Governance Strategies for Living Technologies: Bridging the Gap between Stimulating and Regulating Technoscience

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Abstract The life sciences present a politically and ethically sensitive area of technology development. NBIC convergence—the convergence of nanotechnology, biotechnology, and information and cognitive technology—presents an increased interaction between the biological and physical sciences. As a result the bio-debate is no longer dominated by biotechnology, but driven by NBIC convergence. NBIC convergence enables two bioengineering megatrends: "biology becoming technology" and "technology becoming biology." The notion of *living technologies* captures the latter megatrend. Accordingly, living technology presents a politically and ethically sensitive area. This implies that governments sooner or later are faced with the challenge of both promoting and regulating the development of living technology. This article describes four current political models to deal with innovation promotion and risk regulation. Based on two specific developments in the field of living technologies—(psycho) physiological computing and synthetic biology—we reflect on appropriate governance strategies for living technologies. We conclude that recent pleas for anticipatory and deliberative governance tend to neglect the need for anticipatory regulation as a key factor in guiding the development of the life sciences from a societal perspective. In particular, when it is expected that a certain living technology will radically challenge current regulatory systems, one should opt for just such a more active biopolitical approach.

1 NBIC Convergence and Living Technology

Up to now, engineering has been about building artifacts from nonliving material or influencing living organisms, for example through breeding. Today's technosciences are loaded with a higher ambition: to design and build artifacts and systems with lifelike features, such as the power to repair themselves, to grow and reproduce, to adapt and evolve, to show emotion, or to make complex decisions. Long-term ambitions range from building living cells from scratch to designing autonomous robots. Short-term

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ambitions include creating self-healing materials or developing cameras that can detect aggressive behavior. The words "living technology" capture this broad engineering trend in a clear and vivid way [4, 5].

1.1 NBIC Convergence

NBIC refers to four key technologies: nanotechnology, biology, information technology, and cognitive sciences. The interplay between those technologies is called NBIC convergence and is thought to be crucial for the successful development of new areas like molecular medicine, service robotics, ambient intelligence, personal genomics, and synthetic biology. This joint set of engineering fields promises a "new technology wave" [19].

Traditionally, the natural sciences have been divided into the physical sciences and the biological sciences. The physical sciences, like chemistry and physics, studied nonliving systems, while the biological sciences studied living systems. NBIC convergence challenges this historical divide and signifies the gradual dissolving of the tight borders between the physical and biological sciences [12–14, 31]. The convergence of the physical and biological sciences goes both ways, and each way represents a bioengineering megatrend. Arthur [1] describes these two megatrends with the catchphrases "biology is becoming technology" and "technology is becoming biology." "Biology is becoming technology" concerns the way the physical sciences (nanotechnology and information technology) enable progress in the biological sciences. This megatrend implies that we are increasingly looking at and understanding living organisms in mechanical and informational terms. The second bioengineering megatrend is driven by convergence in the opposite direction. Here the biological sciences—insights into biological and cognitive processes—inspire and enable progress within the physical sciences, including materials science and information technology.

1.2 Living Technology

The trend "technology is becoming biology" implies that technologies are acquiring properties we associate with living organisms, like self-assembly, self-healing, reproduction, and intelligent behavior. "Technology is becoming biology" is about bringing elements of lifelike systems into technology. Bedau et al. [5] therefore speak about "living technology." This development strongly relies on so-called biomimicry or biomimetics. The Swiss Blue Brain project presents an example of brain mimicry [15]. The engineers involved are building a computer model of the brain of a hamster based on physiological measurements. The aim is to get a better understanding of the brain and brain disorders. This way of reengineering the brain down to the molecular level may also contribute to the field of artificial intelligence. Moreover, engineers want to go beyond the mere mimicking of nature, and make steps in the direction of biologically, neurologically, socially, and emotionally inspired approaches toward science and engineering.

1.3 A Politically and Ethically Sensitive Area

The life sciences present a politically and ethically sensitive area of technology development [2]. Historically the bio-debate has been driven by developments in biotechnology, and in particular genetic engineering. Because of the increased interaction between the biological and physical sciences, NBIC convergence is radically broadening the bio-debate [31]. Apart from genetic interventions, the societal aspects of information-technological interventions in the bodies and brains of animals and human beings will take center stage in the political and public debate. But also, the "technology becoming biology" trend, which embodies an increase in bio-, cogno-, and socio-inspired artifacts, is expected to lead to various controversial issues. The prospect of living technologies becoming intimately integrated into our social lives will cause governments to face the challenge of how to both promote and regulate the development of living technology.

