OFFICE OF TECHNOLOGY ASSESSMENT
AT THE GERMAN BUNDESTAG

Arnold Sauter
Steffen Albrecht
Davy van Doren
Harald König
Thomas Reiß
Rüdiger Trojok

assisted by
Sebastian Elsbach

Synthetic biology – the next phase of biotechnology and genetic engineering

Chapter VI.
DIY-Bio(techno)logy –
Actors and perspectives

November 2015
Working report no. 164

Chapter VI. DIY bio(techno)logy – actors and perspectives

This Chapter is a translated part of TAB Working Report no. 164:
Synthetic biology – The next phase of biotechnology and genetic engineering. Final report of the TA project (2015). (Originaltitel: Synthetische Biologie - die nächste Stufe der Bio- und Gentechnologie. Endbericht zum TA-Projekt. doi:10.5445/IR/310104566)

Translation: Anile Tmava (2024, funded by the John Fell Fund 'Viral Project')

A summary of the full report in English is available here: doi:10.5445/IR/1000137286

Büro für Technikfolgen-Abschätzung
beim Deutschen Bundestag (TAB)
Neue Schönhauser Straße 10
10178 Berlin

Tel.: +49 30 28491-0
Fax: +49 30 28491-119
buero@tab-beim-bundestag.de
www.tab-beim-bundestag.de

Cover photo: BCL (Georg Tremmel & Shiho Fukuhara), Common Flowers – Flower Commons, 2009. Photo by Kristof Vrancken/Z33

The Office of Technology Assessment at the German Bundestag (TAB) is an independent scientific institution which advises the German Bundestag and its committees on questions of scientific and technological change. TAB has been operated by the Institute for Technology Assessment and Systems Analysis (ITAS) of the Karlsruhe Institute of Technology (KIT) since 1990. It has been cooperating with the Helmholtz Centre for Environmental Research – UFZ, the IZT – Institute for Futures Studies and Technology Assessment and VDI/VDE Innovation + Technik GmbH since September 2013.

CONTENTS

DIY BIO(TECHNO)LOGY – ACTORS AND PERSPECTIVES VI.

In recent years, an increasingly self-confident, emerging movement of amateur biological researchers has been observed, often associated with the topic of synthetic biology (Synbio).

As will be shown below, DIY biologists are certainly not yet practicing Synbio in the strict sense, and in most cases, their technological and equipment standards lag years behind current professional levels. However, there are at least three important reasons to examine this phenomenon in the context of this report:

> First, the technological gap could shrink or even disappear altogether, especially if a central goal—or vision—of Synbio in the strict sense becomes a reality, namely the digital modeling and automated production of synthetic organisms.
> Second, DIY biology is already contributing to the debate on the perspectives of Synbio (in the broader sense), its social utility and desirability, and particularly the public's right to genuine participation in the research and innovation process.
> Third, concerns about potential biosafety and biosecurity risks associated with DIY activities are regularly raised, and in the United States, these concerns are being addressed by security agencies through direct intervention in the DIY bio scene (see Chapter VI.4.4).

The future significance of these aspects is naturally difficult to predict with precision. However, dismissing them with statements like "this will remain the same for the foreseeable future" or "this will never amount to anything" seems increasingly inappropriate in a time when communication and behavioral patterns are changing globally and across all social strata with unprecedented speed (Sauter 2013, p. 20). The starting point for the following discussion was the report by Engelhard/Hagen (2012), which, through interviews with actors from public and private research institutions, explored whether and what influences they expect from the DIY biology movement. A first deepening of the subject was carried out through a short expertise by Rüdiger Trojok (2012), along with a commentary report by Christof Potthof (2013) from the Genetic Ethical Network (Gen-ethisches Netzwerk e. V.). The final elaboration was conducted by Rüdiger Trojok in the course of another short expertise (Trojok 2014) and as an ITAS employee during the final report preparation.

LOCATING DIY-BIO 1.

The term Do-it-yourself Biology (DIY-Bio) refers to a very heterogeneous community of amateur researchers who conduct their experiments in domestic environments, rented lab spaces, or within clubs that operate small private laboratories (Engelhard/Hagen 2012, p. 31). Due to the conceptual similarity of the participants to the traditional computer hacker scene, members of this community, particularly in German-speaking regions, are often labeled as "biohackers." Terms like garage biology, outlaw biology, biohacking, biopunk, or DIY-genomics are used synonymously or at least are largely overlapping with DIY-Biology. However, some of these are also considered subfields or parallel movements. What they all have in common is that they involve biological, mostly biotechnological, and sometimes genetic research conducted outside of academic institutional research (Engelhard/Hagen 2012, p. 31). There is some terminological ambiguity concerning cyborgs and transhumanists, who are occasionally also referred to as biohackers, but they will not be further discussed here (Heil/Coenen 2013).

The participants in DIY-Biology can be divided into two groups: on the one hand, those with academic backgrounds in biological or biotechnological research, and on the other hand, those who are amateurs in biology (Engelhard/Hagen 2012, p. 31). The latter group is recruited from various natural and computer sciences, electrical engineering, and includes professionals such as engineers, as well as artists, designers, or entrepreneurs. Among the first group are some former iGEM participants who see DIY-Biology as an opportunity to work in a freer and more creative manner alongside institutionalized research. Alternatively, these may be researchers who wish to pursue extraordinary or very personal research projects alongside their academic careers, which they cannot realize within institutional research (Engelhard/Hagen 2012, p. 32). In recent years, a group of observers has also formed around DIY-Biology, including journalists, social scientists, philosophers, politicians, and not least, security agency personnel (see Chapter VI.4.4).

An exact determination of the size of the biohacker scene is not possible, as there is no reliable data, and in many cases, the classification of participants as startups, academics, artists, or genuine amateurs is unclear. It is estimated that there are globally a few thousand active biohackers. To best capture this heterogeneous scene, the following will provide a chronological overview of its development. This development can be roughly divided into four phases, which, however, proceed at different speeds locally/regionally and therefore blend into one another.

> Phase I: Pioneers in Art
> Phase II: Global Networking
> Phase III: DIY-Bio Founding Era
> Phase IV: Further Development of the Scene – Between Commercialization and Open Source

The four phases each highlight the first appearance of key players, their backgrounds, and their influence on both the DIY-Bio scene and society at large. It should be noted that the actors emerging in each phase generally remain constant stakeholders in the scene throughout its subsequent development, continuing to exert influence:

The first phase ("Pioneers in Art"; Chapter VI.2) dates back to the early 1990s when a small avant-garde art scene began engaging with biological themes and materials, laying the intellectual foundation for further development. This was followed in the early 2000s by a phase of "global networking" (Chapter VI.3), during which the scene—mainly consisting of scientists and students pursuing independent research ideals—gradually organized itself online. This development reached a preliminary peak in 2008 with the establishment of the digital networks "DIYbio.org" (with its namesake Google mailing list) and "Hackteria.org" (with a mailing list and associated documentation wiki). Through these networks, the scene began to exchange ideas globally, becoming visible and thus sparking public and institutional interest. The third phase ("Founding Era"; Chapter VI.4) is marked by the attainment of a critical mass of local participants, leading, since 2010, to the increasing establishment of so-called biohacker or makerspaces as venues for the community to meet in person. In various locations around the world, labs and communal spaces were and are being set up for the collaborative execution of diverse projects. In this context, issues of biosafety are among the topics of discussion. This process has continued steadily since then. A new characteristic of the current fourth phase is the increasing "development of the scene – between commercialization and open source" (Chapter VI.5), characterized by the creation of startups and professionally organized events such as trade fairs or festivals. These trends toward commercialization now raise specific questions for the scene—traditionally based on open exchange—about intellectual property and the underlying legal concepts. This chapter, therefore, draws a comparison to the open-source movement in the IT world. Finally, in Chapter VI.6, a future scenario is presented, which was conceived within the European biohacker scene. The concept of "Bio-Commons" addresses the questions raised in the previous chapters regarding the cultural integration of biotechnology, freedom of research, safety needs, and the common good-oriented economic use of new inventions, proposing a productive solution approach.

PHASE I: PIONEERS IN ART 2.

BIOART 2.1

Bioart is the artistic engagement with biological matter, such as tissues, bacteria, or living organisms in general, and/or the critical examination of biotechnology, including genetic manipulation, cell culture, and cloning. This art form is produced in laboratories, studios, and galleries. There are varying opinions on whether Bioart exclusively includes works related to living organisms or if it also encompasses related fields like medicine and biological research (Pentecost 2008).

Consequently, Bioart can be categorized under either "Science Art" or "Art Science." The former refers to the artistic processing of scientifically relevant materials or methods without significantly altering their content. The latter involves art produced using scientific methods or addressing scientific topics without claiming scientific validity. Science fiction falls into the "Art Science" category. The complexity of synthetic biology and its diverse theoretical possibilities attract participants from various backgrounds. In particular, the still undefined potential of synthetic biology leaves ample room for artistic interpretation and utopian ideas. In the early 1990s, a small, international avant-garde art scene began to emerge, focusing on biological materials and contexts. This scene has addressed ecological issues, adapted practices from modern biotechnology to create artworks or performances, and raised critical questions about the role of science in society.

For example, the Critical Art Ensemble (CAE), founded in the USA in 1987, has a long tradition of engaging with biotechnology and political activism (Potthof 2013, p. 16). The artist collective has highlighted the possibilities of using biotechnological interventions as a form of protest against genetically modified crops by the Monsanto Company (Critical Art Ensemble 2006). “They demonstrated what amateur science could achieve with relatively little effort, such as producing a substance that, when sprayed, would color Monsanto's Roundup Ready genetically modified plants without affecting other organisms in the field.”

In contrast, artist Eduardo Kac pursued a "contrary" approach by creating transgenic organisms as "art objects." In 2000, he created a transgenic rabbit by integrating a gene from the deep-sea jellyfish Aequorea victoria into its genome, which produced green fluorescent protein (GFP) (Fig. VI.1). Kac declared his intention to welcome the rabbit as a new member of his family, aiming to stimulate a public debate to highlight the social and ethical implications of genetic technology.[1]

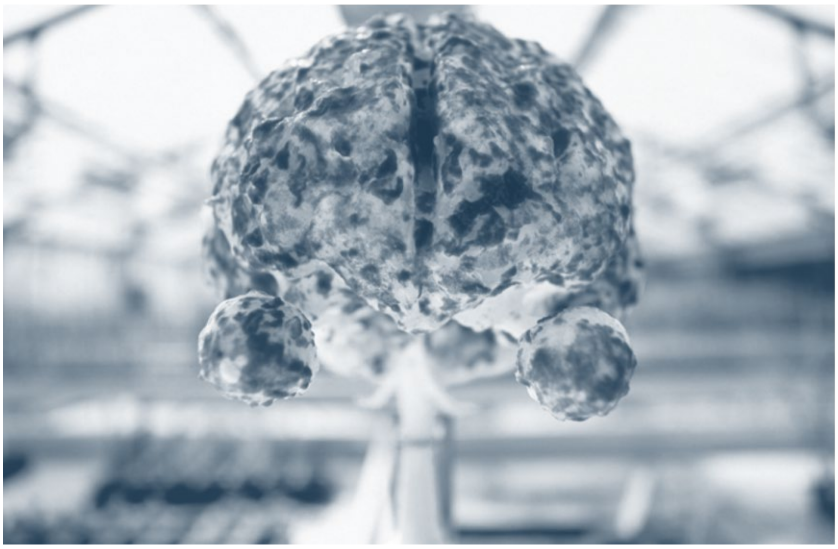
Fig. VI.1 Eduardo Kac in 2000 with His GFP Rabbit Named Alba at Home

Source: Chrystelle Fontaine; www.ekac.org/gfpbunny.html#gfpbunnyanchor (Accessed 30.11.2015)

Another example of using transgenic organisms as material for an art object is the glowing brain by the artist Jun Takita. A three-dimensional scan of his brain was enlarged and printed in plastic, then planted with transgenic moss that had integrated genes from a self-luminous unicellular organism (Fig. VI.2). This biologically glowing brain was subsequently installed in a lighthouse on the French coast, replacing the light bulb. The artwork was intended to highlight the role of humans as creators who intervene in the cycle of life.

1 www.ekac.org/gfpbunny.html (30.11.2015)

Fig. VI.2 Glowing Brain Made of Transgenic Moss ("Light, Only Light", First Version)



Source: Yusuke Komiyama; http://juntakita-artworks.blogspot.de/2012/03/light-only-light-light-only-light.html (Accessed 30.11.2015)

In contrast, artist Paul Vanouse took a primarily humorous and reflective approach. He exaggerated the minimalist concept of biohacking by performing the polymerase chain reaction (PCR) manually, in stark contrast to the usual industrial, highly automated method. He carried out this process in the Canadian wilderness, far from civilization, using only buckets of water heated by a campfire.[2]

Among the galleries, artist networks, and museums that bring Bioart to a broader audience, notable examples include the Center for PostNatural History[3] in Pittsburgh, USA, the German art gallery Art Laboratory Berlin[4], and the Ars Electronica Center[5] in Linz, Austria. The Center for PostNatural History presents its exhibitions in the style of classic natural history museums, but exclusively with preserved organisms that have been created by humans—whether through traditional breeding or as transgenic organisms. Art Laboratory Berlin, founded in 2006 by an international team of art historians and artists, serves as a platform for interdisciplinary exhibition projects, such as those exploring the intersection of art and natural sciences in an international context. The Ars Electronica Center was

2 www.paulvanouse.com/dwpcr.html (30.11.2015)
3 www.postnatural.org (30.11.2015)
4 www.artlaboratory-berlin.org (30.11.2015)
5 www.aec.at/news/ (30.11.2015)

The Ars Electronica Center, established in 2009, regularly features exhibitions on genetic technology, synthetic biology, and life sciences in general. It provides visitors and artists with access to an on-site biology lab and hosts an annual art festival. With the BIO·FICTION Science Art Film Festival[6], held in Vienna in 2011 and 2014, Bioart has found a dedicated platform at the intersection of citizen science (see Box VI.2 in Chapter VI.3.1), synthetic biology, and film art.

An influential network in the art scene is the Finnish Bioart Society[7], which focuses on the natural sciences, particularly biology. Since 2008, it has operated a polar research station in Kilpisjärvi, in the far northwest of Finland. In addition to creating original artistic works, the Society aims to stimulate public discourse on synthetic biology, biotechnology, and bioethics. It serves as a hub connecting science and art, offering regular seminars and workshops at a biology lab in Helsinki as well as at the polar station.

Overall, art in the context of biology represents a niche that is often reduced to the visualization and communication of scientific concepts. Some explicit artistic engagements with biology also stem from research policy interests in communicating science and technology. Artist Oron Catts comments on this phenomenon in an email to Engelhard/Hagen (2012, p. 50), stating: "… it is quite striking to see how artists and designers have been opted to engineer public acceptance for a new technology that does not really exist. I see Synthetic Aesthetics as being part of that. What is interesting with Synthetic Biology is that the funding for artists and designers has been put in place very early in the game by the proponents of SynBio as opposed to anything else I experienced in the context of art and new knowledge/technologies."

When the initiative and funding for artistic activities come from projects and resources focused on biological, biotechnological, or economic goals, the line between independent art and public information becomes blurred. While art can continue to play an important role in communicating, critiquing, and exploring potential societal impacts, it can also become instrumentalized, where the purpose of art shifts toward preparing the public for biotechnological developments. Regarding ethical boundaries, it is not entirely clear that art is fundamentally freer than science in this domain. Although artistic methods are particularly well-suited to address ethical questions in all their complexity, often in an exaggerated and provocative manner, this freedom can also come with challenges and limitations. The German artist collective Hybrid Video Tracks, for example, explicitly understood its

6 http://bio-fiction.com (30.11.2015)

7 http://bioartsociety.fi (30.11.2015)

contributions as a critical standpoint on the spread of biosciences and biotechnologies.[8]

At the same time, artists who work with biotechnological methods are not spared from criticism; in fact, they often provoke it—and frequently intend to do so. An example is Eduardo Kac's fluorescent rabbit: while the breeding of transgenic laboratory animals with jellyfish genes is routine biotechnology largely unnoticed in research labs, the transfer of this technology into an art project was highly controversial and generated enormous media attention (Costa/Philip 2008; Lindner 2007)

ART AND DIY-BIO 2.2

Due to the high effort that bio- and gene technology has required up to now, artists generally cooperate with scientific institutions and use materials, organisms, and methods already established for scientific purposes in their work. In the context of trends to co-opt art for science communication, it can be difficult for artists to maintain a critical distance from the subjects they address. Moreover, large institutions like the Ars Electronica Center primarily expect works with a strong public impact. While these can also be critical of science, they leave little room for the subtle critique found in "fine arts," as shown in smaller galleries like Art Laboratory Berlin, which tackle more complex ideas and themes, requiring more time and contemplation from the viewer. To avoid commercial pressure from sponsors and internal success pressure within the art world, and to work independently and autonomously with gene and biotechnology methods despite financial limitations, some artists in the early 1990s attempted to establish their own, cheaper methods, in the spirit of the DIY-Bio movement. As a result, artists have been an influential part of the movement from the beginning. Over the past few years, the projects, ideas, and goals of the two scenes have increasingly overlapped and intertwined. Artists benefit from the technological knowledge and the new, affordable methods and materials that biohackers develop. In turn, artists inspire "non-artist" biohackers with project ideas as well as socially critical perspectives. The interactions are as varied as the individual participants.

8 See also www.hybridvideotracks.org and www.blue-genes.de/index.html for texts by Hybrid Video Tracks, Critical Art Ensemble, Tissue Culture & Art Project/SymioticA, Thomas Lemke, Agentur (Kobe Matthys), Andrea zur Nieden, Paul Vanouse, and others. The catalog entries are documented online on the pages of the exhibition "Put on your Blue Genes" (30.11.2015).

