Design as the Machines Come to Life

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Synthetic biology's champions describe a technology that will not only change the way we live and the world around us, but one that might even "save humanity," a "green" weapon against looming threats of energy shortage, disease, hungry populations and climate change. Theirs is a dream of a sustainable future, powered by a human-designed biology, controlled by the logic of engineering. While this promised technology may still be a science, its enthusiasts hope that it could help repair our troubled industrialized landscape: Humanity's needs and consumer desires could be neatly balanced with our planet's limited resources, as our machines come to life.

Frontispiece
***Natural and Artificial Products Overlap*. Photograph by Theo Cook. Art direction by Kellenberger–White, 2012.**

The big promises attached to new technologies often fail to materialize in quite the way we imagine, but they can still affect how we see the future. This envisaged easy-to-engineer biotechnology is no different. Synthetic biology is attracting not only scientists, engineers, governments, social scientists, and investors, but also a growing influx of artists and designers, keen to understand better synthetic biology's potential implications for the world we live in. While it may not change the world, synthetic biology could give us ways to change the way we think about it.

Experiments, Artifacts, and the Design Perspective

As one of these artists and designers working with synthetic biologists, I have learned that the same words can convey very different, even opposite meanings. In art and design, I use the "experiment" as an open-ended process to open up and reveal potential ideas; in science, the "experiment" is a tool to generate data to test a hypothesis. Repeating an experiment and achieving the same results is key to the scientific method, whereas the experimental process in art often seeks out the exceptional or unique. Artifacts may emerge from experiments. In science, the "artifact" is an outlying bit of data—an erroneous, often human-induced thing that can be ignored, like the distortion caused by the curvature of a lens. Conversely, for the artist or designer, the artifact is the focus of our attention: We are actively *making things*.

But it is another shared word that has made synthetic biology so intriguing to me: "design." In synthetic biology, civil and mechanical engineers, biologists, computer scientists, chemists, and mathematicians all talk about "design." Some even describe themselves as designers. Their molecular blueprints may be executed at the genetic scale, constructed by invisible living machines, but just as biology is bigger than the sum of its parts, so too is their vision.

This seems to be the true novelty of synthetic biology: a field of technoscience proposing, as design does, to make things, rather than focus on understanding existing ones. The engineering ideals of standardization, abstraction, and decoupling are intended to make it easier, quicker, and cheaper to manipulate biology, with less scientific knowledge. If achievable, the dream of deskilled biological design hints at shifting boundaries to come, as the design of applications, rather than DNA, becomes the bioengineer's focus. With designed organisms that will supposedly target cancers, produce novel foods, act as data storage devices, self-repair buildings, or even detoxify the ground beneath us, I see synthetic biology being presented as a design discipline of the future, modeled on—and validated by—design, the existing business of producing stuff.

As I became entangled in synthetic biology, I had to learn as I went along. Even if the medium was exotically biological, there seemed to be affinity in "design"; this word that I assumed had common meaning. But like "experiment" or "artifact," "design" takes on different meaning in synthetic biology than the design I know. We each use the term to meet our discipline's very different ends. Although synthetic biology is described as an engineering discipline, it includes scientists, so language and attitudes to design vary even within the field. Engineering is focused on necessity: solving a defined problem, like designing the structure of a bridge. Science, in contrast, studies life—or the world we live in—as it is, from complex proteins interacting to the forces causing those interactions. But design, as I know it, is different. Design, whether of a building or a chair, is about possibility, experimenting with life as it could be.[1] Architects design buildings that will frame life that has not yet happened. Design projects into our future, creating new possibilities out of existing matter.

Working at the blurred edge of design and art, I investigate what design is and does, curious as to what it can do beyond just translate technologies into things for us to consume. When I first encountered synthetic biology, the language emphasized simplicity: Lego-like BioBricks, aspirations of standardized plug-and-play systems and drag-and-drop design interfaces, all accessible to the non-biologist. Researching the role of design in a biotechnology revolution, I was speculating on what designers might be doing in this century, who they would be, and how they might be trained. With a "Registry of Standard Biological Parts" already cataloged in a freezer humming away at MIT, supplying thousands of undergraduates apparently churning out new parts and applications for the International Genetically Engineered Machine (iGEM) competition, this novel biotechnology sounded tantalizingly close to fruition. I was curious from a design perspective: If biology could indeed be transformed into both machine and material, what were the disruptive possibilities that could affect everything from materials to manufacturing systems to aesthetics? What were the unknowable implications of an unstable—and hence possibly destabilizing—technology on our lives?

