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Synthetic Biology

— AN INQUIRY

Linda Dubec

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Supervisor: Richard Langlais
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CPS: International Master's Programme in Human Ecology
Human Ecology Division
Department of Human Geography
Faculty of Social Sciences
Lund University

Department:	Human Geography
Address:	Kulturgeografi Lunds Universitet
	Sölvegatan 12
	223 62 Lund
Telephone:	+4646-222 86 90

Title and Subtitle:	Synthetic Biology — An Inquiry
Author:	Linda Dubec
Supervisor:	Richard Langlais
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Abstract: Synthetic biology, a branch of the life sciences, can be summarized as the deliberate attempt to design living organisms. It is an emerging technoscience and a potential platform technology portrayed as possibly the next industrial revolution. This thesis is an inquiry into synthetic biology; an exploration based on observations in text. An explorative tool is the question: What is synthetic biology? I explore accomplishments, applications and approaches within synthetic biology such as BioBricks and the standardization of biological parts; the 'birth' of Synthia (*Mycoplasma laboratorium*); de-extinction; synthetic biology as a potential assistant in nature conservation; and the quest to replace agricultural production and fossil sources for oils and chemicals through the engineering of microbes. I conclude that synthetic biology is guided by an engineering vision and a reductionist paradigm in that: biology is seen as a science that can be made predictable; biological organisms are approached with an anti-complexity view; parts of an organism are seen as sufficient for properties of the whole; and species are seen as detached from their ecological context. I also conclude that synthetic biology is challenging culturally fixed boundaries and understandings and that it explains life as software, or as information process and code. I also conclude that it is a mystification of production, a fetish that conceals rather than reveals and a project of ecological modernization. Finally, I conclude that synthetic biology is producing an idea that any living being potentially can be any other which I suggest needs more inquiring.

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‘The end of our foundation is the knowledge of causes, and secret motions of things; and the enlarging of the bounds of human empire, to the effecting of all things possible. […] We have […] large and various orchards and gardens, wherein we do not so much respect beauty as variety of ground and soil, proper for divers trees and herbs […]. In these we practice likewise all conclusions of grafting, and inoculating, as well of wild-trees as fruit-trees, which produceth many effects. And we make by art, in the same orchards and gardens, trees and flowers, to come earlier or later than their seasons, and to come up and bear more speedily than by their natural course they do. We make them also by art greater much than their nature ; and their fruit greater and sweeter, and of differing taste, smell, color, and figure, from their nature. And many of them we so order, as they become of medicinal use. ‘ We have also means to make divers plants rise by mixtures of earths without seeds, and likewise to make divers new plants, differing from the vulgar, and to make one tree or plant turn into another. […] We make a number of kinds of serpents, worms, flies, fishes of putrefaction, whereof some are advanced (in effect) to be perfect creatures, like beasts or birds, and have sexes, and do propagate. Neither do we this by chance, but we know beforehand of what matter and commixture, what kind of those creatures will arise.” (Bacon 1906 [1627]: 265, 267-268)

INTRODUCTION

The 21st century is the century of biology. Scientific advancement in the life sciences, such as the successful mapping of the human genome, is defining the current time period (Venter and Cohen 2004; Cookson 2010) where the interest in the texture of life is, to say the least, immense and constantly developing. Achievements of one particular section of the broad field of the life sciences, especially focused on the minimal parts of living organisms, have led to beliefs that humans are playing God, tinkering with nature and now able to not only read, but also write the code of life. It is discussed as a potential platform technology (Thompson 2012: 1), meaning that it can enable "rapid and diffuse innovations and simultaneous product development in diffuse markets, often targeting sectors of the economy that have traditionally been thought to have little relationship to one another" (Thompson 2012: 1). Its applications are thought to be limited only by imagination and it could potentially be the next industrial revolution (Heaven 2013; Schmidt 2010). It can be summarized as "the deliberate attempt to design living organisms" (Calvert 2008: 394). *It* is called synthetic biology.

In this thesis I aim to explore synthetic biology by methodologically relying on *inquiry*, as described by Paul Rabinow (2008), and conduct a kind of fieldwork in text in an attempt to, in an explorative manner, answer the question: What is synthetic biology? With this question I aim to go beyond the mere definition of synthetic biology and produce an understanding of it by linking together accomplishments, applications and approaches within the field.

This thesis is philosophical, where philosophy is understood as "…a creative activity of conceptual inquiry which frees us of attachment to specific models and doctrines" (Drengson 2010: 27). It is a contribution to the academic fields of technology and values and human ecology. In the former, emphasis is put on developing

> …critical forms of thought that allow us to understand, evaluate, appreciate, and criticize the ways in which technologies reflect, as well as change, human life, individually, socially, and culturally (Hanks 2010: 1)

and in the latter, focus is put on understanding and evaluating interrelations of humans and the rest of nature. I also aim to contribute to what Nikolas Rose (2013) calls for in relation to the life sciences, namely a *fieldwork in philosophy*, or "…empirical investigations of the operative philosophy of the biologists themselves" (N. Rose 2013: 22). This, Rose suggests, is necessary in order to understand how the notion of life is shaped, as well as looked upon in the contemporary sciences of life.

The thesis is structured as following. The first chapter, *Inception*, outlines how I arrived at the idea of exploring synthetic biology and why it is relevant; then follows a description of the methodology applied — *Inquiry* as described by Paul Rabinow (2008). After that I dedicate a chapter to describing *The Field*, which is news media articles, interviews and videos; academic writings such as articles and books; and recordings and videos from conferences. The chapter also outlines what has guided me in my choices of texts. Following this are five chapters dedicated to different aspects of synthetic biology. The first one, *Synthetic Biology*, deals with definitions and distinctions of the field; the second, *Like Lego*, focuses on the standardization of biological parts (BioBricks) and the engineering paradigm of synthetic biology; the third, *Playing God*, takes its starting point in the birth of the first synthetic organism; the fourth chapter discusses *De-Extinction*, i.e. the idea to use synthetic biology to revive extinct species as well as synthetic biology as a potential application for nature conservation; the last chapter of the five, *Replacing Agriculture*, discusses synthetic biology as a seemingly new production technology. The thesis ends with my *Reflections and Conclusions* on the topic and the process.

INCEPTION

Synthetic biology emerged out of first being "in the corner of my eye", to becoming a topic at the very center of my field of vision; a transition that occurred during the period I spent in Canada in the autumn of 2012. There I worked as a research intern for five months at the ETC Group's[1] headquarters in Ottawa and a shorter period at the organization's office in Montreal where I engaged in research around synthetic biology for the Conference Of the Parties (COP) 11 of the Convention on Biological Diversity (CBD) that took place in Hyderabad, India in October 2012. Besides assisting the organization with my research, I learned about synthetic biology which created a will to explore it further. I was intrigued by, for example, tiny pieces of text, like this one that I stumbled upon in a book called *Biopunk*:

[1] ETC Group or, Action Group on Erosion, Technology and Concentration, is an international civil society organization that works to address socioeconomic and ecological issues surrounding new technologies (see, http://www.etcgroup.org/).

> Synthetic biology promises the ability not just to read genes but to write them, like printing out letters on a page in a pattern that creates a picture no one has ever seen before. In bioprophets' wildest imaginings, hacking human genes could mean making yourself into something more than human. Then again, inventing ourselves anew is the essence of individualism. Maybe giving ourselves tails or wings or chlorophyll-covered skin is just being human, fully realized, free to make ourselves into whomever or whatever we want to be. Maybe that freedom means we will not have to wait for nature anymore. This may or may not be desirable, but these are the dreams that stoke the biopunk imagination, fueled by *Blade Runner*, radical libertarianism, Newton, Darwin, and a fierce will to power and transcendence. (Wohlsen 2011: 16-17, emphasis in original)

Write and hacking genes, more than human, being human fully realized, we won't have to wait for nature anymore, a fierce will to power and transcendence; this resulted in what best can be described as an intellectual itch; a craving to explore and understand. Freeman Dyson, considered a godfather to synthetic biology (Newman 2012), contributed to this itch by writing that:

> In the post-Darwinian era, biotechnology will be domesticated. There will be do-it-yourself kits for gardeners, who will use gene transfer to breed new varieties of roses and orchids. Also, biotech games for children, played with real eggs and seeds rather than with images on a screen. Genetic engineering, once it gets into the hands of the general public, will give us an explosion of biodiversity. Designing genomes will be a new art form, as creative as painting or sculpture. Few of the new creations will be masterpieces, but all will bring joy to their creators and diversity to our fauna and flora. (Dyson 2005).

Domestication of biotechnology, biotech games for kids, genetic engineering creating an explosion of biodiversity, designing genomes as art form, diversity to our fauna and flora; all these phrases motivated me to take on the task to explore synthetic biology further.

Besides these textual representations of synthetic biology, that to me initially sounded like it being closer to science fiction than anything that could be even close to 'out there' — a part of our contemporary world — I learned during my time with the ETC Group that synthetic biology is emerging and that it currently is a rapidly developing and expanding field. This means that it is constantly changing, and that it does not take long for the field to produce new accomplishments and approaches. This made me even more intrigued and I saw the necessity of an explorative approach to understand what synthetic biology is and to be able to capture the new aspects of it. I thus set out to follow my itch. As Paul Rabinow suggests,

> …industrial societies have indeed provided the resources necessary for some to conduct a leisured, if not leisurely, exploration of things. Given this space, and for as long as it lasts, we should be hard at work thinking, writing, inquiring. (Rabinow 2008: 49)

As long as there is a space for us to explore, we should keep ourselves busy, thinking, writing and inquiring.

METHODOLOGY

— INQUIRY

Early on in the shaping of this study I wanted to do a kind of fieldwork in text; observing through reading. This led me to rely on *inquiry* as described by Paul Rabinow (2008) as methodology. Inquiry

> …begins midstream, always already embedded in a situation, one both settled and unsettled. […] Thus, it is perfectly appropriate to begin with tentative parameters of a situation to be inquired into and tentative understandings of what is at stake. (Rabinow 2008: 8)

Inquiry is explorative in that it begins with tentative parameters and understandings. It begins in the middle of something ongoing; I am thrown onto a carousel in motion. I am diving into the field searching in all directions for hints and clues; i.e. I go 'out and about' on Infobahn.

> Thus, to claim to know beforehand precisely what one is going to do, or to find, […] would constitute bad method, poor logic, and falsely disciplined inquiry. Or, more accurately […] run the risk of not doing inquiry at all. (Rabinow 2008: 8)

At the heart of inquiry is the indeterminate; it is both open-entranced[2] and open-ended. I would do myself a great disservice to, before the start of inquiry, impede exploration by trying to know what I want to know, thus risking not doing inquiry at all. Inquiry is also, however, a type of constructivism that arises in the indeterminate situation.

> [T]he inquirer is not outside the situation, nor is she in a position such that she could construct something that was not to a degree present already […]. (Rabinow 2008: 9)

[2] Entranced is here meant to be interpreted both as entrance, where I enter, but also entranced as in captivated.

Although I am attempting to not construct the situation already before entering the field, it is necessary to construct the situation as inquiring into it. The construction relies on what is found and does not take a pre-given theory as a starting point. However, the knowledge and views of the world that I have affect what I am able to discover and how I construct what is inquired into:

> …*inquiry is situated* and its goal is to isolate something in the world that is causing or occasioning effects. […] Form giving is […] an essential goal of "describing" a problem and of shaping an inquiry. Description rather than explanation is the goal, but *description is not a naïve act* but one that can arise only within a process of inquiry that is engaged in one or another type of form making. (Rabinow 2008: 9, emphasis added)

The attempt here to explore synthetic biology is *situated*, both in my pre-understandings of the topic and the world, but also in itself: synthetic biology is situated; I cannot successfully describe it by detaching it from its dependencies to the rest of the world. This inquiry is thus an attempt to describe synthetic biology by critically admitting my pre-understandings of the topic, the world, and the place of the topic in the world. Description does not mean the ability to detach oneself from the studied but instead implies being engaged in giving form to what is inquired into.

> [I]t is only through discovering and giving form to elements that are already present that the inquiry can proceed. Hence the process involves staying in the midst of the things of the world and transforming them in specific ways so as to give them the kind of determinative form that can be known. (Rabinow 2008: 9)

I have to lay out the stepping-stones, and pave the way, for the description. One discovery builds on the previous ones; I understand differently depending on what I have understood before, and inquiry can only proceed if I have discovered, determined and described what is inquired into so that it can be known.

To summarize, inquiry starts in an ongoing, indeterminate situation where the inquirer cannot be certain, before the actual inquiry, on how to go about, or what to find. However, as the topic is inquired into, the inquirer constructs the topic. This construction is situated in the inquirer's pre-understandings what is being inquired into and its place in the world. Inquiry can proceed only if what is inquired into is discovered, determined and described.

Some reflection on credibility is necessary here. Credibility can be described as "…the production of "reality-like" effects—the ways in which an account's "authenticity," grounded in an everyday shared reality, is guaranteed" (Atkinson 2001: 90). However, what is relevant, real and true, is relative (Rabinow 2008: 50), or rather, relational; "…knowledge is neither a representation nor a construction but a *relation* between the knower and the known" (Hornborg 2001: 159). So, in order to understand this 'relation' we must explore who the knower is, but this

> …does require a keen understanding of what aspects of the self are the most important filters through which one perceives the world and, more particularly, the topic being studied. (Behar 1997: 13)

In relation to this there are some aspects that I have identified as important that need to follow the reader throughout this inquiry regarding credibility to shed light on my pre-understandings and "where I'm coming from". First of all, as described in the previous chapter, synthetic biology was only in the corner of my eye until I arrived at ETC Group, giving the ETC Group close to a gate-keeping role for the development of this thesis. It is important to understand that I engaged in learning about synthetic biology from a critical point of view and this has followed me in my exploration of the topic for this thesis; leading on to the second point:

I have an academic background belonging to the fields of Environmental Science and Human Ecology. Environmental Science and Human Ecology have much in common in that topics, issues and problems are treated as interdisciplinary, and human thought and action and environmental issues are seen as interconnected. Both academic fields deal with issues of sustainability of humans and non-humans in this world and both fields work with 'following connections' across boundaries — disciplinary, geographical, cultural, discursive and historical. To me, inquiring into synthetic biology thus means having questions of sustainability in mind. It is a filter through which I perceive the world. On top of this, I am an emotional being, genuinely concerned about the present and future relationships of human, non-human beings and our shared habitat. These emotions have been with me throughout this inquiry into synthetic biology.