While some biohackers with scientific backgrounds, for example, begin to produce and exhibit art, artists start constructing scientific apparatuses. Some of the resulting works, such as those by the Critical Art Ensemble, take a critical stance on society and technology, while others, like those by Eduardo Kac, appear affirmative. Potthof (2013, p. 17) interpreted the connection between the DIY-Bio and art scenes as an approach to overcoming the emotional rejection of transgenic biotechnology in the public sphere. Instead, through education and communication about genetic technology, an informed opposition is made possible. The artistic interpretation of the subject thus serves as a vehicle to facilitate understanding of biotechnology and as a means to productively process visions, hopes, and fears (Critical Art Ensemble 2006).

A characteristic of projects emerging from this connection is the difficulty in categorizing them as either science or art. In part, this ambiguity is intentional, as it allows the creators to avoid the politicization of their work; in part, it is an unintended consequence of their non-institutional working methods. Whether artists and biohackers claim scientific legitimacy for their work depends on the individuals involved and the nature of the project. An example of the cross-pollination between these scenes is the idea of "Bio-Commons" (Chapter VI.6), which was developed at the Finnish "Pixelache Festival." This annual festival explores themes at the intersection of art, science, and media and was co-organized in 2014 by the Finnish Bioart Society. Recently, institutionalized research and art have also started to open up to the activities of artists and biohackers. This is evidenced by the increasing presence of both scenes at events like the BIO·FICTION Science Art Film Festival and the exhibition of DIY-Bio scene works by galleries such as the Ars Electronica Center.

PHASE II: GLOBAL NETWORKING 3.

THE DIY-BIO SCENE 3.1

One of the core goals of biohackers is to make the knowledge and methods of life sciences accessible to a broader public (see Box VI.1). To achieve this, in the early 2000s, a number of mostly young scientists and engineers around the world began to network in digital forums, exchange experiment protocols, and discuss projects. Initially, these were mainly local groups or networks that developed within circles of friends and colleagues around the early pioneers.

By now, this has evolved into a global, highly decentralized citizen science community (see Box VI.2).

BOX VI.1: HACKING AND JUGAAD

Hacking means taking objects or ideas out of their original context and giving them a new function. The term "hacking" can also be understood more generally as tinkering, experimenting, or "frickling" (tinkering), meaning the exploration of technical possibilities for the sheer fun of playing with technology and materials. In the context of computer security, the term is often used to describe how so-called hackers "engage with security mechanisms and their vulnerabilities. While the term includes those who seek out security gaps to expose or fix them, it is more commonly used by mass media and the general public to refer to people who illegally exploit such gaps in foreign systems. Accordingly, the term is heavily loaded with either positive or negative connotations."[9]

In the context of the DIY-Bio scene, the hacking concept is a central, recurring motif. The term "Jugaad," imported from Indian Urdu, is related to hacking and describes an innovative solution to a problem, often in the form of a simple workaround. In both cases, existing rules or restrictions are bypassed to handle complex issues in the simplest possible way. Unlike hacking, which in the Western world increasingly represents an intellectual, artistic, or aesthetic expression, Jugaad arises from material necessity and serves as a survival tactic. Jugaad is particularly regarded in India as a management strategy for "frugal innovation." Frugal innovation enables the use of marginal resources with minimal gain by reducing product complexity to a functional minimum (Crabtree 2012). Hacking and Jugaad practices are based on the need to do what seems necessary and feasible, regardless of existing conventions or supposed constraints.

For digital information exchange, widely used platforms such as Wikis, as well as communication via Twitter, Skype, Dropbox, Mendeley, and other online services, are of fundamental importance. As online presence grew, more participants joined continuously, leading to an ever-increasing exchange of information, primarily focused on tips and tricks for developing and using lab materials and equipment to set up one's own lab with the lowest possible financial expenditure.

9 http://de.wikipedia.org/wiki/Hacker_%28Computersicherheit%29 (30.11.2015)

BOX VI.2: CITIZEN SCIENCE: "TOP DOWN" AND "BOTTOM UP"

The term Citizen Science, which has become widespread in recent years (Finke 2014; Ziegler et al. 2015), primarily refers to research projects designed by scientists in which citizens, as more or less knowledgeable participants, are actively involved in data collection (Hennen/Pfersdorf 2014, pp. 49 ff.). This can be described as "science with citizens," with its advantage lying in the large number of participants, which could not be achieved within the organized scientific system. Typical traditional examples include bird, butterfly, and other animal species counting projects. Since the advent of personal computers, this also includes providing computing power for astronomical observations. More recent projects utilize mobile devices or even variants of computer games. [10]

DIY-Biology represents another type of Citizen Science, more in the sense of "science *through/by* citizens," harking back to the origins of modern science in the late 17th century, when research was initially conducted privately, primarily by aristocrats and later increasingly by citizens driven by intellectual curiosity. The type of professional scientist, employed publicly or privately, only emerged at the end of the 19th century. DIY-Science in hacker or makerspaces or "fabrication laboratories" (FabLabs) (see Chapter VI.4.1) invokes the constitutionally guaranteed freedom of research (Article 5, Paragraph 3 of the Basic Law). The idea is that research and science should not be the exclusive domain of an academic elite but should be accessible to all citizens. Theoretically, anyone should be able to engage in research, regardless of their prior education or affiliation with an established research institute or commercial lab.

Citizen Science also takes on a more explicitly political connotation through the demand, expressed by some participants, for greater societal involvement in public research funding decisions. Representatives of organized civil society play a particular role in this (Ober 2014; Veciana/Neubauer 2014). Various forms of participation are now being promoted by research policy, although active support for DIY-Biology is not yet included.

Unless explicitly stated otherwise, all three forms are referred to under the overarching term Citizen Science in the further text.

---

10 www.buergerschaffenwissen.de (30.11.2015)

The initial participants of the mailing lists were primarily students of life sciences, amateur or non-specialist scientists, including engineers, as well as former biologists who had changed careers. Key early figures include Jason Bobe and Mackenzie Cowell, founders of the website "DIYbio.org" and the DIY-Bio Google mailing list. Bobe is also involved in the "Personal Genome Project,"[11] initiated by geneticist George Church, a prominent representative of synthetic biology, at the Harvard Medical School (HMS) of Harvard University. The "DIYbio.org" website is considered the most successful mailing list in the DIY-Bio scene and has served since its founding in 2008 as a hub for promoting and connecting the DIY-Bio community. However, the geographic focus of the participants is predominantly in the United States. The first and still most active network in Europe, also founded in 2008 by Yashas Shetti, Marc Dusseiller, and Andy Gracie, is "Hackteria.org." The organization was nominated for the Zedler Prize for Free Knowledge in 2012,[12] which is awarded annually by Wikimedia Germany – Society for the Promotion of Free Knowledge. "Hackteria.org" consists of a Wiki[13] and a website that collects and presents the projects of the organizers and their network. In addition to focusing on Switzerland and Central Europe, the network has strong connections to Asia, particularly Indonesia and India. Alongside these international networks, there are numerous local initiatives, mainly in major urban centers and cities. Although the initial hype faded shortly after the founding of "Hackteria.org" and "DIYbio.org" around 2009, the scene continues to spread globally and now encompasses all continents except Australia.

Since around 2010, the still globally networked scene has begun to split into regional subgroups. In Europe and North America, for example, the scene has grown across borders through physical gatherings and now meets several times a year in various cities on these continents for workshops and events. Additionally, although less frequently, intercontinental meetings take place. Depending on the country and the general attitude or orientation towards life sciences, different focal points have emerged.

In addition to strongly apolitical entrepreneurship in the tradition of Silicon Valley, there are grassroots democratic, nihilistic, idealistic, anti-authoritarian, and anti-capitalist tendencies that manifest in various forms and combinations. Despite a clear majority of men in the scene, some women with strong meritocratic influence are also present, and feminist positions are represented. Some biohackers are indifferent

---

11 www.personalgenomes.org (30.11.2015)

12 www.wikimedia.de/wiki/Pressemitteilungen/PM_6_12_Zedler (30.11.2015)

13 http://hackteria.org/wiki/ (30.11.2015)

or even opposed to the politicization or elevation of their activities as a new form of democratic citizen science and have little interest in societal debates. However, due to the new technological possibilities promised by synthetic biology, questions of ethics and intellectual property cannot be fully addressed or answered within traditional political frameworks. The increasing technological emancipation makes critical reflection within the scene inevitable and creates new potential political and ethical fault lines among participants. For example, the development of the "Code of Ethics" revealed that utilitarian tendencies are much more prevalent in North America than in Europe. Through the increasing integration of bioartists (see Chapter VI.2), as well as border-crossers from philosophy and social sciences, these groups have now taken on a central and guiding position in the European and Asian scenes, promoting greater self-reflection within the biohacker movement. This is reflected in a stronger focus on social and ethical issues in the European DIY-Bio scene. Despite the many differences, there is a common foundation in the global scene, consisting of a fascination with technology, a strong affinity for the internet, a technoprogressive attitude, and an interest in open-source and open-access ideas (see Chapter VI.6).

CODES OF ETHICS

Because the DIY-Bio scene operates outside established institutions, there has been and continues to be an intense debate about self-identity and potential self-imposed obligations. In institutionalized (biological) science, there are few incentives for individual reflection on one's actions or for formulating ethical standards. This can be attributed to the fact that in many laboratories, scientists work largely isolated from the "real" world, often on very small-scale issues, where the connection to the overarching, possibly problem-solving projects is hardly recognizable or relevant to the specific work. Additionally, biological work usually involves strict regulations and specialized safety officers who ensure compliance. This largely removes individual responsibility, reducing the need to independently consider the broader consequences of one's work. Although large research organizations have now formulated codes of ethics that emphasize both institutional commitment

and the awareness and responsibility of individual employees, this does not guarantee that the attitudes expressed in the codes are genuinely internalized (see Chapter IV.2.2). The situation is fundamentally different when biohackers work in hackerspaces without legal, organizational, and financial infrastructure.

The first public stance on this topic came from biohacker Meredith Patterson with her widely noted "Biopunk Manifesto," which she presented at the symposium "Outlaw Biology? Public Participation in the Age of Big Bio" organized by the

UCLA Center for Society and Genetics. In this manifesto, she applied the ideals of the Cypherpunks (a self-designation of some privacy activists) to biology and citizen science (Ledford 2010). She emphasized the necessity of (natural) scientific education as a prerequisite for the ability to engage in science/research and underscored the right of every individual to independently engage in scientific or research activities. Patterson highlighted the sense of responsibility and accountability among biopunks, but she opposed what she perceived as the paternalistic approach of the precautionary principle, which she argued had only a research-inhibiting effect.[14]

The scepticism towards the intention and impact of the precautionary principle, which plays a central role in EU environmental legislation (e.g., as the basis of Directive 2001/18/EC) and in global agreements under the leadership of the UN (e.g., in the Cartagena Protocol on Biosafety; Federal Government 2003), is a well-known point of divergence between Europe and North America regarding possible risks of technologies in general and biotechnologies in particular—this difference is evident even within the biohacker community. As discussions about ethics and responsibility intensified towards the end of the 2000s, coupled with the growing media hype around biohacking, many participants on the DIY-Bio mailing list felt compelled to develop their own ethical code. The corresponding reflection process, conducted through public and private discussions on the internet, lasted about a year. This culminated in two conferences organized by Jason Bobe and the WWICS, one held in London in spring 2011 and the other in San Francisco in summer 2012.

The discussions resulted in two different draft codes of ethics, one from the European delegation and one from the North American delegation (see Table VI.1). Differences can be seen in several areas, such as the sub-point on education ("education"). While the North American delegation members (mostly representatives of community labs; see Box VI.3 in Chapter VI.4) focused only on the possibilities, the European scene fundamentally considered both the benefits and implications (Engelhard/Hagen 2012, p. 35).

14 http://maradydd.livejournal.com/496085.html (30.11.2015)

TAB. VI.1 COMPARISON OF THE EUROPEAN AND NORTH AMERICAN VERSIONS OF THE DIY-BIOETHICS CODE DRAFTS (DIFFERENCES IN ITALICS)

European "Code of Ethics" Draft May 2011	North American "Code of Ethics" Draft July 2011
Modesty: *Know you don't know everything.*	***Tinkering:*** *Tinkering with biology leads to insight; insight leads to innovation.*
Respect: Respect humans and all living systems.	***Environment:*** Respect the environment.
Transparency: Emphasize transparency and the sharing of ideas, knowledge, data, *and results.*	**Transparency:** Emphasize transparency and the sharing of ideas, knowledge, and data.
Safety: Adopt safe practices.	**Safety:** Adopt safe practices.
Open Access: Promote citizen science and decentralized access to biotechnology.	**Open Access:** Promote citizen science and decentralized access to biotechnology.
Education: *Help educate* the public about biotechnology, *its benefits and implications.*	**Education:** *Engage* the public about *biology*, biotechnology, and *their possibilities.*
Peaceful Purposes: Biotechnology *must* only be used for peaceful purposes.	**Peaceful Purposes:** Biotechnology *should* only be used for peaceful purposes.
Responsibility: *Recognize the complexity and dynamics of living systems and our responsibility towards them.*	
Accountability: *Remain accountable for your actions and for upholding this code.*	
Community: *Carefully listen to any concerns and questions and respond honestly.*	

Source: adapted from Eggleson 2014 and http://diybio.org/codes

Further fundamental differences between the two codes are evident in the formulations regarding *modesty*, *responsibility*, *accountability*, and *community* (Tab. VI.1; Bowser/Shanley 2013; Eggleson 2014). The European version emphasizes a self-reflective and responsible attitude of the biohackers, while the North American code highlights *tinkering*, in the sense of an emancipatory and innovative approach to biology through "learning by doing." The differing orientation is evidently rooted in the regulatory and cultural contexts in which biohackers operate in the USA and Europe. While in North America, the biosecurity discourse was dominated by the experience of terrorism, in Europe, there is a significantly greater sensitivity to environmental issues (Seyfried et al. 2014).

A significant difference between the European and North American "Code of Ethics" compared to Patterson's "Biopunk Manifesto" lies in the statement to apply "safe practices." This implies—at least in Europe—the practical application of the precautionary principle in the form of adherence to genetic engineering regulations (see Box VI.4 in Chapter VI.4.4).

The Freiburg iGEM team of 2011 developed, as a response based on the European conference on the "Code of Ethics" and inspired by the Hippocratic Oath, a "Synbio Oath." Although it is very similar in content to the statements of the European "Code of Ethics," it goes beyond a mere code as a binding self-commitment in the form of an oath. It was presented at the first European iGEM Jamboree in 2011. As early as 2009, the iGEM organizing committee, together with the then head of The Biological Weapons Convention of the UN, Piers Millet, specifically recommended the development of their own codes, thereby continuing the efforts of the DIY-Bio community to establish a code as universally valid as possible.[15]

A "Code of Ethics," developed by students and biohackers themselves for participation in iGEM, could familiarize young synthetic biology students from the outset with the ethical, ecological, and social dimensions of their work. Building on the preliminary work in the DIY-Bio scene, iGEM also offers the opportunity to promote an international and particularly transatlantic dialogue about the values and goals of those engaged in synthetic biology. However, it largely depends on the competition organizers how deep such a discourse can go and how much importance it is given.

All efforts to introduce ethical guidelines for the scene remain de facto non-binding, as there are no mechanisms to enforce them and sanction misconduct if necessary. For example, the IAP (2014) also sees a great need for (further) clarification among scientists and the public and recommends the further development of "Codes of Conduct" for synthetic biology, with explicit inclusion of the DIY-Bio scene. Although the codes are not binding so far, they are significant for the scene, particularly for group identity formation and as a signal to the public about their own

15 http://2009.igem.org/Security (30.11.2015)

goals and concerns. The topic is regularly addressed at international meetings. Considerations based on this, for example, were incorporated into the development of the Bio-Commons concept (Chapter VI.3.6).

QUESTIONS ABOUT THE FREEDOM OF SCIENCE 3.2

The term "freedom" plays a major role in the debate around DIY biotechnology, as well as synthetic biology—sometimes explicitly, sometimes implicitly. A typical narrative of DIYbio as citizen science is the "breaking down of ivory towers" or a "democratization of science," which is supposed to lead to more freedoms for citizens.

The authors of the article "We Genetic Tinkerers" (Charisius et al. 2012) wrote that "most of the important discoveries were made by people who had the freedom to research without restrictions. Or who took this freedom." However, they leave open what they base their assumption on. They do not illustrate what they consider to be an "important discovery" or what exactly counts as "researching without restrictions" (Potthof 2013, p. 11).

Another aspect of freedom was emphasized by many of the synthetic biology scientists interviewed by Engelhard and Hagen (2012), who pointed out that the new technical possibilities create much greater experimental freedom and thus more freedom in the conceptual development of experiments.[16] The resulting freedom to do things that were previously not possible was seen by many as a central motivation to switch to synthetic biology and is characteristic of the often perceived new research culture (Engelhard/Hagen 2012, pp. 21 f.). Thus, in the theme of freedom, there is a clear parallel between the experiences and motivations of institutional scientists in synthetic biology and the actors in the DIY-Bio scene.

Students who participated in the iGEM competition and then started to engage in biohacking establish a personal continuity between the two areas and influence the endeavors and ideas in the DIY-Bio scene regarding what is feasible and what should be, revitalizing its open and transdisciplinary ethos.

However, it remains unclear to what extent this new research culture substantially differs from the past developmental phases of science. Potthof (2013, p. 10) argued that novelty is a constant companion of science, research, and development, and

[16] Engelhard and Hagen (2012) conducted interviews for their report with 22 researchers in the field of synthetic biology (13), as well as with experts in social sciences, humanities, and law (4), and active artists (5).

therefore, the freedom to do new things is not something special but was also granted to researchers in earlier generations. Examples from the past include the new possibilities and insights gained from the first use of computers or electron microscopes.

