.2K backward citations) through 2007 and 314 synbio social science articles (8.7K backward citations) through May 2014. For discussion of methods and results, see [1] and [2]. **References:** [1] Shapira, P., Youtie, J., Porter, A.L. (2010). [The Emergence of Social Science Research in Nanotechnology](#). *Scientometrics* 85(2), 595-611. [2] Youtie, J., Shapira, P. (2014). [A Comparison of Social Science Research in Synthetic Biology and Nanotechnology](#). Working Paper.

Synthetic Biology as Social Construct: Imaginations as Accountable Material Democratic Social Formations?

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I INTRODUCTION

This brief discussion paper attempts to provide some productive ideas for a new and timely interdisciplinary research program being considered by US NSF (but in principle of value and relevance more generally) on societal aspects of synthetic biology (henceforth, 'synbio'). I start with the question: what do we mean by social research on synthetic biology as a major field of modern technoscience? Here, one key point I need to make at the outset, taken for granted by most (but by no means all) scholars in my own field of Science and Technology Studies or Sociology of Scientific Knowledge (STS-SSK), is that social research in such technoscientific fields has to include a sociological, historical and in-part philosophical understanding of the technoscientific *knowledge-cultures* which define the field of synbio (or any other technoscientific domain). I return to what this means for a social sciences/humanities (SSH) research agenda on synbio in Section III below. However we should immediately note that this has to involve much more than only attempts to identify and/or anticipate downstream 'social impacts' of synbio, but also has to include a focus on upstream social-political-economic-cultural questions. This is a different SSH research agenda from the downstream one; and it is not a replacement, but an additional, often neglected, agenda.

One further reason that an SSH research approach has to move upstream and into the insides of technoscientific knowledge-cultures from the more usual downstream and external presumptions and framings, concerns the recognized importance of understanding public responses to the technoscience concerned (again, this is a general matter, for any technoscience). This is the point (Wynne, 2007, 2014) that we cannot begin to understand those public responses, until we also first investigate: what is the technoscience which we suppose those publics are experiencing, and to which we assume they are responding? This is a specifically STS-SSK approach to public attitudes and responses, and is different from most mainstream social scientific approaches such as social psychology or psychometrics, where implicitly the 'black-box' of the technoscientific knowledge-culture, including its modes of promotion and legitimation to society, funders, etc., is left unopened and unproblematized. This important 'reflex' lacuna was pointed out in the earliest days of 'public understanding of science' research (Wynne, 1992), but it still needs to be addressed. Thus-far it is only approaches informed by STS-SSK which are equipped, and willing, to do this.

In the next section I describe some premises which I identify as informing dominant institutional (eg policy for synbio, as well as synbio scientific) discourses in this domain, and raise some problems with those typically unquestioned or unproblematized premises and promises. I then attempt to delineate different and more realistic starting points from which such a research program could be designed and developed, and worked into practice as an interdisciplinary collective learning program, in government, industry, and university research and teaching. This is necessary brush-clearing for our main focus, which is on a productive SSH research agenda for synbio in all its variants.

II UNEARTHING HIDDEN HUMAN, AND SOCIAL, DIMENSIONS

If as I assert, there are human and social, and possibly normative dimensions of an important R&D&I field like synbio which remain concealed or unstated (not necessarily deliberately, but also inadvertently), this has important consequences for what we hope to be an accountably informed and reflexively developing democracy. The conventional downstream social sciences research approach, by framing appropriate agendas as about social impacts, even if *anticipating* future social impacts, effectively describes the upstream technoscientific knowledge-culture as devoid of any social or human dimensions. In effect therefore it says that there are no social or human questions here, and that these only arise once social impacts begin to be generated, directly or indirectly. Even regulatory and governance frameworks which ‘gate-keep’ the technoscientific R&D into (usually) commercial societal innovations, frame these stages of innovation as ‘science-only’, through risk assessment.