THE FIELD

This inquiry is a field work in text. Text is here considered to be speech, writing, visual image or a combination of these (Jørgensen and Phillips 2002: 68). The texts used here is a combination of news media articles, interviews and videos[3] and academic writings such as articles and books. The majority of the texts are found online.

Text as field means that I am relying on a combination of others' representations of synthetic biology and its practitioners, practitioners' own words as selected by others (in the case of interviews) and to some extent also practitioners' own words in terms of publications, lectures and interviews for my observations. Therefore it can be argued that I am using observers' observations as material; that I am observing observers observing (Rabinow 2008: 64-65). This means that I am relying on others' descriptions and interpretations as foundation for my own discovery, determination and description of synthetic biology and this is an important premise for this inquiry.

When searching for text on the topic I have included 'synthetic biology' as a search term. The initial searching took place in Lund University library search engine which was followed by extensive reading of academic publications. Once a *theme* was discovered, focus was put on collecting texts on this particular theme by using terms related to the theme (for example: playing God, Frankenstein, BioBricks, de-extinction, mammoths, Synthia, artemisinin, Amyris, as well as names of key practitioners of synthetic biology etc.) combined with 'synthetic biology'. My ability to identify keywords has been crucial in the search, and the identification of keywords emerged alongside the discovery of texts. The searching was widened to include sources other than academic ones, for example news magazines. Note that this is only an example of how themes are built up. Extensive reading has been necessary to outline a theme within the topic and to demarcate one theme from another.

During my time at the ETC Group, I subscribed to an emailing list for synthetic biology critics.[4] On this list, news (articles, blog-entries, conferences, research results etc.) about synthetic biology is shared by subscribers and sometimes discussions develop where subscribers express their views on what is posted. My subscription to this list has been

[3] The videos refer to recorded lectures and interviews. The interviews and videos I rely on have been used solely because of what is being said, and have been transcribed when quoted in the thesis.

relevant for my acquisition of knowledge around synthetic biology since, in several cases, texts and news (for example on the release of research results as well as synthetic biology conferences) posted on this list have become contributions to my exploration of synthetic biology. It can thus be considered a type of bias since the postings of others have influenced me to follow threads and leads that I perhaps would not have done otherwise and thus also lead to the risk that I may have missed certain threads and leads that I might have followed otherwise.

To summarize, this inquiry is based on various sources and texts acquired through extensive reading and searching (where the identification of keywords have been a key), influenced to some degree by an emailing list for synthetic biology critics. From these texts themes have emerged. The next chapter is the first of these themes and deals with definitions and distinctions of synthetic biology.

SYNTHETIC BIOLOGY

The term synthetic biology was coined in 1912 by French chemist Stéphane Leduc (De Lorenzo and Danchin 2008: 822; Newman 2012: 13). Biology refers to the study of life and living organisms, their structure, evolution, distribution and functioning. The word synthetic in synthetic biology is often read as artificial or unnatural; however, synthetic also refers to *synthesis*, which is the opposite of analysis, meaning synthesizing, or putting together (Calvert 2010: 96). Voosen (2013) writes that if you "ask five people the definition of synthetic biology, you'll get six different answers, because one person is bound to be conflicted". Numerous attempts have been made to summon, in one sentence, what this emerging field is all about:

> [S]ynthetic biology aims to design and engineer biologically based parts, novel devices and systems — as well as redesigning existing, natural biological systems (Kitney and Freemont 2012: 2029).

> [Synthetic biology] means essentially reprogramming cells to do things they wouldn't ordinarily do and also engineering complex biological systems outside of cells (Flannery 2010: 453).

> Synthetic biology is 'the code name for engineering using the machinery of the cell, from tinkering with existing organisms all the way to the design of life from scratch' (McEuen and Dekker 2008: 11 quoted in van den Belt 2009: 257).

> The aim of synthetic biology is to reduce organisms to their simplest organic components, add newly created organic components to the mix, and reassemble the parts into novel organisms (Cole-Turner 2009: 137).

> [Synthetic biology] refers […] to the creation of synthetic biological systems that are programmable, self-referential, and modular (Cho and Relman 2010: 38).

> [Synthetic biology is] 'the design and construction of new biological parts, devices and systems and the re-design of existing, natural biological systems for useful purposes' (Syntheticbiology.org n.d).

The list of suggested definitions is long. As can be seen, there are some common themes in these definitions. Authors use the words reduce, design, construct, reprogram, engineer, tinker, re-design, reassemble and create to describe what is being done. They use cells, biological systems, biological parts, existing natural biological systems, and organisms, referring to what are being exposed to the act. And, the important descriptive words or phrases that helps grasp what it means when you put the act and the acted on, together: novel, do things they wouldn't ordinarily do, programmable, self-referential, modular and useful purposes.

When considering these definitions, synthetic biology seems to have its focus on the doing; the act. "According to long-standing philosophical tradition, science is about knowing and understanding, whereas technology is about doing" (De Lorenzo and Danchin 2008: 822) and this suggests that synthetic biology is not so much a science as it is a technology. However, the knowing and the doing seem to be quite inseparable, and a suggested term for synthetic biology — a kind of classification — is that it is a fusion of technology and science; a technoscience (Thompson 2012).[5] Calvert takes another stance here by suggesting that synthetic biology can be called "the engineer's approach to biology" (2010: 96), something that De Lorenzo and Danchin support by stating that: "[f]or many of its practitioners, the answer is clear: synthetic biology is about engineering and not about science" (2008: 822). The guiding idea of synthetic biology is thus to apply the view of an engineer on living systems and through that make biology become a predictive science (Kelle 2012: 1) which means to see biological systems as "a combination of individual functional elements — not unlike those found in man-made devices" (De Lorenzo and Danchin 2008: 822).

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[5] The term technoscience is a blurring of the distinction between science and technology "to acknowledge that ever since the modern era, work at the forefront of the natural sciences has often been accompanied by advances in the ability to construct or manipulate artifacts and devices, as well as the mastery of novel techniques…" (Thompson 2012: 5).

> The idea is both simple and attractive: in the same way that a machine can be disassembled and catalogued as individual components—such as hard disks, screens, keyboards and memory chips—living systems might also be broken down into a list of components that can be rewired for a specific purpose. (De Lorenzo and Danchin 2008: 823)

Synthetic biology, in applying this engineer-view on living systems, hopes to succeed where genetic engineering[6] failed (Calvert 2010: 97). Synthetic biologists distinguish their practice from that of genetic engineering in several ways. First, by using methods and approaches that conceptually lies closer to engineering by using standardized parts and formalized design processes (Calvert 2010: 97). It also distinguishes itself from genetic engineering because of the 'sophistication' in the work: "In genetic engineering one gene at a time is modified or added, whereas in synthetic biology a whole specialized metabolic unit can be constructed" (Calvert 2010: 97). Construction and re-design of biological organisms thus occur on a systems level instead of moving single genes as in genetic engineering.

In summary, synthetic biology is a technoscience — a fusion of technology and science — and an engineer's approach to biology with the aim to make biology become a predictive science. The next chapter takes us further into this engineering view on biology where living systems are seen as machines, or a combination of individual functional elements.

LIKE LEGO

— BIOBRICKS AND THE STANDARDIZATION OF BIOLOGICAL PARTS

In 2003 a student course started at the Massachusetts Institute of Technology (MIT) with the goal to let students design biological systems to make cells blink. In 2004 this course evolved into a competition with five participating teams; marking the dawn of iGEM. iGEM is short for the International Genetically Engineered Machine competition and it is an international undergraduate synthetic biology competition.

The idea with iGEM is for students to build biological systems to operate in living cells (Hilgartner 2012: 198; iGEM n.d.) and the projects presented at the competitions have included banana and wintergreen-smelling bacteria, an arsenic biosensor, a rainbow of

[6] Genetic engineering refers to genetic recombination, i.e. to move naturally occurring DNA across species (Cole-Turner 2009: 138).

pigmented bacteria (iGEM n.d.), and Bacteriophotography; a contribution at the 2005 competition by students from the University of Texas. The students making the Bacteriophotography started with the bacteria *Escherichia coli* and added *biological parts* made at the University of California in San Fransisco. These parts made the bacteria sensitive to light so that depending on the intensity of the light, the bacteria produced varying amounts of a coloured substance. The more light, the less colour the bacteria produced. This resulted in the bacteria making their surroundings black unless exposed to light, thus making them act similar to a photographic film but with a resolution of 100 megapixels per square inch (Simonite 2005).

The parts that students use in the competition to build their biological systems come from The Registry of Standard Biological Parts which is a "continuously growing collection of genetic parts that can be mixed and matched to build synthetic biology devices and systems" (Registry of Standard Biological Parts n.d.). The Registry was founded in 2003 at MIT and its purpose is to provide resources — genetic parts — or BioBricks as they are also called, to for example iGEM teams and academic labs. The metaphor used by the registry for its BioBricks is well-known: Lego (Calvert 2010: 99).

The idea of standardizing biological parts into BioBricks puts emphasis on some fundamental concepts that are ruling and guiding when it comes to how biological systems are perceived (Calvert 2010: 97-99). The first one is the conviction that it is possible to build hierarchies of parts, devices and systems and this is known as *abstraction*. Secondly, it is believed that complex problems can be broken down into less complex ones and be addressed independently, this is called *decoupling*. And, finally, that no matter what the parts are connected to, they are seen to maintain their inherent properties, i.e. they are considered to be *modular*[7] (Hilgartner 2012: 196; Calvert 2010: 97-99).

Abstraction, decoupling and modularity as concepts are supportive of an anti-complexity view on biology.[8] It is supporting a conviction "…that a single component of a complex system […] can be sufficient to account for the properties of the whole…" (Newman 2012: 12). Several synthetic biologists have expressed synthetic biology's approach to reduce or even

[7] Modularity is an engineering term meaning that parts can be extracted and inserted from and to different systems without functional change (Calvert 2010: 98).

[8] This statement and the discussion that follows assume that biological systems are complex because this is how they historically have been perceived (Calvert 2010: 101).

eliminate, rather than embrace biological complexity. Tom Knight[9] suggested that "an alternative to understanding complexity is to get rid of it" (quoted in Ball 2004: 625). Or, as George Church[10] suggests: "You focus on parts of the science that you understand and clean out the parts that you don't understand" (quoted in Breithaupt 2006: 22-23). This desire to eliminate biological complexity is summarized by Heinemann and Panke:

> As the complexity of existing biological systems is the major problem in implementing synthetic biology's engineering vision, it is desirable to reduce this complexity. (2006: 2793 quoted in Calvert 2010: 98)

Synthetic biologists are convinced that biological complexity "might be an eliminable accident of historical accumulations over evolutionary time" (Calvert 2008: 393) and that synthetic biology ultimately will lead to the illumination of a hitherto undiscovered simplicity in nature (Calvert 2008: 393).

To sum up, the standardization of biological parts, the BioBricks, rely on an anti-complexity view of biological systems where parts of the systems are seen as sufficient to account for properties of the whole. Practitioners of synthetic biology approach complexity as something that one should get rid of, rather than understand and an overarching vision is to, through synthetic biology, discover a hidden simplicity in nature. All these aspects establish the core of the paradigm of synthetic biology.

> A paradigm is a world view, a general perspective, a way of breaking down the complexity of the real world. As such, paradigms are deeply embedded in the socialization of adherents and practitioners: paradigms tell them what is important, legitimate, and reasonable. Paradigms are also normative, telling the practitioner what to do without the necessity of long existential or epistemological consideration. But it is this aspect of paradigms that constitutes both their strength and their weakness — their strength in that it makes action possible, their weakness in that the very reason for action is hidden in the unquestioned assumptions of the paradigm. (Patton 1978: 203 quoted in Lincoln and Guba 1985: 15)

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[9] Tom Knight is a former scientist at MIT and now works with synthetic biology at Ginkgo Bioworks (see: http://ginkgobioworks.com/).

[10] George Church is professor of Genetics at Harvard Medical School, professor of Health Sciences and Technology at Harvard and MIT and Founding Core Faculty Member and leader of the Synthetic Biology Platform at Wyss Institute for Biologically Inspired Engineering at Harvard University. Church is also the founder of synthetic biology company LS9 (see http://www.ls9.com/) and a co-founder of a company named Ark Corporation (see Regalado 2013a).

A paradigm acts as a framework for thought and action for practitioners guided by that particular paradigm. It eliminates the need, among the practitioners within that paradigm, to discuss the guiding philosophy of their practice since the *modi operandi* are embedded in the paradigm itself. As suggested by Patton, this makes action possible, but the reasons to why action is possible are hidden within the undisputed conventions of the paradigm.

The undisputed conventions of synthetic biology include approaching biological systems with the view of an engineer; meaning that complexity is eliminated, biological parts are standardized and considered modular, and synthetic biologists are guided by the idea that they someday will reveal a fundamental simplicity in nature. These views are somewhat naturalized due to the unquestioned assumptions inherent to the engineering paradigm. A crucial question is posed by Calvert, and that is

> …whether biological systems are actually comprised of functional modules, or if they are simply best understood as such by the engineering approaches that are adopted in synthetic biology. (2010: 99)

The need to, on the one hand, get rid of complexity rather than understanding it, and, on the other hand, suggest that synthetic biology will reveal a hitherto hidden simplicity in nature might seem a bit self-contradictory. The question that follows is: Is the suggested simplicity of nature found through synthetic biology practice, or is it imposed on biological systems through the engineering paradigm of synthetic biology? Jane Calvert concludes that "…there is the potential for the blurring of ontology and epistemology, because the reshaping of nature in synthetic biology is tied up with scientists' own epistemic practices" (2010: 101). As written earlier, biological complexity is standing in the way for the realization of the engineering *vision* of synthetic biology, a vision to succeed where the earlier field of genetic engineering failed. This vision is what guides practice and thus, relying on standardization of biological parts seems not only legitimate, but desirable when the vision of biology as a predictable science of engineering is guiding.