One explanation for the desire for freedom among biohackers lies in the currently established university structures and their operational daily routines. These are filled with work and learning conditions perceived as restrictive in the institutions, due to numerous rules, obligations, hierarchies, dependencies, and pressure to succeed. A frequently cited motivation for participation in the DIY-Bio scene by students and university scientists is the lack of opportunities for development and career prospects at their institutions. In the science journal Nature (2013), the activities of the DIY-Bio scene were judged largely unserious in an editorial, but within the same context, the relevance of the freedom gained by the participants in the scene was emphasized.

This new freedom appears not only as the result of new or better "playful" methods but also as a consequence of leaving institutionalized research culture. Baker (2015, p. 112) similarly argued that DIY-Biology is evolving into a career opportunity for young synthetic biology researchers, thereby opening up new freedoms.

Potthof (2013, p. 18), however, questioned the previously mentioned claim of some DIY activists to a "democratization of science" concerning their contribution to a broader societal emancipation. While any use of biotechnological equipment and the independent execution of biotechnological procedures and experiments outside of the usual professional contexts can be seen as a positive expression of self-empowerment, such self-empowerment currently tends to be paired with very individual and minimally political interests. Therefore, his fundamentally positive assessments are accompanied by significant reservations, particularly due to the anti-regulatory efforts that accompany the various manifestations of DIY biotechnology and synthetic biology (Potthof 2013, p. 18). It is therefore still too early to judge whether the DIY-Bio scene can be considered part of an emancipatory movement.

Whether Potthof's (2013) characterization of the DIY-Bio scene as a "movement" is accurate, however, is questionable. Due to the previously described very different motives, attitudes, and issues among biohackers, it is unlikely that a politicization and unification behind a common idea will occur, at least not in the sense of established political camps or positions. However, this does not mean that the actors in the scene are generally apolitical or incapable of exerting political influence. Kera (2012) views hackers as "'Anonymous' and collective force, tricksters and jokers rather than typical revolutionaries," who appear as a group without a concrete agenda, only loosely and spontaneously in individual actions. In this way, the scene can react very quickly to new situations and adapt flexibly to new technological and societal developments. Whether an action is affirmative or critical is context-dependent. Contradictory positions within the scene are thus more the rule than the exception.

DIY-BIO AND INSTITUTIONALIZED SCIENCE 3.3

Most of the synthetic biology experts interviewed by Engelhard/Hagen (2012) were familiar with the term DIY-Biology, but only two knew of specific projects (including Ellen Jorgensen from Genspace). This relative unfamiliarity already suggested that DIY-Biology had not had a significant influence on institutional research in the past. The most important arguments for the general lack of influence were that research is too expensive, a fully equipped laboratory is needed, and lay knowledge is insufficient to conduct serious research (Engelhard/Hagen 2012, p. 36). One of the researchers interviewed saw the DIY movement as a temporary phenomenon, noting that one can only find a niche and possibly succeed in the early phase of a new technology with relatively simple means. Nediljko Budisa even sees a conflict between the desire for societal participation in research and the demand for credibility that society places on science. According to Budisa, credible research can only be conducted on the basis of solid education, which is often not present in the DIY-Bio scene. Overall, the institutionalized researchers interviewed gave DIY-Biology little chance of contributing anything significantly new to research (Engelhard/Hagen 2012, pp. 37-38). In an internal project discussion, Gleich and Giese[17] also questioned the competence of the DIY-Bio scene to conduct research that is reproducible, methodologically correct, and transparently documented. The most likely benefit was seen in terms of public acceptance. However, it was criticized that garage biology could amplify the public risk discussion about synthetic biology, potentially leading to stricter regulations for institutionalized research.

In contrast, an editorial in Nature (2010) emphasized a potential positive contribution of the DIY-Bio scene: "Biohackers are an example of the growing 'citizen science' movement, in which the public takes an active role in scientific experiments. Citizen science can help stimulate public support for science, and can introduce fresh ideas from novel disciplines."

In 2011, Ellen Jorgensen presented Genspace[18] at "SB5.0: the Fifth International Meeting on Synthetic Biology" (organized by the BioBricks Foundation [BBF]) with

---

17 Gleich and Giese were authors of a second external report commissioned within this TA project, c.f. Gleich et al. (2012).

18 www.genspace.org (30.11.2015)

the statement, "An informed and scientifically literate public is an essential part of synthetic biology advocacy." She subsequently won the only poster award in the category "Science and Society." The award justification explicitly recognized the achievement of "Community Labs" in increasing public acceptance of synthetic biology. This indicates an interest from institutionalized research in utilizing DIY-Biology, or more specifically, the Community Labs, for public outreach (Engelhard/Hagen 2012, pp. 34-35).

The DIY-Bio scene has had a concrete influence on the activities of institutionalized research through the iGEM competition in recent years. The 2009 iGEM team ArtScience Bangalore, led by Yashas Shetti, co-founder of Hackteria, was among the earliest protagonists of the scene. Due to the lack of a permanently available suitable biotechnological laboratory, they improvised their own lab equipment from household items. This Jugaad approach (Box VI.1) and, in particular, the associated artistic engagement with synthetic biology were met with interest at the 2009 iGEM Congress. The team's influence was so strong that artistic interpretations of this kind are now specifically encouraged through the awarding of dedicated prizes.[19] Furthermore, the 2011 Freiburg iGEM team presented the "Synbio Oath" at the iGEM competition, and the 2012 University College London iGEM team conducted an extensive survey among biohackers. In the 2014 iGEM competition, a separate category, "Community Labs," was introduced for the DIY-Bio scene, with a dedicated lecture series and specially awarded prizes.[20] After an exhibition by biohackers Martin Malthe Borch and Rüdiger Trojok at the Medical Museion in Copenhagen[21], the University of Copenhagen adopted the citizen science approach. They purchased an OpenPCR device (see Chapter VI.5.1), which was evaluated by a team of scientists, and discussed the Open Knowledge concept concerning devices, materials, genes, and information. In an interview with Radio 24syv, Birger Lindberg Møller emphasized the important role universities have in relation to the amateur movement, which includes promoting proper and ethical conduct of experiments, but also being inspired by the philosophy and enthusiasm of this new movement.[22] Most of the experiments and projects carried out by the DIY-Bio scene may appear to have little relevance in the context of institutionalized research by the prevailing standards there. Nevertheless, the DIY-Bio scene possesses at least a significant novelty value and can convey a positive research spirit to scientists and amateurs alike through a

---

19 http://2014.igem.org/Tracks/Art_Design (30.11.2015)

20 http://2014.igem.org/Tracks/Community_Labs (30.11.2015)

21 http://healthsciences.ku.dk/news/news2013/biohacking (30.11.2015)

22 http://synbio.ku.dk/news/diybio_radio24syv (30.11.2015)

playful approach, while also opening up new possibilities for interaction between the public and the life sciences.

PHASE III: DIY-BIO FOUNDING ERA 4.

The primary activity of most biohackers has been and continues to be the collection and creation of laboratory equipment. In home labs (also known as Egolabs) and hackerspaces, biohackers have designed a series of biological experiments, simplified and replicated lab protocols and equipment over the past few years. With the increasing global networking since the early 2000s, local groups in large metropolitan areas reached a critical number of participants around 2008, making it financially and organizationally feasible to establish their own physical spaces for intended projects. These so-called hackerspaces (Box VI.3) enable biohackers to maintain more elaborate laboratories by sharing costs among a larger group of people, thereby expanding the technical capabilities of the participants. Either existing hackerspaces provided space for biohackers' projects, or new groups formed to open their own lab. The work carried out there covers topics in art, education, social criticism, and technological innovation. It doesn't matter whether the interests are artistic, scientific, both, or neither, or if they are only relevant to the participants themselves. The common characteristics of hackerspaces are their porous structures with flat hierarchies, transdisciplinary work that extends to the complete dissolution of disciplines, and openness to unconventional ideas. Emphasis is placed on education—following Humboldt's ideal of general education—and communication with the public. The goal is to allow any interested citizen to experiment and tinker in the lab without the formalized, exclusive, and often outdated teaching methods of schools and universities, without selective university entrance exams, pressure to perform in everyday studies, and free from discrimination based on age or gender. Hackerspaces therefore attract people from all walks of life, including elementary school students, university students, artists, designers, professional scientists, and even Silicon Valley entrepreneurs looking to transition from the computer industry to biotech. In the loose structures of the communal workshops, the boundaries between disciplines often blur, as does the distinction between teachers and learners. Most of these spaces are operated on a nonprofit basis. Depending on the country, some hackerspaces receive public funding, but most try to finance themselves through membership fees and donations. There are now at least 60 biology-related hackerspaces worldwide, the majority of which are in North America and Europe.

BOX VI.3: HACKERSPACES

Hackerspaces, sometimes also referred to as Makerspaces or Community Labs, are a mix of offices and workshops or labs for all sorts of activities. In these Community Labs, which are usually organized as associations, lectures, courses, and discussion forums are held. Hobby researchers and tinkerers are connected through social networks, where they exchange results, protocols, and blueprints for self-built devices. Most Hackerspaces focus on electronics and computer technology, but "dirt rooms," where wood, metal, and other building materials can be processed, are also very common.

Hackerspaces often receive material donations from companies in addition to the financial contributions of their members. These donations might include electronic waste or functioning old devices, which are then repaired or disassembled in the Hackerspaces. Generally, Hackerspaces provide their members with very affordable access to materials and knowledge, offering maximum freedom for individual projects and ideas without predefined goals or commercial expectations. This fosters interdisciplinarity and opens up intellectual free spaces. In addition to their own projects, courses and seminars for members and the public are frequently offered.

A commonly chosen organizational form is meritocracy, a structure based on open discussions. Those who are most engaged and possess the most expertise enjoy the greatest respect and, consequently, have more influence on internal decisions. Other Hackerspaces are supported by grassroots democratic associations or, less frequently, by private companies. The first Hackerspace in the world, **c-base e. V.**[23], was founded in 1995 in Berlin. As of December 2014, there are over 1,800 Hackerspaces registered on "Hackerspaces.org" globally, with a presumably much higher number that are unregistered.

DIY-BIO LOCATIONS 4.1

The first biohackerspace was the House of Natural Fiber (HONF)[24] in Yogyakarta, Indonesia, founded in 1999 by a group of artists and designers led by Venzha Christ. It is part of the pioneers in the art scene (see Chapter VI.2.1) and became known in the Western world through the Hackteria network. Notable projects by HONF

23 www.c-base.org/ (30.11.2015)
24 www.natural-fiber.com/ (30.11.2015)

include the construction of small and affordable spectrometers to measure pollutants in local waters and educational courses on traditional fermentation techniques.

In the USA, BioCurious in San Francisco and Genspace in New York are the most prominent hackerspaces. BioCurious[25] was founded in 2009 by a team led by biologist Tito Jankowski, inventor of the OpenPCR device (see Chapter VI.5.1), and entrepreneur Eri Gentry through a crowdfunding campaign on Kickstarter.com. The hackerspace operates a laboratory designed for molecular biology work and offers workspaces for up to 30 people, as well as space for lectures. It resembles a school in style, with guided work taking precedence. Its proximity to Stanford and Berkeley universities and Silicon Valley, along with its high public profile, gives the space a special status as a showcase project of the DIY-Bio scene in the USA. Eri Gentry was honored with the "Champions of Change" award by the White House in 2013 for her engagement as a Citizen Scientist.[26]

Genspace was founded in 2010 in New York by journalist Dan Grushkin and molecular biologist Ellen Jorgensen. It was the first DIY biology lab to meet Biosafety Level 1 standards (see Box VI.4 in Chapter VI.4.4). Ellen Jorgensen gained years of experience in the biotechnology industry before deciding to fully transition into DIY biology. She gave a talk about the biohacker scene at TEDGlobal 2012 in Edinburgh.

In Europe, the Waag Society[27], an institute for art, science, and technology in Amsterdam, is one of the most renowned citizen science labs with its "Open Wetlab." The Waag Society is part of a long transdisciplinary tradition of art and science communication, which reached global fame with Rembrandt's 1632 painting "The Anatomy Lesson of Dr. Tulp"—the painting is still housed on site. The Open Wetlab is led by biotechnologist Pieter van Boheemen, an IT entrepreneur and co-developer of the DNA analysis device Amplino (see Chapter VI.5.1). The Open Wetlab, an S-1-certified biology lab, offers "Do-it-with-others" workshops[28] for the public. Its latest project is the "Biohackademy," a multi-week training program that teaches participants how to improvise their own molecular biology lab affordably.

25 http://biocurious.org (30.11.2015)

26 www.whitehouse.gov/champions/citizen-scientists (30.11.2015)

27 https://www.waag.org/nl (30.11.2015)

28 This designation actually captures the character of DIY-Biology, especially the hackerspaces, much better than "do it yourself" (which primarily refers to the contrast with institutionalized expertise).

Currently, the largest biohackerspace in Europe is La Paillasse[29] in Paris. The nonprofit organization behind it, led by founder and biologist Thomas Landrain, received support from the mayor of Paris for its establishment. The space is equipped with a functional biotechnology lab and recently added workrooms for neurobiology, drone technology, and textile work. Some of the space's projects are exhibited in the art gallery "La Gaîté lyrique." The equipment for the biotechnology lab was donated by Genopole[30], France's largest biotechnology cluster, and the Paris city administration. However, the hackerspace does not yet have an S-1 license. La Paillasse has already spun off two branches in Lyon and Manila, Philippines, which are centrally managed from Paris.

In Austria, the Open BioLab Graz Austria (OLGA)[31] was founded in 2013 as an open community lab for molecular biology and biohacking and is part of the Realraum – Association for Technology in Culture and Society. The OLGA hackerspace has a fully equipped molecular biology lab and is S-1 certified. The founding members, Alexander Murer, Bernhard Tittelbach, and Martin Jost, also founded the company Briefcase Biotec GmbH in 2014 (see Chapter VI.5.1).

In Berlin, there has been Biotinkering e. V.[32] since 2010, which collaborates with the Raumfahrtagentur[33] hackerspace and the Art Laboratory Berlin to conduct public workshops on molecular biology at irregular intervals. Publicly engaged members of the association include Lisa Thalheim and Rüdiger Trojok. All members of the association hold academic degrees, most of them in biology. Thalheim has set up a small molecular biology analysis lab in the Raumfahrtagentur's premises. Trojok also runs a private egolab. Some microbiological studies are thus technically feasible, but transgenic experiments are not allowed without S-1 lab certification.

Other European biohackerspaces include brmlab[34] in Prague, Hackuarium[35] in Lausanne, Biohackspace[36] in London, Biologigaragen[37] in Copenhagen,

29 www.lapaillasse.org (30.11.2015)
30 www.genopole.fr (30.11.2015)
31 http://realraum.at/wiki/doku.php?id=olga:olga (30.11.2015)
32 https://www.biotinkering-berlin.de (30.11.2015)
33 www.raumfahrtagentur.org (30.11.2015)
34 http://brmlab.cz (30.11.2015)
35 http://hackuarium.strikingly.com (30.11.2015)
36 http://biohackspace.org (30.11.2015)
37 http://biologigaragen.org (30.11.2015)

Biotweaking[38] and the Universal Research Institute (UR)[39] in Zagreb, to name just a few. Additionally, there are various small groups, studios, museums[40], and labs in different stages of development. Besides group-based concepts in hackerspaces, there are several individuals who conduct their own experiments in egolabs. Notably, even individuals without academic biological training have successfully carried out experiments such as PCR, gel electrophoresis, and gene manipulation independently. For example, Urs Gaudenz, an engineer for microtechnology and inventor, has designed a series of state-of-the-art machines for the biohacker scene in his egolab called "GaudiLabs." [41] He provides them to the public for free with detailed documentation on the Hackteria Wiki and on YouTube. The most prominent solo biohacker is biologist Cathal Garvey[42]. After completing his master's in biology, he obtained an S-1 license and worked alone for two years in a basement room in his parents' house on a new plasmid vector for Bacillus subtilis, with the goal of creating a biohacker kit for private individuals and schools for educational purposes. However, a fundraising campaign to generate a market-ready product failed, so he did not pursue the project further.

TECHNOLOGY DEVELOPMENT AND PROJECT EXAMPLES 4.2

The worldwide collaboration of the still very small scene is increasingly facilitating the application of lab protocols. As the scene grows, a steadily increasing number of documented biohacks are available online. [43] As technology becomes more simplified, the possibilities for biohackers correspondingly expand. The current capabilitiesof biohackers regarding electronics and devices are comparable to those of professional laboratories in the mid-1990s. However, the situation with molecular biology work is mixed. On the one hand, vast amounts of high-quality theoretical information are freely available on the internet; on the other hand, there are difficulties in practically applying the protocols in non-professional labs. The "paywalls" of scientific publishers pose a significant barrier but are not an insurmountable obstacle to the flow of information. Scientific publications are shared

---

38 http://biotweaking.com (30.11.2015)

39 http://ur-institute.org (30.11.2015)

40 www.museion.ku.dk (30.11.2015)

41 www.gaudi.ch (30.11.2015)

42 www.indiebiotech.com; https://www.indiegogo.com/projects/indiebb-your-first-gmo (30.11.2015)

43 www.instructables.com/howto/biology (30.11.2015)

privately or through reference management programs like "Mendeley." The increased inclination of internet users and academic scientists to share their knowledge as open source significantly promotes the transfer of knowledge across the scene and beyond. The biggest challenges for hobbyists currently arise in sourcing materials for a lab, securing space, and ensuring sustainable funding for both. Obtaining consumables, especially chemicals, also raises questions about proper handling and disposal, which excludes the use of certain chemicals outside professional labs. Another obstacle is that many companies do not deliver to private individuals because they fear reputational damage if this becomes public. Biologist and journalist Sascha Karberg experienced this firsthand when his supplier of oligonucleotides informed him that they would no longer supply him after his DIY-Bio research.