Digging deeper, it seems that synthetic biology's headline rhetoric addresses "humanity's needs", rather than our needs as individual, diverse and complex humans, within a diverse and complex ecosystem. Synthetic biology is projected as disruptive technology that also promises to disrupt nothing (figure 3.1). Pumping out limitless "green" jet fuel to feed planes or designing bacteria that secrete the same non-biodegradable plastics that already trouble us addresses neither the failures of our existing infrastructure nor entrenched attitudes to the ecosystem and our place in it. This simply substitutes existing mechanical machinery with biotechnological processes: manufacturing the same liquid fuel in vats, rather than extracting it from the earth. Such heady pursuit under way discourages reflection and cultural analysis of the unique issues and novel design opportunities a living technology presents.

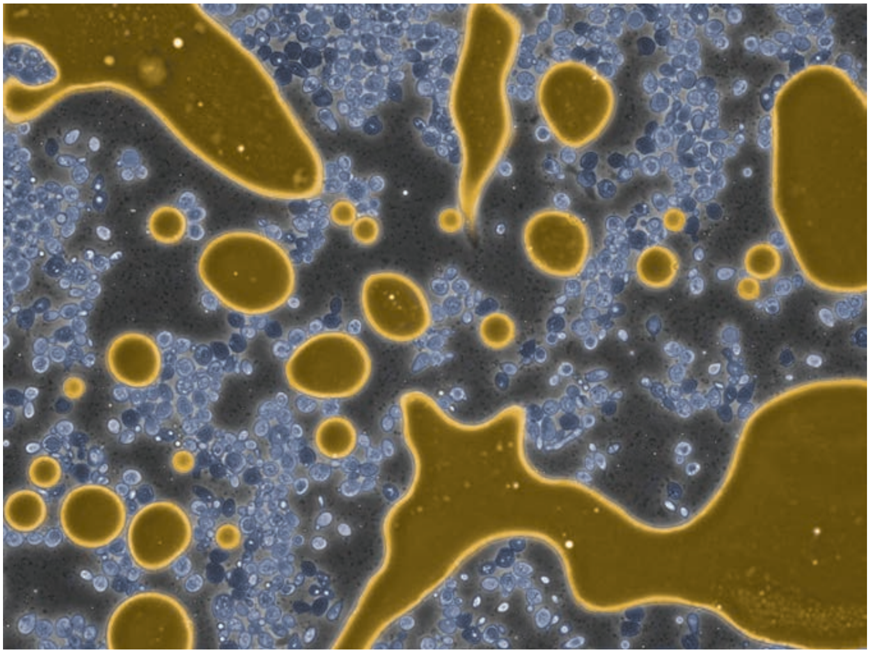


Figure 3.1
Is synthetic biology a disruptive technology that also promises to disrupt nothing? Bacteria are being engineered to secrete existing liquid fuels to power existing engines, emitting the same kinds of pollution that we know to be problematic. Courtesy of Amyris, Inc.

This chapter uses design as a critical lens to understand these aspects of synthetic biology better. To engage this design perspective, I first investigate how design got to where it is and what it means in its more "traditional" practice ("From Nature to Design"). Then in the section "The Redesign of Life," I consider how nature—and especially biology—is already more entangled within the designed products of culture than we tend to think. We then can examine how synthetic biology approaches the question of design, straddling the divide between nature and culture as it shapes biology ("New Designs on Biology"). The simplifications of the Lego analogy break down amid the complexity of cellular networks. If synthetic biology is truly a disruptive technology, then clinging to existing analogies of mechanical and electronic technology may hinder sustainable, ethical, and imaginative design, if that is what we seek.

Although an outsider to science and engineering, I wonder if biology can keep up with the dreams of synthetic biology. My initial reactions to the technology have endured. The seductive appeal of clever science is contrasted with an irrational unease that this technology somehow interferes with the "natural" order of things, amid concern over the potential long-lasting social, political, and physical effects of designing objects, systems, and machines with the very same stuff that we are made of. These issues are raised in the penultimate section "Machines for Living and Living Machines." How do we begin to unpack the social, political, scientific, and cultural complexity of this design vision? It is these areas of uncertainty that make synthetic biology's implications more interesting to explore than the much-peddled narratives of world salvation or biological apocalypse and, as discussed in the previous chapter, make it an interesting partner to art, with its ability to reveal and revel in the flawed.