This article has the purpose of reflecting on this political challenge. We will first describe the strengths and weaknesses of four current political models in dealing with the dual task of promoting and regulating science and technology. Next, we will look at two specific examples of living technologies: (psycho)physiological computing and synthetic biology. We will reflect on the state of the art of these developments and what kind of regulatory challenges they raise. Moreover, we will inquire what kind of governance strategies would be appropriate to deal with these two examples of living technologies. In the final section, we will compare the findings from these two cases with the four political models that we have discerned in Section 2. From this we will draw some conclusions on how to deal with the governance challenges that are put forward by the development of living technologies.

2 The Political Challenge of Promoting and Regulating Innovation

Politics has the dual task of both stimulating and regulating science and technology. History shows various political approaches to this challenge. Here, we distinguish between four political models, which differ in the way they look at science and technology and its societal meaning (see Table 1). With regard to the public promotion of science and technology, some crucial elements are whether this activity is seen as value free or value driven, and to what extent its outcomes are seen as predictable. Related to these aspects, policymakers will perceive science and technology as an activity that might or might not be influenced through public interventions.

With regard to regulation, the role of public awareness about positive and negative social effects of science and technology and public trust in the political system to deal with these issues is important. Judging the possibility of assessing and/or anticipating potential negative effects of science and technology is another important aspect.

Positions also differ with respect to who should be involved in signaling, anticipating, and dealing with potential negative effects. We discern two models that rely on government-led risk regulation, either beforehand or after the fact. The other two models rely on the more decentralized governance of science and technology, that is, the involvement of a variety of societal actors in policymaking and/or the innovation process.

2.1 Reactive Regulation

Reactive regulation is the dominant model at this moment. Schot [22] describes this as the *modernist* practice of managing technology. The core of this practice, which gradually emerged during the 19th century, lies in separating the promotion from the regulation of technology. Science and technology development are politically positioned as neutral, value-free activities and justified by the promise of societal benefits to come. Moreover, science and technology are regarded as unpredictable. It is thought to be impossible to steer science and technology and subject them to democratic scrutiny beforehand. Regulators are therefore not involved in steering science and technology, but only in mitigating afterward its negative side effects in society.

This model has been criticized in many ways. For example, the German sociologist Ulrich Beck argues that this modernist regulatory practice is disempowering the political system, because "The political institutions become the administrators of a development they neither have planned for nor are able to structure, but nevertheless somehow justify" [3, p. 187]. Since the 1960s, various alternative ways of dealing with the democratic deficits of the modernist practice of managing technology have been developed [28]. These alternatives can be grouped under the term technology assessment (TA). "TA combines an awareness about potential negative and positive effects of technological change with the belief or hope that one can anticipate on these effects" [28]. Below we discuss three models that have developed within the history of technology assessment. Our analysis focuses on how these models deal with the dual political task of stimulating and regulating science and technology.

2.2 Anticipatory Regulation

During the 1960s, public awareness grew of potential health and environmental risks related to new technologies. Also the social influence of technology became widely acknowledged. At the same time, a TA movement was born in the United States, which resisted the idea that technological development was unpredictable and therefore not subject to democratic scrutiny. This movement claimed that rational scientific techniques would make it possible to forecast the direction of technology and

Table 1. Four political models to deal with the dual task of promoting and regulating science and technology (S&T). TA: technology assessment.

Political model	Promotion of S&T		Regulation of S&T	
	Science & technology	Political interference	Societal meaning of S&T	Political interference
Governmental approaches:				
Reactive regulation	• Value-free activity • Unpredictable	*Promotion*	• Promise of societal benefits • Unpredictable	*Reactive regulation*: Mitigating negative effects afterward
Anticipatory regulation	• Value-free activity • Possible to forecast direction	*Forecasting S&T*: Promotion & forecasting S&T	• Awareness of positive and negative effects • Possible to assess these in an early stage	*Classical parliamentary TA*: Informing legislators so that they can regulate negative effects in advance
Governance approaches:				
Deliberative governance	• Value-laden activity • Public acceptance of S&T is not self-evident	*Public understanding of science*: Promotion & informing broader public	• Negative social effects may diminish public trust in political system	*Participatory TA*: Early public involvement to stimulate public trust in politics
Anticipatory governance	• Value-laden activity • Unpredictable • Possible to influence technological paths	*Constructive or real-time TA*: Promotion & social reflection & public involvement	• Possible to deal with most social aspects in the design process	Anticipation of social aspects during R&D will make regulating negative effects less necessary and surprising

identify and evaluate in an early stage its potential secondary consequences [6]. This idea drove the institutionalization of classical parliamentary TA in the United States in the early 1970s and a decade later in several European countries. Classical parliamentary TA is built on the promise that the social sciences can provide early indications of the probable beneficial and adverse impacts of the applications of technology. Moreover, this timely information should enable decisionmakers to steer and regulate technological change in an anticipatory fashion.