However, experience also shows that such problems can be circumvented with a little extra effort by ordering from small companies, abroad, or through acquaintances with a university delivery address. Howard Simon, a former legal advisor for DNA2.0, Inc., a gene synthesis company in the USA, has, for example, offered to deliver to private individuals. However, the costs of such services quickly exceed the budget of biohackers. Thus far, it is mainly startups and professional artists working in collaboration with universities who take advantage of these offers.

In the DIY-Bio scene, a wide range of projects is undertaken. These range from simple breeding experiments and fermentation techniques to gene analysis and even genetic manipulation of organisms. It can be assumed that the technologies and methods used generally function as intended. However, the work is typically not published in scientific, peer-reviewed journals and does not usually claim "traditional" scientific rigor. Some of the work is perceived as art and is, for example, exhibited in galleries. At the other end of the spectrum of activities, some biohackers are working on developing commercial applications and products. Examples of company formations will be explored in more detail in Phase IV (see Chapter VI.5.1).

A popular topic of traditional biology within the DIY-Bio scene is "urban gardening." This refers to the cultivation or growing of plants in urban spaces. Using easy-to-build, often computer-assisted systems, ordinary plant cultivation is technologically enhanced and made automatically controllable through various affordable sensors for light, CO2, humidity, and pH levels, as well as pump systems and LED lighting. Often, modern greenhouses are installed on rooftops or similar locations for urban gardening projects[44].

Another traditional application field is fermentation processes, such as wine, vinegar, or cheese production. A favorite within this category is the cultivation of the bacterium Gluconacetobacter xylinum, a component of kombucha cultures, which produces a cellulose-like polymer that can be used as a textile material. Designer Suzanne Lee, for example, uses this material to create clothing and presents the process as biohacking.[45]

A global project within the DIY-Bio scene, involving several dozen biohackers (including Denisa Kera, Pieter van Boheemen, Martin Malthe Borch, etc.) for several years, is the workshop series "BioStrike: Open Antibiotics Discovery," which addresses the highly relevant issue of spreading antibiotic resistance. The goal is to raise awareness among a lay audience by demonstrating where resistant bacteria are found and how they spread, while also guiding workshop participants in independently searching for new antibiotics. Using various microbiological protocols, potentially antimicrobial substances are tested for their effectiveness, and the results are shared online. Although the chances of discovering something medically significant are initially low, the educational value of the workshop series is exceptionally high.

An example of successful high-tech hacking is the "dipole trap" (also known as an "optical tweezer") developed by members of the Hackteria network at GaudiLab in 2013. A dipole trap is a highly focused laser used to capture and move microscopically small particles, such as individual bacteria, within space. These devices are in the research stage at universities and are built into advanced Zeiss microscopes. The biohackers managed to create a dipole trap from a DVD burner, combined with a microscope improvised from a webcam. The device was functionally viable and cost around 20 euros in materials, making it approximately 10,000 times cheaper than commercial offerings.[46]

---

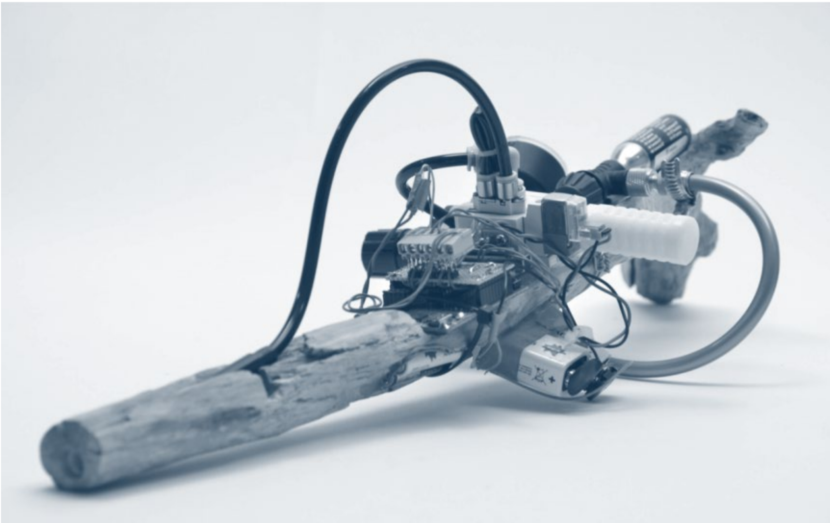
44 "Urban gardening" is understood here in the international context as urban and decentralized agricultural technology. The common practice in Germany of combining "urban gardening" with ecological farming is not explicitly meant by this. The two practices overlap only partially.

45 https://www.youtube.com/watch?v=43gOAZ_mGmg (30.11.2015)

46 www.youtube.com/watch?v=BT6NgV5XQqQ (30.11.2015); http://hackteria.org/wiki/index.php/DIY_Laser_tweezer,_cell_trap,_oligo_synthesis (30.11.2015)

Another hack of modern biotechnology is a "Gene Gun" made from kitchen utensils by Rüdiger Trojok. A Gene Gun is a scientific air pressure device used to shoot DNA into cells with the help of small gold particles. The added DNA can then be released from its carrier particles within the cell and integrated into the cell's genome. Gene Guns were central tools of genetic technology in the 1990s—many of today's genetically modified plants were created using this technology. The device was improvised from a whipped cream dispenser, an air hose, and a pen casing. After some test attempts in the Biologigaragen hackerspace, the project to create a reliably functioning DIY Gene Gun was discontinued due to a lack of practical use. Prototypes of this series were later exhibited at the Medical Museion in Copenhagen and the Ars Electronica Center in Linz.

Fig. VI.3 Artistic Interpretation of the "Gene Gun" by R. Trojok



Source: Martin Malthe Borch

In 2014, as part of the glowing plant project by biotechnology student Andreas Stürmer, a tobacco plant was genetically modified with the green fluorescent protein (GFP), a well-known marker gene. The gene was inserted into a strain of Agrobacterium, which is capable of transferring the gene into plant cells. The Agrobacterium was then applied to specific spots on the plant. Gene transfer occurred at the points of contact, and the plant glowed when exposed to UV light. The ultimate goal of the project is to create a self-illuminating plant, positioning Stürmer in competition with the U.S.-based Glowing Plant Project (see Chapter

VI.5.1). The fluorescent tobacco plant was also exhibited in the S-1 laboratory at the Ars Electronica Center.[47]

MEDIA RESONANCE 4.3

Since 2009 in the USA and around 2012 in Europe, the DIY-Bio scene has generated considerable media attention, especially given the small number of active participants in the scene. Even the Office of Technology Assessment (TAB) became aware of the topic primarily through media coverage. The tone of many reports has been similarly mixed: on the one hand, the risks of decentralized genetic technology were highlighted, while on the other hand, the new perspectives that the DIY-Bio scene opens up for biotechnology and synthetic biology were also emphasized. The narrative accordingly oscillated between "hype" and "horror." Biohackers were depicted as potential terrorists while their creative and unconventional approach was simultaneously praised as technological emancipation. The most comprehensive accounts in Germany are found in the book "Biohacking – Gentechnik aus der Garage" (Charisius et al. 2013b) and the thematically identical film documentary "Die Gen-Köche" (Schlichter/Karberg 2012). The promotion by Bavarian Broadcasting (BR) provided the typical media narrative: "Genetic research in a home lab? That’s possible, say the two filmmakers and biologists, and they want to prove it in their film. The homemade paternity test, the genetically modified tomato, or the bioweapon from the hobby room. A fascinating field that also causes fear."

This pattern is found in almost all portrayals. Various horror visions, often associated with "killer viruses," were repeatedly sketched by journalists in print media and broadcasting. It is notable how often reports are based on irrational fears of a danger postulated by the journalists themselves, for which there are no realistic preconditions. However, there were also several neutral interviews and positive portrayals. For example, Hessian Broadcasting linked the biohacker scene to a quote from Bill Gates to emphasize its innovative potential: "‘If I were a teenager today, I’d be hacking biology,’ says Microsoft founder Bill Gates. Because not only computers can be hacked, but also gene codes. And that’s what so-called ‘biohackers’ do with passion."

In the ZDF (German public TV broadcaster) crime production "Dina Foxx,"[48] biohackers even appeared as world saviors who had to defeat a plague caused by a

47 https://diyspartanbiotech.wordpress.com (30.11.2015)

48 http://dinafoxx.zdf.de (30.11.2015)

ruthless pharmaceutical company while simultaneously fighting against terrorist environmental activists.

Thus, the media perception of the DIY-Bio scene is as diverse (and sometimes contradictory) as the scene itself. In the USA, there was particularly frequent reporting on the topic in prominent media between 2008 and 2010, but the hype quickly subsided. In Germany, it started with a delay but has maintained a relatively steady level of about 10 to 20 reports per year in major media (radio, newspaper) since 2010. This occasionally leads to the perception that biohacking is a trend that has "spilled over" from the USA. In reality, however, the European scene is even larger, more active, and roughly the same age as the American one. The delayed reporting seems to be purely a media phenomenon. The dramatic portrayal of the topic is exacerbated by the high-profile interventions of the FBI, which has been monitoring the scene for years and actively interacting with it (Chapter IV.4.4). Overall, the media attention for the relatively small scene of a few hundred to a thousand active hobbyists and only a few dozen full-time professionals is enormous. This can be partly explained by the unconventional appearance of some scene members, the artistically inspired and thus attractive presentation of science, and a new pragmatism regarding technology. Another factor is widespread skepticism about genetic engineering and the informational asymmetries concerning bioscientific expertise among many journalists and the public. This mixture lends the topic an exaggerated drama—at least in light of the actual technological achievements of the biohackers, which, while something qualitatively new, have had rather modest real-world impacts so far.

BIOSECURITY QUESTIONS 4.4

The danger scenarios described by journalists concerning biohackers are not primarily an invention of the media but stem, among other things, from earlier assessments by security authorities and statements from various committees. The global increase in online activities of the DIY-Bio scene around 2008 and the subsequent establishment of new biohackerspaces triggered discussions among experts on both biosafety and biosecurity issues from (Chapter IV) (Bennett et al. 2009; Lloyd's 2009).

Concerns arose that amateur scientists could accidentally cause accidents affecting people and the environment (bioerror), engage in intentional criminal acts (biocrime), such as the production of illegal drugs, or even consciously or unconsciously support terrorist activities (bioterror). It is essential to distinguish between traditional bio(techno)logical methods and modern genetic technology (or synthetic biology in the broader sense). Security experts in the USA became particularly concerned about the increasing use of transgenic techniques in combination with the availability of (potentially dangerous) gene sequences in large scientific bio-databases.

BIOTERROR

The fear that biosecurity risks, particularly as a result of genetic engineering work, could arise from the biohacker scene has appeared repeatedly in various documents over the years (Pamlin et al. 2015; WEF 2014), often without a detailed examination of the actual capabilities and capacities of real-life DIY biologists.

Concerns about bioterror typically originated from scenarios and simulations developed years earlier by U.S. security agencies on the topic of synthetic biology (CIA 2003). The situation in virus research within high-security laboratories (Chapter IV.2) was projected onto the still-young DIY-Bio scene. A typical resulting assumption was that terrorists would deliberately use the biotechnological resources of biohackerspaces and, using genetic engineering methods, develop biological weapons, such as highly toxic substances or highly pathogenic disease-causing agents (up to genetically enhanced "killer viruses").

However, the feared increase in pathogen virulence is not easy to achieve (and would be highly dangerous for the experimenters), with a more likely scenario being the amplification of existing pathogens (Chapter IV.2.3). But even "just" making these pathogens capable of being weaponized and causing significant harm is anything but simple and requires extensive specialized knowledge and experience ("tacit knowledge"), which is likely only found in the military domain. Most accidents and attacks involving biological agents have direct links to military and intelligence activities. For example, the 2001 anthrax attacks in the USA were carried out by a U.S. military employee who had access to the pathogens and the corresponding high-security laboratory equipment in a military lab (Warrick 2010).

For the overall assessment of a theoretical genetic engineering bioterrorism threat, two additional conditions must be considered that are entirely independent of the nature of the actors and their lab organization:

- The examples of bioterrorism, in terms of both their number and the number of victims, are very small compared to terrorist attacks using conventional weapons.
- The few examples from recent years did not involve the use of genetic engineering methods.

In recent years, several articles have appeared in scientific journals analyzing the underlying assumptions regarding the DIY-Bio scene and largely debunking the originally expressed fears (Boheemen/Vriend 2014; Grushkin et al. 2013; Jefferson et al. 2014a and 2014b; Landrain 2012; Revill/Jefferson 2014; Seyfried et al. 2014). The main assessments can be summarized as follows:

- The biohackers, with their technical capabilities, still significantly lag behind professional laboratories.
- Conducting genetic engineering work is still knowledge-, time-, and cost-intensive. Successful development of transgenic products generally exceeds the capacities of individual biohackers.
- Along with a consciously practiced culture of openness and public orientation, this makes misuse in publicly accessible hackerspaces much less likely than in non-public specialized laboratories.
- Technical equipment and gene sequences alone do not accomplish much; extensive experiential knowledge ("tacit knowledge") is crucial.
- However, the latter could also develop over years in hackerspaces, which is why monitoring and control of genetic engineering work—just as in conventional laboratories—are necessary.
- Real bioweapons that could cause significant harm require not only biological but also (bio)weaponry knowledge (and often corresponding delivery systems) that is not freely available.

BIOCRIME

Technical and capacity-related obstacles also arise when considering the potential criminal use of synthetic biology methods in the broader sense. If one compares the current situation to the use of chemical-synthetic technologies, the production of drugs using genetic engineering methods appears to be a plausible scenario, especially since the existing market for illegal drugs and performance-enhancing substances could potentially mobilize large sums of money on the black market. Laboratories financed by organized crime with professional equipment could theoretically acquire the potential to produce synthetic drugs using genetic engineering methods. However, such secret labs, about which little is naturally known, cannot definitively be counted as part of the DIY-Bio scene.

BIOSECURITY OVERALL

The threat of bioterrorism from hackerspaces as a result of genetic engineering work appears to be extremely low overall—as concluded by PCSBI (2010a, p. 159) and the United Nations Interregional Crime and Justice Department (UNICRI 2012, pp. 101 ff.). Genetic engineering research, and particularly its use for the targeted creation/modification of complex biological functions, relies on a vast amount of scientific data and generally requires an established network of researchers working together on complex problems. An organizational structure with terrorist or criminal goals capable of handling such tasks is unlikely to develop within the globally connected, transparent, and community-oriented DIY-Bio scene. The danger of misguided lone wolves seems much greater in official biomedical and military (and/or possible intelligence) research laboratories, due to the technical capabilities there and the generally lower level of public oversight. However, after a technological leap that significantly increases the technical capabilities of DIY biologists, the situation could change in the future. Considerations on this are made in Chapter VI.6 as part of the future scenarios.

BIOSAFETY

But what about unintended or unforeseen dangers, i.e., biosafety? Here, too, it is not about DIY biology per se but specifically about the possibilities of genetic modifications and the risks of releasing genetically modified organisms that are either genuinely dangerous or undesirable to (parts of) society (microorganisms, plants, or animals). A release could be unintentional or, theoretically, intentional. Key criteria for assessment include the ecological and health hazard potential as well as the survivability and thus the spread potential of the organisms in the environment. Again, biohackers are (still) massively lagging behind with their technical capabilities, and extensive experiential knowledge is crucial; however, there is no doubt that biohackers can create GMOs (examples can be found in Chapter VI.4.2), and an undesirable, potentially dangerous situation may arise not only when genetic modifications are made with profound knowledge but possibly even more so when they are made unknowingly.

The basic assessment regarding known (registered) or public DIY laboratories must be based on the legal situation in Germany and Europe, which only permits genetic engineering experiments in specially licensed laboratories. As described, there are only a very few examples of such labs among hackerspaces in Europe, all of which only have a license for working with organisms of the lowest safety level (see Chapter VI.4.1). The same regulations apply to these labs as to the countless genetic engineering laboratories at universities and other research institutions (Box VI.4).

The situation is different concerning genetic engineering work in the USA, which is not fundamentally regulated but rather depends on certain procedures and the expected product of the respective project (see Chapter IV.1.3). For example, the

Glowing Plant Project did not require official approval. However, even if the project were successfully carried out, which is still completely unclear (see Chapter VI.5.1), no serious environmental dangers are likely to arise (among other reasons because no survival advantage for the glowing ornamental plants is expected).

In contrast, a proposed project to create transgenic vaginal microorganisms (whether seriously intended or not; see Chapter VI.5.2) hinted at a completely different dimension of biosafety concerns: if biohackers were to begin altering the human microbiome (the entirety of microorganisms living on and in humans), health risks could result. This danger should not be underestimated even now, as it appears that a regulatory gap is opening up in Europe and Germany. Neither the Genetic Engineering Act nor the Medicinal Products Act addresses a genetic modification brought about by a person on themselves; however, the microbes could theoretically be transmitted from person to person and thus be released. It is currently unclear what type of modification of one's own microbiome should be permissible and where the boundaries lie. Therefore, questions already arise regarding the possibilities of preventive control beyond the aforementioned self-regulations in the form of the "Code of Ethics" and short of merely referring to the already restrictive regulation of genetic engineering.

PREVENTIVE CONTROL OF DIY BIOLOGY – BY SECURITY AUTHORITIES OR THROUGH OPEN SOCIAL DISCOURSE?