Synthetic biology may aim to design, but as we will see, it draws on engineering design, the realm of problem solving, not the design practiced in disciplines as diverse as fashion, architecture, or communication. Oron Catts and Ionat Zurr critiqued the engineering mindset in Chapter 2, but the contemporary design mindset needs scrutiny as well. The system of industrialized production that incorporates contemporary design means that many designers also find themselves engaged in problem solving, perpetuating unsustainable processes without really being able to address them. Emerging and unorthodox design attitudes, such as "problem finding" and "problem making," which uncouple design from commercial production, are challenging this position, with potential to offer paradigm shifts in the way that we design and engineer things. These may provide the revolutionary moments we seek. Their possible relevance for synthetic biologists' design ambitions will be explored in the final section of this chapter, "New Models for Biological Design."

Synthetic biology does not just present ethical problems to be resolved or technical solutions to existing problems, but fundamental dilemmas with no one answer. Synthetic biologists—and designers—need to design differently to seek a common good, one that does not imply saving a broad-brushed "humanity." Investigating the roles that design could play within synthetic biology, in the process can we also challenge attitudes to how and what we design? Tackling synthetic biology from a design perspective, perhaps we can do what design as a discipline does best: establish possibilities and, through artifacts, experiment with "life as it could be."

From Nature to Design

The verb "to design" has come to define, in some ways, what it is to be human. Language helps us to communicate ideas through words; design translates ideas into things. Design in its most basic sense helps separate what we make from what already exists: natural menaces, living and nonliving, from which we must protect ourselves to survive. But how do we understand design today, beyond a process of translation between concepts and technologies into tangible things or experiences?

Simply defined, design is the act of planning and then making something. This creative process encompasses the way that things or ideas are conceived, the way they are made, the way they look, and the way they function. Originating in the Latin word *designare*, "to designate," design implies a collaborative, hierarchical, or linear process of production.[2] Designing is not the same as creating; things are not made from scratch.[3] Designed things are a synthesis of ideas and values.

In the past two centuries, the engineering vision of the Industrial and Information Revolutions has transformed the world we live in. Crucial to that process has been design, as it matured into a collection of distinct disciplines that today shapes much of our experience of the world. It was from the grime and smoke of the nineteenth century British Industrial Revolution that designers first emerged, separating their role from that of the stonemasons building or craftsmen weaving. The wholesale change in our lives and environment as Western cities grew, dominating tracts of wild landscape, was synonymous with the emergence of mass consumption. Suddenly, industry's great machines and its workers churned out more stuff for us to consume than our forebears could ever have imagined. Designers helped differentiate this stuff from that produced by competitors, while assembly lines and the division of labor kept it uniform. Humans became consumers to give purpose to the machines' function, and the mass of stuff marked "progress" in our own lives.

Design was integral to the transition from living technologies (horses as transport, clothing from plant fibers) to a world of the nonliving, like sports cars and nylon stockings—the products of mass production, of desirable uniformity and uniform desires. Design gives form to the functions dreamt up by scientists and salesmen. Combustion engines fuelled cars; industrial springs inspired new archetypes like the adjustable desk-lamp; transistors powered personal computers. New technologies inspired the design of new products; new products demanded new technologies to enable their design. Design is so integral to the mechanisms of our consumer economy that since the 1920s, strategies of obsolescence—products designed to fail—have only helped to perpetuate our desire to consume more.[4]

Design, once separate from function—the realm of the engineer—was concerned with just the look and form of things. Now design permeates every stage of the process of making things. Design critic Deyan Sudjic describes the "language of design as the genetic code of our society."[5] By this logic, our ability to make plans and put them into action, a process that underpins societies' cultures, economies, religions, fashions, politics, and pretty much all other endeavors, is design. We are all designers now: designing information architectures, cities, communications, shoes, political revolutions, military campaigns, experiments, and even living organisms. Design itself is uncoupling from the physical object as design thinking and design management gain status as new paradigms of business innovation strategy. By these measures, in English at least, we lack the words to describe such a breadth of activity. Design, as philosopher and anthropologist of science Bruno Latour argues, has come to stand in for anything that is "planned, calculated, arrayed, arranged, packed, packaged, defined, projected, tinkered, written down in code, disposed of and so on."[6]