> [S]cientific paradigms are socio-historical constructs – not given by the character of nature, but created out of social experience, cultural values, and political-economic structures. . . . the actual objects of inquiry, the formulation of questions and definitions, and the mythic structures of scientific theories are social constructs. Every aspect of scientific theory and practice expresses socio-political interests, cultural themes and metaphors, personal interactions, and professional negotations [sic] for the power to name the world. (Bird 1987: 256 quoted in Hajer 1996: 258)

A scientific paradigm is a social construct; however, in the case of synthetic biology the construction and guidance of the paradigm goes beyond the power to *name* the world, as Bird suggests, to include altering and adapting parts of it to match the paradigm. Why is the question of the constructed engineering paradigm of synthetic biology so important? Because it reveals that whatever truths are claimed through synthetic biology, need their constructed context, and the context is the engineering paradigm. Applying ideas of abstraction, decoupling and modularity, and removing, rather than embracing, biological complexity to make sense of models[11] on how biological systems should behave is only legitimate if the dominant worldview is that of reductionism, or, fragmentalism. It is a self-fulfilling prophecy in that it both constructs what is real and makes sure what it observes fits this reality. In the next chapter a continuation on biological systems and life, through the view of engineering, is presented; starting off with the world's first self-replicating organism whose parent is a computer.

PLAYING GOD

— THE FIRST LIVING ORGANISM WHOSE PARENT IS A COMPUTER

The bacteria *Mycoplasma genitalium* has one of the smallest genomes known to science. In 1995 its genome was sequenced,[12] making it the second living organism to be sequenced after the bacteria *Haemophilus influenza*. The sequencing of *M. genitalium*, due to it being the smallest known genome at that time, raised questions of what is needed for survival of an organism (Fraser et al. 1995), leading researchers at the J. Craig Venter Institute (JCVI)[13] to attempt to strip *M. genitalium* of all its 'non-vital' genetic parts. A long process began and about 15 years later, in May 2010, Craig Venter[14] announced that, *Mycoplasma laboratorium*, also known as Synthia, the first synthetic living organism and "the first self-replicating

[11] Calvert (2010: 101) writes that a "rather audacious example of how epistemic practices can come to influence biological materiality is given by synthetic biologists who say that if they discover that their models of biological phenomena do not work, then they will simply engineer the biological parts to fit the model better … rather than changing the model to make it a more accurate representation of the biological system, which is how biological research would have proceeded in the past."

[12] Genome sequencing means to determine the DNA sequence of the genome of an organism.

[13] JCVI is a research institute founded by Craig Venter (see, http://www.jcvi.org/).

[14] Craig Venter has founded Celera genomics (see, https://www.celera.com/), Synthetic Genomics (see, http://www.syntheticgenomics.com/) and The J. Craig Venter Institute (JCVI). He was one of the first to sequence the human genome. Craig Venter is working at JCVI.

species we've had on the planet whose parent is a computer" (Venter quoted in Wade 2010) had been born. Venter describes the process leading up to this moment in history:

> Well this has been about a fifteen year process, it started back in 1995 when we sequenced the first two genomes in history, including the smallest genome, that of *Mycoplasma genitalium*. And we set out a goal to try and understand what the smallest genome you could have as an operating system, to try and understand the basic components of life. It's taken us through this long journey, much longer than we ever anticipated, but that's what happens when you enter into areas that nobody has ever been before. So at first we had to learn how to write the genetic code to synthesize pieces because the largest piece that ever has been synthesized other than our work has been only 30,000 letters. And the first chromosome we were trying to make was over 500,000 and the one that we ultimately made and report in this paper is over 1,000,000 letters of genetic code. And we start with four bottles of chemicals and the computer code in the computer, the digital code in the computer, from DNA sequence. […] So, we start with the pieces of DNA […] only about 50-80 letters long—that's pretty much the limit of what you can make with a chemical synthesizer. So everything we make from that has to be putting these little pieces together, much like having a box of Legos and having to assemble them back in the right order to get what you started with […]. […] Also this is now the first time where we've started with information in the computer, built that software molecule—now over a million letters of genetic code—put that into a recipient cell and had this process start where that information converted that cell into a new species. So this becomes a very powerful tool for trying to design what we want biology to do. (Venter 2010, my transcription)

The process leading up to the 'birth' of this synthetic organism started with sequencing the genome of *Mycoplasma genitalium*. This led the scientists to want to understand what the smallest genome an organism could have 'as an operative system' which led to the removal of the genetic material that was 'surplus' (The Guardian 2010) so that they could *minimize* the genome. It was then synthesized, first into little pieces[15] using four bottles of different chemicals[16] — just like having a box of Legos, as Venter explains — and then further synthesized until the entire genome had been put together.[17] The goal with this project, as

[15] This is called oligonucleotides or oligos (Church and Regis 2012: 146).

[16] Nucleobases, A, C, T and G.

[17] To make sure that the scientists were not fooling themselves to think that they had created something new if they actually had not, they decided to watermark the synthesized genome using a code language that they themselves had created (Venter 2010). So in the synthesized genome, all the names of the researchers that had been involved in the project, a couple of quotes — "adding a little philosophy to the genetic code" as Venter (2010) describes it — and a URL-address were inserted (so that anyone who cracked the code could let the researchers know about it) (Venter 2010).

Venter describes, was to understand *the basic components of life*. The *software molecule was built* and *converted* the cell into a new species. When the modified, synthesized genome was inserted into a recipient cell, which had been emptied of its original DNA (Collins 2012: 10), the cell "booted up", and Synthia was born. And this, Venter concludes, becomes a very powerful tool for *the attempt to design what 'we' want biology to do*. Venter's description is a continuation of several elements discussed in the previous chapter regarding the engineering paradigm of synthetic biology. First of all, the scientists approached *Mycoplasma genitalium* with the idea that it had excess genetic material. This displays the attempt to get rid of biological complexity — of elimination of material lacking significance for the organism's survival. Secondly, the 'pieces' are seen as Lego, a language we recognize from the BioBricks. With this project, the goal was to understand the basic components of life which I trace to the attempt of synthetic biologists to reveal an underlying simplicity of nature. And, finally, it is a tool for humans to design and *build* biological systems, thus attempting to make biology a predictable science. Back to Venter again:

> [T]his is an important step we think, both scientifically and philosophically. It certainly change [sic] my views of definitions of life and how life works. It's pretty stunning when you just replace the DNA software in a cell, and the cell instantly starts reading that new software, starts making a whole different set of proteins and within a short while all the characteristics of the first species disappear, and a new species emerges from this software that controls that cell going forward. When we look at life forms, we see them as sort of fixed entities, but this shows in fact how dynamic they are, that they change from second to second. And that *life is basically a result of an information process, a software process. Our genetic code is our software.* (Venter 2010, my transcription, emphasis added)

Venter suggests that this marks an important step philosophically since it changes definitions of life and how life works and he concludes that life is basically a *software process*, a process of *information* that can be traced to the genetic *code*.

> New terminology and new metaphors don't just reflect changing realities; they create shifts in the narrative, open the way for shifting realities, make change possible. Language doesn't simply innovate to accommodate the new ways of seeing the world—it plays an active role in creating new views. (Buck 2011: 14)

Referring to life as software makes way for change on how life is viewed. This *linguistic construction* accommodates new ways of perceiving life. It is one step further in applying not only engineering language but also computer language, where complex biological processes are reduced to being nothing but the result of an information process.

Both before, but even more so after the creation of Synthia, a substantial discussion was emerging in media[18] about humans defining and creating life and that synthetic biologists are not only playing with biological Lego, but that they are playing God. The notion of humans playing God is not new but is through synthetic biology rather seeing a revival (Braun et al. 2013: 40). It can nevertheless be seen as a concern about a point in time where humans are entering a previously unvisited territory and leads to a question: Have humans, through the achievements of synthetic biology, gone from modification to creation? In other words: from *homo faber* to *homo creator*?[19] George Church states that synthetic biologists are

> …acting as engineers, possibly as intelligent designers. The religiously-inclined would not put humans in the same league with the "Intelligent Designer", or God. As creative as we become, and as industrious and as good as we are at designing and manufacturing living things, which we've been doing since the stone age—no matter how good we get at that, it's like calling a candle a supernova. A candle is not a supernova; it's not even in the same league. And we, as intelligent designers, are not in the same league as the "Intelligent Design" forces that started the whole shebang. We're not designing sub-atomic particles from scratch; we're not designing galaxies. We're really not even designing the basic idea of life; we're just manipulating it. (quoted in Brockman 2006)

Church states that humans are not, and can never be, God, or Intelligent Design, but should instead be seen as engineers or intelligent designers and that synthetic biology is just a continuation of something that has been going on since the stone age. Drew Endy[20] follows the same line by stating that:

> I don't view those projects [reprogramming the bouquet of bacteria] as creating life, but rather construction projects. For me as an engineer, there's a big difference between the words creation and construction. Creation implies I have unlimited power, perfect understanding of the universe, and the ability to manipulate matter at

[18] See for example: The Sun 2011; Samson 2011; Morton 2011; Winston 2010; Rutherford 2012; MacLeod 2010a; Hickman 2008; Jha 2012; Singer 2010; Sample 2010a; McFadden 2009; Ropeik 2010; Brown 2010; Sample 2010b; Adam and Sample 2004; Adams 2010; MacRae 2010; Sethi 2012; The Telegraph 2010; Lynas 2011; Alleyne 2010; Highfield 2007; Macleod 2010b. This is not an exhaustive list.

[19] Humans as *homo faber* refers to technical acquisition and modification of nature, whereas *homo creator* means technical (re)creation of nature (see further: Braun et al. 2013: 38).

[20] Drew Endy is Assistant Professor of bioengineering at Stanford University. He is a co-founder of the Registry of Standard Biological Parts (see, http://partsregistry.org/Main_Page).

> a godlike level. That's not what I have. I have an imperfect understanding, a budget, limited resources, and I can only manipulate things quite crudely. In that context, with those constraints, I'm a more humble constructor. (Drew Endy quoted in Reed 2009)

Endy, just as Church, emphasizes that he is an engineer and a 'humble constructor' rather than a God. Both Endy and Church differ between creation and construction, similar to the distinction of creation and modification, *homo faber* and *homo creator*. According to Braun et al. (2013) humans can never be creators but rather co-creators, never operators but rather co-operators in the 'grand design'. In this sense, humans can still be considered *homo faber,* tinkering with and modifying nature, but never (re)creating it. However, this does not satisfy how playing God is used here. Alongside God came another metaphor, namely Frankenstein.

An example of this is an article, in the UK newspaper The Sun named *'Frankenstein' doc creates life*, referring to Craig Venter's Synthia, where Emma Morton writes that "opponents of genetic engineering condemned the experiment as dangerous Frankenstein-style tampering with nature" (Morton 2011). Van den Belt (2009), in his article *Playing God in Frankenstein's Footsteps: Synthetic Biology and the Meaning of Life*, helps clarify at least why Frankenstein is present here:

> Synthetic biology puts heavy pressure on many of the culturally entrenched distinctions and demarcations that are constitutive of our symbolic order. It shifts or blurs the boundaries between matter and information, life and non-life, nature and artefact, organic and inorganic, Creator and creature, the evolved and the designed. In science and technology studies, entities that challenge the settled boundaries of nature and society are often designated as 'monsters'. Like the creations of synthetic biology, Victor Frankenstein's creature was a prime example of a 'monster' in this particular sense. (Van den Belt 2009: 259)

Synthetic biology is a monster in the human symbolic order. It challenges our culturally fixed distinctions, dichotomies, boundaries and understandings which lead to conclusions that Craig Venter is 'playing God' and treading in Frankenstein's footsteps. The use of these metaphors is thus not so much describing an actual shift from humans as modifiers to humans as creators, as discussed above, but can rather be seen as a perceptual crisis in our understanding of ourselves and our previously 'fixed' cultural boundaries, boundaries that now, through synthetic biology, are facing a re-organization.

From this chapter it can be concluded that Synthia was an extension of the reductionist view seen in the previous chapter in the scientists' quest to get rid of biological complexity, viewing genetic material as Lego, and the hope to reveal a hitherto undiscovered simplicity of nature. Synthia was also an important experiment for human ability to design and construct biological systems which is an extension of synthetic biology's attempt to make biology become predictable and a science of engineering. The language used around Synthia accommodates new ways of perceiving life, namely as nothing but a software process, information, and code. The metaphors that were used around this happening — playing God and Frankenstein — tells us that synthetic biology creates a perceptual crisis where culturally entrenched distinctions are challenged. In the next chapter focus is put on another godlike activity, namely that of resurrecting extinct animals and using synthetic biology in species conservation.

DE-EXTINCTION

— RESURRECTION OF EXTINCT SPECIES

The Pyrenean ibex (*Capra pyrenaica pyrenaica*) was a wild goat, or bucardo, living in the Pyrenees for thousands of years. Its horns were long and curved, it could weigh up to 220 pounds and it was an excellent survivor of harsh winters (Zimmer 2013). Throughout the centuries the bucardo experienced a decline in number as a result of hunting, and in 1989 scientists concluded that only around a dozen individuals were left. A decade later, in 1999, only one individual, a female named Celia, remained. In order to keep track of this last individual, a radio collar was put on Celia, but after only nine months, a team from Ordesa and Monte Perdido National Park found her with her head crushed from a falling tree (Zimmer 2013; Gray and Dobson 2009). The International Union for the Conservation of Nature (IUCN) changed the status of the Pyrenean ibex from EW, meaning extinct in the wild to EX, meaning extinct (Church and Regis 2012: 10); this marked the end of the days of the bucardo.

