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Chapter 8

Who Let the "Social Scientists" into the Lab?

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Introduction: Moving Away from 20th Century LCA

One of the reasons why new emerging technologies such as synthetic biology create growing public anxiety is they have now become part of the forces shaping the new era called "The Anthropocene" (Crutzen, 2002; IGBP, 2010; Robin & Steffen, 2007). In this situation, humans need to adapt to a new global environment that has never existed before, which is mostly created by us and with no clear references to the past to guide individual and collective action. Under the current trends of accelerated global change, where multiple socio-ecological

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constraints are increasingly intertwined (Rocktrom *et al.*, 2009), the development and diffusion of new technologies take on a completely new dimension: They not only serve to fulfill existing human needs and desires but become major forces shaping the dynamics of global systems in ways that in turn call for new and rapid forms of human adaptation.

In this context, traditional analyses focused on unveiling the potential health or environmental effects of new technologies, including life cycle analysis (LCA), are very much welcome, albeit insufficient to assess the broader aspects of sustainability of synthetic biology. What is at stake is our ability to understand the long-term viability of the new patterns of socio-ecological and socio-technical systems, which are likely to emerge from 21st century technological developments.

When it comes to LCA of emerging technologies, only limited research effort has been devoted to understanding the socio-economic impacts resulting from the introduction of new technologies within society. In contrast, considerably more attention has been paid to their impacts on the environment. Hybridization in the process of assessing ecological and socio-economic implications would benefit from being explored. What choice of indicators will make it possible to track important social values within a particular socio-ecological system? What are the social dimensions to be sustained? What tradeoffs have been made in the past between social and ecological sustainability and why? Traditional LCA is focused on tracking the environmental, and in some cases the economic, impacts of a technology. It is necessary to add the societal impact of emerging technologies to LCA to better understand the dynamics within the social formations driving sustainability transitions.

Given that we live in social systems that are organized, for the most part, around a plurality of values, research aimed at exploring social implications of emerging technologies should also involve anticipatory and participatory thinking. They should rely on experimental ways to integrate complex forms of knowledge assessment with more inclusive forms of stakeholders' engagement and citizen deliberation. One of these challenges is to improve the visualization of the socio-ecological and socio-technological choices we are faced with and to foster networks that bring practitioners together with scholars to promote the co-evolution of diverse forms of knowledge. A more inclusive form of LCA would be a useful tool in facing these challenges.

This chapter thus takes as its point of departure the assumption that LCA would gain from developing new ways of assessing innovations that are pluralist, inclusive of multiple disciplines, and, to a greater extent than at present, capable of implementing reflexive change and mutual learning, while maintaining a common focus on social robustness and sustainable, meaningful, and responsible developments. To this end, this chapter will explore the potential of using, upstream in LCA, collaborative epistemic networks such as interdisciplinary *trading zones* among scientists, engineers, ethicists, and social scientists.

A second assumption proposed in this chapter is that the articulation of plural techno-scientific visions and scenarios has to be embedded upstream in the LCA. First of all, interdisciplinary assessments of techno-scientific scenarios through trading zones would gain from occurring before the situation is locked in. If occurring upstream, these assessments will help understand the main factors, constraints, and drivers that are part of the technological innovation process. Moreover, trading zones organized upstream in LCA would contribute to addressing and translating technological uncertainties about potential risks to health and ecosystems in a way that can be treated by policy makers on a non-ambiguous mode. Finally, useful LCA will have to deal with the future in terms of both the evolution of technological innovation and its interaction with society, the environment, and other technologies. Again, trading zones would improve predictive accuracy if aggregating, upstream in the process, diverse perspectives from a variety of sources.

It is also proposed in this chapter that interdisciplinary trading zones upstream in LCA would be beneficial, especially if they allow the inclusion of downstream actors—such as end users and policy makers—in the technological innovation process. Contexts of innovation may be seen to consist of complex and intersecting knowledge and information-infused relations of professionals, technologies, laypersons, users, innovators, business and policy makers forming new constellations of collaboration, experimentation and reflection to meet societal challenges. An upstream dialogue between researchers and policy makers, for example, would help identify moments of safety or regulatory uncertainties in technological trajectories.

State of the Art: Crossing the Line "In and Out" the Laboratory

Recent research in Science and Technology Studies (STS) has been conducted with a goal to develop new theoretical frameworks based on trading zones, shared expertise, moral imaginations, and epistemic cultures that show promise for understanding and facilitating interdisciplinary collaborations (Gorman, 2004; Gorman & Mehalik, Gorman *et al.*, 2004; 2002; Knorr-Cetina, 1999).

Trading Zone, Interactional Expertise, and Cross-Field Collaborations

The metaphor of a "trading zone" was first developed by Peter Galison to explain how scientists and engineers from different disciplinary cultures manage to collaborate across apparently incommensurable paradigms (Galison, 1997). Through case studies in physics, Galison found that different epistemic communities had to first develop jargons, then pidgins, and finally full-scale creoles to be able to share perspectives across their own scientific paradigms. He noticed that despite coming from contrasting scientific paradigms, experts were able to develop communication processes that can be seen as a trading zone. In this trading zone, experts use what Bromme calls a group-specific language, which usually relies heavily on the development of metaphors as a bridge between different epistemic paradigms (Bromme, 2000). The concept of trading zones has been significant to better understand interdisciplinary collaborations. The "trade" metaphors adequately portray the way academic experts are increasingly used to meeting, exchanging ideas, learning from each other, and then returning to their epistemic community with concrete "goods" in the form of improved research practices.

In parallel with the reflection on trading zones, Collins and Evans (2002) have described the different levels of expertise that play a role in interdisciplinary collaborations: one of special interest to our research is the interactional form of expertise. The interactional expert corresponds to an agent who understands enough of the language and norms of the different epistemic cultures involved in the trading zone to facilitate the trade. For example, early in the development of MRI, surgeons interpreted as a lesion what an engineer would have recognized as an artifact of the way the device was being used; this breakdown in the creole between these communities was recognized and solved by an interactional expert who had a background in both physics and medicine (Baird & Cohen, 1999).

Trading zones might also incorporate collective overarching goals such as sustainability. Indeed, sustainability has emerged as the ascendant policy issue of the 21st century. While we continue to argue about the true definition of "sustainability"—particularly since it has become a fashionable buzzword for the policy community and related funding agencies—the challenge of converting our present socio-technical system to a "sustainable" system has developed as a new master narrative, inspiring policy discourse both in Europe and the United States. Trading zones that build around these collective overarching narratives need to apply what has been defined as "moral imagination" (Werhane, 1999). The concept of moral imagination assumes that human beings learn practical ethics from deep stories, collective archetypes, and unconscious, or often emotive dimensions of a problem or paradox that become models for ethical behaviors (Johnson, 1993). These stories are usually invisible, unquestioned, and progressively adopted as simple accounts of the reality (Sethi & Briggle, 2011). Moral imagination reasserts that these stories are contingent views that need to be confronted with the "epistemic other" (Wynne, 2009), when a serious dialogue about different world views is at stake.

This notion of moral imagination might also help shed light on some of the controversies around anticipatory governance. When it comes to anticipating human futures, some trends in STS have started to develop empirical methodologies that are capable of guiding decision making toward visualizations and framings that endorse multiple and varied values. These STS researchers have begun to reflect on models for engaging civil society actors and wider publics in the process of envisioning and assessing technological futures (Guston *et al.*, 2002; Sarewitz, 2005).

Epistemic Cultures and Negative Knowledge

The framework of epistemic cultures analyzes the dynamics of knowledge production—their amalgams of arrangements and mechanisms bonded through affinity, necessity, and historical coincidence (Knorr-Cetina, 1999). This framework might be useful to explore the potential for new modes of cross-sector (public/private) and cross-disciplinary collaboration between the life sciences and social sciences to develop reflexivity in scientific practices. Synthetic biology, in particular, has witnessed the development of these "lab-scale interventions" (Fisher, 2007; Rabinow & Bennett, 2009). The rationale behind these collaborative ventures is to identify social and ethical controversies further upstream in the R&D process. These collaborations also promote bridges that enable the communication of ethical and regulatory insights from the social sciences and bioethics component back to the laboratory. At the same time, such collaborative practices would benefit from being anchored in trading zones involving outsiders to the lab and non-institutional networks such as DIYBio or private conglomerates.