Future designers of functional living machines—plants, animals micro-organisms—will be descendants of plant and animal breeders, genetic engineers, mechanical engineers, and scientists, but they will also claim heritage from design. Making biology easier to engineer is a driving aim of synthetic biology. To meet this goal of deskilling the biological design process, synthetic biologists already liberally borrow from design. In architecture, design, and engineering, computer-aided design (CAD) software has become ubiquitous; "bio CAD" is now an emerging software market, intended to facilitate drag-and-drop design of DNA. If this is achievable—which is much debated—how much would a biological designer need to know about biology to design it well? Even if biological expertise remains essential, will future biological designers have more in common with today's designers, scientists, or engineers? This depends in part on what synthetic biologists understand by design itself.

Synthetic biology and design today may both be concerned with function, but while synthetic biologists design, they are not "designers" in the same sense. Designers are focused on our interactions with objects and their function, generally operating at a bigger, user-centric scale. The designer is better equipped as a generalist, in contrast to the scientist (and in synthetic biology, the engineer, too), who is a specialist, an expert in the detail of how things work, not whom they work for. The designer's elasticity enables translation across scales and industries to get stuff made. A fashion designer needs to understand cloth, pattern cutting, supply chains, manufacturing, marketing, and have the cultural knowledge that informs the creative design process. Architects learn history, but they also learn basic structural engineering to enable them to collaborate effectively with structural engineers: This is a form of "deskilling", enabling adaptability.

Just as design no longer has a single meaning, there is no universal design process. For bioengineers, design is the means toward a practical solution. It is problem solving defined by efficiency and necessity, a balance between parameters such as cost and function, and interpreted through design pipelines, cycles, and endpoints. Design works differently. It may sometimes be communicated as a distilled, linear path, like "Discover, Define, Develop, and Deliver," but the reality is messier.[7] Designers respond to a brief through research and also think through making: sketching and prototyping, producing unexpected ideas along the way. Live review, integral to architecture education and other design disciplines, comes in the form of critique (the "crit" or "charrette") where work in progress is debated with a panel of critics. While a final design may appear polished, good design itself remains an open-ended process; the unexpected is encouraged. For the engineer or scientist, design's lack of verifiable solutions and its enthusiasm for subjective value judgments, compared to the objectivity projected by the scientific method, may even be alarming. This is not to suggest that science and engineering are not inherently creative processes. As part III of this book will show, the Synthetic Aesthetics residents recognized in each other's work the uncertain, winding processes of discovery. Rather, will future synthetic biologists need to be versed in both bioengineering and also human-scale design? Architects may once have designed the structure of their designs but now collaborate with engineers; perhaps product designers will work with synthetic biologists to help design the function of biotech products or even organisms themselves, like the IDEO "living" packaging suggested in chapter 9.

As we seek the limits of what we should design using synthetic biology, what we design is as important as how it is designed. Design innovator John Thackara notes, "We tend to think of products as lumps of dead matter: inert, passive, dumb. But products are becoming lively, active, and intelligent. Objects that are sensitive to their environment, act with some intelligence, and talk to each other are changing the basic phenomenology of products—the way they exist in the world."[8] Thackara is referring to electronic products, but enabled by synthetic biology, lively products may become living ones. This may mark the paradigm shift between synthetic biology's designs and what has come before. As we redefine our interactions with living things, we will need to develop a design discourse around the cultural function and the design itself of biological products.

Such appraisal is almost absent in mainstream design today. Design ethics and criticism are underdeveloped, despite the saturation of design in our everyday lives. Design operates in a complex tangle of other industries and expertise, part of a wider cultural system of divided production that we have come to accept as the norm. As professionals, designers are generally not the owners of the ideas they generate, nor accountable for the functions to which they give form.[9] They work to a brief given by the client, whether a dress, museum, or banking system. The designer delivers the best design within the constraints, loyal to the brief. As a service, the work is less about the designer's personal values, but rather about identifying with the values imbued in the project. Critique of the logic of the system at large is in normal circumstances beyond their remit, for designers as well as scientists and engineers.