Before Celia died in the year 2000, a biologist named Dr. José Folch collected skin scrapings from the ears of the bucardo and stored the sample to preserve the genetic line of the Pyrenean ibex. In 2002 Dr. Folch together with veterinarian Alberto Fernández-Árias and an international expert team began what they called Experiment One which was an attempt to bring back the Pyrenean ibex from extinction by using the samples from Celia's ears (Church and Regis 2012: 135).

The scientists put domestic goats into a state of "superovulation"[21] to get a substantial amount of mature egg cells. Through a process known as nuclear transfer, they replaced the nucleus[22] of the domestic goat egg cell with the nucleus from Celia's cells (collected from her ears) and through a process known as electrofusion[23] the somatic cells[24] from the ears of Celia fused with the egg cells. In total, there were 54 embryos carrying the genes of Celia (Church and Regis 2012: 136; Zimmer 2013). After placing the eggs into the goats, none of the attempts resulted in successful pregnancies and that was the end of Experiment One.

In the winter of 2003, the research team started Experiment Two, transferring 154 embryonic bucardo cells into the wombs of 44 goats, resulting in five pregnancies but only one that lasted to term. On July 30 in 2003 a caesarean section was performed and a Pyrenean ibex with identical DNA to Celia was born.[25] This marked a turning point in history: "For on that date, all at once, extinction was no longer forever" (Church and Regis 2012: 136).

Almost a decade later, in April 2013, a conference was held in Cambridge. It was a meeting of two in many ways different fields, namely conservation biology and synthetic biology. The event, named *How will synthetic biology and conservation shape the future of nature?*, was a platform for conservation biologists and synthetic biologists to meet and discuss "…the implications that synthetic biology may have on the natural world and conservation and develop new thinking and new strategies to cope with the potential challenges and opportunities" (Wildlife Conservation Society 2013). This event was a part of a growing interest in how synthetic biology can play a role in the conservation of endangered species and *de-extinction* of species such as the Pyrenean ibex.

From the successful attempt to bring back the bucardo from extinction in 2003, Piña-Aguilar et al. (2009: 344) concluded that: "…extinct species resurrection is not a matter of hope; it is a reality". By using technologies such as nuclear transfer (as with the Pyrenean ibex) and

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[21] Using hormone treatments (Church and Regis 2012: 136).

[22] The cell nucleus is what contains most of the cell's genetic material.

[23] Researchers apply two short pulses of electrical current to each cell (Church and Regis 2012: 136).

[24] A somatic cell is any and every other cell in a mammalian body except for the gametocytes and undifferentiated stem cells (ScienceDaily n.d.).

[25] Despite a successful pregnancy the newborn Pyrenean ibex died after just 10 minutes due to lung failure.

induced pluripotent stem cells (iPS)[26] scientists hope to be able to bring back species from extinction. One animal facing de-extinction is the passenger pigeon.

The passenger pigeon lived in North America until 1914 when it became extinct due to over-hunting. Perhaps the most well-known characteristic of it is that the skies could be completely darkened for hours as the birds flew in flocks of up to one billion individuals (Regalado 2013b). The reintroduction of the passenger pigeon would be done by altering the DNA of for example the band-tailed pigeon or the rock pigeon (Gannon 2013; Regalado 2013b). A team of researchers, including George Church, have now used a 100-year old passenger pigeon from a museum and put together around one billion letters of its DNA (Gannon 2013).

Another animal facing de-extinction is the woolly mammoth. The woolly mammoth lived in some parts of northern Asia, North America and Europe and went extinct approximately 3,700 years ago due to hunting and habitat loss (Line 2013). Some well-preserved mammoths have been found in the Siberian permafrost (Gannon 2013) however, there is no intact mammoth DNA and therefore it would be necessary for scientists to modify elephant DNA 'towards' mammoth DNA. The mammoths would therefore be referred to as 'neo-mammoths' (Shanks 2013). George Church suggests that since a reason for the extinction of the mammoth was human hunting (as was also the case with the passenger pigeon and the Pyrenean ibex):

> …the question arises whether we have an obligation to bring these creatures back, not as circus sideshow attractions but as part of a focused scientific attempt to increase genetic diversity by reintroducing their extinct genomes into the global gene pool. (Church and Regis 2012: 137)

Another perhaps even more controversial extinct species that synthetic biologist George Church wants to bring back, is the Neanderthal. In his book *Regenesis – How Synthetic Biology Will Reinvent Nature and Ourselves*, Church suggests that:

> …the reintroduction of Neanderthals would give *Homo sapiens* a sibling species that would allow us to see ourselves in new ways. It might give us an inkling into

[26] Induced pluripotent stem cell refers to the process where any cell in the body can be transformed into any other type of cell through "forcing" the cell into a pluripotent state. In other words, this means that by using the technology of iPS it is possible to take a blood cell (or any other cell) and turn it into for example a heart tissue cell. The potentials with this technology is thought to be for example the tailoring of medications before treatments to see how certain cells from a patient would react to treatment (see, Duncan 2011). Besides this, it leads to possibilities to create "…functional eggs and sperm for people who are infertile because of age or other issues" but this possibility means as well that "…with iPS cells, it's at least theoretically possible to make eggs from a man's skin cell, or sperm from a woman. In other words, the technology could one day let two men, or two women, have children that share both their genes" (Regalado 2013a).

> another form of human intelligence, or of different ways of thinking. There might even be health benefits if Neanderthals proved to be resistant to diseases like AIDS or tuberculosis, for example, or diseases that coevolved with *Homo sapiens* like smallpox, polio, syphilis or the next surprise pandemic. (Church and Regis 2012: 141-142)

Bringing back the Neanderthal could possibly lead to health benefits and give us humans a possibility to see ourselves in new ways, Church states. There is no intact DNA from the Neanderthal, nor is it possible to find any since the samples are very old. However, fragments of DNA have been found and organized from several samples, giving scientists a clue about what the DNA of the Neanderthal might have looked like (Church and Regis 2012:).

As we saw in the previous chapter, where I described how Craig Venter had synthesized the *Mycoplasma laboratorium* from four bottles of chemicals, it is possible to synthesize DNA from information stored in the computer, but this is not practically possible with the Neanderthal since its DNA is three billion base pairs (as compared to the genome of *Mycoplasma laboratorium* consisting of approximately one million base pairs) (Church and Regis, 2012:146). Instead, George Church suggests that the Neanderthal could be resurrected by taking an already existing genome closely related to the Neanderthal (read: the human genome) and then "[r]everse-engineer it into existence" (Church and Regis 2012: 146). Once the physical genome of the Neanderthal is placed in a stem cell

> …the next step would be to place it inside a human (or a chimpanzee) embryo, and then implant that cell into the uterus of an extraordinarily adventurous human female — or alternatively into the uterus of a chimpanzee. (Church and Regis 2012: 147-148)

From the viewpoint of George Church who is working on these progressive and controversial projects, there are numerous benefits with bringing back species such as the passenger pigeon, the woolly mammoth and the Neanderthal,[27] and have them walk the Earth again. For example, researchers pro bringing back the mammoth argue that the mammoth was a key species for maintaining the steppes of Siberia that today are tundra since the mammoths, and other large herbivores, were grazing and fertilizing the grasslands with their manure (Zimmer 2013). Russian ecologist Sergey Zimov is trying to 'turn back time' on the Siberian tundra by

[27] Jacob S. Sherkow, in an interview regarding an article co-written with Hank Greely stated: "Bringing back a hominid raises the question, 'Is it a person?' If we bring back a mammoth or pigeon, there's a very good existing ethical and legal framework for how to treat research animals. We don't have very good ethical considerations of creating and keeping a person in a lab" (quoted in Sumner and Carey 2013)

bringing in herbivores such as horses and muskoxen to a certain area of Siberia which he calls ‘Pleistocene Park’ (Zimmer 2013). This ‘re-wilding’ of areas (which occurs in several places around the world (Brand 2013)) supports the idea to not only bring back species from extinction, but to bring back entire ‘extinct’ ecosystems and Sherkow and Greely (2013: 33) suggest that this could lead to substantial benefits since a restored Arctic steppe, which they believe bringing back the mammoth could contribute to, would replace the current ecologically less rich tundra. Sherkow and Greely believe that reviving also extinct plant species might lead to for example the discovery of new drugs (2013: 33).

Just as seen in the previous chapter with Synthia, questions about humans playing God has emerged in relation to projects of de-extinction but questions about humans playing God has also been raised in relation to humans driving these animals to extinction in the first place (A. Rose 2013; McGuinness 2013). A kind of guilt is expressed: We did wrong, and now we have the possibility to correct this wrong by reintroducing the species we have driven to extinction, so, why should we not? Stewart Brand[28], during his talk at the TEDx event *DeExtinction*, hosted by National Geographic, that took place in Washington on the 15th of March 2013, stated that:

> …humans have made a huge hole in nature over the last ten thousand years. We have the ability now, and maybe the moral obligation to repair some of the damage. (Brand 2013, my transcription)

Similar thoughts around whether or not and to what extent humans have obligations to do something about past actions through de-extinction, were expressed by Hank Greely[29] during his talk at the same event:

> Take the passenger pigeon. Climate change, habitat change; a bunch of things may have contributed [to its extinction], but you know, I think […] the main force leading to its extinction […] was a bunch of Americans and Canadians with shotguns and rifles, and railroads to ship the corpses to market [passenger pigeons were a cheap and abundant source of meat]. We killed them. If we killed them, and now we have the ability to bring them back, do we have a duty to bring them back? Do […] we owe it to them? And this is tricky; those birds are gone, we’re not bringing them back. You and I didn’t shoot them, some of our ancestors did. […] There’s this deeper problem when you’re dealing with non-humans; we know about owing rights to humans, owing duties to humans. What kind of duties to justice do

[28] Stewart Brand is an author and president at the Long Now Foundation (see, http://longnow.org/)
[29] Hank Greely is a Professor of Law at Stanford University.

> we owe to non-humans? And if we do owe them, how far does it go? All extinct species? How hard do we have to work? How much do we have to spend? (Greely 2013, my transcription)

The synthetic biology de-extinction project is like a collision of doubt and excitement in the present, of attempts to save, or at least change, both the past and the future:

> We are bringing back extinct species in order to preserve biodiversity, to undo harm that humans have caused in the past and restore ecosystems, and because it's just the right thing to do (Ryan Phelan, quoted in McGuinness 2013).

As can be seen in the statement by Greely above, there are a lot of questions related to this. What is needed to bring back a species? Its habitat as well? With the passenger pigeon, its main source of food was the American chestnut, a species which now is nearly extinct in the wild (Sherkow and Greely 2013: 32). Bringing back a species thus requires bringing back its ecological context, which now has changed dramatically:

> [L]ess than 200 years ago, billions of passenger pigeons migrated each year between the eastern United States and Canada. Today, those regions have far more humans, far larger urban centers, very different agriculture, and largely transformed ecosystems (Sherkow and Greely 2013: 32).

And how many individuals are needed to have a population? If considering the passenger pigeon whose perhaps most characteristic behaviour was to fly in groups of up to one billion individuals; will bringing back a few of them really make out the species? As David Ehrenfeld, conservation biologist at Rutgers University, stated: "The birds will live in a cage labeled 'Passenger Pigeon,' but they won't be, not really…" (quoted in Regalado 2013b) since they "would not have the same […] "culture" as their extinct predecessors" (Sherkow and Greely 2013: 32).

A species has a place within an ecosystem. The relationship is interconnected and complex. The potential use of synthetic biology to bring back extinct species is not admitting this complexity and I believe this is an extension of the underlying reductionism of synthetic biology we have seen examples of in the previous chapters in different ways. Not only are organisms seen as conglomerates of parts that can be standardized, or the results of a software or information process; through de-extinction an entire species are looked at as independent of their ecological context and something that can be "reverse-engineered" with another species as a biological platform. The different levels of reductionism are striking. Perhaps the real reason, however, to why de-extinction is even considered, is expressed in this paragraph:

> The last benefit might be called "wonder," or, more colloquially "coolness." This may be the biggest attraction, and possibly the biggest benefit, of de-extinction. It would surely be very cool to see a living wooly mammoth. And while this is rarely viewed as a substantial benefit, much of what we do as individuals—even many aspects of science—we do because it's "cool." (Sherkow and Greely 2013: 33)

Seeing a woolly mammoth, would be cool. And that, the authors suggest, is a main argument of de-extinction.

The application of synthetic biology to save species does not only refer to species that have already gone extinct but also includes the attempt to save endangered species. Conservation biologists and synthetic biologists that met during the conference on de-extinction in Cambridge (Wildlife Conservation Society 2013) also discussed how the modification and release of certain organisms could protect animals such as frogs and bats from fungus epidemics (McKie 2013), and the possibility to engineer heat-resistant coral reefs to better handle climate change (Marine Science Today 2013). The idea to modify and harvest algae that grow when an excess of nutrients from fertilizers end up in the ocean has also been discussed (McKie 2013):

> One idea is to create a synthetic alga that makes some form of biofuel. […] [Algal] Blooms would be highly lucrative and could be harvested. Thus the water would be cleared up from the revenue made from the alga's biofuel. (Paul Freemont[30] quoted in McKie 2013)

The suggestion here is thus to modify an algae to produce some kind of biofuel and then let that algae live in the ocean, and when a bloom occurs due to high availability of nutrients (as a result of excess nutrients), these blooms would be worth harvesting since they produce a type of biofuel and this, it is suggested, would reduce the spreading of dead ocean zones. Another example of the meeting of conservation biology and synthetic biology is in the suggestion of using modified bacteria that express the plant hormone *auxin*[31] to prevent desertification:

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[30] Paul Freemont is Chair of Protein Crystallography, Head of the Division of Molecular Biosciences and co-Director of the EPSRC Centre for Synthetic Biology and Innovation at Imperial College, London.

[31] This was first presented at the iGEM competition of 2011 by a team from Imperial College, London (see, iGEM 2011).