Part of the dynamics within epistemic cultures, the notion of "negative knowledge" (Knorr-Cetina, 1999) and the problematization of the non-production of knowledge (Proctor & Schiebinger, 2008), might illuminate some of the controversies around the safety/societal implications of synthetic biology. The concept of negative knowledge seeks to analyze the limits of knowing, the mistakes we make in trying to know, the things that interfere with our knowing, what we are interested in, and what we do not really want to know. This notion of negative knowledge might give insight into the way research agendas are built and delimited, especially when it comes to research oriented toward solving societal ills.

In this contribution, we postulate that trading zones have the potential to improve LCA by integrating interdisciplinary assessments through gradual co-production of methodologies, analyses, and concepts. Trading zones could act as spaces for the articulation of plural scenarios about technological innovations and, *ipso facto*, promote the transmission of social, ethical, and regulatory controversies from social sciences to the lab and vice versa. Trading zones could also act as spaces for the articulation of plural forms of LCA—the LCA itself, not the technology, becomes the boundary object—with the view to help improve the process of engaging members of the trading zone in more mutually beneficial trades. The merit of using trading zones goes beyond learning about a certain technological pathway taken as the boundary object. The merit of the trading zone is in the "cohabitation" it creates, in the interactive and iterative dynamics it instills between technological actors.

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Case Study: Probing the Concept of Trading Zone within Synthetic Biology

To explore the potential of using trading zones upstream in LCA, this chapter will focus on a case study inspired from the emerging field of synthetic biology. The extensive use of engineering concepts and metaphors in the emergence of synthetic biology in public and political discourses portrays the field as one easy to grasp and, at the same time, a very appealing and promising endeavor. These mechanistic representations are anything but new in biotechnology and genetic engineering, where metaphors or images constructed to represent new processes, products, and their potential effects have widely adopted mechanistic models. A good example is the use of "chassis"—sometimes "safe chassis"—to define the basic functionalities of a bacterial genome on top of which forward-engineered biological systems can be implanted. One of the subsequent challenges lies in assessing the power and role of these metaphors within trading zones between not only scientific and engineering disciplines but also social sciences and humanities. A corollary is to work from the potential of cross-disciplinary collaborative methods to study and develop two-way communication processes about societal, ethical, safety, and regulatory issues from the social sciences to the laboratory and vice versa.

The above-mentioned case study explores how trading zones actually function as a space to produce reflexivity for the life sciences involved in synthetic biology and the social sciences interested in the related implications. The reflexive governance of science and technology seeks to understand the contingencies on and conditioning by its own representations and interventions in the process of social choice. Reflexive collaborative thinking on the social and normative dimensions of synthetic biology and its applications is furthermore of paramount importance for policy-making communities: What is the impact of the synthetic biology community and its engineering practices on social or biological systems? What roles do engineering metaphors play in the regulatory debate about safety? As an innovative and potentially disruptive technology, will the benefits of synthetic biology outweigh the costs?

A Glance at Our Biotechnical Futures

Approximately 30 years ago, eminent scientists Waclaw Szybalski and Anna-Marie Skala pointed to new developments in science, which they suggested were giving birth to a "synthetic biology," a genetic frontier they placed beyond the mere analysis and description of existing genes to encompass the design of novel gene arrangements (Szybalski & Skala, 1978). Although Szybalski and Skala's 1978 assessment smacked then of prognostication, developments in genetics in the past two decades have made their vision a more concrete reality. In particular, advancements in DNA synthesis and sequencing have enabled the engineering of micro-organisms from discrete, or off-the-shelf, chemical parts, even allowing scientists to "design to specification" micro-organisms capable of performing novel functions. In 2006, for example, University of California–Berkeley researcher Jay Keasling and his colleagues at Amyris Biotechnologies succeeded in engineering a microbe to produce artemisinin, an ingredient in anti-malarial drugs. Another milestone was achieved in May 2010 by J. Craig Venter—an important figure in deciphering the human genome—and his research team when they successfully assembled the first synthetic bacterial genome and used it to take over a cell.

Thus, by promising a range of applications from bioenergy to biosensors, synthetic biology promises to have a transformative impact on the ways we engineer and manufacture biological matter. In brief, this new technology could turn specialized molecules into tiny, self-contained factories, creating cheap drugs and clean fuels. The following vision, described by Rob Carlson in an article in the *IEEE Spectrum* magazine, is a good example of the potential ontological changes we may be facing in this journey toward the molecular economy (Carlson, 2001:15):

> "In 50 years, you may be reading *IEEE Spectrum* on a leaf. The page will not actually look like a leaf, but it will be grown like a leaf. It will be designed for its function, and it will be alive. The leaf will be the product of intentional biological design and manufacturing. Rather than being constantly green, the cells on its surface will contain pigments controlled by the action of something akin to a nervous system. Like the skin of a cuttlefish, the cells will turn color to form words and images as directed by a connection to the Internet of the

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day. Given the speed with which the cuttlefish changes its pigment, these pages may not change fast enough to display moving images, but they will be fine for the written word. Each page will be slightly thicker than the paper *Spectrum* is now printed on, making room for control elements (the nervous system) and circulation of nutrients. When a page ages, or is damaged, it will be easily recycled. It will be fueled by sugar and light. Many of the artifacts produced in 50 years and used in daily living will have a similar appearance and a similar origin. The consequences of mature biological design and manufacturing will be widespread, and will affect all aspects of the economy, including energy and resource usage, transportation, and labor."

This vision is simultaneously futuristic and foreseeable, reminding us that synthetic biology is ultimately part of a technological continuum anchored in the Enlightenment and constantly progressing through techno-scientific breakthroughs, such as recombinant DNA technologies.

Behind this impression of a continuum, however, there is something salient in the visions populating synthetic biology; through intentional biological design and manufacturing, engineered life forms—from engineered yeast to Venter's "synthetic cell"—are becoming "factories" on their own. In short, while laboratories have grown into "factories" through twentieth century's collective imaginaries, today synthetic biology design turns the living cell itself into a factory. To this effect, Galison (1999) remarkably analyzed how scientific practices and understandings have evolved through the nineteenth century from an Enlightenment culture seeking to unveil nature's true face to a regime of mechanical objectivity. Scientific practices have progressed from those of intervening genial individuals to ones at ease building and supervising precise machines. The following excerpt depicts the transformations occurring within the sanctuary of the laboratory (Galison, 1999:33–34):

"Many features of the laboratory and factory coincide; they are deeply linked, and often co-produced. One can point, for example, to worker discipline, centralized power sources, and architecture—as well as shared political economic ideals of maximizing work and minimizing waste. But for our purposes here, the key commonality is the joint fascination with the reduction of individual variability through the use of machines: the production of regularity as a positive virtue that

> was simultaneously moral and epistemic. It was here that the quieting of the will met the discipline and self-restraint of the factory.
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> ... Scientific laboratory workers had long taken on the mantle of self-disciplined supervisors of machine. When scientists announced with pride in objectivity that they would do nothing to impose individual variation on the regular, uniform, and reliable output of their machines, they were testifying not only to the power of science in industry, but to the conjoint understanding of laboratory and factory."

The vision of a future inhabited by "living factories" constitutes a significant and symbolic pace on the road to the molecular economy. It epitomizes and reinforces what some have called the production of "biovalue" within a "moral economy of hope" (Rose and Novas, 2005:442, 452):

> "Biology is no longer blind destiny, or even a foreseen but implacable fate. It is knowable, mutable, improvable, eminently manipulable. Of course, the other side of hope is undoubtedly anxiety, fear, and even dread at what one's biological future, or that of those one cares for, might hold. But whilst this may engender despair or fortitude, it frequently also generates a moral economy of hope, in which ignorance, resignation, and hopelessness in the face of the future is deprecated. This is simultaneously an economy in the more traditional sense, for the hope for the innovation that will treat or cure stimulates the circuits of investment and the creation of biovalue.
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> ... It also tries to encapsulate the ways in which life itself is increasingly locked into an economy for the generation of wealth, the production of health and vitality, and the creation of social norms and values."