Nevertheless, common to many designers, scientists, and engineers is a motivating optimism, a belief that their work in its small way can contribute to making the world a better place. It need not be a cure for cancer; a well-designed milk carton can be life improving, too. With its instinctive ethical imperative to "do good," how has design been subdued into a service industry sometimes detached from its more humane ideals?

One reason may be because as designers, manufacturers, governments, and consumers, we view the products of culture as somehow independent from the natural world. We see the human touch as transformational, describing the things we craft from nature's materials library as "man-made," "artificial" or "synthetic," that is, synthesized from different things, but even this perceived separation of ourselves from nature is itself a cultural construct. The ecological crisis of climate change shows that human activity and design are never independent from nature.

Today's products before and beyond their functional lives—from the chemistry of their component materials to their life beyond disposal—are not considered the consumer's, nor the designer's, responsibility. In faraway places, others dig holes to extract raw materials, which somewhere else are irretrievably converted into consumables. Once a product's useful life is over, we relinquish it, its toxic components sent back to the ecosystem out of sight, incinerated, buried, or prolonged through recycling. Products are still conceived of in terms of life spans, not life cycles, disregarding knowledge of limited resources.[10]

Perpetuating this mindset that begins at purchase and ends with disposal, consumers are increasingly enticed to enjoy disposable pleasures. For example, the textile industry is one of the most polluting on Earth; it spews out more and more on-trend clothing intended to last a season, while these fashion seasons themselves are ever shortening. Objects are becoming more difficult to deconstruct and repair, or just uneconomical to do so, reinforcing a replacement culture. Amazingly, our definition of good design still includes all these characteristics; parameters of aesthetics, cost, profit, utility, and desire dominate. In the future, good design may mean taking into account long-term thinking, rather than pursuing short-term need and problem solving. Synthetic biology appears to be fitting into the existing systems of design, but we could challenge this. The question whether the ethical burden of the designed object lies with the consumer, designer, manufacturer, or shareholder remains as neglected yet relevant for design as it will be for synthetic biology and the design of living machines.

The relegation of responsibility over what we make is perhaps a curious remnant of attitudes contemporary with the beginnings of consumer society in the late seventeenth century, even before industrialization. Then, blank patches on the world map still indicated territory rich for seemingly limitless exploration and exploitation. With centuries of change behind us, our planet now extensively cataloged, we stubbornly cling to antiquated visions of plenty and a renewable world rich with infinite resources. The birth of modern science, and with it the concept of "progress" that is imbued in modernity, has only helped to enforce a cultural emancipation from nature, placing technology in opposition to the creations to the natural world. Our current ecological situation may well be symptomatic of this phenomenon.[11] Change must come from all parts of the system to be effective, not just from design or technology.

The Redesign of Life

Addressing this perceived need for novel approaches, synthetic biologists are promising a century defined by an engineered biology with the transformational potential of the Industrial and Information Revolutions. Biology—and life with it—will be remastered for the design and construction of useful things. As "design" has come to describe most human activities, synthetic biologists have easily adopted it. But something as significant as designing life should not merge unquestioned into design's sprawl. Synthetic biology will shrink the gap between what we make and what we are, merging our neat categories of nature and artifice.

Instrumentalizing life in itself is not new territory. We may perceive nature and culture as separate entities, but natural and artificial materials have long intertwined in designed objects in a far more complicated narrative. We already design with nature, and specifically biology, in many ways. Before we consider synthetic biology's design ambitions for biological things, we should consider the ways in which things are already made from biology.

Harvested plants and slaughtered animals are manufactured into designed objects. Natural cellulose fibers provide our material staples, from cotton and flax for clothing, to wood for construction and paper. Some natural, biodegradable materials are now luxuries compared to their synthetic stand-ins: from furs and leathers like cowhide to stingray shagreen—graspable even when slippery with sweat on the hilt of a sword—to rubber and cork from trees, protein fibers secreted by silkworms, cashmere wool from goats, horse hair, and bone (figure 3.2). All these biological materials supplement a nonliving "natural" palette including stone and clay, and all are shaped by the artificial: technologies from spinning, tanning, firing, to bleaching pervade what we describe as "natural" materials.