This model of anticipatory regulation elicited many critical comments. Most fundamentally, the possibility of predicting the medium- and long-term social effects of complex technological systems was doubted. Accordingly, the claim of anticipatory decisionmaking based on predictive knowledge was regarded as illusionary [21]. Besides, it was doubted whether a small number of experts and political decisionmakers would have the capacity to make wise decisions about science and technology. These critiques have led to two governance-based approaches to deal with the dual task of stimulating and regulating science and technology.

2.3 Deliberative Governance

The deliberative governance model is based on the idea that informing legislatures about the social effects of technology is not sufficient. It is also necessary to involve the broader public in policy dialogues on technological change [26]. At the time parliamentary TA was institutionalized in Europe, this idea found fertile ground in Denmark and the Netherlands. During the 1970s, those countries had experienced the rise of social activism related to technology-related practices. In particular, many citizens became involved in the anti-nuclear-energy movement. As a result, controversies over technologies came to be seen as a problem between the government, the parliament, and the wider public. Legislators regarded public engagement as a legitimate add-on to representative democracy. As a result, a class of methods to involve a broad variety of actors in technology assessment were developed, which is normally referred to as "participatory TA" [12]. This involvement has taken various forms, including citizens' panels and juries, scenario workshops, roundtables, and consensus conferences [25].

Participatory TA is regularly criticized for having little impact on the political decisionmaking process [10]. In spite of this criticism, various forms of public deliberation have become more established over the last two decades. In particular, these forms have come to play a central role in the fourth model, which we call anticipatory governance [13]. This model is not so much focused on the relationship between government and society, as on the need for public engagement in science. It builds on the recognition that TA as a practice—within both the anticipatory regulation and the deliberative governance model—had become "lodged in institutions advising national parliaments," which according to Guston and Sarewitz [9, p. 96] "isolated TA from the R&D enterprise itself." At the beginning of this century, concerns about the science-society relationship and calls for public dialogue became part of the mainstream policy discourse in America [9] and Europe [12]. This provided fertile ground for the anticipatory governance model.

2.4 Anticipatory Governance

The anticipatory governance model is guided by the idea that social effects of technology should not be anticipated and accommodated from *outside* the innovation process, but *within* science and technology development itself [23]. This model builds on the tradition of constructive technology assessment [22] and the insight that science, technology, and society coevolve. Anticipatory governance does not envisage directly influencing regulatory practices, but addressing social issues by influencing design practices. This approach has been promoted under various headings. Think of ELSI research (linking research on ethical, legal, and social issues to publicly funded R&D programs, like the Human Genome Project in the United States), real-time TA [9], and upstream public engagement [33]. By positioning (participatory) TA as an integral part of the R&D process it was thought that many negative societal impacts could be foreseen during the innovation process and thus prevented. This would diminish the burden of regulating science and technology. As Sarewitz [21, p. 20] explains: "Rather than depending on the willingness of politicians to overcome their values and interests in making decisions about technology, real-time technology assessment seeks to build learning into the innovation process itself. This does not mean of course, that regulation will no longer be necessary, but it could mean it would be less necessary, and less surprising when it did become necessary."

2.5 Increased Institutional Preparedness

To what extent have these alternative models the potential to bridge the political and institutional gap between stimulating and regulating the technosciences? Answering this question depends on the way one conceptualizes technology development.

2.5.1 Linear Model of Technology Development

Both the reactive and the anticipatory regulation model are guided by an exogenous and linear model of technology development [28]. "Exogenous" implies that technology is developed in isolation from society. The linear model holds that new technological products emerge from the successive steps of basic research, applied research, exploratory development, engineering, manufacturing, and marketing toward commercialization. The idea that technology development leads to unpredictable societal progress leads to the dominant recent practice of managing technology. The core of this *modernist* practice lies in separating the promotion from the regulation of technology. This reactive regulation model implies no attempt to bridge the R&D and regulatory practice. The political standpoint that supports this practice is the argument that science and technology development are value-free activities. This ideological position ignores the fact that technology is deeply embedded in social, cultural, economic, legal, and political practices. Various social actors, with various visions and interests, are involved in innovations. By denying the value-ladenness of science and technology, the modernist practice provides the most powerful parties ample room to shape technology in their own interest. Such a laissez-faire, free-market attitude, thus, politically tends to favor the position of vested interests.