In the USA, civilian security authorities (especially the FBI) have taken on the task of monitoring biohackers, primarily for biosecurity reasons. In 2009, the FBI launched an "Outreach Program," aimed at establishing contact with the DIY-Bio scene and related university researchers, and since then has organized several workshops. Biohackers and university scientists are encouraged to report suspicious activities to FBI agents and "Weapons of Mass Destruction Coordinators" present in every city in the USA (Charisius et al. 2013a). According to Edward You, head of the "Outreach Program," suspicious behavior includes staying in the lab after hours without an obvious reason or the use of dual-use chemicals and materials (Berger et al. 2012). Politically aggressive statements should also be reported. Biohackers from Europe and Asia were also invited to the third "FBI DIYbio Outreach Workshop" in 2012. Europeans were given contact details for FBI agents located in European cities and were encouraged to get in touch with them. The legal legitimacy of such foreign activities by a U.S. federal police agency appears questionable. Additionally, there are serious doubts about the scientific expertise of the FBI. For example, the agency failed to scientifically solve the 2001 anthrax case correctly. The U.S. Government

Accountability Office (GAO)[49] recently submitted an investigation report to the U.S. Congress documenting the significant methodological weaknesses of the FBI's approach (GAO 2014).

However, the DIY-Bio scene in the USA initially reacted with some suspicion, not least because the FBI had falsely charged art professor and peace activist Steve Kurtz as a bioterrorist in 2004. Kurtz had critically engaged with the U.S. government's bioweapons program.186 To this end, he presented harmless bacteria in art exhibitions, which he had cultured in his improvised home lab—completely harmless and legal (UNICRI 2012, p. 120). The bacterial cultures were discovered after a firefighter on-site reported the sudden death of Kurtz's wife, and subsequently alerted the FBI, which then stormed his house with biohazard equipment and assault rifles. Kurtz himself was interrogated for 22 hours on suspicion of "bioterrorism" and the murder of his wife. He was later charged with "postal fraud," but the case was ultimately dismissed in 2008 due to a lack of evidence (Critical Art Ensemble/Institute for Applied Autonomy 2009; Kurtz 2005).

This incident created uncertainty and fear among scientists and biohackers alike, leading to both defensive and accommodating reactions to the FBI's later outreach activities. Ultimately, many DIY biologists adapted to the FBI's wishes. Daniel Grushkin of Genspace wrote several critical articles about military involvement in biotechnology but simultaneously cooperated with the FBI. His motivation was to gain better public standingfor DIY biology through positive endorsement from the FBI, as the Genspace team otherwise feared aggressive reactions from extremist religious groups or environmental activists. Mackenzie Cowell of "DIYbio.org" commented: "I think it’s a good thing that [Ed You (FBI Agent)] is part of the community – there’s a shadow of it feeling sinister, but for the most part it’s cool…. If we’re going to walk the walk, we have to be able to talk to the FBI." (according to Lempinen 2011)

The U.S. military has also shown increasing interest in synthetic biology and biohacking for some time. The Defense Advanced Research Projects Agency (DARPA) and the Defense Threat Reduction Agency (DTRA) directly finance activities by hackers and biohackers or plan to do so.[50]

In Europe, particularly in Germany, the situation for the DIY-Bio scene is fundamentally different. The bioterrorism concerns of security authorities are apparently much lower than in the USA, and there have been no known activities

49 The GAO is an associate member of the European Parliamentary Technology Assessment (EPTA) network (www.eptanetwork.org/) (30.11.2015).

50 http://radar.oreilly.com/2012/12/darpa-big-data-military-open-source-agile.html

directed toward biohackers. Instead, biohackers must contend with widespread skepticism about genetic engineering among much of society, at least regarding the non-medical use of GMOs outside of closed production facilities. Biohackers must therefore not only adhere to stricter legal requirements (which, for most, means refraining from genetic engineering work), but they also face greater pressure to justify their activities compared to the situation in the USA.

BOX VI.4: BIOLOGICAL SAFETY LEVELS AND GENETIC ENGINEERING LABORATORIES

The biological safety level (BSL) is a classification for the hazard level of biological agents. This classification is standardized by Directive 2000/54/EC on the protection of workers from risks related to exposure to biological agents at work for the European Union and implemented in Germany through the Ordinance on Safety and Health Protection at Workplaces with Biological Agents (Biostoffverordnung – BioStoffV). A similar classification is also used by the Centers for Disease Control and Prevention in the USA. Risk Group 1 includes biological agents that are unlikely to cause disease in humans. Risk Group 2 includes biological agents that can cause disease in humans and may pose a hazard to workers. However, it is unlikely that they will spread in the population, and effective prevention or treatment is usually possible. Risk Group 3 includes biological agents that can cause serious disease in humans and may pose a significant hazard to workers; there is a possibility of spreading in the population,but effective prevention or treatment is usually possible. Risk Group 4 includes biological agents that can cause serious disease in humans and pose a significant hazard to workers. The risk of spreading in the population may be high, and effective prevention or treatment is usually not possible.

The BioStoffV assigns four safety levels to the four risk groups of biological agents. The classification is based on the infection risk; simply put, the more dangerous a biological agent is, the higher its risk group. Laboratories that handle biological agents must implement specific safety measures. The safety levels build upon each other, so the regulations for lower safety levels also apply to higher levels. For laboratories working with genetically modified organisms, a similar classification into four biological safety levels applies under the Genetic Engineering Act (GenTG) and the Regulation on Safety Levels and Safety Measures for Genetic Engineering Work in Genetic Engineering Facilities (Gentechnik-Sicherheitsverordnung – GenTSV). In laboratory jargon, these are referred to as S-1 to S-4 laboratories. S-1 laboratories require compliance with general hygiene measures, use of equipment with special labeling, and, depending on the federal state, specific structural and equipment requirements. S-2 laboratories require spatial designation, labeling, and access control of work areas. For biological agents in Risk Group 3 or 4, access must be restricted to qualified and reliable personnel. There are also numerous regulations regarding occupational safety. For example, according to the BioStoffV, exhaust air must be filtered, and there are strict rules for materials (e.g., waste) leaving the laboratory. In addition to the facility operator of a genetic engineering lab at any safety level, a safety officer is also required to monitor the facility and its operations. Both the facility operator and the safety officer need extensive qualifications to be allowed to work in these roles, including a completed biology degree at the master's or diploma level, proof of expertise, and three years of professional experience in molecular biology. In addition to the personnel requirements, there are costly requirements for the construction of a genetic engineering facility and a ten-year documentation obligation for all activities. As a result, it is de facto legally impossible for individuals to conduct genetic engineering work, even at the lowest safety level

A reference to personal interest, a vague hope for later commercial viability, artistic freedom, or simply the joy of experimenting is not sufficient in Germany to exempt DIY biologists, even for activities considered harmless, from strict regulations. On the other hand, in the course of a general trend of elevating citizen science and "maker cultures," they are increasingly successful in justifying why their involvement is socially beneficial and what contributions they might make to a sustainable economy. Chapter VI.6 delves deeper into the question of how DIY biology could be better regulated in a manner acceptable to all parties involved.

A more extensive societal discussion with the DIY-Bio scene is currently taking place within the framework of the EU-funded project "SYNENERGENE," which promotes dialogue among various international governmental and civil society stakeholders about the possibilities of synthetic biology and explores its future potential. The goal is to formulate a European governance strategy in line with the EU Commission's RRI (Responsible Research and Innovation) program (EC 2013; more on this topic in Chapter V.2.6)

PHASE IV: FURTHER DEVELOPMENT OF THE SCENE – BETWEEN COMMERCIALIZATION AND OPEN SOURCE

PREVIOUS START-UPS AND CURRENT TRENDS 5.1

Following the founding phase of hackerspaces, there was increasing professionalization within the DIY-Bio scene. In most cases, DIY biology is still pursued as a hobby or adopted by artists for their projects. However, due to the success of the scene, more and more professional engineers, entrepreneurs, and scientists joined the hackerspaces, while the students and amateurs who were involved from the beginning also gained experience. As a result, there are now increasing numbers of participants whose motives for engaging in DIY biology are commercial in nature, leading to the founding of start-up companies out of hackerspaces.

Some projects in the past have been successful in developing cheap and simple laboratory equipment and analysis kits, for example, for developing countries (Engelhard/Hagen 2012, p. 35). Many commercial biohackers see themselves in the tradition of garage developers from the early days of the computer industry in the 1980s, aiming to bring new impulses and ideas to biotechnological research in unconventional ways. They seek to develop applications using biotechnological methods that are not being actively pursued by academic or industrial research actors. Projects target, for example, medical point-of-care diagnostics (i.e., mobile, individualized, patient-specific) or decentralized food quality testing. In doing so, the entrepreneurs benefit from the free exchange of ideas and information fostered by the open-source culture of the DIY-Bio scene. Currently, there are a few dozen start-ups worldwide.

The first commercially successful project was the OpenPCR device developed by BioCurious co-founder Tito Jankowski (see Chapter VI.4.1). In 2010, he and his colleague Josh Perfetto developed a device (also known as a thermocycler) that can be used to copy, analyze, and modify DNA through the polymerase chain reaction (PCR). The patent for the invention of PCR dates back to 1986 and had just expired. Since its invention, PCR has been a central method of genetic engineering in all biology laboratories. The OpenPCR device is competitively priced at $599, and over 400 units have been sold, many to schools. The design data, software codes, and application protocols are available as an open-source project and can be downloaded from the company's website under an open license.[51]

The Canadian start-up Synbiota, Inc., supported by venture capital investors, operates a web portal for synthetic biology where users can design, manage, document, and present projects. This includes open-source tools for the genetic design of plasmids. The service is specifically aimed at the DIY-Bio scene but is also available to other interested scientists and engineers. Basic functions are free, with additional features and tools available through subscription. The platform explicitly aims to enable decentralized and collaborative open-source and crowdsource projects.[52] Synbiota is a partner of the Irish start-up accelerator IndieBio, which is the world's first start-up accelerator in the field of synthetic biology and supports entrepreneurs. According to their own statements, more than 3 million euros have been directly awarded or raised by partners so far.[53] One of the supported projects is "Kilobaser," developed by Briefcase Biotec in 2014 (see Chapter VI.4.1). The goal is to miniaturize and decentralize DNA synthesis by developing a kind of desktop DNA printer. So far, venture capital investors have invested well over 500,000 euros in the project. Due to pressure from investors, the project is no longer being carried out as an open-source development but is instead intended to become a patented product.[54]

A particularly PR-attractive but in many ways questionable project associated with the DIY-Bio scene is the Glowing Plant project[55] (see Chapter IV.1.3). It managed to raise around 1 million US dollars through a crowdfunding campaign on the website "Kickstarter.com," with the promise of sending out seeds of self-glowing transgenic plants. Although the team utilized the resources of the BioCurious biohackerspace and sought expertise within the DIY-Bio scene, the Kickstarter campaign was essentially launched by professional entrepreneurs, each running their own companies, and advised by seasoned PR strategists and venture capitalists within the U.S. synthetic biology industry. At the time the campaign was launched, there was neither a product nor a concrete idea of how or whether the project could be technically implemented. Only afterward did external scientists provide the necessary know-how and materials. Experts, however, strongly doubt the fundamental feasibility of creating a visibly glowing plant. The project primarily

51 http://openpcr.org (30.11.2015)

52 https://synbiota.com (30.11.2015)

53 https://synbiota.com/indiebio (30.11.2015)

54 http://kilobaser.com (30.11.2015)

55 https://www.kickstarter.com/projects/antonyevans/glowing-plants-natural-lighting-withno-electricit (30.11.2015)

appears to be a successful PR campaign for some companies in the synthetic biology sector, including Cambrian Genomics, a Silicon Valley-based company funded by over 10 million US dollars in venture capital, which aimed to develop DNA laser printing technology (Sullivan 2014).

Another project announced by Cambrian Genomics involved creating transgenic vaginal microorganisms that would smell like peaches, again referring to it as biohacking. This, like the Glowing Plant project (ETC Group/Friends of the Earth 2013), sparked intense opposition within the DIY-Bio scene and from anti-GMO NGOs (Tiku 2014).

The fact that Cambrian Genomics could even hope to receive a positive response to such projects illustrates the fundamentally different situation in the U.S. compared to Europe and especially Germany. Not only are the regulatory frameworks for applying genetic engineering more lenient, but there is also greater openness to technology in society (which is not to say that there is no vocal criticism of genetic engineering—though it does not hold the same majority support and socio-economic relevance). In Silicon Valley (and the U.S. overall), there appear to be enough venture capitalists willing to fund even very vague project ideas with substantial sums—an aspect often highlighted as a competitive advantage in innovation debates, particularly compared to conservative Germany in this regard. That a lot of money is also lost, and questionable projects are sometimes funded, is perhaps often overlooked.

Start-ups like Cambrian Genomics deliberately capitalize on the generally positive public image of biohackers, the narrative of emancipation, and the scene's vocabulary—thereby endangering it through so-called "hackwashing." This situation presents a dilemma for biohackers. On one hand, start-ups and venture capital generate urgently needed jobs, but on the other, the slowly developed forms of open and trusting collaboration are being compromised and ultimately questioned by the intrusion of commercial interests.

If the technical capabilities of DNA synthesis and genetic manipulation—potentially further simplified by genome editing methods (see Chapter IV.1.2)—continue to advance as rapidly as many observers expect, the range of activities, particularly for an increasingly professionalized and commercialized DIY-Bio scene, is likely to expand significantly. A dynamic development similar to the late 1980s in the personal computer industry would then not be out of the question—and would raise significant questions about the safety of the technology, the handling of intellectual property, and societal responsibility as a whole (see Chapter VI.6).

With the goals and characteristics of the previous DIY-Bio scene, which is based on open and collaborative cooperation outside established scientific and economic structures and processes, the professional start-ups—aside from the habitus and external appearance of the actors, similar to parts of the computer and internet industries—are likely to have little in common. Successful small businesses are expected to be, as in the past, acquired by larger players in fields such as pharmaceuticals, food, or the chemical industry, depending on their area of activity.

CHALLENGES OF THE OPEN-SOURCE APPROACH IN DIY-BIOLOGY 5.2

For non-commercialized DIY biology, especially as technologies become more powerful, cheaper, and more accessible, the question will arise, in addition to biosafety issues, of who will benefit from future results: How can it be ensured that information, knowledge, and products are designed in a way that allows them to be used by as many people as possible for socially desirable or meaningful purposes—and not quickly dominated by individual interests and leading to concentrations of power? This chapter outlines some prerequisites and previous activities, with further considerations presented in Chapter VI.6.

PROBLEMS OF PATENT PROTECTION IN THE LIFE SCIENCES

Commons (also known as "Allmende") are abstract or physical entities that everyone can use. They are "free" if they are usable without permission or if permission is granted in a neutral manner. Examples include air for breathing or publicly accessible knowledge such as classical literature. In this context, "Open Access" means unlimited access to the common good. The concept of "Open Source" further demands the disclosure and free use of the underlying raw materials or data—such as the source code of software in information technology or the construction plans for hardware projects.

Since the provision of goods incurs costs, market participants are forced to act economically. Inventions are considered intellectual property, similar to artistic works. Copyright law ensures inventors and artists exclusive usage rights in the form of patents or copyright, not least to compensate for the effort involved in inventing and to create incentives for development.

The source of inventive and research activity is simultaneously the free, non-profit exchange of information and materials in science (i.e., Open Access)—where free access to information is not synonymous with the absence of intellectual property claims. Protection rights are intended, especially in the field of science and research, to ensure that the latest state of knowledge can be used for further development—rather than being kept secret to gain potential competitive advantages.

However, the source codes of information technology and many results of bioscientific research (e.g., in the form of DNA sequences) are not adequately covered by traditional substance and process patents. For the protection of bio(techno)logical developments or inventions, a special biopatent law was developed in Europe, which culminated in the adoption of Directive 98/44/EC on the legal protection of biotechnological inventions (Biopatent Directive) in 1998. However, there are ongoing disputes over the applicability, validity, and scope of the protective provisions, whose detailed presentation would exceed the scope of this report. For example, the long-standing disputes over the patentability of human gene sequences (as the basis for the BRCA test for breast cancer risk) or of cell lines derived from individuals and then modified, as well as the applicability of patent law in general in the field of animal and plant breeding (where other legal systems were established), have gained particular notoriety. In Germany, the federal government has established a biopatent monitoring system to identify and assess impermissible or questionable biopatents on crops and livestock. The most recent report states (Bundesregierung 2014, p. 3): "It is not clearly discernible from the Biopatent Directive whether plants and animals that have been obtained solely by 'essentially biological processes' are also excluded from patenting as products."

Since the 1990s, German research policy has specifically and vigorously promoted the commercialization of public research in general and biotechnology in particular. Special (patent) exploitation agencies have been established at universities and large research institutions, such as the Max Planck Society (MPG) or the Helmholtz Association, to systematically assess the marketability of scientific work results and support researchers or their institutions in patenting and commercializing these results through licensing agreements or even direct spin-offs. Patents have also become an evaluation criterion for the performance of research programs, institutes, and individual scientists in scientific organizations and academic institutions. At the same time, empirical studies suggest that patent rights, for example, in biomedicine, human genome research, or biotechnology, can explicitly hinder (follow-up) research and innovation (Galasso/Schankerman 2014; Murray/Stern 2007; Williams 2013). Similar to information technology, in genetically based plant breeding or biopharmaceuticals, there have now emerged almost impenetrable accumulations of intellectual property or usage rights, known as "patent thickets" (Galasso/Schankerman 2014). Combined with high costs for filing and legally enforcing rights, this can tend to lead to market failure in the form of increasing centralization among a few large companies (for example, in the global seed industry, where the TOP 3 hold over 50% and the TOP 10 over 75% market share; ETC Group 2013a, p. 6). This can also have a negative impact on academic science if patent-protected methods cannot be used due to cost or legal uncertainty (Galasso/Schankerman 2014; Murray/Stern 2007). A current example of the contentiousness of patent law issues is the dispute over CRISPR/Cas technology (Kupecz 2014).