In 1856, as mass-produced steel rolled out of the steel mills, 18-year-old William Henry Perkin was working away at his lab bench, tasked with synthesizing the antimalarial chemical quinine. Instead, he accidentally invented the first synthetic dye, mauveine. This was the beginning of the era of synthetic chemistry and with it the arrival of a new library of materials for modern society. Such milestones are not only driven by need or accident, but also by desires. In the 1930s, the holy grail of synthetic textiles—artificial silk—was finally obtained, prompted by drivers of political necessity and the fashion for silk stockings (among other silk products). Importation of Japanese silk was causing diplomatic headaches with the outbreak of World War II; DuPont's Nylon was at last the solution to the problem of unpatriotic hosiery. Nylon joined many other

Figure 3.2
Transformed into shagreen wallets and tabletops, it can be strange to discover that luxury leather goods are cut from the skin of a ray fish. Courtesy of Iowa State University Library.

synthetic products, mostly petroleum-based polymers poured from test tubes that were seen as bettering nature. By the 1950s, synthetic chemistry came to define progress as glossy plastics and space-age living, enhancing our cultural appreciation of mass-produced uniformity. But the oil fueling these laboratory alternatives to natural materials is itself "natural," made of dead organisms accumulated over millions of years. Similarly, chemical components of many of the drugs we use were found by "bio prospectors," plant hunters seeking out natural compounds in the wild. These molecules are then copied chemically. Despite the revolutionary impact of synthetic chemistry and its crude oil alchemy, biology remains the source for our materials library.

If the separation between artificial materials and their natural counterparts is complicated, so too is the opaque use of biological materials within "artificial" products. To investigate this, designer Christien Meindertsma tracked all the products made from one carcass, Pig 05049, an animal dismembered and converted into a wealth of materials from pork chops and bacon to ammunition, train brakes, automobile paint, soap, heart valves, bone china, cigarettes and hair conditioner, thereby revealing how little so many of us know about the living origins of the things we consume every day.[12]