> Auxin is a powerful stimulant of root growth and that makes it very useful when tackling certain ecological problems […] In particular, it can stimulate the growth of grasses in areas into which deserts are spreading by boosting grass growth with synthetic auxin – which can hold back the spread of deserts. (Richard Kitney[32] quoted in McKie 2013)

Besides the obvious irony of modifying something to be able to preserve it, using synthetic biology and modified organisms in conservation mean applying a reductionist technofix to a complex ecological issue because again, a species has a place within an ecosystem and this is a complex relation. It might also lead to a more "relaxed" attitude to ecological issues such as biodiversity loss and desertification: If we have a technology to fix this problem for us, then why bother with trying to prevent it from happening in the first place since we can just 'restore' it if we want to?

As Craig Venter explained to us in the previous chapter when Synthia was born "…this becomes a very powerful tool for trying to design what we want biology to do" (Venter 2010, my transcription). It is about what humans want biology to do. We can turn a bandtailed pigeon into a passenger pigeon, an elephant into a mammoth, and a human into a Neanderthal. I believe the best way to describe this is what Newman calls "biological postmodernism".

> The postmodernist turn […] by devaluing nature and natural distinctions, has supported arguments […] that genetic engineering of crops is no different in principle from either traditional plant breeding or, for that matter, the natural evolutionary process. Coordinately with these efforts, evolution, for its part, has been mischaracterized by biological postmodernists […] as a product of random search that readily crosses and blurs species boundaries, *potentially transforming all biological forms into all others*. (Newman 2009: 6, emphasis added)

Since the reductionist view of synthetic biology translates life and biological systems into pieces, code, information and software, there is no boundary that demarcates one species from another, one organism from the next, and through the technological possibilities of synthetic biology, humans have a powerful tool to design what biology should do. This, I argue, is only possible if the synthetic biology perception of organisms, species, and biology is successful.

To summarize this chapter, through the successful attempt of using somatic cell nuclear transfer to bring back the Pyrenean ibex in 2003, extinction is no longer forever. Today, ten

[32] Richard Kitney is Professor of Biomedical Systems Engineering in the Department of Bioengineering and Senior Dean and Director of the Graduate School of Engineering and Physical Science at Imperial College, London.

years later, synthetic biology is seen as a potential technology to revive extinct species and assist in species conservation. The ways in which this is described, I argue, is a continuation of the reductionism presented in previous chapters where organisms, and now also entire species, are seen and approached as detached from their ecological context. While some scientists see numerous advantages in bringing back extinct species, I believe it is fundamentally wrong since it is based on the idea that humans can, and should, control biology and that one organism can be a mere platform for becoming another through reverse-engineering. This whole approach of "potentially transforming all biological forms into all other" (Newman 2009: 6), or "I can make anything out of anything" (Morton 2013: 21); a band-tailed pigeon into a passenger pigeon, an elephant into a mammoth, a human being into a Neanderthal, are all examples of 'biology going postmodern'. In the next chapter this argument is continued but the focus is instead put on the quest of synthetic biology to replace agricultural production. The question is, however: Does it, really?

REPLACING AGRICULTURE — AND WHAT ELSE?

> [A]nything that can be made in a plant can now be made in a microbe (Jay Keasling[33] quoted in Thomas 2013).

Through synthetic biology it is now possible to engineer microbes to make them produce anything produced by a plant. Microbes are turned into biological factories and production is shifting from taking place in the fields to taking place in large vats, or does it?

Perhaps the most well documented case of this development is the production of the anti-malarial medicine artemisinin. Artemisinin is derived from the one-year crop sweet wormwood (*Artemisia annua*), a plant with roots in Eurasia that has been used as a medical herb in China for millennia and was discovered to be a potent anti-malarial drug in China in the 1970s (Hansen 2012; Paulson 2013). Today, sweet wormwood is grown by farmers in China, India, Vietnam, Madagascar, Kenya, Tanzania and Mozambique (Thomas 2013) on an area of approximately 20,000 hectares (A2S2 n.d.), making it the most farmed medicinal plant by area globally (Hansen 2012). The production of artemisinin as an anti-malaria drug has

[33] Jay Keasling is Professor in chemical and biomolecular engineering and bioengineering at University of California, Berkeley.

been encouraged by the World Health Organization's (WHO) recommendations to use ACT (artemisinin-based combination therapy) against malaria; recommendations that came in 2002 (Shretta and Yadav 2012: 1). Due to high volatility in production and market prices, the supply and demand of artemisinin seldom match, leading either to an over-supply, with farmers getting low compensation for their sweet wormwood crop, or under-supply, leading to not enough available raw material and thus not enough anti-malarial medication (Shretta and Yadav 2012: 2).

In 2002 Jay Keasling co-founded a company named Amyris, located in California. The first goal of this company was to produce artemisinic acid, a precursor to artemisinin. Backed up by a grant from The Bill and Melinda Gates foundation, Keasling's team set out to engineer yeast to produce artemisinic acid in vats. On April 11th, 2013, Sanofi (who was given the production license from Amyris in 2006 (Grushkin 2012)) launched the commercial production of engineered yeast-derived artemisinin at their production site in Italy, aiming for producing 35 tons of artemisinin in 2013 and 50 to 60 tons in 2014, which corresponds to between 80 and 150 million ACT treatments (Sanofi 2013).

The original idea with the semisynthetic production of artemisinin, using the engineered yeast developed by Amyris, was to support the volatile market and supplement it when there is a shortage in supply. However, during a conference in Cambridge in April 2013[34], Jay Keasling announced that "[e]arly on, it was not about replacing the agricultural form […] and now I think it's nearly inevitable that it will shift over" (quoted in Thomas 2013). Keasling explicitly expressed that the aim has shifted from supplementing the existing agricultural production, to "replace the entire world supply" (quoted in Thomas 2013).

This announcement clearly states that the plant-based, agricultural production of artemisinin, now taking place in Asia and Africa through the cultivation of sweet wormwood, will be replaced with a semi-synthetic production taking place in large vats on industrial production sites under the control of one of the largest pharmaceutical companies in the world.[35] From a production efficiency point of view, this makes perfect sense: The cultivation of sweet wormwood takes 12-18 months from sowing to harvest (PATH n.d.) and the crops are affected by external factors such as weather conditions. The microbes, on the other hand, are not affected by weather and the whole process of producing the drug from using the microbes

[34] See Wildlife Conservation Society 2013.

[35] Sanofi-Aventis is the second largest pharmaceutical company in the world by 2009 sales numbers (ETC Group 2011).

takes less than three months: “You get an order, you fire up the bioreactors, and you ship it out” as Keasling described it (quoted in Peplow 2013:160).

Artemisinin is only one example in a long list of agricultural products that are underway of being replaced with a semi-synthetic version through synthetic biology. The list of products include Stevia, Vetiver, Patchouli, Star Anise and Rubber.[36] Evolva, a synthetic biology company based in Switzerland, is currently developing semi-synthetic versions of saffron and vanilla, among others. Saffron is the most expensive spice in the world and consists of the stigmas of the saffron crocus (Evolva n.d.a). Through producing a semi-synthetic version of saffron, Evolva states that the price will go down, complexities in the current supply chain will be eliminated, and customization of the products for certain preferences is possible:

> We create new ways to make “tried and tested” natural ingredients – for example the ingredients that make saffron look, taste and smell like saffron. The existing production methods for many such ingredients have significant problems (too expensive, too variable, not pure enough, too limited in scale, not ecologically sustainable, etc.) and by solving these problems we can widen the number of people who can enjoy, and benefit from, these ingredients. (Evolva n.d.d)

Evolva plans to have a saffron-product available for the market in 2015-2016 (Evolva n.d.a). Similar ideas are portrayed around the production of a semi-synthetic version of vanilla. Evolva entered a pre-production phase of their semi-synthetic version of vanilla in early 2013 (Evolva n.d.b) and the CEO at Evolva, Neil Goldsmith, announced in a press release that he

> …strongly believe that fermentation as an innovative and sustainable way to produce vanillin is a very attractive alternative to the traditional production routes (Evolva 2013).

Besides the agricultural products that usually are derived from farming practices, synthetic biology is also used to produce fuels and chemicals that are aimed to replace the ones derived from fossil fuels. The difference between the traditional idea with biofuels derived from crops (such as corn- or sugarcane derived ethanol) and this microbe-derived biofuel is that this time the microbes have been engineered to produce a close to exact replacement of the original fossil fuel or petroleum derived product; they can therefore be referred to as bio-fossil-fuels (Morelle 2013).

[36] For an extensive (but not up to date) list of synthetic biology products that are currently under development, see Synthetic Biology Project 2012.

> Synthetic biologists hope to change the microorganisms they are working with so that the oil they produce is chemically similar or identical to the oils that are currently used in today's transportation and energy infrastructure. *These microbes would become "living chemical factories" that can be engineered to pump out almost any type of fuel or industrial chemical* (de Morsella 2011, emphasis added).

Several companies have been formed, set out to produce the synthetic biology derived chemicals and fuels (see de Morsella 2011 for a non-exhaustive list). What is striking about this development is the idea that microbes can produce anything and everything we humans want and need. The possibility to engineer a microbe to produce any compound, as long as the necessary modifications are discovered, has led to the idea that

> …in the future, making materials and commodities – actual physical stuff – would no longer be a resource problem but a genetic programming problem. (Grushkin 2012)

In the previous chapter I discussed synthetic biology and de-extinction as an example of a biological postmodernism where any organism potentially can become any other organism. This notion is expanded here and takes a new turn since not only can an elephant potentially be a mammoth, as we saw in the previous chapter, but a microbe can be a crocus, or an oil-well. It is *just* a matter of knowing how to make it become just that.

The application of synthetic biology to solve production shortages, problems and transitions is also followed by a language of sustainability. Evolva writes that:

> We see that […] the "hidden chemistry" of nature, and in particular of food, is a treasure trove for new products that improve health, wellness and nutrition. [W]ith innovative biosynthetic technologies we can unlock this wealth for the benefit of individuals across the globe. *And do so in a sustainable manner*. (Evolva n.d.c, emphasis added)

Or LS9, a company aiming to produce fossil fuel replacements and chemicals, writes that

> *To sustain life as we know it*—with a growing population in the billions—practical, commercially relevant technologies that offer renewable alternatives to petroleum-based products are essential. LS9 is delivering these products and technologies to the world, today. (LS9 n.d.a, emphasis added)

LS9 is also emphasizing that the company is developing a "sustainable fuel and chemical technology" (LS9 n.d.b). Another example is Synthetic Genomics:

> The world is facing increasingly difficult challenges today. Population growth resulting in the growing demand for critical resources such as energy, clean water, food and medicine are taxing our fragile planet. *To fulfill these needs we need disruptive technologies. We believe genomic advances offer the world viable, sustainable alternatives.* (Synthetic Genomics n.d., emphasis added)

These are just a few examples of the language used by these companies expressing a conviction where synthetic biology is seen to be almost like a technological white knight, here to take humanity away from the path of numerous interweaved crises that our current production systems are built on. This idea of synthetic biology as a technology of sustainability can be seen as, what Hajer calls, ecological modernization because it "…starts from the conviction that the ecological crisis can be overcome by technical and procedural innovation" (1996: 249). What is also striking about this is that

> …it makes the 'ecological deficiency' of industrial society into the driving force for a new round of industrial innovation. As before, society has to modernize itself out of the crisis. (Hajer 1996: 249)

The "crisis" is an incentive for more innovation, modernization and technological development. The only solution to the problems caused by the old industry is another round of new industrial innovations and new companies grow on the mess caused by the older industry.[37]

Despite synthetic biology being portrayed as a possible industrial revolution, one may wonder: what are the means of production in this seemingly new production system where microbes can produce everything we want and need? For example, assuming that the engineered microbes still needs some type of precursors to produce things; what do the microbes eat? The answer is sugar. The engineered microbes that can produce synthetic biology versions of saffron, vanilla, rubber, artemisinin, fuels, chemicals, and whatever you can imagine, needs sugar to be able to produce anything at all. The next question is then, where and how is this sugar produced? LS9 use a mix of sugar cane (from Brazil, Hawaii, Southeast Asia etc.), corn syrup (from U.S., China), sweet sorghum syrup (from U.S., Brazil, Australia, etc.), molasses (from Brazil, Hawaii, Southeast U.S. and Asia, India), glycerin

[37] Despite their novelty, many of the new synthetic biology companies have partnered with, or are funded by, as Ed Gillespie put it: "the *'Four Horsemen of the Corporate Apocalypse'* – Big Oil, Chemicals, Pharma and Grain" (Gillespie 2013, emphasis in original) and the old industry is thus still in the game. For more information about the partnering between corporate giants and synthetic biology companies, see The International Civil Society Working Group on Synthetic Biology (2011: 13-14).

(from U.S., Brazil, Europe, Southeast Asia, China) and biomass hydrolysate from numerous sources (LS9 n.d.c). Solazyme, a company that produces oil and 'bioproducts' uses "a range of low-cost plant-based sugars" (Solazyme 2012) in their production which they suggest to be sugarcane, corn and stover, miscanthus, switchgrass, forest residue and waste streams (Solazyme n.d.).

The majority of the feedstock the synthetic biology companies are depending on for their microbial production comes from agricultural produce. Some of the synthetic biology companies are thus attempting to replace agricultural production of certain crops by relying on another type of agricultural production. A highlighted example of this is Amyris' partnership with Cosan to provide them with sugar feedstock and distribute their synthetic biology derived petroleum-products. Cosan's joint venture with Shell, Raízen, is the world's largest producer of sugar and ethanol from sugarcane (Businesswire 2011). Brazilian sugarcane production has been criticized for leading to biodiversity loss through monoculture practices, heavy reliance on industrial inputs such as fertilizers and pesticides, but also in taking place on land that at least indirectly leads to displacement of peoples and deforestation of rainforest (Friends Of The Earth 2008: 15-16). At this point, I believe we have to rethink the statement by Grushkin (2012) that

> …in the future, making materials and commodities —actual physical stuff — would no longer be a resource problem but a genetic programming problem.