This situation, often characterized by a large number of rights holders with unclear and sometimes contradictory claims, can ultimately lead to the "tragedy of the anticommons"[56] due to non-disclosure of knowledge and patent hoarding. According to this concept, the multitude of rights holders makes it impossible to achieve a socially desired outcome (for the field of biomedicine: Heller/Eisenberg 1998). One approach through which international governmental organizations, industry, and some universities are attempting to address this problem is patent pools, where partners mutually and "bundled" license inventions to each other (Zimmeren et al. 2011).

PREVIOUS OPEN-SOURCE INITIATIVES

In addition to the trend towards patenting and commercialization of bioscientific results, large databases have emerged, particularly through quantitative projects focused on producing large amounts of data in genomics and proteomics research. These databases are publicly accessible and often freely usable due to the public funding of research projects and to ensure rapid scientific progress (see Chapter VI.5).

These databases are growing exponentially due to increasingly powerful DNA sequencing and other analysis technologies, and the various databases and information are becoming increasingly interconnected. These include biochemical metabolic variants, protein expression patterns, 3D structural information on cell components, as well as data on ecological relationships. Currently, the largest database is GenBank from the USA. The largest European database is EMBL-EBI, which, however, only has about one-tenth the size of GenBank.

56 https://de.wikipedia.org/wiki/Tragik_der_Anti-Allmende (30.11.2015)

BOX VI.5: BIOLOGICAL DATABASES AND THEIR TERMS OF USE

Public Domain or CC0 Licenses (see Box VI.6): Information can be freely used by anyone for any purpose.

- *GenBank* is a platform for nucleotide and protein sequences as well as other biological data and is operated by the U.S. National Center for Biotechnology Information (NCBI)[57].
- *EMBL-EBI* (The European Bioinformatics Institute)[58] is part of the European Molecular Biology Laboratory and includes nucleotide sequences, protein structures, expression profiles, as well as data on entire cells and organisms.
- *The Protein Data Bank* (PDB)[59] is managed by the Research Collaboratory for Structural Bioinformatics (RCSB), supported by the National Science Foundation, the National Institutes of Health, and the U.S. Department of Energy. It is a database for 3D structural data of proteins and nucleic acids.
- *The 3-Million Genomes Project* was launched in 2011 by the Beijing Genomics Institute (BGI)[60] in China and aims to decode 1 million genomes each from humans, plants and animals, and microorganisms.

Commercial Databases: License acquisition required before use, partly available for research purposes.

- *Genome Online Database* (GOLD)[61] is operated by the U.S. Department of Energy Joint Genome Institute. The institute cooperates with U.S. companies and is partially funded by them.
- *Kyoto Encyclopedia of Genes and Genomes* (KEGG)[62], Japan, is a collection of online databases containing genomic, enzymatic, enzyme, and signal pathways, and biological chemical data. Since 2011, due to lack of funding, the service is no longer offered for free.

Many biohackers advocate for the maximum accessibility and usability of all bioscientific knowledge as public domain and point to the positive experiences with the open-source culture of the computer scene. In the information sector, the abandonment of defensive protection rights since the 1990s has greatly accelerated

57 www.ncbi.nlm.nih.gov/genbank/ (30.11.2015)
58 www.ebi.ac.uk (30.11.2015)
59 www.rcsb.org/pdb/home/home.do (30.11.2015)
60 www.nationalgenebank.org/en/research.html (30.11.2015)
61 https://gold.jgi.doe.gov/ (30.11.2015)
62 www.kegg.jp/ (30.11.2015)

the development of technology through the simplified exchange of computer codes. To facilitate this, computer hackers established copyright-based licenses (Creative Commons; see Box VI.6) (Lerner/Tirole 2005). Such an open-source license model allows a large, decentralized community of programmers to collaboratively work on lengthy and complex projects. Wikipedia and the Linux operating system are often cited as particularly prominent successes. Ultimately, open-source codes have also enabled the rise of Google. The company continues to provide its own developments under open licenses (e.g., the Android smartphone operating system).[63]

While some economically successful projects in the information industry are based on collaboration under the conditions of copyright, the business model in biotechnology is mainly based on patents.

BOX VI.6: CREATIVE COMMONS OR CC LICENSES

Through CC licenses, holders of copyrights and related rights grant additional freedoms to all interested parties. This means that anyone can do more with CC-licensed content than copyright law would ordinarily allow. CC licenses create material pools, from which not only can resources be taken, but contributions can also be voluntarily added. In many communities, it has become common practice to use open license models instead of reserving all rights strictly. Without free licensing, any use must first be cleared with the copyright holder. This increases the burden on others, leading to content either not being used at all or being used without permission—neither of which is in the interest of the copyright holders. A release of one's content, even if limited, supports the mutual growth and preservation of the shared material pool. Commercial considerations can also favor CC licensing: Innovative small companies rely on the rapid dissemination of their content, but due to a lack of recognition, they find it difficult to achieve this and often remain unknown. Publishing under a free license often leads to significantly wider distribution of the content, as potential users can freely access it, and today, specific platforms and search engines are already designed to search for freely licensed content. Additionally, "share-alike" clauses can be used to ensure that all derivative developments must be shared under the same conditions. For example, only non-commercial uses may be permitted.

Source: Adapted from http://de.creativecommons.org/was-ist-cc (30.11.2015).

63 https://developers.google.com/open-source/projects (30.11.2015)

The Australian initiative Cambia attempted to establish a Biological Open Source (BiOS) system more than 20 years ago. Its goal was to transfer the concept of free software from information technology to biological innovations. Richard Jefferson (2006), founder of Cambia (see Chapter VI.5.3), justified this goal as follows: "Extraordinary efficiencies occur when the tools of innovation are shared, are dynamically enhanced, have increased levels of confidence (legal and otherwise) associated with their use, and are low or no-cost." To achieve this, new technologies under BiOS were to be patented but then made available under a special BiOS license, ensuring free access. The primary target group was scientists. However, patent registration is complex and costly (making it barely affordable for individual scientists, such as those in the DIY bio scene). Therefore, releasing patented technologies under open licenses, as proposed by BiOS, is not very attractive. Due to a lack of demand, Jefferson has since abandoned the BiOS idea and now focuses on monitoring and documenting patents (Bundschuh 2012).

The open-source idea has been programmatically significant from the outset in the development of synthetic biology, particularly in the iGEM competition (see Chapter II.2.2), the activities of the BioBricks Foundation (BBF)[64], and numerous other initiatives that aim to freely share genetic material with colleagues, such as the Toolbox of the BIOSS Centre for Biological Signalling Studies at the University of Freiburg.[65] The BBF, which also serves as a biobank for the results of iGEM teams, was founded in 2003 by scientists and engineers as a non-profit organization. It aims to ensure that synthetic biology serves the public interest. The BBF introduced its own standard, the "BioBrick™ Public Agreement" (BPA), into the discussion of intellectual property rights in biotechnology.[66] "BPA is a free-to-use legal tool that allows individuals, companies, and institutions to make their standardized biological parts free for others to use. ... The BioBrick™ Public Agreement was developed for sharing the uses of standardized genetically encoded functions (e.g., BioBrick™ parts) but, in practice, can be used to make free the sharing of any genetically encoded function that you might already own or make anew."

The founding of the BBF was explicitly aimed at triggering a self-reinforcing development in synthetic biology, similar to what has been observed in many open-source community projects in software development. A central goal was the standardization and quality control of "bio bricks," i.e., molecular genetic functional units for specific cellular functions that were intended to serve as future design

---

64 http://biobricks.org/ (30.11.2015)

65 www.bioss.uni-freiburg.de/cms/toolbox-home.html (30.11.2015)

66 https://biobricks.org/bpa (30.11.2015)

elements for synthetic organisms. The open access was intended to build a dynamic open-source community to enable the rapid and effective development of synthetic biology technology as a public good (Bennett 2011). However, the bio bricks concept has not yet proven sufficiently viable. On the one hand, it has mostly not been possible to ensure the standardization and functionality of bio bricks; on the other hand, there is legal uncertainty regarding third-party patent claims on the offered bio bricks. The bio bricks developed as part of the iGEM competition, which make up a large portion of the BBF's inventory, are often insufficiently tested. These problems are perhaps not coincidental for a system that, with relatively limited resources and time investment, aims to capture as many participants as possible without significant public or private funding.

The success of future open-source projects in DIY biology will thus largely depend on whether functional, reusable biomaterials (e.g., standard organisms and gene systems) can be established and made generally available (see Chapter VI.6).

PHASE V: FUTURE SCENARIOS

"If it's not true, it's still a good invention."
—Giordano Bruno (1585)

This chapter presents some societal and political visions of representatives from the DIY bio scene regarding the technological development of life sciences. The portrayal is based on activities and discussions by scientists, artists, entrepreneurs, and hackers from the European and Asian DIY bio scenes within the framework of the "SYNENERGENE" project coordinated by ITAS (see Chapter V.2.7), which has deliberately developed some of the ideas that have emerged in recent years and placed them in a political context. The goal was to describe scenarios for a constructive approach to DIY biology without ignoring potential problems in the areas of biological safety or intellectual property rights. Two timeframes are distinguished: mid-term, i.e., within the next ten years, and long-term, i.e., beyond ten years. The further into the future the scenarios extend, the more speculative their nature necessarily becomes.

APPLICATIONS 6.1

To date, the effectiveness of the methods used, the knowledge of biological interrelationships, and the power of the theories and models of synthetic biology with regard to the ability to fundamentally alter or largely artificially create organisms are very limited. However, this could change significantly in the mid-term, thereby greatly expanding the action radius of biohackers—especially if the costs of laboratory equipment and materials continue to drop significantly, particularly for DNA synthesis (which has already happened with DNA sequencing). The general trend is toward decentralization of technology and simplification of applications. In the longer term, the miniaturization and automation of nearly all laboratory equipment and activities will likely be added. Biological reactions will likely be carried out in portable devices controlled by computers through lab-on-a-chip technology. As knowledge advances and methods become more sophisticated, the technology will also increasingly function in an automated manner.

The prerequisites for simple and reliable production of transgenic organisms include affordable and readily available synthetic DNA, the automation of molecular biological methods, and well-characterized and standardized molecular tools and organisms (Chapter VI.5.2). These advancements promise shorter iteration cycles in the development of increasingly complex products. Even if one assumes that the theoretical foundation of molecular and cell biology (in the sense of a comprehensive systems biology) does not fundamentally advance and predictive capabilities based on computer models for the "behavior" of genetic constructs remain unreliable, the time and cost required to conduct Synbio experiments are likely to decrease dramatically, thereby increasing the success rate based on automated trial-and-error experiments.

Once the technical foundations are established, more and more (DIY) biologists will have the opportunity to carry out complex genetic engineering projects, even in smaller-scale endeavors, to develop and test new products. In the long term, it is conceivable that many small companies could produce genetically engineered products, similar to the operations of today's small and medium-sized software companies. With some imagination, one could envision decentralized "programmed" transgenic organisms for everyday use, such as bacteria that produce perfume compounds (Bercovici 2014), improved yogurt bacteria for digestion and dental hygiene, or modified ornamental plants and pets (see the "techno-moral vignettes" of the Rathenau Institute; Chapter V.2.3). Affordable, simple technical solutions requiring minimal resources could also be of great value for medical diagnostics and research in developing countries.

Whether this will happen on a scale similar to the start-up scene of the computer industry remains to be seen in the coming years. The retrospectively peculiar misjudgments regarding the powerful computers that are now present in virtually all areas of life, as formulated by experts as recently as the 1980s, suggest that the possibility of a widespread DIY (Syn) biology future should not be dismissed outright (Potthof 2013, p. 30).

If we assume that gene analysis and synthesis techniques will proliferate to a degree similar to that of computers and mobile devices, a vastly greater quantity of biological data (including new, "artificial" genome sequences) will be generated and uploaded to online databases in the long term. The evaluation and application of this vast amount of information would undoubtedly take place globally and in a decentralized manner through internet-based technologies. The expected decentralization of DNA synthesis technologies would also make it possible to produce transgenic or synthetic organisms anywhere.

In addition to the use of Synbio methods in the production facilities of industrial biotechnology (Chapter III.1), whose goods are transported around the globe with great energy expenditure, products with high added value could in the future be produced locally using biotechnological processes. The necessary gene sequences – as a central resource – could be transmitted digitally (or physically in the form of durable DNA by post) and used on-site. The technology thus offers the possibility of being shared, modified, and managed like software, with direct material products as the result (similar to "conventional" additive manufacturing processes).

In practical terms, this would mean that value creation akin to that in the pharmaceutical industry, product processing as in the digital economy, and organization and production as in agriculture could be united in a single industry. This vision describes a variant of a future bioeconomy (Chapter III.6), where biohackers or start-ups from their environment would play a central role in building and testing the necessary information and production networks. It is easy to imagine a spread comparable to mobile technology in developing and emerging countries. Based on a relatively simple infrastructure (i.e., decentralized, miniaturized, and automated laboratory technology for sequencing and synthesizing DNA as well as for digital analysis of biomaterials), individual scientists could work cooperatively yet independently on developing synthetic constructs. Such a development could lead to an equalization of technological capabilities between developing, emerging, and industrialized countries. Since such a decentralized synthetic biology could become extremely powerful, it would be crucial to exercise caution to minimize misuse and harm to humans and the environment while maximizing benefits. Therefore, complex questions about safety, law, and justice in the use of technology, as well as the underlying knowledge and its application, will need to be answered in the coming years:

How should the release of self-replicating organisms be socially legitimized in the future, also across national borders? How can environmental policy concerns and measures to maintain an intact biosphere be appropriately addressed? How much freedom can individual scientists/DIY biologists be given in the future, and when will the legitimacy of third parties (e.g., authorities) be required? How could the control of experiments in a global context work as knowledge and technology continue to decentralize? Who can and should exercise this control function, and what criteria will determine the legitimacy of experiments? How can illegitimate intrusions by authorities, especially intelligence agencies, into the private affairs of scientists/DIY biologists be politically, legally, and technologically contained? How can a self-determined and responsible approach to sensitive information from genome analyses be established in the face of total digital surveillance?

In the following Chapters VI.6.2 and VI.6.3, proposals for answering some of these questions will be presented.

INFRASTRUCTURE AND SECURITY 6.2

Future biological and other security measures could only function globally and in a decentralized manner in a fully globalized and decentralized utilization system. Therefore, mechanisms would need to be developed in the medium term to reliably capture and neutrally evaluate the activities of the DIY bio and art scene, start-up companies, large industries, and academic research equally. The current security architecture for gene synthesis, for example, provides that companies voluntarily commit to checking the credibility and professionalism of those ordering genes before synthetic DNA is delivered (Chapter IV.2.2). In the past, this has led to confusion and misjudgments in individual cases, such as when artists ordered DNA for genetic engineering work. An individual review of DNA buyers in this manner would no longer be feasible once gene synthesis is truly decentralized, as digital sequence information would then suffice to produce the respective gene independently. The intentional or unintentional release and spread of transgenic/synthetic organisms would thus become much easier and almost uncontrollable.

Overly restrictive regulatory or security requirements could, however, have a similar effect to what has been observed historically with prohibition laws. Inappropriate surveillance and control measures, exercised, for example, as a political or administrative reaction to exaggerated threat scenarios, could prevent artists, scientists, and biohackers from working freely or push their activities into illegality, increasing the likelihood of negative developments while simultaneously hindering positive ones.

Practically speaking, most available knowledge about genetic data – the central resource for Synbio – is already accessible online in databases. Therefore, a good starting point would be to manage and monitor who accesses this data and for what purposes.

To prevent security problems, it seems logical to review the digital planning of the use of security-relevant sequence data online before they are ever introduced into non-native organisms. In the future, this task should be undertaken by the global scientific community, which would be significantly expanded by DIY biologists, rather than by a few gene synthesis companies as it is today. Given the vast amount of information and activities, it would be necessary to distribute the responsibility for reviewing the data among as many scientists as possible. Through mechanisms like reputation systems based on scientific performance and personal authentication when working with relevant information, the necessary security could be ensured, as it would always be clear who is accessing the data and for what purpose. While this model might only be suitable with limitations for commercial use and high-level research that sometimes requires confidentiality for competitive reasons, it should be well-suited for a public-interest-oriented DIY biology community.

Although in the medium term, it is not a realistic scenario, particularly in Europe, in the longer term, it should be considered under what conditions physical "containment" of genetically modified microorganisms – at least in part – could be relinquished as the highest principle. Assuming a solid understanding of the ecological impacts of transgenic or synthetic organisms, sequences and/or organisms already known to be safe could, for example, be fully released. Physical containment and its strict regulatory oversight could then be limited to unsafe microorganisms and their applications. It would only be necessary to verify in cases involving security-relevant sequences whether the individual can comply with the necessary security measures.

All uses or changes in the databases must be clearly visible, transparent, and traceable for everyone. To build the necessary trust in the databases among the participating scientists, decentralized data systems based on redundant storage and encryption technology could be the methods of choice. It should also be ensured that an organized review of data usage does not lead to the centralization of data storage itself, thereby avoiding unbalanced control by a few individuals over the data, as this would pose a high risk of intentional or unintentional data manipulation or direct influence on scientists. Additionally, users of the databases could establish a network through personal contacts, within which scientists could exchange more sensitive materials with greater trust. Audit systems could be established to enable regular self-monitoring and optimization of working practices.

Moreover, the databases must operate reliably and efficiently, with good scalability to manage the expected exponential growth of information. The more universal and user-friendly the access to these databases for their usage and review, the more users will voluntarily engage with them. As the collective knowledge about gene sequences, their distribution, and dynamics within ecosystems expands, the ability to interpret the genetic designs available online would improve. This would help ensure fundamental safety and quality of genetic engineering work and products without the need to withhold information or rely on central control authorities. Such a network would maintain, update, and manage the databases while providing global access to all interested in free knowledge exchange. The more users there are, the more effectively a digital global self-governance system for synthetic biology applications could function, promoting responsible and equitable use of the technology.