As we saw, this reactive model was criticized for its lack of awareness of the negative effects of science and technology, and the lack of institutional preparedness to deal with those effects. Anticipatory regulation aims to improve the preparedness of legislatures to deal with new emerging technologies. Guided by a linear model of technology development, and the belief that technology's effects on society can be forecasted, classical parliamentary TA was a clear attempt to bridge the gap between the R&D and regulatory practice. In fact, within this paradigm integrating TA within the political decision-making process actually bridges the gap. This argument can at least be made on the national level. The international nature of science and technology development, as well as business practices, however, introduces new levels of complexity with regard to regulating technology on an international or even global scale. This undermines the regulatory power of national states. At the same time, the lack of institutional capacity and international political preparedness to create and maintain regulatory practices to deal with the negative side effects of science and technology on a global scale is problematic.

2.5.2 Coevolution of Technology and Society

During the 1970s and 1980s *science and technology studies* (STS) developed a new paradigm to understand the relationship between science, technology, society, and politics. It was found that technology not only affects society, but is also shaped by society. This notion of unpredictable evolutionary co-construction of science, technology, and society opened up a new venue for thinking about democracy and technology. It showed that the politics of science and technology is not only a matter of regulatory, but also a matter of societal and R&D, practices. Based on this new and rich dynamic picture of technology development, classical parliamentary TA came to be criticized for working in isolation from society and also the R&D process. As we saw, two new governance approaches were developed to overcome these weaknesses and introduce TA in practices outside the regulatory one. The deliberative governance model aims at stimulating societal stakeholders to get involved in public and political debates on science and technology. Anticipatory governance aims to build social reflection into the R&D practice. Moreover, the notion of upstream public engagement promotes involving societal stakeholders within the R&D process. It is interesting to note that these two governance-based approached are criticized for being isolated from the political decisionmaking process [16, 27]. Lyall et al. [18, p. 270] even warn against the "'soft' wrapping of governance without the underpinning of 'hard' government."

2.5.3 Conclusion

It follows that anticipatory regulation, deliberative governance, and anticipatory governance provide ways to integrate technology assessment in regulatory, societal, and R&D practices, respectively (Table 2). These models provide complementary ways to increase the institutional preparedness to deal from a societal and political perspective with the development of new technologies. These models, however, do not form an integral way to bridge the gap between stimulating and regulating science and technology. While anticipatory regulation focuses on the political decisionmaking process, it is isolated from society and the R&D process. In their turn, deliberative and anticipatory governance have a strong tendency to neglect regulatory practice.

Lyall et al. [17, p. 10] therefore argue that the challenge for the future governance of the life sciences is "to incorporate the most useful aspects of governance-based approaches and reconcile them with the still necessary systems of regulation in a way that does not exclude key stakeholders from the policy debate." In the research project Making Perfect Life [30, 31], we have tried to look at NBIC convergence, including living technology, from both a governance and a regulatory perspective.

3 Living Technology as a Bioengineering Megatrend

The STOA project Making Perfect Life (MPL) [30] studied (psycho)physiological computing [7] and synthetic biology [24] as two examples of living technology, which illustrate the megatrend of technology becoming biology. The MPL project also focused on the rise of human whole genome sequencing [14] and the development of new neuromodulation techniques [32] as two areas that exemplify the megatrend of biology becoming technology. The aim of the MPL study was to highlight the (European) governance challenges arising from these four fields of 21st-century bioengineering. Our analysis focused on the extent to which the *sociotechnical dynamics* related to these four fields challenge current *regulatory practices*.

In the near or more distant future, living technologies may be applied within various social practices. For example (psycho)physiological computing may be used for surveillance or gaming. We prefer to speak of sociotechnical practices. New bioengineering technologies may be adopted in relatively stable sociotechnical practices, but also lead to significant changes of established practices, or new emerging sociotechnical practices. With regard to the dynamics of these practices, current forms of regulation may be perceived as adequate, as being put under pressure, or as no longer adequate. In the MPL project we have mapped, on the basis of this analytical framework, a variety of sociotechnical practices in different fields of bioengineering along two dimensions, providing us

Table 2. Overview of the four political models and their attempt to integrate technology assessment (TA) in regulatory, societal, and R&D practice, respectively. The symbol "+" indicates an attempt to integrate TA in a certain practice; "(+)" indicates a weak attempt; "0" indicates no attempt.

Political model	R&D practice	Societal practice	Regulatory practice
Reactive regulation	0	0	0
Anticipatory regulation	0	0	+
Deliberative governance	0	+	(+)
Anticipatory governance	+	(+)	0

with an overview of (1) the ways in which sociotechnical practices are (re)shaped by new bioengineering technologies and (2) the extent to which regulatory frameworks are challenged by these practices. Figure 1 maps how new advances in four bioengineering fields are (potentially) changing existing sociotechnical practices and enabling the emergence of new ones. Figure 2 shows to what extent the various sets of sociotechnical practices (may) challenge existing forms of regulation.