Production relying on microbes is just as dependent on agricultural production (and thus also land) as earlier production systems. What has changed is that the foundations of the production have been mystified. The idea that synthetic biology is a technology that can create everything out of nothing (no longer a resource problem) and thus let us escape previous production problems and environmental degradation related to previous practices, is nothing else than a grand illusion, and the problem lies in "…our way of conceptualizing the relationship between sociocultural constructions and material processes" (Hornborg 2001: 9-10). This branch of synthetic biology is a fetish because it mystifies unequal relations (Hornborg 2001: 132) that takes place (technological development on one hand and environmental degradation on the other). Replacing old production systems with synthetic biology can be seen as a fetish in that it is given a kind of autonomous agency as a problem solver, however, what it obscures, or mystifies, are its own foundations and dependencies for existence.

A fetish boils down to that it "tend[s] to *conceal* rather than to elucidate" (Thoden van Velzen, 1990: 78, quoted in Hornborg 2001: 139, emphasis in original) and, as Ihde (2010: 139, emphasis in original) states, "[w]hat is *revealed* is what excites; what is concealed may be forgotten." If synthetic biology is seen as a solution to previous production problems, this is only because we fail to see the unequal relations which are a precondition for its existence.

> Its [industrial technology's] power to conduct work "in itself," as it were, is a cultural illusion. It is the productive potential of the fuels and other raw materials which is at work in our machines, not the machines "in themselves." (Hornborg 2001: 12)[38]

To summarize this chapter, through synthetic biology it is possible to engineer a microbe to produce anything that is produced by a plant and previous practices, i.e. farming, are seen as obsolete and inefficient. The use of synthetic biology to build living microbial factories goes even further to include tailored oils and chemicals that commonly are derived from fossil fuels. These possibilities have led to beliefs that production will in the future no longer be a matter of resources but of genetic modification. I argue that this development is another round in the biological postmodernism outlined in the previous chapter where any living organism potentially can turn into any other, and here this takes the shape that a microbe can turn into a crocus or an oil-well. The companies who are producing the engineered microbes adopt a language of sustainability which I see follows the line of Hajer's description of ecological modernization because it starts with the conviction that the problems created by the old industry can be solved through a new round of industrial innovation. We have also learned that synthetic biology companies are attempting to produce agricultural compounds by relying on another type of agriculture as feedstock for the microbes. I argue that this is a mystification where the foundations of microbial production are obscured and where unequal relations are hidden under a layer of attributed autonomous agency; therefore it is a fetish. The next chapter includes reflections on the methodology, summarizes my conclusions from this inquiry and gives suggestions for further research.

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[38] Hornborg, assisted by a dictionary, suggests that technology is the science of mechanical and industrial arts, whereas machine is any contrivance for the conversion and direction of motion; an apparatus for doing some kind of work (2001: 121). Through this analysis, he uses machine for what one may be used to call technology, but the use of the word technology to represent what should be referred to as machines, writes Hornborg, "…implies that they [Westerners] are celebrating their "knowledge" and skills for making these material contrivances available to them, rather than the contrivances themselves." (2001: 121)

REFLECTIONS AND CONCLUSIONS

This chapter starts with reflections on relying on inquiry as method and text as field, discussing the knowledge that has been produced, my position and credibility. It continues with the conclusions that can be drawn from the inquiry, a reflection on whether or not and in what ways these conclusions contribute to the task I set up for myself in the beginning of this thesis, and ends with suggestions for further inquiring.

My vision in choosing inquiry as a method for this thesis was to be able to explore synthetic biology as a topic. Inquiry as described by Paul Rabinow (2008) is to set out in the indeterminate — to discover — and to construct and give form to, or determine, what is discovered so that it can be described and known. The strength in this method, combined with my approach of viewing texts on synthetic biology as a field in which I can observe and inquire, has been my fairly unrestrained ability to 'walk' between topics, sources and ideas. In this sense, the method has served the purpose for which I chose it. However, it is necessary to ask the critical question: what kind of knowledge has been produced?

When describing the method in the beginning of this thesis, I pointed out that inquiry is situated; i.e. that my *position* as a person plays an important role in how the inquiry is conducted. I identified that some crucial aspects of this was (1) learning about synthetic biology while working for the ETC Group, (2) having an academic background in environmental science and human ecology, (3) perceiving the world through a 'filter' of sustainability, and (4) me as an emotional being; concerned about the future of humans, non-humans and our shared habitat. In relation to the inquiry and the results, I still see all these aspects as having been relevant for the shaping of this thesis and as aspects of my *situation*.

First of all because, as stated in the beginning, through my work at the ETC Group I learned about synthetic biology from a critical perspective and I subscribed to the emailing list for synthetic biology critics. Both of these aspects have contributed to this inquiry both in terms of material and arguments. Secondly, my academic background has led me to see connections and links which I might have not seen otherwise, as well as adding more of a critical perspective to synthetic biology. An example of this is applying the ideas of ecological modernization and fetishism to synthetic biology in the chapter *Replacing Agriculture*.

Thirdly, me seeing the world through a filter of sustainability has perhaps not been very visible in the inquiry as such, but is reflected in me giving significance to the reductionist paradigm of synthetic biology in different levels since this reductionism is the very opposite of how I believe that humans should think of themselves and/in the rest of nature in order for this interrelation to be sustainable. My idea of sustainability is not limited to this, but this is the major aspect of it reflected in this inquiry. The fourth aspect is me as an emotional being. This has affected my path by me simply being emotionally affected (sadness, anger, frustration, or 'this is madness') by different aspects of synthetic biology. For example, I chose de-extinction as a theme partly because I was shocked by the idea of bringing back species from extinction, and because I could not understand the mindset of thinking of a species and a being as something the can be 'reverse-engineered' into another; this also being connected to my idea of sustainability in that I do not agree with the notion of beings as mere floating matter, available for mental and physical reconstruction according to human ideas and needs. Or, as Susana Gura puts it: "The concept of life as a conglomerate of parts that can be replicated or exchanged is simply wrong" (2010:76). If I would have been a proponent of synthetic biology, I surely would have written a completely different thesis by perhaps stopping at, and not questioning the notion that synthetic biology can and will solve a whole bunch of problems, but, I just do not believe in miracle technologies, and therefore I am critical.

In exposing these aspects of my position, I intend to clarify and create transparency on what has guided me in this inquiry. With this I also intend to clarify aspects of credibility, which I presented as being the production of reality-like effects (Atkinson 2001: 90) and stated that what is relevant, real and true is relative (Rabinow 2008: 50), or rather, relational (Hornborg 2001: 159). The knowledge produced here is thus a kind of meeting of me and the topic. However, what is crucial in relation to this is my choice of field which I stated is a combination of others' representations of synthetic biology and its practitioners, practitioners' own words as selected by others (in the case of interviews) and practitioners' own words in terms of publications, lectures and interviews. Again I believe that this diverse material has, similar to the method, contributed to my fairly unrestrained ability to 'walk' between topics, sources and ideas.

Second-order observations, as it can be called, give the second-order observer (myself) the possibility to also observe *how* what is being observed by first-order observers (synthetic biology) is being described (Rabinow 2008). I believe this has contributed to this inquiry for example by my ability to discuss how synthetic biology is being perceived; as a platform technology, as an industrial revolution, as a multi-problem solver, as synthetic biologists playing God and treading in Frankenstein's footsteps and so on. Using other people's interpretations leads to the question of who has produced the interpretation and whose perspective is represented. I do not claim to represent someone else's perspective than my own since I am the one who has interpreted these observations. Important in regard to this is that the second-order observations have only been used as parts in my exploration to 'reach' synthetic biology as a topic. However, a fundamental issue is that I cannot detach the topic from the perspective of the observer.

What I have contributed with is my unique perspective on synthetic biology. Thus, I do not claim that this inquiry is repeatable, generalizable or transferrable but should be seen as a part in the constantly developing wider sphere of knowledge and perspectives around the emerging field of synthetic biology.

With that said, I now turn to what can be concluded from this inquiry. The most fundamental conclusion is that synthetic biology is guided by a reductionist engineering paradigm which takes its form in several ways; (1) biology is approached as something that can become a predictive science, (2) biological organisms are approached with an anti-complexity view where complexity is not something that should be understood but rather eliminated and (3) that parts of biological organisms are seen as sufficient for properties of the whole.

In relation to this I have also concluded that a paradigm is a social construction and that it guides its practitioners but also obscures the reasons to why a certain action, or practice, is possible. As seen in the chapter *Like Lego*, synthetic biology — guided by the engineering paradigm — tends to not only construct ways in which to name the world but also constructs biology to fit the engineering vision. This occurs through a self-contradiction where on the one hand biological complexity is eliminated and on the other, synthetic biology is thought to be able to reveal a hidden simplicity in nature. This "blurring of ontology and epistemology" as Calvert (2010: 101) states means that biological organisms are reshaped to fit the engineering paradigm.

I have also concluded that synthetic biology is challenging culturally fixed distinctions, boundaries and understandings and that the use of language such as playing God and Frankenstein is thus not so much marking a change in human ability to alter nature but can rather be seen as a perceptual crisis. In relation to use of language around synthetic biology and as an extension of the reductionist paradigm I can also conclude that life is defined as software, or information process and code.

Synthetic biology is portrayed as a problem-solver for a range of issues. Bringing back species, it is said, could give us higher biodiversity, new medicines etc. And synthetic biology is also seen as a potential assistant in nature conservation. This, I argue, can again be related to the reductionist paradigm of synthetic biology since species are approached as detached from their ecological context. It is also problematic, I argue, to think of complex ecological issues such as desertification as solvable through the application of a technofix since this may lead to a relaxed attitude towards these issues which are then seen as "fixable". Synthetic biology, in the form of engineering of microbes, is seen as a problem-solver of issues related to agricultural production as well as seen as a technology that can be used to produce fuels and chemicals that commonly are derived from fossil fuels. However, this notion, I argue, is mystifying the foundations on which microbial production rely; namely agricultural production elsewhere. I thus conclude that it is a fetish that conceals rather than reveals. Synthetic biology in the form of microbial production is also a project of ecological modernization since the problems produced by the old industry are thought to be solved by introducing another round of industrial innovation and technological development.

My final conclusion, which is also the one I am most concerned about, is the idea that in synthetic biology, any living being can potentially be any other. An elephant can become a mammoth, a microbe can become a crocus; a pattern that can be called biological postmodernism, as stated by Newman (2009). The living organism no longer has a "natural" boundary but is instead "open for construction" through being seen as a conglomerate of parts that can be altered.

In relation to the question posed in the beginning of this thesis — what is synthetic biology? — I can summarize my conclusions in that synthetic biology is

- (still) the deliberate attempt to design living organisms
- A technoscience
- A project guided by a reductionist paradigm
- An engineer's approach to biology
- An attempt to standardize parts of biological organisms; seen as sufficient for properties of the whole
- An attempt to eliminate biological complexity

- A project thought to one day reveal an underlying simplicity in nature
- A classification of life as a software process, information process or code
- A project seen as a tool for humans to control biology
- A re-construction of biology to fit an engineering vision
- A monster in the human symbolic order that challenges culturally fixed distinctions
- An attempt to bring back species from extinction
- An anti-complexity view on species and ecological issues
- A technofix
- A mystification and a fetish
- A project of ecological modernization
- A type of biological postmodernism

Synthetic biology is not one thing, but rather, as seen in the list above and throughout this thesis, a lot of things. Perhaps synthetic biology, in being a lot of things, is a no-thing? Eric Wolf explains

> By turning names into things we create false models of reality. By endowing nations, societies, or cultures [or emerging technosciences] with the qualities of internally homogeneous and externally distinctive and bounded objects, we create a model of the world as a global pool hall in which the entities spin off each other like so many hard and round billiard balls. Thus it becomes easy to sort the world into differently colored balls, to declare that "East is East, and West is West, and never the twain shall meet" (Wolf 2010 [1982], p. 6).

Synthetic biology is not a homogenous, externally distinctive, and bounded object. It is a *name* that comprises a lot of things. I believe this is an important conclusion which explains why this thesis ended up in a long list of conclusions on what synthetic biology is.

In the very beginning of this thesis I outlined a task for myself. One dimension of this was to contribute to the fields of technology and values and human ecology. In the former, the focus is to "…understand, evaluate, appreciate and criticize the ways in which technologies reflect, as well as change, human life, individually, socially, and culturally" (Hanks 2010: 1) and in the latter the aim is understanding and evaluating interrelations of humans and the rest of nature. I believe I have contributed to these very broad fields in several ways but perhaps mainly by showing how synthetic biology changes and challenges ideas and perceptions of life, organisms, species and ecological issues; what is seen as a problem and what is seen as a solution, and the important role a certain world-view can play in these formulations. I have also contributed to Nikolas Rose' (2013) call for a fieldwork in philosophy, to understand how the notion of life is shaped, by diving into the guiding paradigm of synthetic biology and modestly clarifying how the notion of life and living organisms is constructed within this particular branch of the life sciences.

Among my conclusions and along the path of my inquiry I have discovered several topics that need further exploration. The first one is generally to continue tracking synthetic biology since it is a constantly developing field. Secondly, to continue the discussion on the guiding engineering paradigm of synthetic biology and what potential consequences this might have for humans and the rest of nature. Third, in relation to the attempt to replace agriculture; a) understand the potential impact of synthetic biology on humans and nature through the mystification of production and b) investigate the potential impact on farmers who today are the ones producing what synthetic biology aims to replace. And, finally, continue to explore biological postmodernism and the notion that any being potentially can become any other being. As long as we are given the space to explore our world, we should keep ourselves busy exploring. The thinking, writing and inquiring continues.

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REFERENCES

A2S2. n.d. *Artemisia Data*. [http://www.a2s2.org/]. Accessed: 2013-04-26.