However, how such a distributed system of responsibility and management could realistically be implemented in the long term, given the globally diverse interests, regulatory frameworks, and societal positions, cannot be simply described. The considerations presented here are visionary scenarios intended to serve as a basis for discussion, in line with the "Vision Assessments" presented in Chapter V.2.1 (Grunwald 2012). The same applies to the concept for the public-interest-oriented use of technology discussed below.

BIO-COMMONS 6.3

As described in Chapter VI.5.2, the existing concepts for protecting intellectual property, such as patents and copyrights, can fail in the context of modern life sciences, leading to the "tragedy of the anticommons," i.e., the prevention of socially desirable outcomes. However, the unlimited dissemination and use of knowledge can also have negative consequences if ethical and ecological dimensions are not considered. A global, decentralized use of synthetic biology could accelerate the overconsumption of natural resources, thereby exacerbating the "tragedy of the commons" in areas like biodiversity (TAB 2014c, p. 116 ff.). This issue becomes particularly pressing when humans themselves are used as a resource or subject in synthetic biology.

Since these discussions involve fundamental questions about the very concept of life, cultural values—such as those related to bioethics and biopolitics—are of utmost importance and must be an integral part of any further discourse. Within the internal discussions of the DIY-bio scene, there has been a call to strive for a global ethical minimum consensus. Given new technological possibilities, it seems necessary for the future to readjust the boundary that distinguishes between alienable and inalienable nature, such as that of the human body. Currently, there is a debate on the permissibility of genetically altering the human microbiome (the totality of all benign bacteria living on and within humans) and making it subject to proprietary rights such as copyrights and patents.

Thus, with the tragedies of the commons and the anticommons, there is a dual collapse of regulatory concepts that can benefit neither the individual nor society and the economy as a whole. How might such an imbalanced innovation system be restored? One solution to the economic, bioethical, biopolitical, and security issues of a globally decentralized synthetic biology, discussed within the DIY-bio scene, is the idea of Bio-Commons, developed within the framework of "SYNENERGENE" in 2014. The concept of Bio-Commons aims to enable the economic use of "synthetic constructs" while ensuring free and fair access to materials and information, thereby preventing the appropriation of the technology by particular interests of individual state or private actors.

A fundamental reform of intellectual property protection in the life sciences, according to the Bio-Commons idea, would include the ability to acquire protection claims in an unbureaucratic and inexpensive manner (ideally completely free of charge) for a rather short duration (a few years) and to enable an open-source and open-access use with share-alike clauses (so-called "viral" clauses). A short duration is necessary due to the very rapid innovation cycles in biotechnology and the high complexity of the products. Share-alike clauses, as known from copyright-based Creative Commons licenses (Box VI.6 in Chapter VI.5.2), allow many individual actors in the private and public sectors to contribute their knowledge to a pool, making all entries usable under the same conditions. By using share-alike clauses, anyone building on knowledge under the protection of such a license is compelled to license their innovations under the same conditions, leading to a self-reinforcing growth of knowledge under this licensing concept.

If such licenses were used in large databases, large amounts of knowledge could be collected in a short time through a "viral" spread of this licensing model (as was the case with open-source projects like Linux and Wikipedia). Licenses that promote the release of knowledge are ideal mechanisms for making dormant knowledge usable and thus preventing a "knowledge lock-in." Moreover, it should become possible to design usage licenses that require adherence to ethical standards. Thus, ideas and related knowledge could be made available as a common good while being tied to certain conditions. These conditions would create competition among licenses, with the licensing model that convinces the most scientists growing the fastest. The more knowledge that is gathered under a licensing regime, the more attractive and effective its continued use becomes.

The attractiveness of a licensing model would not necessarily be tied only to its potential for monetization. By decoupling the assessment of the success of a discovery or invention from its market value, moral or ethical concepts could also increase the attractiveness of a licensing model. For example, nature and biodiversity protection or the exclusive peaceful use of the knowledge could be stipulated in the license. Policymakers could, within the framework of public research funding, stipulate or at least favor certain forms of licensing. A key advantage of the Bio-Commons model would also be that the community, or the entire interested public, could always verify the safety and quality of the information.

Since the resource of a future bioeconomy would essentially be digital codes that could be processed like software, while the physical product (physical DNA, protein, cell, organism, etc.) would be the used good, fundamentally, a common, non-rival consumption would be possible. The tragedy of the commons scenario is excluded in such non-exhaustible, shareable resources. Additionally, a Bio-Commons regulation would effectively prevent the tragedy of the anticommons. The enabled maximum societal control could minimize the risk of misuse without unnecessarily restricting the potential of the technology. The consistent focus on democratically legitimized, or at least more widely participatory and ethically framed, usage purposes should allow innovations in synthetic biology to be developed as sustainable action options in the medium and long term.

CONCLUSION AND OUTLOOK 7.

Hacking involves removing objects or ideas from their original context and giving them a new function. In industrialized countries, this is often a creative and playful engagement with technology, while in developing countries, the approach (known as Jugaad in this context; Box VI.1 in Chapter VI.3.1) can provide practical solutions to everyday problems. In both cases, existing rules or perceived limitations are bypassed to handle complex issues in the most elegant way possible. One of the core concerns of biohackers is to make the knowledge, materials, and methods of life sciences accessible to a broader audience.

DEVELOPMENT AND CONCERNS OF DIY-BIOLOGY 7.1

The current level of biohackers' abilities in electronics and equipment is comparable to that of professional biotechnology laboratories in the mid-1990s. Through the increasing global networking of the DIY-bio scene, the necessary knowledge and materials are spread worldwide, synchronizing the technical standards over time. The need for (natural) scientific education as a prerequisite for the ability to conduct independent research is emphasized, and often the right of every individual to engage in independent research is articulated. Here, research can be understood as both exploratory learning and relevant to professional (both academic and industrial) research as well as art.

The fundamental opportunity for every person worldwide to access scientific knowledge, combined with the easy practical applicability of biohacker technology, makes this form of technological progress predestined to spread globally in a decentralized manner, similar to computer technology. There is already significant participation by researchers and amateurs in developing and emerging countries like Indonesia and India. Empowerment through the use of technologies that can fundamentally affect life, such as genetic engineering and synthetic biology, significantly expands the scope of action for the involved actors and should be understood as a technological emancipation effort of a global citizen science movement. This effort typically does not fit within the established framework of institutional research, as this is often constrained by bureaucratic rules, rigid hierarchies, and an aging workforce (at least in Europe), leaving little room for young biohackers to pursue their own activities. Around 2008, nonprofit-operated biohackerspaces emerged worldwide in major metropolitan areas of industrialized and emerging countries, serving as semi-publicly accessible biolabs. The work conducted there covers topics such as art, education, social criticism, technological innovation, and future scenarios. This offers members and visitors the option to learn and apply molecular biology techniques independently, without reliance on schools and universities. The common features of hackerspaces are their permeable structures with flat hierarchies, interdisciplinary work, and openness to unconventional ideas.

The increasing technological emancipation of the DIY-bio scene and its media presence have sparked critical discussions on societal issues. These discussions address problems within the scientific system, ethical, environmental, and biosafety concerns. Efforts to introduce their own ethical guidelines in the form of "Codes of Ethics" have so far been limited in their reach, given the international DIY-bio scene's significant heterogeneity. The scene has also engaged with the intellectual property system in life sciences, which is increasingly perceived as inadequate (Chapters VI.5.2 and VI.6.3). An important assessment of this overall report is that a comprehensive political and legal restructuring of intellectual property management will be one of the main tasks for the global community in the coming years (or likely even decades), particularly in biotechnology/synthetic biology (Chapter VII.2.6). As the "digital share" becomes increasingly important in synthetic biology, the development of intellectual property rights in the digital goods sector, which has been highly controversial for several years, will be crucial.

The activities within the DIY-bio scene initially sparked discussions among biosafety experts (especially in the USA). Concerns arose that biohackers could harm the environment or people through mistakes (bioerror), knowingly or unknowingly engage in criminal activities (biocrime), or even carry out bioterrorist activities. However, these concerns have been significantly relativized and largely dispelled in recent years after closer analysis of the situation.

In contrast, a different problem emerges concerning the efforts of authorities (at least in the USA) to control or even steer the DIY-bio scene. The success prospects are fundamentally low because the DIY-bio scene is naturally decentralized, and hackerspaces, with their relatively simple technical equipment, require only minimal infrastructure that can be easily installed and relocated. If undue surveillance pressure were exerted (for example, as a political and bureaucratic reaction to exaggerated media threat scenarios) and professional scientists withdrew from the scene for self-protection, thereby relinquishing their influence on amateurs (e.g., regarding adherence to safety regulations), this could ironically increase the likelihood of missteps (at least in the direction of bioerror).

The culture of transparency and free online communication within the DIY-bio scene, as well as the public accessibility of hackerspaces, should, in principle, ensure a good level of safety due to mutual social control. In Europe, all biotechnological activities are additionally covered by regulations like the German Genetic Engineering Act (GenTG). While safety concerns have moved to the background, especially in the USA, the economic potential arising from the scene's innovation power is now the focus, with the first venture capitalists beginning to fund startups within the scene. If successful new products emerge from today's startups, an independent economic sector could develop.

The economic potential of biohacker startups is unlikely to rival the established biotechnology or pharmaceutical sectors even in the medium term, but it could still grow to a significant size or merge with these industries, thereby increasing their diversity.

The fundamental importance of findings from modern life sciences and the new possibilities of biotechnology raise the question of which societal groups, and thus which guiding principles and societal models, will shape development in the future. The young DIY-bio scene is already providing relevant impulses for the debate on the perspectives of synthetic biology (in the broader sense), its societal usefulness, and desirability. Although the scene currently consists of only a few thousand active members, its future development remains uncertain. Potthof (2013, p. 16) assumes that the range of possible positions that could be adopted by DIY-bio groups and similar actors could be as broad as the scene's heterogeneity: from emphasizing the economic opportunities resulting from the founding of new biotechnology companies, to positively influencing public opinion regarding the societal potentials of genetic engineering, to developing competent techno-critical positions modeled after the Chaos Computer Club.

In this sense, the biohacker movement undoubtedly has a model character, as it represents diverse opinions, experiments with ideas, and offers the opportunity to identify and discuss future developments early on.

CITIZEN SCIENCE AS AN IMPORTANT PART OF CLOSER INTEGRATION BETWEEN SCIENCE AND SOCIETY 7.2

The significant media attention toward the still relatively small DIY-bio scene indicates an (unsatisfied) societal need to engage more deeply with the topics of modern biosciences. The media success of the DIY-bio scene compared to the public presence of universities and other research institutions is remarkable. For several years, biohackers have managed to garner impressive public attention despite minimal budgets and experiments that are noticeably simpler than those conducted in far better-equipped and funded state institutions.

The interest in DIY-biology underscores the need for universities and other research institutions not only to communicate more openly with society but also to provide concrete opportunities for public participation in research projects in the spirit of citizen science (Chapters VI.3.1 and VII.2.4). To achieve this, flatter hierarchies and an open and transdisciplinary exchange among scientists and with the public would be beneficial.

To bring about the necessary modernization of academic practices, fundamental structural reforms and significantly more financial resources for teaching and public engagement would be required within research funding and at universities and other institutions. Among other things, career incentives for open publishing (Open Access) of results and for popular science work would be a necessary prerequisite for greater transparency and a more public-oriented approach.

However, there is a fundamental question of whether universities could be overburdened in their research and teaching activities by having to engage in such public education and participation work. The non-academic organization of the DIY-bio scene holds potential to promote broader societal understanding of modern biosciences. Therefore, it seems overall necessary to strengthen the new initiatives of the DIY-bio scene and thus the claim of this part of the citizen science movement for genuine participation in the research and innovation process, even in their independent organizational forms, and to promote this interface between research, art, and the public.

A significant positive effect of public participation within an advanced citizen science program would be that closer contact between science and society would lead to increased mutual feedback, making it possible to "break down the ivory towers." Engaged citizen scientists can bring new impulses to research through creative and interdisciplinary thinking, ask critical questions, and thus point out deficiencies in research funding, processes, and structures. However, greater public influence on research also demands more awareness of problems, responsibility, and expertise. A correspondingly supported citizen science scene could carry out the necessary public education work and make the knowledge gained through public funds for academic research accessible to a broader audience.

Hackerspaces, as politically neutral ground, offer suitable spaces for citizens to independently educate themselves on scientific and technological issues and can simultaneously provide a platform for the required public dialogue.

This can be achieved through a combination of education about the facts and the artistic aestheticization of the topics and materials. The boundary between free art and public information is fluid. Through critical and artistic reflection on epistemic questions about the boundaries of the living, ethical questions about the use and manipulation of the living, societal questions about worldviews, and practical applications in designing future spaces and products, citizens' awareness of the impacts of research can be heightened. This makes the actual risks and opportunities of modern life sciences technologies more tangible to the public, fostering an independent, informed, and enlightened position.

Moreover, in this engagement, visions for a sensible approach to technology can be developed, as is currently happening in the DIY-bio scene on the topic of synthetic biology (Chapter VI.6). The genres of bioart and biofiction can also serve as sources of inspiration for future research projects by professional scientists (Hennen/Pfersdorf 2014; Karberg 2012). By democratizing science in this way, citizens could take responsibility and participate in forward-looking developments. The DIY-bio scene could then play an important role in mediating, critiquing, and exploring the potential societal consequences of the biosciences. The better the dialogue between citizens and research succeeds, the easier it could become to integrate knowledge acquisition and progress.

PROMOTION THROUGH MODERATE DEREGULATION? 7.3

Targeted promotion of DIY-bio activities, such as those in the USA by the WWICS or in the Netherlands by the Waag Society (Chapter VI.4.1), has not yet occurred in Germany. While public lectures at universities, the involvement of universities in the iGEM competition, and startup programs for inventors that provide money and access to materials can be considered forms of support, they are relatively limited. The establishment of "biotechnological high schools," particularly in Baden-Württemberg (with 24 such schools, and a few others in Hesse and Saxony), has been significant. Graduates of these schools bring with them a solid theoretical and experimental knowledge base and can conduct serious research even without a university degree or after a short time.

To prevent the unilateral appropriation and instrumentalization of the scene's potential by the economic interests of the biotechnology industry or other lobbying groups and to foster independent development, public support for DIY-bio activities and, especially, the necessary infrastructure would be required. Direct state support for hackerspaces (of which there are over 120 in Germany; Fig. VI.4), fab labs (about 40), museums, galleries, and similar institutions interested in biotechnology would be an appropriate measure.

Fig. VI.4 Existing Hackerspaces in Germany (as of November 2015)

Source: http://hackerspaces.org/wiki/Germany (30.11.2015)

However, such educational measures would be at least partially ineffective due to the very strict regulation of biological work in general and especially genetic engineering, as the learned skills can hardly be utilized. So far, genetic engineering work, even at the lowest safety level S1, i.e., "... genetic engineering work ..., which, according to the state of scientific knowledge, does not pose a risk to human health and the environment" (§ 7 GenTG), is only allowed in Germany to specialists and under strict protective measures (Box VI.4 in Chapter VI.4.4). The high costs incurred due to regulation and safety measures also significantly hinder the operation for non-profit purposes, and even the operation of an S1 laboratory in a hackerspace is only possible in exceptional cases due to the high costs of safety measures (Chapter VI.4.1).

In universities and selected schools, organisms and genetic systems of safety level 1 are already routinely used for educational purposes. In the sense of freedom of art and research, it seems appropriate to grant citizens more freedom to develop independent activities outside these educational institutions and to achieve a generally freer handling of biological materials (including transgenic ones), if they do not pose a risk to human health and the environment, even for private purposes. Specifically, an adjustment of the safety requirements at the lowest safety level could be considered. Two specific perspectives offer themselves for this:

"S1/2" SAFETY LEVEL

To simplify the approval requirements for the operation of "safety laboratories," genetic engineering work with organisms of risk group 1 (no risk to humans and the environment) could be permitted in all laboratories based on a notification requirement, but without special requirements. This would mean:

> Elimination of GenTG-specific structural, technical, and organizational requirements for S1 laboratories;
> Reduction of GenTG-specific recording and archiving obligations for S1 experiments.

To ensure that experimenters comply with basic biological safety standards, the introduction of a competency test would be sensible, enabling the conduct of such genetic engineering experiments. The prerequisites for obtaining such a certificate of competence should, however, be adapted to the current educational situation of biologists in Germany and could, for example, be based on the level of a bachelor's degree with a focus on molecular biology. The certificate of competence would thus be a step down from the previously required expertise, which qualifies one to operate a genetic engineering facility only after three years of molecular biology work experience following a master's or diploma degree.

SELF-CLONING WHITELIST

The currently existing legal provisions could be utilized and expanded, particularly with regard to the opt-out clause of Directive 2009/41/EC, for long-established standard experiments in education and training. Self-cloning is already exempt from the GenTG:

"... as long as it is not a project involving release or placing on the market, and as long as genetically modified organisms are not used as donors or recipients, the following are also not considered methods of genetic material alteration: self-cloning of non-pathogenic, naturally occurring organisms, consisting of a) the extraction of nucleic acid sequences from cells of an organism, b) the reintroduction of the entire or part of the nucleic acid sequence (or a synthetic equivalent) into cells of the same species or into cells of phylogenetically closely related species that can exchange genetic material through natural physiological processes, and c) any prior enzymatic or mechanical treatment. Self-cloning can also include the use of recombinant vectors if they have been safely used in this organism over a long period" (§ 3.31 GenTG).