This transition toward increasing reliance on the production of biovalue and the techno-scientific promises that surface in the aftermath presents a kaleidoscope of interesting epistemological and ontological claims. These claims predominantly rely on metaphors borrowed from engineering imaginaries and practices. For example, the influence of materials and computer engineering helps to explain synthetic biology's dominant vocabulary, with frequent references made to bricks, building blocks, fabs, open source, debugging, and plug-ins (Serrano, 2007). The extensive use of engineering concepts and metaphors in the emergence of synthetic biology portrays the field as one easy to grasp and, at the same time, a very appealing and promising endeavor (Specter, 2009). These mechanistic representations are anything but new in biotechnology and genetic engineering, where metaphors or images constructed to represent new processes, products, and their potential effects have widely adopted mechanistic models. Beyond the need to sketch the functioning of biological systems, these models also convey the implicit reassurance that these systems can be optimized and that they are reliable and under control; their behavior is predictable. This reassuring concept has also affected the design of regulation; mechanistic metaphors have been used as examples of mitigating uncertainties and managing safety aspects (OTA, 1989). Additionally, the effects of these images and metaphors are amplified by the fact that, as with most emerging sciences, the practitioners in charge of mapping synthetic biology are also concurrently inventing it (Sethi & Briggle, 2011).

There is no doubt that a lot of innovation will occur in the interstitial spaces between the disciplines involved in synthetic biology. But this emerging multidisciplinary smorgasbord will provide challenges in terms of the ability of new fields to regulate their own actions, anticipate unintended consequences, communicate effectively with each other and the public, and solve what some political scientists call "collective actions." There will likely be new challenges in managing ethical, social, and legal issues at the boundaries between disciplines. These emerging entanglements will give rise to questions and controversies—matters of concern—that we propose to highlight in the following point.

Engineering Life or Engineering for Better Life?

Synthetic biology inspires controversy by claiming it can "engineer life." The claim is unprecedented among major scientific disciplines and suggests a commensurately unprecedented change to the way people understand and value nature. By virtue of its transformative objective, synthetic biology is at the forefront of what has been termed the "Molecular Economy" (Rejeski, 2010), as this integrative science borrows techniques and methodologies from a variety of disciplines, including genetics, molecular biology, information technology, and nanotechnology. Synthetic biology harnesses these fields in pursuit of the design and development of biological systems, frequently of high complexity, which do not occur in nature; the technology offers wide application in fields as diverse as energy, medicine, and materials engineering (Endy, 2005; Rodemeyer, 2009; Serrano, 2007). While promising great scientific innovation, particularly in the spaces between traditional disciplines, synthetic biology also presents serious challenges. The emerging technology's regulation and development, its ability, or lack thereof, to control for unintended consequences, and its very identity, especially its communication and relationship with non-scientific audiences, represent significant contemporary obstacles.

Paralleling the field's burgeoning development and applications—in particular at the interfaces between individual disciplines—new and still unimagined ethical, legal, and social dilemmas will likely emerge in the near future and significantly challenge the existing frameworks that guide scientific practice. While synthetic biology will no doubt blaze its own trail, the pathway it follows will likely resemble that of another pillar of the molecular economy: recombinant-DNA technology. Its emergence similarly sparked unimagined ethical, legal, and public health concerns, not all of which are yet resolved (Wright, 1986a,b).

Above all, in the scientific and public spheres, synthetic biology fits into a regime of innovation based on techno-scientific promises and therefore is epitomized through metaphors and narratives that involve the articulation of a vision (Wynne *et al.*, 2007). Often this articulation takes the form of hype. Vision and hype are both types of discourse that look toward the future. The vision of synthetic biologists is a future where humans engage in the large-scale design and creation of new life forms that are exquisitely tailored for human purposes. The genetic engineering of organisms and the extensive design and manufacture of living things from virtual genetic sequences blur the line between machine and organism, life and non-life, and the natural and the artificial and thus transform the relationship between humankind and nature in ways that are exciting to some people but troubling for others (Bedau *et al.*, 2009; Pauwels, 2009).

In the near future, there might be a need to explore the readiness of the engineering profession to address the ethical and social issues associated with our bio-technical futures. The possibility of error,

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human and otherwise, is the reason why it is important to consider history when we think about future technologies. How well have we managed the introduction of other technologies? Have we, as a society, learned anything?

Synthetic biology thus crosses important technological frontiers, like the boundary between science and engineering, and is part of what has been called the "New Biology" (NRC, 2009). Such a revolution in the life sciences, its nature and goals, preferably would require parallel adaptations in societal governance, but despite the efforts of visionary researchers to overcome the divisions between the two cultures of humanities and natural sciences (Jasanoff, 2004), the New Biology has been imagined mainly under the auspices of biologists, other natural scientists, mathematicians, and engineers. A comprehensive understanding of the epistemic, ontological, and normative changes induced by this New Biology paradigm would benefit from the involvement of researchers from humanities, including social sciences and bioethics.

The "Two Cultures" Gap Revisited with Synthetic Biology

The successive reformulations of the nature and objectives of the life sciences—described in the above two sections—would gain from being accompanied by corresponding changes in the way synthetic biology is governed by and introduced into society. Thus far, policy responses to the development of new hybrid biological constructs have been quite limited in scope. Responses often take the form of creating ethics committees to study the implications of particular trajectories of research (EGE, 2009; PCSBI, 2010). This chapter argues in favor of a more comprehensive approach, addressing synthetic biology's full potential to influence human futures.

Too often, the public and policy debates surrounding synthetic biology have been narrowly focused around a utilitarian calculation of its technological benefits versus its potential regulatory risks. Although the technical aspects of synthetic biology policy are immensely important, spanning from controversies on ownership to socio-technical implications to biosecurity and biosafety concerns (nobody would like the re-engineered flu virus to mysteriously escape from the lab), fundamental questions about *what* applications of synthetic biology would advance societal goals and be considered sustainable are ignored and thus it limits the discussion to the opinions of a few technocratic elites. We need to think how to develop plural forms of LCA that are open enough to different epistemic cultures to be able to integrate these fundamental questions about how and when research in synthetic biology is being conducted to answer specific social and sustainability goals. This section continues with a recollection of attempts to consider different interests and concerns at the crossroad between science, society, and sustainability.

Some recent research initiatives have started to revisit what C. P. Snow called the "Two Cultures." Snow saw a growing divide between the cultures of the sciences and the humanities; a divide that continues to present an obstacle to responsible education and problem solving. The research initiatives discussed above promote different ways in which the cultures of science—far from standing apart from the rest of the academic disciplines—are in timely conversations with the cultures of the humanities, the social sciences, the arts, and the law.

One of these initiatives is called "lab-scale intervention." Nanotechnology—and to a limited extent, synthetic biology—has witnessed the development of these new modes of cross-disciplinary collaboration between natural sciences and humanities, which help develop reflective scientific practices (Fisher, 2007; Fisher & Schuurbiers, 2009; Fisher *et al.*, 2006). The rationale behind these collaborative ventures is to identify moments of ethical uncertainty and social controversies high upstream in the R&D process. These collaborations are also supposed to promote the transmission of ethical and regulatory issues from the social sciences and bioethics back to the laboratory. Encouragingly, recent studies show that it is possible to form an interdisciplinary trading zone in which a scientist and a humanist jointly explore a cutting-edge topic in nanotechnology (Fisher, 2007; Gorman *et al.*, 2004). Concretely, engineers and humanists become actively involved in the process of knowledge exchange, better described as "knowledge-trading," and consequently some engineers and humanists develop long-term interactions, building trust and enabling mutual learning by working together in hybrid collectives.