The four diagrams in Figure 1 depict a total of 20 different sociotechnical practices. The diagrams show that bioengineering technologies in the four areas studied are expected—at the same time—to leave certain practices more or less untouched, to lead to shifts in other existing sociotechnical practices, and to create new sociotechnical practices. In this last category we also find some bioengineering technologies that still have a highly speculative nature. This sociotechnical dynamics can be found both in familiar bioscientific areas relating to the human body and the brain (shown in the upper two diagrams), and in areas representing the emerging field of living technologies (shown in the lower two diagrams).

In the area of *(psycho)physiological computing*, Böhle et al. [7] identified seven (potential) application fields. In all these fields vital personal data are collected and interpreted by computer-based systems in order to adapt their own functionality or appearance to the mental or physical states of users. Health care and care of the elderly and the infirm are seen as the first areas where such biocybernetically adaptive systems will find use. Gaming presents a new sociotechnical practice where these systems will likely find early adoption. *Mind reading* is an example of a highly speculative future application. In the new emerging engineering science of *synthetic biology*, practices of standardization—including technical, safety, property, and broader societal standards—are seen as a first priority by major proponents of the field [24]. Standardization practices should enable short- and medium-time applications, based on more rapid and radical forms of re-engineering life. Building living cells from scratch belongs to the long-term ambitions of the field.

Figure 2 shows to what extent current practices of regulation are or may be challenged by the set of 20 sociotechnical practices that were identified. In all four bioengineering areas an extensive and complex patchwork of established regulations already exists. This system of regulations will shape the sociotechnical dynamics in these fields, but may also be challenged by those developments. According

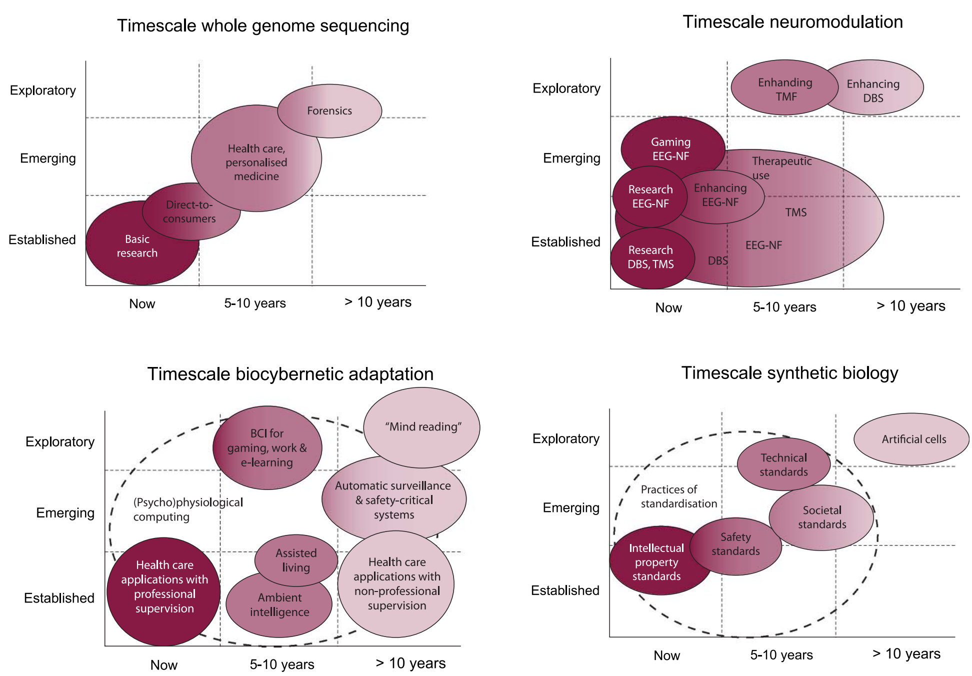

Figure 1. Sociotechnical dynamics in four different areas of 21st-century bioengineering (based on [30]).