This exemption for self-cloning experiments is already practiced in some applications. For example, the "Blue Genes" experimental kit by Roche Deutschland Holding GmbH is distributed as educational material to schools. With this genetic kit, students can reintroduce a gene into a safety strain of E. coli that had previously been removed from the bacterial chromosome. A plasmid, deemed safe in genetic engineering practice, is used as the vector—though it must still be considered recombinant. The ZKBS (Central Commission for Biological Safety) confirmed in a statement the applicability of the self-cloning paragraph (ZKBS 2001). Such experiments could also be suitable for non-professional contexts. However, the complexity of natural processes, particularly the assertion that all natural ways in which genetic material is exchanged also count as self-cloning, makes practical interpretation of the law very challenging.

It would therefore be beneficial, within the existing legal framework, to establish a universally applicable and continuously expandable list (whitelist) of biological materials that would provide legal certainty for genetic engineering work outside registered laboratories. This list could include all established and recognized safe biological substances (genes, vectors, organisms, etc.). Biological substances listed in such a whitelist system could be used and (in the case of DNA) recombined without the need for approval and without the burdensome containment measures required for specialized genetic engineering laboratories. Approval by a central authority should at least have nationwide validity in Germany, but ideally be introduced at the EU level. Existing exemptions for proven gene sequences and established standard organisms should be harmonized EU-wide. The corresponding biological materials could be distributed by universities or other public institutions, such as the Leibniz Institute DSMZ German Collection of Microorganisms and Cell Cultures GmbH[67] under open (and possibly non-commercial) usage licenses. A revision of the GenTG should also be considered in general, as it currently only pertains to economic value creation and scientific research (§ 1.3 GenTG). It would be appropriate to expand the purpose of the law in the sense of the constitutionally anchored freedom of research to include its use in art and citizen science.

67 www.dsmz.de/de/start/schueler-und-lehrer.html (30.11.2015)

LITERATURE

EXPERT REPORTS COMMISSIONED 1.

Engelhard, M., Hagen, K. (2012): Bedeutung der Grenzüberschreitung zwischen Disziplinen und Akteuren in der Synthetischen Biologie. Europäische Akademie zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen Bad Neuenahr-Ahrweiler gGmbH, Bad Neuenahr-Ahrweiler

Gleich, A. von, Giese, B., Köngstein, S., Schmidt, J.C. (2012): Charakterisierung der Synthetischen Biologie einschließlich einer Darstellung möglicher Entwicklungsperspektiven und gesellschaftlicher Einflussmöglichkeiten. aforetec GbR, Bremen

BRIEF EXPERT REPORTS AND OPINIONS 2.

Potthof, C. (2013): SynBio & DIY unter besonderer Berücksichtigung der zivilgesellschaftlichen Teilhabe und neuer Sicherheitsfragen. Kommentargutachten im Auftrag des Büros für Technikfolgen-Abschätzung beim Deutschen Bundestag. Gen-ethisches Netzwerk e. V., Berlin

Trojok, R. (2012): DIYbio und Citizen Science. Eine Beurteilung im Kontext der Synthetischen Biologie. Expertise für das Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, Kopenhagen

Trojok, R. (2014): Schlüsselereignisse in der Synthetischen Biologie. Expertise für das Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, Berlin

FURTHER LITERATURE 3.

Baker, B. (2015): DIYbio – alternative career path for biologists? In: BioScience 65(1), S. 112

Bennett, G. (2011): Open technology platforms: (How) Should the BIOFAB give things away? Biofab Human Practices Report 3.0., http://biofab.synberc.org/sites/default/files/HPIP_Report%203.0_v1_0.pdf (16.11.2015)

Bennett, G., Gilman, N., Stavrianakis, A., Rabinow, P. (2009): From synthetic biology to biohacking: Are we prepared? In: Nature Biotechnology 27(12), S. 1109–1111

Bercovici, J. (2014): These startup dudes want to make women's private parts smell like ripe fruit. In: Inc., 19.11.2014, www.inc.com/jeff-bercovici/sweet-peach-probiotics-lady-parts.html (16.11.2015)

Berger, K.M., Wolinetz, C., McCarron, K., You, E., So, K.W. (2012): Bridging science and security for biological research: a dialogue between universities and the Federal Bureau of Investigation. Report of a Meeting, February 21-22 2012, http://

Boheemen, P. van, Vriend, H. de (2014): Do-it yourself biology. Een verkenning van ontwikkelingen in Nederland. Amsterdam, www.waag.org/sites/waag/files/public/media/publicaties/cgm_2014-03_do-it-yourself_biology_een_verkenning_van_ont-wikkelingen_in_nederland.pdf (18.11.2015)

Bundesregierung (2014): Unterrichtung durch die Bundesregierung. Bericht über die Auswirkungen des Patentrechts im Bereich der Biotechnologie unter anderem hinsichtlich ausreichender Technizität sowie hinsichtlich derAuswirkungen im Bereich der Pflanzen- und Tierzüchtung. Deutscher Bundestag, Drucksache 18/2119, Berlin

Bundschuh, A. (2012): Lernprozess oder Misserfolg? In: Gen-ethischer Informationsdienst (GID) 215, S. 15-17

Charisius, H., Karberg, S., Friebe, R. (2012): Wir Genbastler. In: Frankfurter Allgemeine Sonntagszeitung, 29.04.12, S. 57–60

Charisius, H., Karberg, S., Friebe, R. (2013a): Becoming biohackers: The long arm of the law. In: BBC-future, 24.01.2013, www.bbc.com/future/story/20130124-biohacking-fear-and-the-fbi (18.11.2015)

Charisius, H., Karberg, S., Friebe, R. (2013b): Biohacking. Gentechnik aus der Garage. München

CIA (Central Intelligence Agency) (2003): The darker bioweapon future. 03.11.2003, http://fas.org/irp/cia/product/bw1103.pdf (18.11.2015)

Crabtree, J. (2012): More with less. In: Financial Times UK, 19.05.2012, www.ft.com/

cms/s/2/d5612fac-960f-11e1-a6a0-00144feab49a.html (18.11.2015)

Critical Art Ensemble (2006): Die molekulare Invasion. Münster

EC (2013): Options for Strengthening Responsible Research and Innovation. Report of the Expert Group on the State of Art in Europe on Responsible Research and Innovation. http://ec.europa.eu/research/science-society/document_library/pdf_06/options-for-strengthening_en.pdf (18.11.2015)

ETC Group (2013a): Putting the cartel before the horse ... and farm, seeds, soil, peasants, etc: Who will control the agricultural inputs. Communiqué ETC Group No. 111, www.etcgroup.org/putting_the_cartel_before_the_horse_2013 (19.11.2015)

ETC Group (2013b): Vanilla & synthetic biology. A case study. 2013 Update,

www.etcgroup.org/sites/www.etcgroup.org/files/Vanilla_SynBio_case_study_Oct2013.pdf (19.11.2015)

Finke, P. (2014): Citizen Science. Das unterschätzte Wissen der Laien. München

Galasso, A., Schankerman, M. (2014): Patents and cumulative innovation: Causal evidence from the courts. NBER Working Paper No. 20269. www.nber.org/papers/

w20269 (19.11.2015)

GAO (United States Government Accountability Office) (2014): Anthrax. Agency approaches to validation and statistical analyses could be improved. Report to Congressional Requesters, December 2014, www.gao.gov/assets/670/667671.pdf (19.11.2015)

Grunwald, A. (2012): Synthetische Biologie als Naturwissenschaft mit technischer Ausrichtung. Plädoyer für eine »Hermeneutische Technikfolgenabschätzung«. In: Technikfolgenabschätzung – Theorie und Praxis 21(2), S. 10–15

Grushkin, D., Kuiken, T., Millet, P. (2013): Seven myths & realities about do-it-yourself biology. Woodrow Wilson International Center for Scholars, Synthetic Biology Project, Synbio 5, November www.synbioproject.org/process/assets/files/

Hennen, L., Pfersdorf, S. (2014): Public engagement – promises, demands and fields of practice. Deliverable 2.1 of the project »Engage2020«. o. O., http://engage2020.eu/media/D2.1-Public-Engagement-Promises-demands-and-fields-of-practice.pdf (20.11.2015)

IAP (IAP – the global network of science academies) (2014): IAP Statement on realising global potential in synthetic biology: Scientific Opportunities and Good Governance. 07.05.2014, Trieste, www.interacademies.net/File.aspx?id=23974 (20.11.2015)

Jefferson, R. (2006): Science as social enterprise: The CAMBIA BiOS Initiative. In: Innovations: Technology, Governance, Globalization 1(4), S. 13–44, www.bios.net/daisy/bios/3067/version/default/part/AttachmentData/data/INNOV0104_pp13-44_innovations-in-practice_jefferson.pdf (20.11.2015)

Kera, D. (2012): Hackerspaces and DIYbio in Asia: Connecting science and community with open data, kits and protocols. In: Journal of Peer Production 2, http://peerproduction.net/issues/issue-2/peer-reviewed-papers/diybio-in-asia/ (20.11.2015)

Kupecz, A. (2014): Who owns CRISPR-Cas9 in Europe? In: Nature Biotechnology 32(12), S. 1194–1196

Kurtz, S. (2005): Research is not terrorism: Steve Kurtz. In: The Arts Catalyst, 05.02.2005, www.artscatalyst.org/image/steve-kurtz-research-not-terrorism-april-2004 (20.11.2015)

Landrain, T. (2012): Do-it-yourself biology: Challenges and promises for an open science and technology movement. In: Systems and Synthetic Biology 7(3), S. 115–126

Ledford, H. (2010): Garage biotech: Life hackers. In: Nature 467(7316), S. 650–652

Lerner, J., Tirole, J. (2005): The Economics of Technology Sharing: Open source and beyond. In: Journal of Economic Perspectives 19(2), S. 99–120

Lindner, M. (2007): Kunst im Gentech-Zoo. In: Gegenworte 9, S. 71–74

Lloyd's (Lloyd's Corp. London) (2009): Synthetic biology. Influencing development. Lloyd's Emerging Risks Team Report Version 1, www.lloyds.com/~/media/lloyds/reports/emerging%20risk%20reports/syntheticbiology_influencethedebate_july

2009_v1.pdf (20.11.2015)

Murray, F., Stern, S. (2007): Do formal intellectual property rights hinder the free flow of scientific knowledge? An empirical test of the anti-commons hypothesis. In: Journal of Economic Behavior & Organization 63(4), S. 648–687

Nature (2010): Garage biology (Editorial). In: Nature 467(7316), S. 634

Nature (2013): The DIY dilemma. Misconceptions about do-it-yourself biology mean that opportunities are being missed (Editorial). In: Nature 503(7477), S. 437–438

Ober, S. (2014a): Was ist Bioökonomie? Bundesregierung und EU setzen auf biobasierte Industrie. In: Rundbrief Forum Umwelt & Entwicklung (4), S. 2–4

Ober, S. (2014b): Partizipation in der Wissenschaft. Zum Verhältnis von Forschungspolitik und Zivilgesellschaft am Beispiel der Hightech-Strategie. München

Pamlin, D., Armstrong, S., Baum, S. (2015): Global Challenges. 12 Risks that threaten human civilisation. The case for a new risk category. http://globalchallenges.org/wp-content/uploads/12-Risks-with-infinite-impact.pdf (20.11.2015)

PCSBI (Presidential Commission for the Study of Bioethical Issues) (2010a): New directions. The ethics of synthetic biology and emerging technologies. Washington, D.C.

Pentecost, C. (2008): Outfitting the laboratory of the symbolic: Toward a critical inventory of bioart. In: Costa/Philip 2008, S. 107–123

Revill, J., Jefferson, C. (2014): Tacit knowledge and the biological weapons regime. In: Science And Public Policy 41(5), S. 597–610

Sauter, A. (2013): Frickler, Gründer, Bürgerforscher? In: Gen-ethischer Informationsdienst (GID) 221, S. 18–21

Schlichter, A., Karberg, S. (2012): Die Gen-Köche. In: Bayerisches Fernsehen, Erstaus¬strahlung 07.05.2013

Seyfried, G., Pei, L., Schmidt, M. (2014): European do-it-yourself (DIY) biology: Beyond the hope, hype and horror. In: BioEssays: News and reviews in molecular, cellular and developmental biology 36(6), S. 548–551

Sullivan, M. (2014): Cambrian Genomics CEO says his company just raised $10M to »print more DNA«. In: Venturebeat, 20.11.2014, http://venturebeat.com/2014/1120/cambrian-genomics-ceo-says-his-company-just-raised-10m-to-print-more-dna/ (23.11.2015)

TAB (2014c): Inwertsetzung von Biodiversität (Autor: Kehl, C., unter Mitarbeit von Sauter, A.). TAB-Arbeitsbericht Nr. 161, Berlin

Tiku, N. (2014): Male startup founders think your vagina should smell like a ripe peach. In: Valleywag, 19.11.2014, http://valleywag.gawker.com/male-startup-founders-think-your-vagina-should-smell-li-1660896761 (23.11.2015)

UNICRI (United Nations Interregional Crime and Justice Research Institute) (2012): Security implications of synthetic biology and nanobiotechnology. A risk and response assessment of advances in biotechnology. Shortened public version, Turin, www.unicri.it/in_focus/files/UNICRI%202012 %20Security%20Implications%20of%20Synthetic%20Biology%20and%20Nanobiotec hnology%20Final%20Public-1.pdf (23.11.2015)

Veciana, S., Neubauer, C. (2015): Bottom-Up Geschichten nachhaltigkeitsorientierter partizipativer Forschung. Eine partizipative Studie. Vereinigung Deutscher Wissenschaftler e. V., Berlin, www.research-arts.net/download/PartizipativeForschung_

Veciana-Neubauer_2015.pdf (23.11.2015)

Warrick, J. (2010): FBI investigation of 2001 anthrax attacks concluded; U.S. releases details. In: The Washington Post, 20.02.2010, www.washingtonpost.com/wp-dyn/content/article/2010/02/19/AR2010021902369.html?sid=ST2010021904257 (23.11.2015)

Ziegler, D., Pettibone, L., Rettberg, W., Feldman, R., Brand, M., Schumann, A., Kiefer, S. (2015): Beispiel: Citizen-Science-Projekte. Potenzial für Lebenslanges Lernen. In: Weiterbildung 2, S. 18–21

Zimmeren, E. van, Vanneste, S., Matthijs, G., Vanhaverbeke, W., Overwalle, G. van (2011): Patent pools and clearinghouses in the life sciences. In: Trends in Biotechnology 29(11), S. 569–576

ZKBS (Zentrale Kommission für biologische Sicherheit) (2001): Stellungnahme der ZKBS zur Bewertung des »Blue Genes«-Experimentierkastens des Fonds der Chemischen Industrie vom 19. September 2001. Bundesamt für Verbraucherschutz und Lebensmittelsicherheit (BVL), Az.: 6790-10-72-0001, o. O., www.bvl.bund.de (23.11.2015))

APPENDIX

TABLE 1.

LIST OF FIGURES 2.

LIST OF ABBREVIATIONS 3.

ABFTA	Committee on Education, Research and Technology Assessment
BBF	BioBricks Foundation
BBSRC	Biotechnology and Biological Sciences Research Council
BiOS	Biological-Open-Source-System
BMBF	Federal Ministry of Education and Research
BMEL	Federal Ministry of Food and Agriculture
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BTWC	Biological and Toxin Weapons Convention
BUND	Friends of the Earth Germany
BVL	Federal Office of Consumer Protection and Food Safety
COGEM	Commissie Genetische Modificatie (Genetic Modification Committee)
CRISPR	clustered regularly interspaced short palindromic repeats
CWC	Chemical Weapons Convention
DFG	German Research Foundation
DIY	do it yourself

DNA	deoxyribonucleic acid (Desoxyribonukleinsäure)
DURC	dual use research of concern
E. coli	Escherichia coli (Bacterium)
EFSA	European Food Safety Authority
EGE	European Group on Ethics in Science and New Technologies
ELSI	ethical, legal, and societal implications
EPSRC	Engineering and Physical Sciences Council
EPTA	European Parliamentary Technology Assessment Network
ERASynBio	European Research Network for the development and coordination of synthetic biology in Europe
ESF	European Science Foundation
ETC Group	Action Group on Erosion, Technology and Concentration
EU	European Union
FBI	Federal Bureau of Investigation
FuE	Research and development
GeN	Gen-ethical Network e. V.
GenTG	German Law on the Regulation of Genetic Engineering (Genetic Engineering Act)
GVMO	genetically modified microorganism
GVO	of genetically modified organisms
GVP	genetically modified plantIASB International Association Synthetic Biology e. V.
iGEM	International Genetically Engineered Machine Competition
IGSC	International Gene Synthesis Consortium
ITAS	Institute for Technology Assessment and Systems Analysis of the Karlsruhe Institute of Technology
MIT	Massachusetts Institute of Technology
MMLAP	Mobilisation and Mutual Learning Action Plan
MPG	Max Planck Society
NEST	new and emerging science and technology
NRO	Non-governmental organization
NSF	National Science Foundation
NTWG	New Techniques Working Group
PCR	polymerase chain reaction
PCSBI	Presidential Commission for the Study of Bioethical Issues
RNA	ribonucleic acid/Ribonukleinsäure
RRI	responsible research and innovation
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks

STOA	Scientific Foresight Unit (formerly Science and Technology Options Assessment) of the European Parliament
SVMO	synthetically modified microorganisms
SVO	synthetically modified organism
SYBHEL	Synthetic Biology for Human Health
Synbio	Synthetic Biology
TA	Technology assessment
TAB	Office of Technology Assessment at the German Bundestag
TALEN	transcription activator-like effector nuclease
UFZ	Helmholtz Centre for Environmental Research
WHO	World Health Organization
WWICS	Woodrow Wilson International Center for Scholars
XNA	xeno nucleic acid/Xenonukleinsäure
ZFN	Zinc finger nuklease
ZKBS	Central Commission for Biological Safety of the BVL