These long-term, cross-field collaborations are important for two reasons. On the one hand, such collaborations promote continuing communication "inside-out" the laboratory, which helps to ensure that there is mutual understanding and validation of the data produced. This refers to what Fortun and Fortun (2005) have

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described as the "ethnography of ethics"—assuming that reflexivity should also apply to social sciences—and "friendship with the sciences," which pictures a more positive collaborative engagement between lab scientists and embedded humanists. On the other hand, these collaborations sometimes function as forms of extended peer review, which favor cross-fertilization of knowledge (Funtowicz & Pereira, 2005).

In future, these collaborations of researchers from different disciplinary cultures could act as spaces for the articulation of plural narratives and metaphors that promote the transmission of scientific, ethical, and regulatory controversies from the social sciences to the lab and vice versa. This would function as a mirror or a "reflexivity tool" for the life sciences involved in synthetic biology design and the social sciences interested in the related implications. In a "knowledge society," this "reflexivity tool" could also be extended to the public sphere by including policymakers, NGOs, investors, and science journalists.

Ideally, such collaborative practices will require continual conversations with those outside the lab, including policy-making communities and non-institutional networks such as the Do-it-Yourself-Biology community and private conglomerates. Such an early dialogue between researchers and policy makers, for example, would help identify moments of safety or regulatory uncertainties in synthetic biology trajectories, or what Brian Wynne calls "epistemic other" (Wynne, 2009:13): "It is difference manifesting itself as an unknown set of realities, acting themselves as unknowns and beyond our control (but not beyond our responsibility), into a world we thought we controlled." Indeed, policy-making communities do not need only a clear perspective on the challenges posed by synthetic biology to ethics and politics, but they must promote, inside public policy communities, more reflexive thinking on the social and normative dimensions of synthetic biology design.

Though these cross-disciplinary attempts are still nascent, they already raise questions and require us to be critical: to what extent do these collaborative studies lead to better capacity to critically analyze the relevance of synthetic biology promises to societal goals? To what extent do they allow us to collectively experiment with possible alternatives within synthetic biology? To what extent will they succeed in developing co-production among multiple disciplines and perspectives from the outset as opposed to downstream reflection upon the ethical, legal, and social implications of synthetic biology?

Experimental Trading Zone around a Biological Chassis

Setting the scene of this trading zone

As a tentative answer to the above interrogations, this chapter introduces a few empirical reflections that arise from a six-month interdisciplinary study that included a limited group of about 15 experts in synthetic biology, technology assessment (including LCA) as well as regulators and members from civil society organizations. One goal of this working group was to bring together the technical, regulatory, policy and civil society worlds at an early stage of product development, in this case a genetically engineered arsenic test kit, so that concerns might be addressed upstream and during the development stage. A critical mass of the experts involved shared cross-field expertise, which allowed them to cross paradigms from life sciences, to social sciences and policy and, *ipso facto*, to shape and conceptualize the discussions along these boundaries. The working group gathered at several stages of the study in a kind of free-exchange—in which experts from different backgrounds jointly contributed to the eventual result. They also gathered around a common superordinate goal, which was flexible enough to be progressively re-framed. This superordinate goal is one of "sustainability:" the problem of arsenic contamination in Bangladesh and related efforts to create a low cost, low skill, accurate field test kit.

Boundary object

The working group concentrated its effort on the LCA of what could be seen as a boundary object—an arsenic test kit based on a *rE. coli* chassis. The current design uses *E. coli*, lactose, and bromothymol blue where the presence of arsenic causes *E. coli* to break down the lactose and change the pH of the water, resulting in a change of the water color overnight from blue to yellow. The system uses parts that exist in nature; what is new is the combination of them together in the same strain of *E. coli*. The test device uses JM109, a commercially available strain of *E. coli*, engineered so that it cannot survive outside the laboratory and has been mutated to prevent the transfer of genes

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outside of itself. The device is still in the early stages of development, and the developers still envision many hurdles to overcome.

Here some more in-depth reflections on the "chassis" metaphor are needed, especially as it constitutes the boundary object of this trading zone. Every descriptive language is not only metaphoric and interpretative but also developed *ad hoc* to fulfill a certain agenda. As metaphorical and interpretative as it is, the biology as chassis metaphor is now central to the challenge of developing useful and supposedly safe forward-engineered bacteria.

The design of microorganisms endowed with a growing number of edited and chemically produced genes that rewire cells for given purposes constitutes one of the key objectives of contemporary synthetic biology. Yet, such genes may still constitute a very minor portion of the whole bacterial genome, which provides the genetic and metabolic background that allows the synthetic genes to do their program. The metaphor of a biological chassis fits to perfection here, as it evokes the image of an internal framework that supports a man-made object, for example, in a motor vehicle, the wheels and machinery. By the same token, the basic functionalities of a bacterial genome provide a chassis on top of which forward-engineered biological systems can be implanted. The very representation of a chassis suggests the autonomy of the peripheral, implanted genetic circuits in respect to the basic cell physiology and heralds the ease of engineering biological objects with predictable properties. But, beyond these supposedly reassuring claims, how should the broader assessment of this artifact be organized? Discussions within the working group emphasized the caution with which any safety assumptions should be taken into account. Discussants highlight several sources of uncertainty: (1) unlike modular parts used in civil or electrical engineering, biological components are extremely context-dependent; (2) they interact with metabolites and chemicals; (3) their combinations generate emerging properties; and, last but not least, (4) cells which harbor them do not remain the same size, but they grow and multiply. Several of these issues cannot be ignored and make the metaphor even more complex to grasp and delicate to use as a boundary object. In an interesting manner, the plasticity of the metaphor as a boundary object echoes the plasticity of the biological chassis itself.

The divergence between the engineering agenda and the actual properties of biological building blocks highlights the importance of picking the right metaphors and employing the right descriptive language when dealing with living systems. But safety implications are not the only reason to be interrogating the imaginaries that inspire the use of the "chassis" metaphor. In the "chassis" imaginary, the scientists appear as architect and builders, constructing the system in a way that will suit a certain functional purpose. They see themselves as modifying what is already in nature and, *ipso facto*, producing a form of biovalue that has a potential to be developed and commercialized. This way of imagining themselves as somewhat inventing something new rather than only discovering what is already in nature can be seen in connection with a patenting model in which the inventor has the right to appropriation and benefit. The scientific endeavor is considered as a genuine business: scientific activity is seen as fulfilling a particular social need and scientists are seen as entrepreneurs—crucial actors in the sustainability market of non-western countries.

Both the questions of safety and ownership as harbored by the boundary object—the *rE. coli* chassis —have implications for two remaining components of the trading zone, the moral imagination component and the use of interactional expertise.

Moral imagination

In the course of the discussions about the biological chassis, the trading zone participants realized that "efficiency" is a key to understand the ways in which life is imagined in synthetic biology. Particularly in an extreme approach to synthetic biology, a good design is one that is efficient. In the field of synthetic biology, it is common to see a prominent number of applications, which are targeted to enhance "efficient" pathways to sustainability. For instance, designing algae that will efficiently capture CO_2 or designing bacteria that will detect arsenic in water are examples of bioremediation applications. Again, the idea is to design systems that are highly efficient and fully controllable. This efficiency approach to sustainability entails a radically mechanistic way of imagining nature. However, in many other cases, the idea of sustainability is built from differing ways of viewing nature: for instance, when nature is imagined as resisting standardization and being able to behave in unpredictable ways. We see how different ways of imagining the nature and complexity of living systems will influence different views on sustainability and the kinds of actions s and employing the right descriptive iving systems. But safety implications ›e interrogating the imaginaries that " metaphor. In the "chassis" imaginary, hitect and builders, constructing the a certain functional purpose. They see it is already in nature and, *ipso facto*, that has a potential to be developed of imagining themselves as somewhat ather than only discovering what is in connection with a patenting model right to appropriation and benefit. The ered as a genuine business: scientific articular social need and scientists are ial actors in the sustainability market

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to be taken. This focus on the chassis metaphor and the related imaginaries helped open plural and broadly scoped discussions on values.