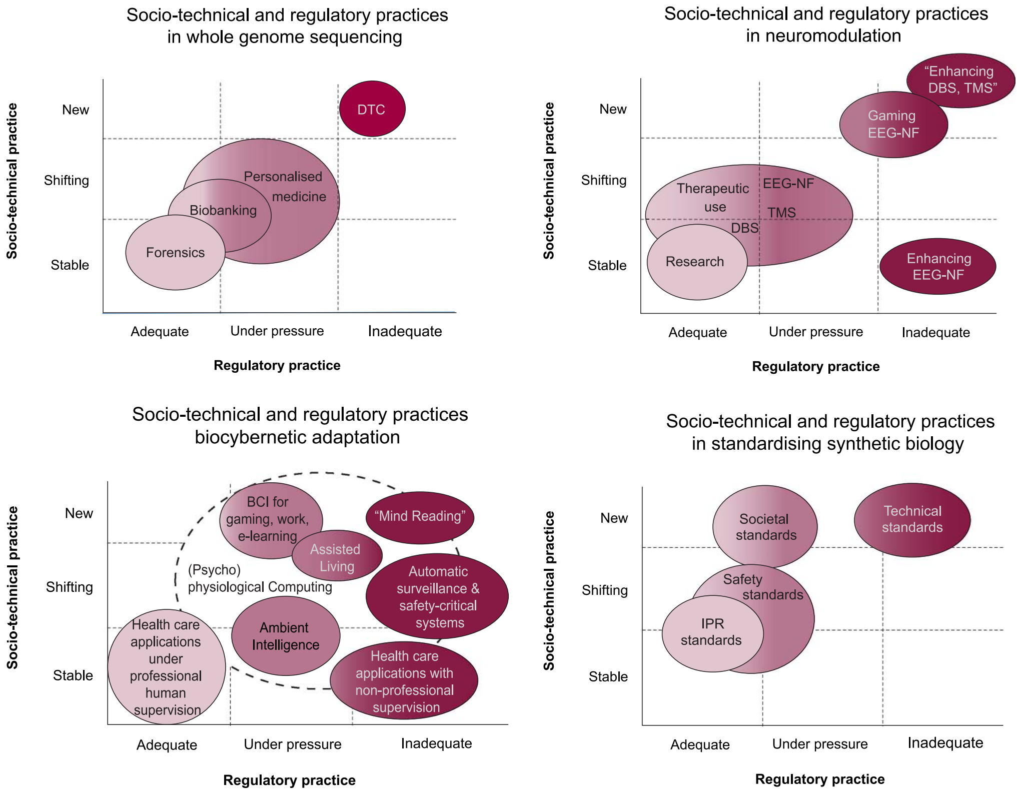

Figure 2. Regulatory challenges in four different areas of 21st century bioengineering (based on [30]).

to Böhle et al. [7], current practices of regulation are adequate with regard to the use of biocybernetic adaptation technologies in health care. The authors believe, however, that with regard to the use of biocybernetic adaptation in the field of ambient assisted living, the regulatory framework is already under pressure and might even become inadequate in the near future. The use of biocybernetic adaptation techniques in safety-critical systems or to automate surveillance is also seen as a future application that will require new forms of regulation.

In two important ways the foregoing analysis is relevant for our discussion of the governance of living technologies. A first point relates to our observation in the beginning of this article that the current bio-debate in our society is no longer driven by developments in biotechnology only. As bio-, cogno-, and socio-inspired artifacts become more and more integrated into our social lives, living technologies will prove to be a politically and ethically sensitive area. Figures 1 and 2 reveal that besides developments that fit within the "biology becoming technology" trend, also developments within the "technology becoming biology" trend already challenge current regulatory frameworks. This is especially true for the developments in the area of (psycho)physiological computing. Second, we have attempted to integrate in our analysis different technology assessment perspectives by including both *governance* and *governmental* approaches. Indeed, the question that has guided our analysis in the MPL project is how to *align* the dynamics of sociotechnical and regulatory practices in the different fields of 21st-century bioengineering.

4 Governance Challenges in Living Technologies

An important starting point for our discussion of this question is the three types of uncertainty that make governmental policies in the field of emerging technologies very challenging: technoscientific uncertainty, uncertainty about social and political values [8, 20], and regulatory uncertainty [11]. The sociotechnical dynamics, mapped in Figure 1, largely relates to expectations about future developments. It follows that political judgments have to be made under *uncertainty about the technological dynamics*, that is, the speed, direction, and nature of technological development. This dynamics, of course, also depends on the amount of political support given to technological development and the way it is guided. In the area of (psycho)physiological computing, applications in health care, assisted living, and gaming can be foreseen in the near future. Other expectations, however, relating to surveillance and mind reading, are much more speculative and uncertain. In the area of synthetic biology it is highly uncertain and controversial if and in what way technical standardization can be achieved [24]. The creation of artificial cells as a prospect is still far away.

As we saw, technological developments change existing sociotechnical practices and can lead to new ones. This dynamics may also influence the *landscape of social and political values* that play a role in public and political debate. For example, the use of biocybernetic adaptation in the field of human-computer interaction may entail shifts in public and political understanding of the values of privacy and autonomy. Moreover, the engineering spirit that drives the emergence of synthetic biology puts into question the value of intellectual property rights, so that communities dedicated to this new science promote an open source mentality.