Adam, David and Ian Sample. 2004. It's life, but not as God planned it. *The Guardian*. 2004-04-01. [http://www.guardian.co.uk/education/2004/apr/01/research.highereducation?INTCMP=SRCH]. Accessed: 2013-04-02.

Adams, Tim. 2010. Craig Venter: The dazzling showman of science. *The Guardian*. 2010-05-23. [http://www.guardian.co.uk/theobserver/2010/may/23/observer-profile-craig-venter?INTCMP=SRCH]. Accessed: 2013-04-02.

Alleyne, Richard. 2010. Scientist Craig Venter creates life for first time in laboratory sparking debate about 'playing god'. *The Telegraph.* 2010-05-20. [http://www.telegraph.co.uk/science/7745868/Scientist-Craig-Venter-creates-life-for-first-time-in-laboratory-sparking-debate-about-playing-god.html]. Accessed: 2013-04-02.

Atkinson, Paul. 2001. Ethnography and the Representation of Reality. In: *Contemporary Field Research: Perspectives and Formulations* (2nd edition). Robert E. Emerson (ed.). Long Grove: Waveland Press. 89-101.

Bacon, Francis. 1906 [1627]. *The advancement of learning and the New Atlantis*. Oxford: Oxford University Press. [http://ia600305.us.archive.org/30/items/advancementnewat00bacouoft/advancementnewat00bacouoft.pdf]

Ball, Philip. 2004. Synthetic Biology: Starting From Scratch. *Nature*. 431(7009):624-626.

Behar, Ruth. 1997. *The Vulnerable Observer — Anthropology that Breaks your Heart*. Boston: Beacon Press.

Bird, Elisabeth Ann R. 1987. The Social Construction of Nature: Theoretical Approaches to the History of Environmental Problems. *Environmental Review*. 11(4):255-264.

Brand, Stewart. 2013. *The Dawn of De-Extinction. Are You Ready?*. TEDx DeExtinction Event organized by National Geographic, TED and Revive and Restore. Washington D.C.:

Grosvenor Auditorium, National Geographics Headquarters. 2013-03-15. [http://longnow.org/revive/]. Accessed: 2013-04-25.

Braun, Matthias, Jens Ried, and Peter Dabrock. 2013. From Homo Faber to Homo Creator? A Theological-Ethical Expedition into the Anthropological Depths of Synthetic Biology. *Worldviews: Global Religions, Culture & Ecology*. 17(1):36-47.

Breithaupt, Holger. 2006. The engineer's approach to biology. *EMBO reports*. 7(1):21-24.

Brockman, John. 2006. Constructive biology: George Church. *Edge: The third culture*. 2006-06-26. [http://www.edge.org/3rd_culture/church06/church06_index.html]. Accessed: 2013-04-03.

Brown, Andrew. 2010. Has Venter made us gods?. *The Guardian*. 2010-05-20. [http://www.guardian.co.uk/commentisfree/andrewbrown/2010/may/20/craig-venter-life-god]. Accessed: 2013-04-02.

Buck, Holly. 2011. *Climate Engineering in the New Media Landscape: Culture, Power, and Climate Control*. Master's thesis, Lund University.

Businesswire. 2011. *Cosan and Amyris Forming Novvi S.A. for Global Production and Commercialization of Renewable Base Oils*. 2011-06-13. [http://www.businesswire.com/news/home/20110613005456/en/Cosan-Amyris-Forming-Novvi-S.A.-Global-Production]. Accessed: 2013-05-07.

Calvert, Jane. 2008. The Commodification of Emergence: Systems Biology, Synthetic Biology and Intellectual Property. *BioSocieties*. 3(4):383-398.

Calvert, Jane. 2010. Synthetic biology: constructing nature?. *Sociological Review Monograph*. 58(Suppl. 1):95-112.

Cho, Mildred K. and David A. Relman. 2010. Synthetic "Life," ethics, national security, and public discourse. *Science*. 329(5987):38-39.

Church, George and Ed Regis. 2012. *Regenesis – How Synthetic Biology Will Reinvent Nature and Ourselves*. New York: Basic Books.

Cole-Turner, Ronald. 2009. Synthetic Biology: Theological Questions about Biological Engineering. In: *Without Nature: A New Condition for Theology*. David Albertson and Cabell King (eds.). New York: Fordham University Press. 136-151.

Collins, James. 2012. Bits and pieces come to life — Scientists are combining biology and engineering to change the world. *Nature*. 483(7387):8-10.

Cookson, Clive. 2010. 'Century of biology' takes time to bear fruit. *The Financial Times*. 2010-03-05. [http://www.ft.com/cms/s/2/e04e5abe-f555-11de-90ab-00144feab49a.html#axzz2POp5Y9E4]. Accessed: 2013-04-03.

De Lorenzo, Victor and Antoine Danchin. 2008. Synthetic biology: discovering new worlds and new words — The new and not so new aspects of this emerging research field. *EMBO Reports*. 9(9):822-827.

De Morsella, Chris. 2011. 12 Synthetic Biology Biofuel & Biochemical Companies to Watch. The Green Economy Post. 2011. [http://greeneconomypost.com/synthetic-biology-biofuel-biochemical-company-17244.htm#ixzz2S87PaLpB]. Accessed: 2013-05-03.

Drengson, Alan R. 2010. Four Philosophies of Technology. In: *Technology and Values – Essential Readings*. Craig Hanks (ed.). United Kingdom: Blackwell Publishing Ltd. 26-37.

Duncan, David Ewing. 2011. Growing Heart Cells Just for You. *MIT Technology Review*. 2011-08-23. [http://www.technologyreview.com/featuredstory/425129/growing-heart-cells-just-for-you/]. Accessed: 2013-05-14.

Dyson, Freeman. 2005. The Darwinian Interlude. *MIT Technology Review*. 2005-03-01. [http://www.technologyreview.com/article/403777/the-darwinian-interlude/]. Accessed: 2013-03-16.

ETC Group. 2011. *Who Will Control The Green Economy?*. [http://www.etcgroup.org/sites/www.etcgroup.org/files/publication/pdf_file/ETC_wwctge_4web_Dec2011.pdf]. Accessed: 2013-05-03.

Evolva. 2013. *IFF and Evolva Enter Pre-Production Phase for Natural Vanillin for Global Food and Flavor Markets.* [http://www.evolva.com/media/press-releases/2013/2/5/iff-and-evolva-enter-pre-production-phase-natural-vanillin-global-food]. Accessed: 2013-05-03.

Evolva. n.d.a. *Saffron*. [http://www.evolva.com/products/saffron]. Accessed: 2013-05-03.

Evolva. n.d.b. *Vanilla*. [http://www.evolva.com/products/vanilla]. Accessed: 2013-05-03.

Evolva. n.d.c. *We see things a little different*. [http://www.evolva.com/]. Accessed: 2013-05-03.

Evolva. n.d.d. *Overall Concept*. [http://www.evolva.com/technology/overall-concept]. Accessed: 2013-05-03.

Flannery, Maura C. 2010. Mimicking Nature, or At Least Trying To. *American Biology Teacher (National Association of Biology Teachers)*. 72(7):452-455.

Fraser, Claire M., Jeannine D. Gocayne, Owen White, Mark D. Adams, Rebecca A. Clayton, Robert D. Fleischmann, Carol J. Bult, Anthony R. Kerlavage, Granger Sutton, Jenny M. Kelley, Janice L. Fritchman, Janice F. Weidman, Keith V. Small, Mina Sandusky, Joyce Fuhrmann, David Nguyen, Teresa R. Utterback, Deborah M. Saudek, Cheryl A. Phillips, Joseph M. Merrick, Jean-Francois Tomb, Brian A. Dougherty, Kenneth F. Bott, Ping-Chuan Hu, Thomas S. Lucier, Scott N. Peterson, Hamilton O. Smith, Clyde A. Hutchison III, J. Craig Venter. 1995. The Minimal Gene Complement of *Mycoplasma genitalium*. *Science*. 270(5235):397-403.

Friends Of The Earth. 2008. *Fuelling Destruction in Latin America – The Real Price of the Drive for Agrofuels*. September 2008, Issue 113. [http://www.foei.org/en/resources/publications/pdfs/2008/biofuels-fuelling-destruction-latinamerica/view].

Gannon, Megan. 2013. Reviving the Woolly Mammoth: Will De-Extinction Become Reality?. *Live Science*. 2013-03-15. [http://www.livescience.com/27939-reviving-extinct-animals-mammoths.html]. Accessed: 2013-04-25.

Gillespie, Ed. 2013. *"Hope is the thing with feathers"*. 2013-04-16. [http://www.futerra.co.uk/author/ed]. Accessed: 2013-05-03.

Gray, Richard and Roger Dobson. 2009. Extinct ibex is resurrected by cloning. *Telegraph*. 2009-01-31. [http://www.telegraph.co.uk/science/science-news/4409958/Extinct-ibex-is-resurrected-by-cloning.html]. Accessed: 2013-04-25.

Greely, Hank. 2013. *De-Extinction: Hubris or Hope?*. TEDx DeExtinction Event organized by National Geographic, TED and Revive and Restore. Washington D.C.: Grosvenor Auditorium, National Geographics Headquarters. 2013-03-15. [http://www.youtube.com/watch?v=HuRk0V2LoMY]. Accessed: 2013-04-25.

Grushkin, Daniel. 2012. The Rise and Fall of the Company That Was Going to have us all Using Biofuels. *Fast Company Magazine*. 2012-08-08. [http://www.fastcompany.com/3000040/rise-and-fall-company-was-going-have-us-all-using-biofuels]. Accessed: 2013-04-26.

Gura, Susana. 2010. Industrial Livestock Production and Biodiversity. In: *The Meat Crisis: Developing More Sustainable Production and Consumption*. Joyce D'Silva and John Webster (eds.). London: Earthscan. 57-79.

Hajer, Maarten. 1996. Ecological Modernisation As Cultural Politics. In: *Risk, Environment & Modernity – Towards a New Ecology*. Scott Lash, Bronislaw Szerszynski, Brian Wynne (eds.). London: Sage Publications. pp. 246-268.

Hanks, Craig. 2010. General Introduction. In: *Technology and Values – Essential Readings*. Craig Hanks (ed.). United Kingdom: Blackwell Publishing Ltd. 1-6.

Hansen, Janne. 2012. *Plants stressed in the fight against malaria*. 2012-10-17. [http://food.au.dk/en/current/news/show/artikel/plants-stressed-in-the-fight-against-malaria/]. Accessed: 2013-04-26.

Heaven, Douglas. 2013. Quality control opens path to synthetic biology's Ikea. *New Scientist*. 2013-03-27. [http://www.newscientist.com/article/mg21729104.300-quality-control-opens-path-to-synthetic-biologys-ikea.html]. Accessed: 2013-05-03.

Heinemann, Matthias and Sven Panke. 2006. Synthetic biology — Putting engineering into biology. *Bioinformatics*. 22(22):2790-2799.

Hickman, Leo. 2008. Is it time yet to play God?. *The Guardian*. 2008-01-25. [http://www.guardian.co.uk/environment/blog/2008/jan/25/playinggod?INTCMP=SRCH]. Accessed: 2013-04-02.

Highfield, Roger. 2007. From reading DNA to writing it. *The Telegraph*. 2007-06-28. [http://www.telegraph.co.uk/news/worldnews/1555891/From-reading-DNA-to-writing-it.html]. Accessed: 2013-04-02.

Hilgartner, Stephen. 2012. Novel constitutions? New regimes of openness in synthetic biology. *BioSocieties*. 7(2):188-207.

Hornborg, Alf. 2001. *The Power of the Machine: Global Inequalities of Economy, Technology, and Environment*. Walnut Creek, California: Altamira.

iGEM. 2011. *Auxin*. [http://2011.igem.org/Team:Imperial_College_London/Project/Auxin/Overview]. Accessed: 2013-05-14.

iGEM. n.d. *About*. [http://igem.org/About]. Accessed: 2013-03-22.

Ihde, Don. 2010. A Phenomenology of Technics. In: *Technology and Values – Essential Readings*. Craig Hanks (ed.). United Kingdom: Blackwell Publishing Ltd. 134-156.

Jha, Alok. 2012. Science Weekly podcast: Playing God with nature. *The Guardian*. 2012-01-16. [http://www.guardian.co.uk/science/audio/2012/jan/16/science-weekly-podcast-playing-god-nature?INTCMP=SRCH]. Accessed: 2013-04-02.

Jørgensen, Marianne and Louise Phillips. 2002. *Discourse Analysis as Theory and Method*. London: Sage Publications Ltd.

Kelle, Alexander. 2012. Beyond Patchwork Precaution in the Dual-Use Governance of Synthetic Biology. *Science and Engineering Ethics*. [Article in Press]:1-19.

Kitney, Richard and Paul Freemont. 2012. Synthetic biology — The state of play. *FEBS Letters*. 586(15):2029-2036.

Lincoln, Yvonna A. and Egon G. Guba. 1985. *Naturalistic Inquiry*. Beverly Hills, California: Sage Publications, Inc.

Line, Brett. 2013. Behind the Cover: April 2013 – Meet the Extinct Animals. *National Geographic*. 2013-04. [http://news.nationalgeographic.com/news/behind-the-cover-extinct-animals/]. Accessed: 2013-04-25.

LS9. n.d.a. *LS9 Inc.* [http://www.ls9.com/]. Accessed: 2013-05-03.

LS9. n.d.b. *Technology Overview*. [http://www.ls9.com/technology/technology-overview]. Accessed: 2013-05-03.

LS9. n.d.c. *Feedstocks*. [http://www.ls9.com/technology/feedstocks]. Accessed: 2013-05-03.

Lynas, Mark. 2011. Geo-engineering, nuclear power and climate change: playing God is good for the planet. *The Telegraph*. 2011-07-12. [http://www.telegraph.co.uk/science/science-news/8631604/Geo-engineering-nuclear-power-and-climate-change-playing-God-is-good-for-the-planet.html]. Accessed: 2013-04-02.