The focus on imaginaries may open up the possibility for two participants in a trading zone to realize that their values on issues like what constitutes sustainability are only "relative" perspectives, and that it is worth comparing these different perspectives (Gorman *et al.*, 2009). Moral imagination is not relativism—not all perspectives are equally true or false. But moral imagination is the capacity to step into another person's imaginary, which stimulates the search for new imaginaries, new solutions.

In contradiction with the idea that sustainability issues—whatever they are—can be solved by a "technological fix" and subsequent education of lay publics, this exchange between two trading zone participants is eloquent:

Participant 1: "There are different reasons for resistance and concern that isn't simply because of ignorance for some. Environmental groups who work with groups around the world have concerns for very real potential risks to environmental safety, public health safety and social economic issues. It's not enough to say 'well if you educate everyone then all those concerns are going to go away.' Looking at what we've already learned from the conversation earlier in the day and what more we will learn as the conversation goes on, that there are some very serious and difficult issues relating to bioremediation and others. The more we learn about the science and the technologies, the more we learn more about the risks that one might be able to identify. It's not enough to just say it's a matter of 'not knowing' or 'ignorance;' it's more about the knowledge that we've gained on the subject, the more concerns that can be raised. And it shouldn't just be dismissed as pure ignorance."

Participant 2: "Is there a slightly mistaken assumption that in order for one to engage in this conversation requires technical knowledge? To do the latter parts of the risk assessment, to answer some of the question in regards to risk and to understand those answers during the risk assessment may take technical knowledge but that, in theory, locks you into looking at only the technical question. If you look at the conversation of risk assessment as one part that sits within the bigger picture of risk management, which also can include the question of what are your concerns and what can be done to take care of those concerns. Not just saying 'this technical reason takes care of those technical concerns,' which can lead into big arguments about 'how can I trust that technical answer if I don't understand the technology.' Looking at risk management procedures, for people who don't necessarily have the technical background but do have concerns. Their questions are 'don't tell me all the reasons why I'm not going to get sick, tell me all the reasons, ways and what you are going to prevent that organism from getting out so I don't get sick.' This directs the developer to thinking about ways to carefully run field tests that don't necessarily require the technical knowledge of all the stakeholders. Creates an environment where the developer is taking these concerns into account and is addressing them and the other stakeholders can see how their concerns are being addressed. One should almost take a step back and look at the bigger picture, viewing the exercise from a risk management perspective when engaging in a multi stakeholder's assessment process."

The above excerpts show how important it is to problematize ignorance as a subject of socio-ecological and socio-technical inquiry. In a way, it is an invitation to problematize the sociological and historical roots of the dynamics that lead to non-production of knowledge about what and who we are supposed to sustain. However, this process of "opening-up," beyond the temptation to avoid complexity and rely on technological fix, is usually promoted by the presence of different forms of knowledge and expertise in the trading zone. We will address this crucial point under the terms of "interactional expertise."

Interactional expertise

The discussion on moral imagination has begun to demonstrate the importance of introducing exogenous normativity into discourses of progress and the role marginalized and unconventional actors play in directing innovation. Such discussion might help to deconstruct the values, reasoning, and framings at stake in controversies over sustainability. In our experimental case study, this part of the discussion on moral imagination was systematically promoted by what can be seen as "interactional" expertise. A majority of the trading zone participants had enough knowledge and understanding of the language and norms of the different cultures involved in the zone to facilitate the trade. These agents were able to draw connections between the issues raised within the scientific and ecological discussions and also to put them into public policy and social b?

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perspectives. More specifically, they did not see the biological chassis only as a scientific invention that serves a specific social purpose but as a "living-tool" or better a "living-process" that would have to be introduced into a web of diverse practices: practices linked to human behaviors, cultures, and socio-ecological systems. Interestingly, what started as a "high-technological" conversation quickly focused on what participants decided to call "human practices." The free exchange of concerns below shows how the dynamic within the trading zone goes progressively from the boundary object—the biological chassis—to the same device being situated within a potential socio-ecological and socio-technical context. The exchange of concerns—the "trade"—acts as a tool producing an attitude of "reflexivity" among the participants.

Participant 1: "We need to understand human behavior in practice in order to evaluate and manage risks. For example, how users will dispose of the biosensor will have significant effects on risks. How human behavior is incorporated into risk models is a key piece of the discussion that is not well understood."

Participant 2: "How do you do human practice identification? You have to get the data from the community—talk to people or watch people. Does EPA have contractors to use to collect this data? There are government restrictions. Often to have to turn over to contractors, can be difficult—things get lost in the translation. EPA makes extensive use of contractors for many things."

Participant 3: "The way technology is deployed is important. What about regional and socio-economic value? People have to understand how to use the device. There is a need for a plan on how to educate the people and to popularize the device. There should be a standard disposal mechanism which should be transmitted to the people. Many people live in the rural areas. They may not know about the arsenic problem."

Participant 4: "Things to look at: survival of *E. coli*. What happens when it dies? What happens to the DNA? How does it die? This gets into values of stakeholders. Is there any harm? Issues of values become important."

Participant 5: "Who are the stakeholders and what are the public concerns relating to the chassis? What are the ecological ramifications for the microbial system? All of these factors and ideas of what is valuable differ."

Participant 6: "The stakeholder should be the planet, break it down into humanity and the ecosystem in which we live. Starting to think about it that way for now you can set that as a threshold, which in some ways makes things a bit more absolute, bound and clear then identifying all the subsets that you think of as a stakeholder. When it comes to micro-organisms that are likely to be released, either in the extremes of being released into the environment or if it's released into the body, then pretty soon after it's going to follow the same path as if it was released into the environment."

This shift in the discussion from the boundary object to the "stakeholders being the planet"— which targets potentially all socio-ecological systems where the device could be implanted—is nothing surprising. Only cross-field models of knowledge exchange—which draw upon and integrate empirical and theoretical elements from a variety of fields—may help in analyzing the interactions between multiple sets of actors as they interact in real-world entanglements. As argued by Voß and Kemp, "Considering the heterogeneity of the elements that play a part in sustainable development, effective problem treatment calls for the use of methods of integrated knowledge exchange that transcend the boundaries between disciplines and between science and society" (Voß *et al.*, 2006: 10-11). They also insist on the benefit of integrating "the tacit knowledge of societal actors"—which is "generated in interactive settings in which knowledge is co-produced by scientists and actors from respective fields of social practice." Concretely, citizen and groups concerned by the issues at stake get actively involved in the process of knowledge production, with the consequent result that some interactions between scientists and laypersons become permanent and build trust and mutual learning by working together in hybrid collectives.

Critical evaluation of the functioning of this trading zone

We understand the experimental trading zone described above as an exercise of "anticipatory governance" (Barben *et al.*, 2007): assuming that promoting reflexivity at an early stage of scientific development may have an impact on scientific practices and policies. We depart from the idea that the scientific endeavor is organized in a way in which room for reflexivity (about, for example, ethical, societal, and socio-economic issues, issues "out of the lab") is rare. From the

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scientific method to the experimental situation, scientific practices rely on a systematic neglect of natural and social complexities and uncertainty. The aim of this experimental trading zone is, therefore, to make possible a rare space in which black boxes can be opened and scientists can concurrently take on their additional role as humans and citizens. We call it experimental for several reasons: first, integrating, upstream in the technological innovation process, such a diversity of fields and sectors is quite innovative; second, instead of being "static" and fixing opinions—a common aspect of stakeholders and public consultations that has been criticized by sociologists of science—trading zones allow for iterative mutual learning and negotiation. The data gathered along the way through laboratory research, reports, schemas, and presentations and shared between trading zone participants are subject to continual questioning, review, and improvement. Within the trading zone, scientists, social scientists, technology assessors, policy makers, and regulators have been encouraged to open the "black boxes" that lie along the path of development of the arsenic biosensor device. This trading zone was an opportunity to "travel out of the lab" and to imagine the possible applications and implications of the biosensor they were in the process of developing.

Trading zone, shared expertise, and moral imagination have only been combined in a few pilot projects called, as mentioned above, lab-scale interventions. This framework needs to be tested and modified in a variety of other interdisciplinary contexts. Eventually, through the below diagnosis, we aim at unveiling some of the difficulties, limitations, and room for improvement when it comes to using trading zone within LCA.