Finally, as shown in Figure 2, sociotechnical dynamics involves *regulatory uncertainty*: Are existing regulatory frameworks still adequate, do they need to be extended to new practices, or should new sociotechnical practices be met by new regulatory rules and models? In the area of (psycho)physiological computing, privacy protection is a point of concern. One must consider that the regulatory implications will also depend on the extent to which privacy is still being viewed as an important political and public value. In synthetic biology the perceived future need for new safety and societal standards crucially depends on whether this field will really turn out to be a game changer.

Given these uncertainties, we will find among actors in the field different and often conflicting understandings of the governance challenges that are arising from developments in 21st-century bioengineering. These alternative understandings involve different views with regard to both the possibility and the desirability of particular bioengineering developments and futures envisioned in the field. In this respect, the question of how to understand these governance challenges and their policy implications is in essence a political issue, and clearly also a controversial one. In other words, it is a political task to decide what the regulatory challenge related to a certain sociotechnical practice is thought or expected to be, and how to deal with it (by regulation or by other means).

4.1 Three Governance Strategies

How to deal, in the light of these uncertainties, with the governance challenges in the field of living technology? As we have argued above, the fundamental governance challenge is to align the dynamics of sociotechnical and regulatory practices. The challenge that policymakers have to face boils down to three political options, based on different understandings of new bioengineering developments as *similar*, *possibly dissimilar*, and *dissimilar* to established sociotechnical practices and related regulatory frameworks (Table 3) [29]. Consequently, the recurrent political question is whether the sociotechnical practice enabled by new bioengineering developments can be considered as substantially equivalent to the sociotechnical practices that the existing regulatory framework intends to regulate.

In the first case—similarity—it can be assumed that new bioengineering developments can be regulated by the existing regulatory framework. In that situation a wait-and-see governance approach, as promoted within the modernist practice of managing technology, seems to be adequate. In the second case—*possible dissimilarity*—seriously addressing the question to what extent the new bioengineering developments may challenge current regulatory systems seems to be an appropriate strategy. Thus, a more active governance approach is needed, including research on ethical, legal, and social issues and stimulating public awareness and debate. In the life sciences, we have seen over the last decade the emergence of such an approach, which can be dubbed bioethics. In the third case—*dissimilarity*—the societal impact of the bioengineering development is expected to be large, and it is expected that

Table 3. Three governance strategies to deal with living technologies, based on different (political) understandings of new bioengineering developments as similar, possibly dissimilar, or dissimilar to established sociotechnical practices and related regulatory frameworks (based on [29, Tables 6 and 7]).

	Governance activities		
Governance strategy:	Wait and see	Bioethics	Biopolitics
Political choice:	Similar	Possibly dissimilar	Dissimilar
Kind of uncertainty			
Socio-technical	• Monitor socio-technical developments	• Monitor socio-technical developments	• Monitor socio-technical developments
Value		• Map ethical and social issues • Map and debate underlying ethical and social values • Create awareness via expert and public debate	• Map ethical and social issues • Map and debate underlying ethical and social values • Create awareness via expert and public debate
Regulatory		• Map legal issues	• Map legal issues • Start revision of the existing regulatory framework or developing new regulatory forms

the existing regulatory framework will have to be revised, or new forms of regulation will have to be developed. Such a political assessment requires an even more active governance approach. We speak of *biopolitics*, which includes taking active steps toward revising the existing regulatory framework or developing new regulatory forms to address societal issues. Let us finally apply these three options for governance to (psycho)physiological computing and synthetic biology as examples of living technology.

4.2 Governance Strategies for (Psycho)physiological Computing

In their discussion of developments in the area of (psycho)physiological computing, Böhle et al. [7] indicate that the current EU data protection paradigm—based on restrictions on data collection and use, purpose specification, security safeguards, and the principle of accountability—no longer matches the current and evolving situation in the field of IT. Nowadays, vast amounts of data are generated and stored in computer systems, which are often operated by many parties from different countries. This makes it harder and harder to comply with the above list of fair information principles. To illustrate this point, Böhle et al. [7] refer to statements of experts who believe that "Projects like Facebook, Ambient Assisted Living and Smart Grids simply ignore existing regulations on privacy and data protection."