Much STS has challenged this dominant institutional boundary-drawing, between ‘science’ and ‘society’, which is also a drawing of boundaries of control, and responsibility. As well as being in states of change themselves (which needs research), these also vary between governance regimes, or national policy cultures (Jasanoff, 1987). The sociology and political economy of these continually emergent processes remains an important object for policy-salient scholarly SSH research (see Section III). These also require synthetic biology as science and engineering, to adopt different approaches and indeed new self-definitions from normal ones, as well as to seek new relationships with diverse new stakeholders, who might help redefine, through policy, funder and public, and internal technoscientific debate, about the proper democratic purposes and priorities for synbio R&D&I (eg Schuurbijs & Fisher, 2009; range of synbio relations with/roles for social sciences: Synberc (Rabinow et al), IC-KCL (Marris), STIR, Fisher *et al*, BBSRC 2010)

A further domain of technoscientific culture which remains too-little researched, for synbio as well as for other fields, concerns the combination of the political-economy of technoscientific knowledge with that of symbolic action (Edelman, 1972). The Lancaster University Cesagen genomics and society centre coined the term, “the political economy of promise”, to describe the ways in which under the intense political economic pressures and expectations following the huge public (and private) funding of the 1990 Human Genome Research Programme, genomics research in particular has become used to projecting spectacularly ambitious but equally spectacularly *questionable* – and with the benefits of hindsight now to evaluate those promises for their delivery or failure to deliver – promises of extravagant social benefits which the R&D will provide. The point is that such promises have falsified themselves substantively and repeatedly, yet as Waterton *et al* (2013) have shown for the salvatory promises of DNA Barcoding of global biodiversity, such promises, crucial for persuasion and big-funding, appear to have little meaning for the credibility of the science making those promises – except paradoxically as a basis for articulating another maybe more extravagant promise to society and its funders, from the (‘failed’?/‘successful’?) technoscience. Implicitly here, technoscientific actors’ imaginaries of future outcomes and societal benefits (thus also, selectively, of societal priority needs, as well as of the appropriate technical-social-economic means of meeting these) from their research are being allowed to intervene in and change society, with no accountability to the society which is funding, and being reshaped by, that technoscientific work. Thus a further upstream dimension of synbio emerges as given in Section III, to be in need of SSH research, with synbio technoscientists’ in collaboration if possible

III SOME PROPOSALS FOR SYN BIO SSH RESEARCH

The brief discussion above indicates some interesting and important, as well as original and path-finding, SSH research agendas, most of which would also need thoroughly prepared interdisciplinary collaboration between SSH and technoscientific researchers, and including commercial, funding, and policy actors too, as appropriate.

(i) What is “Synthetic Biology”?

This research question is raised because there is actually so much confusion and inconsistency about the answer. Moreover, this inconsistency is not something which can be pinned only upon ignorant publics, NGOs, or media, lacking adequate information though they usually are. The synbio technoscientists who are often mistakenly assumed to be fully informed about their own field and any risks which it may carry, should also be investigated by technically informed SSH scholars, as to their own definitions and understandings of synbio, and these analyzed for their inconsistencies, their boundaries, and their implicit definition of the natural and the human. One might well expect these to be systematically differentiated within the synbio technoscientific field in a similar way to those of genomics-related scientists for their own variable understandings of their basic scientific objects, the ‘gene’ and the ‘genome’ (Stotz, Griffiths, & Knight, 2004; Griffiths & Stotz, 2006).

(ii) However the point of asking this question about synbio as a field of technoscientific discourse-practices (as was true of the research on the ‘gene’ question too) is not to assume a singular objective answer and proceed to find and communicate ‘the’ true definition. It is to show the variability of expert synbio practitioner understandings of what they are doing, and of what they believe or claim synbio can do for society. Many such definitions of synbio are straightforwardly conventional biotechnological research. Others range through to completely unprecedented synthetic DNA or novel DNA equivalents whose biological viability, let alone functional value for society is claimed or promised, but untested. In addition the epistemic shift towards the principle as expressed by several leading synbio spokespersons, that to know any natural process, we have to build it and make it work (Dupuy, 2007), has provided legitimation for potentially limitless experimental interventions into society (not to mention, nature) with little realistic prior regulatory assessment in the public interest. This state of affairs suggests an important research agenda concerned to understand what synbio practitioners understand their technoscientific field to be, and on what epistemic foundations they understand it to rest – for example do they believe that government regulation is founded in risk assessment? Is this adequate? How do they think that risk assessment can be done, when the technological objects supposedly subject to that risk assessment, cannot even be precisely defined, as putative causal agents of supposedly definable risks? How does such unfounded risk assessment deal with ‘scientific uncertainties’ (contingencies, ignorance, ambiguity) beyond known consequences of known likelihoods? What further governance questions or appraisal processes might be necessary to address such lacunae, and how could more upstream anticipatory processes be defined, tested, and institutionalized as part of the governance of such emergent technosciences? How might these be developed in conjunction with the new governance approaches to responsible research and innovation (RRI)?