The main success of this trading zone is that it successfully constituted an exercise of anticipatory and inclusive governance. First of all, the exercise happened extremely early in the process—much earlier than usual procedures of assessment—before and during the development stage. While occurring upstream, the trading zone helped understand the main factors, constraints, and drivers that are part of the technological innovation process. Moreover, the trading zone contributed to addressing and translating technological uncertainties about potential risks to health and ecosystems in a way that can be discussed early and treated potentially by policy makers in an inclusive setting. In addition, the trading zone improved participants' predictive accuracy by aggregating, upstream in the process, diverse perspectives from a variety of sources. These perspectives were used to build scenarios to deal with the future both in terms of the evolution of the biosensor and its interaction with society, the environment, and other technologies. The fact that these interdisciplinary assessments of techno-scientific scenarios occurred before the situation was locked in was crucial. This indicates that scenarios might be an important complement to the use of metaphors and group-specific languages within trading zones.

A second success relates to the depth and scope of the discussions happening within the trading zone. The inputs, questions, and criticisms raised by the trading zone participants did not focus only on risks and environmental impacts but span a broad range of concerns from policy and regulatory concerns to issues linked to ownership as well as societal, socio-economic, and cultural implications. Table 8.1 below illustrates some of the concerns expressed by the trading zone participants at the end of the discussion process. These concerns, because they span from very different perspectives, reflect how the trading zone works as a "black boxes opening" tool, as a way of keeping a technological issue complex (Stirling, 2010).

Table 8.1 Matters of concern within the trading zone

Examples of ecological concerns
"What will happen if the biological chassis enters the environment? Yes, every component already exists in nature, but what happens when they are combined? Will the new organism act the same? We don't know. How does the *E. coli* strain change in the field? Is there a risk of it getting stronger? What happens when it dies? When it comes to the synthetic organism and the receiving environment: Are you increasing the fitness of the organism? If it picks up another microbe's genes, can that increase fitness of the organism?"
Examples of policy concerns
"When to involve stakeholders in the LCA process? For what role? Are there faster avenues to provide assurances of environmental safety? What are the current regulatory standards and insurance standards?" "How will the public perceive the chassis? The public has a negative impression of GMOs and *E. coli*. The *rE. coli* chassis is based off of *E. coli*. How can you distinguish the difference between the two? Is it a question of missed perception?"

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Examples of regulatory and socio-economic concerns

"A lack of proof of harm does not equal safety. Where does burden of proof lie? We need to ask the right questions on risks and benefits. Consider the example of a Synbio company, created as private company in US then moved to Brazil. What of the regulatory challenges of US companies working in another country not covered by US regulations? There is the potential for export of harms. We need to treat the socioeconomic issues and the questions of liability. We should not look to the precedent of liability with GMOs and crops as a guide. There are issues in that case related to the fact that it is too hard for farmers to secure compensation for damages from contamination of their non-GMO crops."

Last but not the least, the trading zone gave an important space for the policy, regulatory, and civil society actors to voice their concerns and to intervene with feedbacks related to the development pathway of the biosensor. This reminds us that on the surface of this epistemic variety, a democratically committed knowledge society is supposed to have the scientific and political imaginations to work out how a plurality of social actors could share knowledge, practices, and experiences with diverse scientific, policy, and economic actors (Jasanoff, 2009). Beyond the distributed nature of expertise, what matters most is the consideration of the divergent socio-cultural contexts in which techno-scientific politics take place, *inter alia* the modes of knowledge making in the public sphere and the levels of accountability and trust in the knowledge produced (Jasanoff, 2005).

The critical reflections based on experimenting with trading zones invite us to provide a role for engagement of a more complex kind. In this case, scientists, engineers, and policy makers, sensitized through engagement to wider social imaginations, might decide for themselves to approach science and innovation differently. Interestingly, what interdisciplinary expertise help picture are hidden (1) *questions*, (2) *connections*, and (3) *suggestions* (Wilsdon, 2007): (1) questions might be about *what we don't know* and *how to learn what we should not do*; (2) connections might show the risky entanglements between public–private, global–local interests involved in techno-scientific promises; (3) suggestions might range from anecdotal evidence to alternative practice or alternative technology scenario. As explained by Stirling (2009) about current discourses on sustainability:

> *"Often, the position is expressed as if there were 'no alternatives.' The questions asked are thus typically restricted to 'yes or no?'; 'how much?'; 'how fast?' and 'who leads?' If we move instead to more plural understandings of progress, then the quality of debate—and of the ensuing choices—thereby stands to be enriched. Instead of fixating on some contingently-privileged path, we might ask deeper, more balanced and searching questions about 'which way?'; 'what alternatives?'; 'who says?' and 'why?' This is the essence of a normative, analytic, epistemic, ontological—and consequently intrinsically political—project of 'pluralising progress'."*

Stirling's reflection left us with a daunting yet challenging array of questions of how to open technological controversies to discussion. In this perspective, the work of Arie Rip brings remarkable insights into the value of (1) enabling future-oriented actions between actors who share an environment and (2) supporting them to create narratives about the potential resulting uncertainties and ambiguities (Rip, 2006). More importantly, Rip stresses the need for *diversity* as a source of renewal by creating grey zones and interstitial spaces in existing orders and institutions where dissenting imaginations might be voiced. This reminds us that the ultimate challenge is about reviving atmospheres of our democracies, which allow for the expression of dissenting imaginations. The ultimate challenge is avoiding "high-pace techno-scientific politics" to withdraw from the democratic scene (*learning is forgetting*) and to cultivate the ability of "making things public" and turning "matters of facts" into "matters of concern" (Latour, 2005). At the same time, decisions about technological innovation pathways have to be taken and cannot be indefinitely postponed. The main question thus "simply" becomes: how do we make better decisions by creating a space for mutual learning about technological pathways and their socio-economic and political ramifications. As suggested by this contribution, such a space could be built around an ongoing trading zone. In a vibrant call, Latour invites us to give a chance to what he names *cohabitation* (2005: 20):

> "Can we cohabitate with you? Is there a way for all of us to survive together while none of our contradictory claims, interests and passions can be eliminated?"

It is the unveiling of these improved forms of collaborations that I wished to explore in this contribution. And eventually the term "cohabitation" should be preferred to "collaboration." Indeed, the concept of collaboration itself is a matter to be discussed. Cross-field and cross-sector collaborations have too often been considered as "fusion"—where actors converge toward a premeditated vision or goal, suppressing *ipso facto* the room for a diversity of knowledges, practices, and experiences; too often, collaborations are experienced as an attempt to co-optation—meaning that the instrumental support of a field, such as ethics, philosophy, or sociology, is required to make up for an interdisciplinarity of "façade." The term "cohabitation" entails more: it presupposes that we leave enough room for different frameworks of thinking to seat together, exchange, and ultimately develop visions that are based on a true diversity of claims, knowledges, and imaginations.

This contribution constitutes a thought experiment (Gedanken experiment) around the concept of trading zone. Echoing Latour's quote, this contribution emphasize the importance of the notion of *cohabitation* between fields, sectors, cultures, and ways of approaching regimes of techno-scientific innovation. Ultimately, how do you create the infrastructures so that complex ways of thinking from different fields, sectors, and cultures can meet somewhere and learn from each other? How can we think about forms of "cohabitation," where researchers from different fields could reflect together on research design, research questions, and trajectories? Is it possible for different socio-technical imaginations to cohabit? What are the necessary conditions (institutional, epistemic, political, and cultural) to develop different forms and places for reflexivity in different contexts such as the educational systems, the policy systems, or the laboratories?