MacLeod, Ken. 2010a. Humanity will thank heaven that this creator of synthetic life is playing God. *The Guardian*. 2010-05-21. [http://www.guardian.co.uk/commentisfree/2010/may/21/synthetic-life-playing-god?INTCMP=SRCH]. Accessed: 2013-04-02.

MacLeod, Ken. 2010b. Humanity will thank creator of synthetic life. *The Hindu*. 2010-05-23. [http://www.thehindu.com/sci-tech/science/humanity-will-thank-creator-of-synthetic-life/article434800.ece]. Accessed: 2013-04-02.

MacRae, Fiona. 2010. Scientist accused of playing God after creating artificial life by making designer microbe from scratch — but could it wipe out humanity?. *Daily Mail*. 2010-06-03. [http://www.dailymail.co.uk/sciencetech/article-1279988/Artificial-life-created-Craig-Venter--wipe-humanity.html]. Accessed: 2013-04-02.

Marine Science Today. 2013. Synthetic Biology: Applications and Ethics. *Marine Science Today*. 2013-04-17. [http://marinesciencetoday.com/2013/04/17/synthetic-biology-applications-and-ethics/]. Accessed: 2013-05-14.

McEuen, Paul L. and Cees Dekker. 2008. Synthesizing the future *ACS Chemical Biology*. 3(1):10-12.

McFadden, Johnjoe. 2009. It's time to play God. *The Guardian*. 2009-08-23. [http://www.guardian.co.uk/commentisfree/2009/aug/23/venter-artificial-life-genetics?INTCMP=SRCH]. Accessed: 2013-04-02.

McGuinness, Ross. 2013. The science of 'de-extinction': Can cloning bring extinct animals back to life?. *Metro*. 2013-03-13. [http://metro.co.uk/2013/03/13/the-science-of-de-extinction-can-cloning-bring-animals-back-to-life-3537451/]. Accessed: 2013-05-18.

McKie, Robin. 2013. Call for DNA biologists to join fight against deadly new threats to wildlife. *The Guardian*. 2013-04-07. [http://www.guardian.co.uk/environment/2013/apr/07/fungal-disease-conservation-synthetic-biology]. Accessed: 2013-05-14.

Morelle, Rebecca. E. coli bacteria 'can produce diesel biofuel'. *BBC News, Science and Environment*. 2013-04-22. [http://www.bbc.co.uk/news/science-environment-22253746]. Accessed: 2013-05-03.

Morton, Emma. 2011. 'Frankenstein' doc creates life. *The Sun*. 2011-01-12. [http://www.thesun.co.uk/sol/homepage/news/2981356/Frankenstein-doc-creates-life.html]. Accessed: 2013-04-02.

Morton, Timothy. 2013. Same As It Ever Was. *Volume*. 35:20-22.

Newman, Stuart A. 2009. Renatured Biology: Getting Past Postmodernism in the Life Sciences. In: *Without Nature: A New Condition for Theology*. David Albertson and Cabell King (eds.). New York: Fordham University Press. 101-135.

Newman, Stuart A. 2012. Synthetic Biology: Life as App Store. *Capitalism Nature Socialism*. 23(1):6-18.

PATH. n.d. *From ancient China to a modern lab*. [http://www.path.org/projects/artemisinin.php]. Accessed: 2013-04-26.

Patton, Michael Quinn. 1978. *Utilization-focused evaluation*. Beverly Hills, California: Sage Publications, Inc.

Paulson, Tom. 2013. PATH & Sanofi start major production of synthetic anti-malaria drug. *Humanosphere*. 2013-04-10. [http://www.humanosphere.org/2013/04/path-and-sanofi-to-start-major-production-of-semi-synthetic-anti-malaria-drug/]. Accessed: 2013-04-26.

Peplow, Mark. 2013. Malaria drug made in yeast causes market ferment. *Nature*. 494(7436):160-161.

Piña-Aguilar, Raul E., Janet Lopez-Saucedo, Richard Sheffield, Lilia I. Ruiz-Galaz, Jose de J. Barroso-Padilla, Antonio Gutiérrez-Gutiérrez. 2009. Revival of Extinct Species Using Nuclear Transfer: Hope for the Mammoth, True for the Pyrenean Ibex, But Is It Time for "Conservation Cloning"?. *Cloning and Stem Cells*. 11(3):341-346.

Rabinow, Paul. 2008. *Marking Time: On the Anthropology of the Contemporary*. Princeton: Princeton University Press.

Reed, Alexander. 2009. Designing Life: A look at synthetic biology. *Science in Society*. 2009-01-21. [http://scienceinsociety.northwestern.edu/content/articles/2008/medill-reports/jan/endy/designing-life-a-look-at-synthetic-biology]. Accessed: 2013-04-03.

Regalado, Antonio. 2013a. A Stealthy De-Extinction Startup. *MIT Technology Review*. 2013-03-19. [http://www.technologyreview.com/view/512671/a-stealthy-de-extinction-startup/]. Accessed: 2013-04-25.

Regalado, Antonio. 2013b. An Unlikely Plan to Revive the Passenger Pigeon. *MIT Technology Review*. 2013-03-19. [http://www.technologyreview.com/news/512416/an-unlikely-plan-to-revive-the-passenger-pigeon/]. Accessed: 2013-04-25.

Registry of Standard Biological Parts, n.d. *Main Page*. [http://partsregistry.org/Main_Page]. Accessed: 2013-04-05.

Ropeik, David. 2010. Synthetic life: Perhaps all we have to fear is fear itself?. *The Guardian*. 2010-05-26. [http://www.guardian.co.uk/science/blog/2010/may/26/synthetic-life-fear?INTCMP=SRCH]. Accessed: 2013-04-02.

Rose, Alex. 2013. De-extinction: Should we play God? Sounds like fun to me. (Column). *Denverpost*. 2013-04-02. [http://www.denverpost.com/technology/ci_22925839/google-invents-spam-filter-block-robocalls-from-phones]. Accessed: 2013-05-18.

Rose, Nikolas. 2013. The Human Sciences in a Biological Age. *Theory Culture Society*. 30(1):3-34.

Rutherford, Adam. 2012. Synthetic biology: ‘playing God’ is vital if we are to create a better future for all. *The Guardian*. 2012-07-27. [http://www.guardian.co.uk/commentisfree/2012/jul/27/synthetic-biology-playing-god-vital-future]. Accessed: 2013-04-02.

Sample, Ian. 2010a. Craig Venter creates synthetic life form. *The Guardian*. 2010-05-20. [http://www.guardian.co.uk/science/2010/may/20/craig-venter-synthetic-life-form?INTCMP=SRCH]. Accessed: 2013-04-02.

Sample, Ian. 2010b. Synthetic life breakthrough could be worth over a trillion dollars. *The Guardian*. 2010-05-20. [http://www.guardian.co.uk/science/2010/may/20/craig-venter-synthetic-life-genome?INTCMP=SRCH]. Accessed: 2013-04-02.

Samson, Pete. 2011. I'm not God, says life-in-a-lab doc. *The Sun*. 2011-01-12. [http://www.thesun.co.uk/sol/homepage/news/2983242/Im-not-God-says-synthetic-life-doctor.html]. Accessed: 2013-04-02.

Sanofi. 2013. *Sanofi and PATH announce the Launch of Large-scale Production of Semisynthetic Artemisinin against Malaria*. Press Release 2013-04-11. [http://en.sanofi.com/Images/32474_20130411_ARTEMISININE_en.pdf]. Accessed: 2013-04-26.

Schmidt, Charles W. 2010. Synthetic Biology – Environmental Health Implications of a New Field. *Environmental Health Perspectives*. 118(3):118-123. [http://www.bu.edu/abl/files/ehp.pdf]

ScienceDaily. n.d. *Somatic Cell.* [http://www.sciencedaily.com/articles/s/somatic_cell.htm]. Accessed: 2013-05-14.

Sethi, Nitin. 2012. Synthetic biology raises playing God fears. *The Times of India*. 2012-10-18. [http://articles.timesofindia.indiatimes.com/2012-10-18/science/34554374_1_synthetic-biology-new-genetic-code-scientists]. Accessed: 2013-04-02.

Shanks, Pete. 2013. Should We Be Trying to Bring Extinct Species Back to Life?. *Alternet*. 2013-04-08. [http://www.alternet.org/environment/should-we-be-trying-bring-extinct-species-back-life?paging=off]. Accessed: 2013-04-25.

Sherkow, Jacob S. and Henry T. Greely. 2013. Genomics – What If Extinction Is Not Forever?. *Science*. 340(6128):32-33.

Shretta, Rima and Prashant Yadav. 2012. Stabilizing supply of artemisinin and artemisinin-based combination therapy in an era of wide-spread scale-up. *Malaria Journal*. 11(399):1-10.

Simonite, Tom. 2005. Bacterial films turn to photography. *Nature*. 2005-11-23. [http://www.nature.com/news/2005/051121/full/news051121-8.html]. Accessed: 2013-04-05.

Singer, Peter. 2010. Scientists playing God will save lives. *The Guardian*. 2010-07-13. [http://www.guardian.co.uk/commentisfree/2010/jun/13/science-playing-god-climate-change?INTCMP=SRCH]. Accessed: 2013-04-02.

Solazyme. 2012. *Solazyme and Bunge Enter Into Joint Venture Expansion Framework Agreement for Solazyme Bunge Renewable Oils*. 2012-11-14. [http://solazyme.com/media/2012-11-14-0]. Accessed: 2013-05-03.

Solazyme. n.d. *Technology*. [http://solazyme.com/technology]. Accessed: 2013-05-03.

Sumner, Thomas and Bjorn Carey. 2013. Stanford's Hank Greely presents the ethics of resurrecting extinct species. *Stanford News*. 2013-04-05. [http://news.stanford.edu/news/2013/april/greely-species-deextinction-040413.html]. Accessed: 2013-05-18.

Synthetic Biology Project. 2012. *Inventory of Synthetic Biology Products – Existing and Possible*. 2012-07-27. [http://www.synbioproject.org/process/assets/files/6631/_draft/synbio_applications_wwics.pdf]. Accessed: 2013-05-14.

Synthetic Genomics. n.d. *Synthetic Genomics Home*. [http://www.syntheticgenomics.com/]. Accessed: 2013-05-03.

Syntheticbiology.org. n.d. *Synthetic biology*. [http://syntheticbiology.org/]. Accessed: 2013-04-03.

The Guardian. 2010. Synthetic cells: It's life, but not as we know it. *The Guardian*. 2010-05-22. [http://www.guardian.co.uk/commentisfree/2010/may/22/craig-venter-synthetic-life-editorial]. Accessed: 2013-05-14.

The International Civil Society Working Group on Synthetic Biology. 2011. *A Submission to the Convention on Biological Diversity's Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) on the Potential Impacts of Synthetic Biology on the*

Conservation and Sustainable Use of Biodiversity. [http://www.cbd.int/doc/emerging-issues/Int-Civil-Soc-WG-Synthetic-Biology-2011-013-en.pdf]. Accessed: 2013-05-14.

The Sun. 2011. Scientist 'creates first man-made cell'. *The Sun*. 2011-01-12. [http://www.thesun.co.uk/sol/homepage/news/2981138/Scientist-creates-first-man-made-cell.html#]. Accessed: 2013-04-02.

The Telegraph. 2010. American scientist who created artificial life denies 'playing God'. *The Telegraph*. 2010-05-21. [http://www.telegraph.co.uk/science/science-news/7747779/American-scientist-who-created-artificial-life-denies-playing-God.html]. Accessed: 2013-04-02.

Thoden van Velzen, Bonno. 1990. Social Fetishism among the Surinamese Maroons. *Etnofoor*. 3(1):77-95.

Thomas, Jim. 2013. Synthetic anti-malarial compound is bad news for Artemisia farmers. *The Guardian*. 2013-04-12. [http://www.guardian.co.uk/global-development/poverty-matters/2013/apr/12/synthetic-malaria-compound-artemisia-farmers?CMP=twt_gu]. Accessed: 2013-04-26.

Thompson, Paul B. 2012. Synthetic Biology Needs A Synthetic Bioethics. *Ethics, Policy & Environment*. 15(1):1-20.

Van den Belt, Henk. 2009. Playing God in Frankenstein's Footsteps: Synthetic Biology and the Meaning of Life. *Nanoethics*. 3(3):257-268.

Venter, Craig and Daniel Cohen. 2004. The Century of Biology. *New Perspectives Quarterly*. 21(4):73-77.

Venter, Craig. 2010. Craig Venter: How to make a new life form. 2010-05-20. [http://www.guardian.co.uk/science/video/2010/may/20/craig-venter-new-life-form]. Accessed: 2013-03-28.

Voosen, Paul. 2013. Synthetic Biology Comes Down to Earth. *The Chronicle of Higher Education*. 2013-03-04. [http://chronicle.com/article/Synthetic-Biology-Comes-Down/137587/]. Accessed: 2013-03-28.

Wade, Nickolas. 2010. Researchers Say They Created a ‘Synthetic Cell’. *The New York Times*. 2010-05-20. [http://www.nytimes.com/2010/05/21/science/21cell.html?_r=0]. Accessed: 2013-04-27.

Wildlife Conservation Society. 2013. How will synthetic biology and conservation shape the future of nature?. [http://e.wcs.org/site/PageNavigator/Cambridge.html]. Accessed: 2013-04-25.

Winston, Lord Robert. 2010. Are Scientists Playing God?. *The Sun*. 2010-05-22. [http://www.thesun.co.uk/sol/homepage/features/2983098/Are-scientists-playing-God.html]. Accessed: 2013-04-02.

Wohlsen, Marcus. 2011. *Biopunk: DIY Scientists Hack the Software of Life*. New York: Current, Penguin Group (U.S.) Inc.

Wolf, Eric R. 2010 [1982]. *Europe and the People without History*, Berkeley: University of California Press.

Zimmer, Carl. 2013. Bringing them back to life. *National Geographic*. 2013-04. [http://ngm.nationalgeographic.com/2013/04/species-revival/zimmer-text]. Accessed: 2013-04-25.