Thus, according to those authors, the current privacy protection framework is already clearly under pressure, and widespread introduction of (psycho)physiological computing applications will seriously worsen the already problematic nature of the current regulatory system. Accordingly, they see it as wise to start working in a (pro)active way toward a fair information framework, which will guarantee baseline privacy protection (options 2 and 3). Moreover, future uses of automatic monitoring and surveillance systems and safety-critical systems will not only present a governance challenge with regard to privacy, but also raise discussions about safety (how reliable these new systems are) and about personal autonomy. Böhle et al. [7] argue that there is a need to regulate to what extent such systems should be allowed to function automatically, without human supervision, and to what extent users should be able to overrule the system. As a first step toward regulation, the authors plead for an international academic and societal discourse on these matters (option 2).

4.3 Governance Strategies for Synthetic Biology

In synthetic biology, the basic uncertain factor is whether this new field will be able to turn biology into a real engineering discipline or not. As we have argued above, such an assessment is basically a political decision, given the different and conflicting visions of this issue held by actors in the field. And the political choice that is made will, of course, be partially instrumental in shaping the future. If synthetic biology is seen as substantially equal to the current practice of bioengineering, no real extra public effort will be put into stimulating synthetic biology (option 1). Correspondingly, it is expected that the current regulatory framework is appropriate and there is little need to put extra regulatory effort into dealing with issues of standardization.

Option 3 suggests a totally different story about the governance challenge. Here, high expectations of synthetic biology's potential to radically change the practice of bioengineering would imply massive public efforts to stimulate the field. This option further implies that policymakers will anticipate that the current regulatory regime may come under more severe pressure. This would mean that policymakers have to anticipate the possibility that in the (near) future, gaps with regard to regulating safety and security may appear, intellectual property rights management may change, and societal standards for synthetic biology may become subject of more heated public debate. In this situation of high uncertainty, it may be argued that an open, proactive, and critical approach to synthetic biology (option 2) is the most appropriate governance strategy.

5 Do Not Dismiss the Need for Anticipatory Regulation

Above it was shown that living technology presents a politically and ethically sensitive area, which will increasingly challenge current regulatory systems. This implies that governments sooner or later will be faced with the political challenge to not only promote, but also regulate the development of specific living technologies. Based on the above sections, we may draw some conclusions with regard to this governance challenge (see Table 4).

At this moment the modernist practice of managing technology is still dominant. Thus in that case the political model of reactive regulation is followed to deal with the dual task of promoting and regulating science and technology. It was shown that such a wait-and-see strategy is an appropriate governance strategy in case it is expected that the current regulatory system will not be challenged by the dynamics of sociotechnical practices.

When it is thought that the dynamics of sociotechnical dynamics is likely to challenge current regulatory systems, a more active governance strategy seems to be appropriate, which we have characterized as bioethics. In the life sciences we have seen, over the last decade, the emergence of such a governance strategy, which aims to deal proactively with the ethical, legal, and social implications of R&D. As a result the modernist practice was complemented by activities in ethical commissions, linking

Table 4. The relationship between the four political models to deal with the dual task of promoting and regulating science and technology (S&T) and three governance strategies. The symbol V indicates that a certain governance strategy fits into a certain political model. The use of brackets indicates a partial fit.

	Governance strategy		
Political model	Wait and see	Bioethics	Biopolitics
Reactive regulation	V		
Anticipatory regulation		(V)	V
Deliberative governance		V	V
Anticipatory governance		V	V

research on ethical, legal, and social issues to publicly funded R&D programs, and government-led public dialogue exercises. This bioethics governance strategy is guided by two other political models to deal with the dual task of promoting and regulating science and technology, namely, the deliberative and anticipatory governance models.

In certain circumstances, however, the bioethics governance strategy is not sufficient [29]. In particular, when it is expected that bioengineering developments, including living technologies, will create many tensions between sociotechnical and regulatory practices, stimulating reflection on and debate about scientific developments and their societal implications is not sufficient. In those cases more engaging and democratic forms of biopolitics are needed. Besides attention for techno-scientific uncertainties and value uncertainties (as in bioethics), attention needs to be given to regulatory uncertainties and to the question of how policymakers and politicians might deal with them. Such a biopolitics governance strategy is based on the three TA approaches: besides deliberative and anticipatory governance, also including anticipatory regulation.

To conclude, we have distinguished between three governance strategies in order to bridge the gap between stimulating and regulating living technologies. Based on the extent to which the sociotechnical dynamics, as induced by a specific living technology, is expected to challenge the current regulatory system, one may choose a certain governance strategy. It should be stressed that such a decision is a political one. In case the regulatory system is not expected to be challenged, one can opt for a wait-and-see strategy. When it is regarded as likely that the regulatory system will be challenged in the medium term, a bioethics approach might be taken. In case it is expected that a certain living technology will radically challenge current regulatory systems, bio-ethics is not sufficient; one should opt for a more active biopolitical approach.

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