- (iii) Given the intense promise-based legitimacy discourses of synbio, in face of the very modest actual fulfilment of these justificatory promises and the huge funding invested in the field, how could these promises be included in the agenda of appraisal for governance purposes for such technosciences? How do *internal* technical failures or inadequacies of the technoscience come to be defined as failures caused by external factors such as public ignorance and inability to treat such promises of social benefits as if real evidence-based achievements as distinct from functional myths (Ezrahi, 2013) of synbio and its supposed achievements and societal contributions?
- (iv) how are the technosocial imaginaries and promises formed, on which synbio is fueled? with what combinations of internal technical and external socioeconomic factors? What practical epistemic status do such promises and imaginaries have with technoscientists, funders, policy actors, NGOs, and other stakeholders such as publics? How are these evaluated by this same range of actors, once their promised outcomes are open to evaluation by those affected? What would it take to include these promises as objects of regulatory appraisal for the technology or any specific case of synbio innovation? And on what arguments would this be resisted, by which actors? What further dimensions beyond case-by-case scientific appraisal are required for adequate anticipatory governance of synbio? Why is there no such ‘upstream’ debate even begun, let alone any institutional experimentation with forms of anticipatory appraisal of such promises, when these promises raise such manifestly important societal questions?
- (v) When technoscientific synbio experts state for persuasion purposes that their innovations ‘work’, what does this mean? And how might this be interpreted in different contexts of relevance, for example in laboratory situations, regulatory arenas, funding proposals, media publicity, or in public engagement processes? For example ‘working’ for lab situations, might mean bare reproductive viability (like DNA replication rather than sexual reproduction), whereas for society it might mean more, such as being functionally successful for purposes of introduction of new useful traits into plants or other organisms. Are confusions traceable in such crucial languages of synbio’s claims to ‘work’ for society? How do such confusions confound adequate societal appraisal of and decision-making for synbio, and how could they be better controlled?
- (vi) There are a range of research questions for synbio, in connection with the induction of what Schuurbers and Fisher (2011) call second-order reflexivity of the field, in dialogue with appropriate stakeholders and publics.
- (vii) The same is true of public and other stakeholder dialogues with synbio (BBSRC, 2010), an involvement which could be designed as ‘upstream’ engagement about the driving purposes, and alternatives to, and not only consequences of, synbio research. Who is excluded from defining R&D aims, imaginaries, and social needs for synbio, which could productively direct it better towards meeting social needs and aims?

IV CONCLUSIONS

Probably the most important principle for defining a beneficial SSH research agenda for synbio, is to recognize the historically unprecedented intensity of the promissory political economy which drives and selectively shapes synbio R&D&I. This heralds a shift of epistemic principles, in which the defining importance of the ambitious promises that

constitute the field are recognized as if they were evidence-based when they cannot in principle be evidence-based. These key promises could then be subjected to a novel and expressly experimental process of regular institutional appraisal to inform policy decisions, in regulation of innovations in this field. This becomes especially important not only as a basis of repairing or at least limiting public mistrust, but also to compensate for the fact that synbio objects are elusive as objects for risk assessment or other appraisal methods which rely upon, and effectively claim, prediction of undesired consequences.

It is an as-yet unacknowledged predicament – even a contradiction - for such a dynamic, variable, flexible and distributed domain of technoscience, that one cannot seriously pretend to predict causal consequences, if one cannot even define precisely what is the technology in question which is causal agent of its consequences. Thus if this key, almost the only regulatory/governance instrument is rendered moribund, research to identify, develop and test an appropriate functional portfolio of alternative instruments becomes a vital SSH synbio research agenda.

V REFERENCES (to be completed...)

M. Edelman, *Politics as Symbolic Action*, Chicago University Press, 1972

P. Griffiths & K. Stotz, 2006, “Genes in the Postgenomic Era”, *Theoretical Medicine and Bioethics*, vol.27, 499-521

D Schuurbiens & E Fisher, 2009, “Lab-scale intervention”, *EMBO Reports*, vol.10 (5), 424-427

K. Stotz, P. Griffiths, R Knight, 2004, “How biologists conceptualize genes: an empirical study”, *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, vol. 35 (4), 647–673