Conclusion

The chapter aimed to fill critical knowledge gaps about the role of interdisciplinary interactions at the interface between life sciences and society. In this contribution, we postulate that trading zones have the potential to improve LCA by integrating interdisciplinary assessments through gradual co-production of methodologies, analyses, and concepts. Trading zones can act as spaces for the articulation of plural scenarios about technological innovations and, *ipso facto*, promote the transmission of social, ethical, and regulatory controversies from social sciences to the lab and vice versa. To explore the potential of using trading zones upstream in LCA, this chapter focused on a case study inspired by the emerging field of synthetic biology. The case study explored how trading zones actually function as a space to produce reflexivity for the life sciences involved in synthetic biology and the social sciences interested in the related implications. Beyond the academic community, the case study also included civil society actors and members of the policy-making communities, who needed not only a clear perspective on the challenges posed by synthetic biology to ethics and politics but also to promote inside public policy communities a more reflexive collaborative thinking on the social and normative dimensions of synthetic biology and its applications.

Current innovations, such as synthetic biology, have become part of what can be labeled *global change technologies*, thus engendering new socio-ecological structures that have never existed before on Earth. Innovations open up for possibilities to exploit or develop resources and to potentially improve quality of life in many ways, but they also lead to new structural disruptions, new forms of pollution, and in some cases, new large-scale irreversible transformations in global socio-ecological systems, which can be highly detrimental for sustainability. As such, this ambivalence cannot be handled using many of the assumptions, tools, and models, which have prevailed and have supported the growth of science, technology, and global markets till the present. *Global Change technologies* require carefully crafted appraisal procedures that promote anticipation and reflectivity in many of the prevailing practices in science and policy. Under the present predicament, we cannot afford to wait any longer for the unwanted—although not totally unexpected—negative consequences of global experiments derived from the careless implementation of new technologies. The effects can simply be too costly or just impossible to solve.

Immediate acceptability of synthetic biology cannot be taken for granted either. Corporations and public research institutes engaged in the development of these potentially global change technologies should also be very interested in promoting credible R&D governance arrangements capable of guaranteeing that these innovations fulfill the requirements, demands, and expectations of the societies in ənarios about technological innovations the transmission of social, ethical, and from social sciences to the lab and vice ential of using trading zones upstream in on a case study inspired by the emerging 'he case study explored how trading zones e to produce reflexivity for the life sciences ogy and the social sciences interested in Beyond the academic community, the case society actors and members of the policy-o needed not only a clear perspective on ynthetic biology to ethics and politics but ıblic policy communities a more reflexive the social and normative dimensions of ıpplications.

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which such technologies are to be implemented—e.g., in terms of long-term sustainability. This would require moving away from the twentieth century LCA model and learning how to better place science and technology in an array of socio-ecological contexts, including a long-term, global context. The harnessing of synthetic biology for sustainability will only be possible if special attention is paid to supporting a myriad of agents located at the interface of science, policy, and the public, so they can actively contribute to the development of new appraisal procedures that link these scientific and technological innovations to the current sustainability challenges.

References

Baird, D., & Cohen, M. (1999). Why Trade? *Perspectives on Science*, 7, 231–254.

Barben, D., Fisher, E., Selin, C., & Guston, D. (2007). Anticipatory governance of nanotechnology: foresight, engagement, and integration. In E. Hackett, O. Amsterdamska, M. Lynch, and J. Wajcman (Eds.), *The Handbook of Science and Technology Studies* (3rd ed.). Cambridge, Massachusetts: MIT Press.

Bedau, M., Parke, E. C., Tangen, U., & Hantsche-Tangen, B. (2009). Social and ethical checkpoints for bottom-up synthetic biology or protocells, *Systems and Synthetic Biology*, 3(1–4), 65–75.

Bromme, R. (2000). Beyond one's own perspective—the psychology of cognitive interdisciplinarity. In P. Weingart and N. Stehr (Eds.), *Practising Interdisciplinarity* (pp. 115–133). Toronto: University of Toronto Press.

Carlson, R. (2001). Open source biology and its impact on industry, *IEE Spectrum*, 38(5), 15–17.

Collins, H. M., & Evans, R. (2002). The third wave of science studies, *Social Studies of Science*, 32, 235–296.

Crutzen, P. J. (2002). Geology of mankind: The anthropocene, *Nature*, 415, 23.

EGE (European Group on Ethics in Science and New Technologies) (2009). Opinion n* 25—Ethics of Synthetic Biology. Available at http://ec.europa.eu/european_group_ethics/docs/opinion25_en.pdf.

Endy, D. (2005). Foundations for engineering biology, *Nature*, 438, 449–453.

Fisher, E. (2007). Ethnographic invention: Probing the capacity of laboratory decisions. In *NanoEthics* 1 (2), Springer. Doi: 10.1007/s11569-007-0016-5. Available at http://www.cspo.org/documents/Fisher_ProbingLabCapacity_Nanoethics-07.pdf.

Fisher, E., Mahajan, R., & Mitcham, C. (2006). Midstream modulation of technology: Governance from within, *Bulletin of Science Technology Society,* 26(6), pp. 485–496.

Fisher, E., & Schuubiers, D. (2009). Lab-scale intervention, *EMBO Reports Science & Society*, 10(5), 424–427.

Fortun, K., & Fortun, M. (2005). Scientific imaginaries and ethical plateaus in contemporary U.S. toxicology, *American Anthropologist,* 107(1), 43–54.

Funtowicz, S., & Pereira, A. G. (2005). Quality assurance by extended peer review: Tools to inform debates, dialogues and deliberations, *Theory and Praxis*, 2, 14. Jahrgang–Juni 2005, S. 74–79. Available at http://www.itas.fzk.de/tatup/052/gufu05a.htm.

Galison, P. (1997). *Image and Logic: A Material Culture of Microphysics.* Chicago: The University of Chicago Press.

Galison, P. (1999). Objectivity is romantic, *ACLS Occasional Paper—The Humanities and the Sciences*, 47, 15–43.

Gorman, M. E. (2004). Collaborating on convergent technologies—education and practice, *Annals of the New York Academy of Sciences*, 1013, 1–13.

Gorman, M. E., Groves, J. F., & Shrager, J. (2004). Societal dimensions of nanotechnology as a trading zone: results from a pilot project. In D. Baird, A. Nordmann, and J. Schummer (Eds.), *Discovering the Nanoscale.* Amsterdam: IOS Press.

Gorman, M. E., & Mehalik, M. M. (2002). Turning good into gold: a comparative study of two environmental invention networks, *Science, Technology & Human Values*, 27, 499–529.

Gorman, M., Werhane, P., & Swami, N. (2009). Moral imagination, trading zones, and the role of the ethicist in nanotechnology, *NanoEthics*, 3(3), 185–195. Doi:10.1007/s11569-009-0069-8.

Guston, D., David, H., & Sarewitz, D. (2002). Real-time technology assessment, *Technology in Society*, 24(1–2), 93–109.

IGBP (International Geosphere-Blosphere Programme) (2010). Annual Report 2010. The Royal Swedish Academy of Sciences, Stockholm. Retrieved from http://www.igbp.net/publications/annualreports/annualreports/annualreport2010.5.1b8ae20512db692f2a6800012043.html .

ıvention: Probing the capacity of laboratory
. (2), Springer. Doi: 10.1007/s11569-007-
http://www.cspo.org/documents/Fisher_
ethics-07.pdf.

ham, C. (2006). Midstream modulation of
rom within, *Bulletin of Science Technology*
6.

ı09). Lab-scale intervention, *EMBO Reports*
24-427.

. Scientific imaginaries and ethical plateaus
xicology, *American Anthropologist*, 107(1),

[2005). Quality assurance by extended peer
ebates, dialogues and deliberations, *Theory*
ıg-Juni 2005, S. 74–79. Available at http://
ī2/gufu05a.htm.

' *Logic: A Material Culture of Microphysics.*
ıf Chicago Press.

/ is romantic, *ACLS Occasional Paper—The*
ces, 47, 15–43.

ating on convergent technologies—education
e New York Academy of Sciences, 1013, 1–13.

& Shrager, J. (2004). Societal dimensions of
ding zone: results from a pilot project. In D.
J. Schummer (Eds.), *Discovering the Nanoscale.*

(2002). Turning good into gold: a comparative
ıtal invention networks, *Science, Technology &*
529.

wami, N. (2009). Moral imagination, trading
e ethicist in nanotechnology, *NanoEthics*, 3(3),
s11569-009-0069-8.

z, D. (2002). Real-time technology assessment,
ł(1-2), 93-109.

ere-Blosphere Programme) (2010). Annual
ıl Swedish Academy of Sciences, Stockholm.
//www.igbp.net/publications/annualreports/
eport2010.5.1b8ae20512db692f2a68000120

Jasanoff, S. (2004). *States of Knowledge: The Co-Production of Science and Social Order*. London: Routledge Press.

Jasanoff, S. (2005). *Designs on Nature: Science and Democracy in Europe and the United States*. Princeton, NJ: Princeton University Press.

Jasanoff, S. (2009). Governing Innovation. Paper presented at the Symposium *Knowledge in Question*—A Symposium on Interrogating Knowledge and Questioning Science # 597. Retrieved from http://www.india-seminar.com/2009/597.htm

Johnson, M. (1993). Moral Imagination: Implications of Cognitive Science for Ethics. Chicago: University of Chicago Press.

Knorr-Cetina, K. (1999). *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge, MA: Harvard University Press.

Latour, B. (2005). From realpolitik to dingpolitik or how to make things public. In B. Latour and P. Weibel (Eds.), *Making Things Public—Atmospheres of Democracy* (pp. 14–43). Cambridge: MIT Press and Karlsruhe, Germany: ZKM.

NRC (National Research Council), Board on Life Sciences: Division on Earth and Life Studies. (2009). *A New Biology for the 21st Century*. Washington, DC: The National Academies Press.

OTA (1989). New Developments in Biotechnology: Patenting Life—Special Report, OTA-BA-370. Washington, DC: U.S. Government Printing Office.

Pauwels, E. (2009). Review of quantitative and qualitative studies on U.S. public perceptions of synthetic Biology, *Systems and Synthetic Biology*, 3(1–4), 37–46.

PCSBI (U.S. Presidential Commission for the Study of Bioethical Issues) (2010). *New Directions—The Ethics of Synthetic Biology and Emerging Technologies*, Washington, DC. Retrieved from http://bioethics.gov/cms/sites/default/files/PCSBI-Synthetic-Biology-Report-12.16.10_0.pdf

Proctor, R. N., & Schiebinger, L. (eds.) (2008). *Agnotology: The Making and Unmaking of Ignorance*. Palo Alto: Stanford University Press.

Rabinow, P., & Bennet, G. (2009). Synthetic Biology: Ethical Ramifications 2009, *Systems and Synthetic Biology*, 3, 99–108.

Rejeski, D. (2010). Managing the Molecular Economy, *The Environmental Forum*, 27(1), 30–34.

Rip, A. (2006). A co-evolutionary approach to reflexive governance—and its ironies. In J.-P Voß, D. Bauknecht, and R. Kemp (Eds.), *Reflexive Governance for Sustainable Development* (pp. 82–101). Cheltenham: Edward Elgar Publishing.

Robin, L., & Steffen, W. (2007). History for the Anthropocene. *History Compass*, 5(5), 1694–1719.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, III, F. S., Lambin, E., *et al.* (2009). Planetary boundaries: exploring the safe operating space for humanity, *Ecology and Society*, 14(2), 32. Available at http://www.ecologyandsociety.org/vol14/iss2/art32/"32/.

Rodemeyer, M. (2009). New life, old bottles: Regulating first-generation products of synthetic biology. *Synbio 2*. Washington, DC: Woodrow Wilson International Center for Scholars. Retrieved from http://www.synbioproject.org/process/assets/files/6319/nano_synbio2_electronic_final.pdf.

Rose, N., & Novas, C. (2005). Biological Citizenship. In A. Ong and S. Collier (Eds.), *Global Assemblages: Technology, Politics and Ethics as Anthropological Problems* (pp. 439–463). Oxford: Blackwell.

Sarewitz, D. (2005). This won't hurt a bit: assessing and governing rapidly advancing technologies in a democracy. In M. Rodemeyer, D. Sarewitz, and J. Wilsdon (Eds.), *The Future of Technology Assessment*. Washington, DC: Woodrow Wilson International Center for Scholars.

Serrano, L. (2007). Synthetic biology: Promises and challenges, *Molecular Systems Biology*, 3(158), 1–5.

Sethi, L. M., & Briggle, A. (2011). Making stories visible: The task for bioethics commissions, *Science and Technology*, 27(2).

Specter, M. (2009). A Life of its Own—Where Will Synthetic Biology Lead us? *The New Yorker*, September 28, 2009.

Steffen, W., Crutzen, P. J., & McNeill, J. R. (2007). The anthropocene: are humans now overwhelming the great forces of nature? *AMBIO: A Journal of the Human Environment*, 36(8), 614–621.

Stirling, A. (2009). Direction, distribution and diversity! pluralising progress in innovation, sustainability and development. *STEPS Working Paper 32*. Brighton: STEPS Centre.

Stirling, A. (2010). Keep it complex, *Nature*, 468, 1029–1031. Available at http://steps-centre.org/wpsite/wp-content/uploads/stirling-paper-32.pdf

Szybalski, W., & Skala, A. (1978). Nobel prizes and restriction enzymes, *Gene*, 4, 181–182.

Voß, J.-P., Bauknecht, D., & Kemp, R. (2006). *Reflexive Governance for Sustainable Development*. Cheltenham: Edward Elgar Publishing.

Werhane, P. H. (1999). Justice and trust, *Journal of Business Ethics*, 21(2–3), 237–249.

History for the Anthropocene. *History*

K., Persson, Å., Chapin, III, F. S., Lambin, E.,
ndaries: exploring the safe operating space
ociety, 14(2), 32. Available at http://www.
.4/iss2/art32/"32/.

e, old bottles: Regulating first-generation
ogy. *Synbio 2*. Washington, DC: Woodrow
ter for Scholars. Retrieved from http://
rocess/assets/files/6319/nano_synbio2_

Biological Citizenship. In A. Ong and S.
mblages: Technology, Politics and Ethics as
(pp. 439–463). Oxford: Blackwell.

hurt a bit: assessing and governing rapidly
a democracy. In M. Rodemeyer, D. Sarewitz,
Future of Technology Assessment. Washington,
ernational Center for Scholars.

biology: Promises and challenges, *Molecular*
1–5.

). Making stories visible: The task for bioethics
d Technology, 27(2).

Own—Where Will Synthetic Biology Lead us?
ber 28, 2009.

McNeill, J. R. (2007). The anthropocene: are
ming the great forces of nature? *AMBIO: A*
vironment, 36(8), 614–621.

distribution and diversity! pluralising progress
bility and development. *STEPS Working Paper*
ntre.

omplex, *Nature*, 468, 1029–1031. Available at
g/wpsite/wp-content/uploads/stirling-paper-

78). Nobel prizes and restriction enzymes, *Gene*,

& Kemp, R. (2006). *Reflexive Governance for*
ent. Cheltenham: Edward Elgar Publishing.

ce and trust, *Journal of Business Ethics*, 21(2–3),

Wilsdon, J. (2007). *Public Engagement in Science*, Report of the Science in Society Session, Portuguese Presidency Conference—The Future of Science and Technology in Europe, Lisbon, 8–10 October 2007, Luxembourg: European Commission, EUR 23334.

Wright, S. (1986a). Recombinant DNA and its social transformation 1972–1982, *Osiris*, 2nd Series, 2, 303–360.

Wright, S. (1986b). Molecular biology or molecular politics? The production of scientific consensus on the hazards of recombinant DNA technology, *Social Studies of Science*, 16, 593–620.

Wynne B., Callon, M., Eduarda Gonçalves, M., Jasanoff, S., Jespen, M., Joly, P.-B., *et al.* (2007). Taking European Knowledge Society Seriously, European Commission Report of the Independent Expert Group on Science and Governance, Luxembourg: European Commission, EUR 22700.

Wynne, B. (2009). Daring to Imagine. Paper presented at the Symposium *Knowledge in Question—A Symposium on Interrogating Knowledge and Questioning Science* # 597. Retrieved from http://www.india-seminar.com/2009/597/597_brian_wynne.htm.