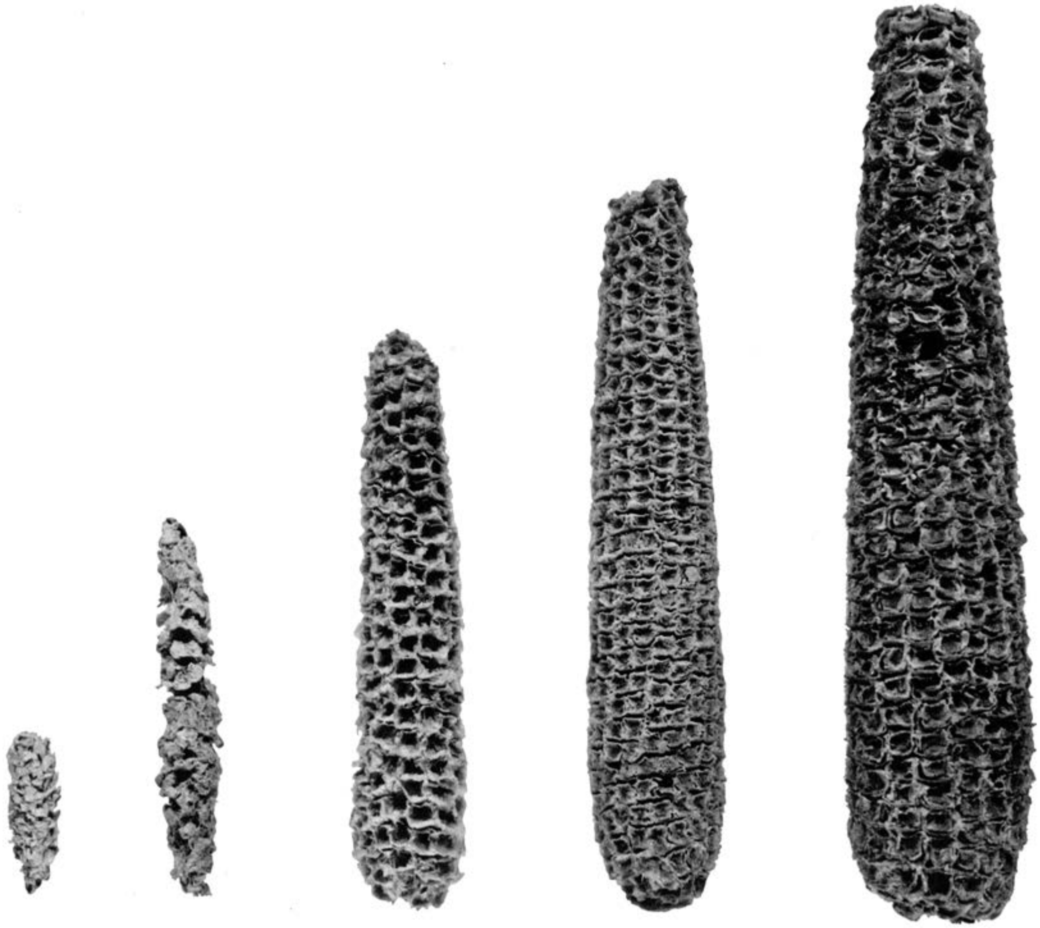


Figure 3.3
Prehistoric (from left) and contemporary maize cultivars reveal the human design influence of thousands of years of farming. Courtesy of Robert S. Peabody Museum of Archaeology, Phillips Academy, Andover, Massachusetts.

When it comes to food, it seems easier to differentiate between processed and natural. Scanning the aisles in the supermarket, the red and juicy tomatoes and the crunchy, sunshine-yellow corn embody nature, plucked from sunny vines or the rolling cornfields printed on the tins. Chewing away, most consumers are unaware that these plants are objects of design, unless they carry a label alerting them to genetic modification (GM), mandatory in the European Union since 1997.[13] Tampering with this classification between natural and "synthetic" food causes anxiety. For some, such an intervention violates the integrity of a "virgin" nature that must be preserved intact. Genetically modified organisms threaten to jump the divide between what should and shouldn't be altered by humans (this of course is not the sole objection to GM).

But even non-GM corn and tomatoes are designed. Humans have been cultivating and domesticating living species for at least 10,000 years for economic as well as aesthetic reasons, whether for pleasure, culture, or intoxication.[14] There are 50,000 known species of edible plants on Earth, but 75% of the world's food intake comes from just 12 plant species and five animal

Figure 3.4
PostNatural Organisms of the Month, from the Center for PostNatural History, an artistic research project that investigates the relationship between culture, nature, and biotechnology and documents biological specimens that have been subject to human design.

species. And of these, just three—maize, wheat, and rice—provide more than half the world's calories from plants. According to the United Nations Food and Agriculture Organization, 75% of crop genetic diversity has been lost worldwide since the beginning of the twentieth century, as agriculture has become increasingly industrialized. Farmers have abandoned local variants for "genetically uniform, high-yielding varieties."[15] A contemporary corn cultivar compared to its prehistoric ancestors reveals this massive redesign in just its size, shown in figure 3.3.

Nutrition, utility, and flavor are altered too as we design with artificial selection, optimizing living things to meet our intentions and desires. Turning cabbages into broccolis and cauliflowers, and cows into high-yielding dairies, horticulturists and breeders have over millennia rendered plants and animals into functional design objects. These organisms, and their modern GM descendants, are the objects that artist Richard Pell collects in his Center for PostNatural History.[16] He argues that natural history museums collect the products of evolution, but human-designed species—from lab strains of *Escherichia coli* to modified goats—should be documented and preserved, too (figure 3.4).

Our nature is almost always unnatural: gardens, wheat fields, and pastures of grazing cows are human-manufactured constructions built from living parts; even wildernesses are state-managed parks. Clinging onto an idea of nature as separate from human activity is a futile and even damaging pursuit when it comes to thinking about what we design and its place in the world. "Nature" is just another human construct, intensified by design.

New Designs on Biology

We may have long designed *with* biology, but synthetic biology is proposing the design *of* biology.[17] This may not be just the iteration of nature: the selective breeding of plants or animals or another manufacturing revolution this time powered by biotechnology. It suggests an fundamental change in the things we consume. Biology becomes more than a material ripe for exploitation; it becomes both software and hardware for manufacturing; a toolbox for a new generation of designers mixing and matching components more akin to computer programs and components. The synthetic chemical age and its lurid plastics may have been an interlude as we return to an era of biological materials. How might synthetic biology's products fit into our classifications of nature and the designed products of culture?

In the 1970s, recombinant DNA—the ability to cut and paste genes from far-flung parts of the living kingdoms—sparked a still-continuing debate: Is this merely an extension of existing biological design or something new? Now, it is claimed that synthetic biology again offers a novel way to fashion biology more successfully into a tool for mass production, differentiated from the bespoke solutions of genetic engineering. Some academic researchers describe synthetic biology as revolutionary, which may help attract funding, whereas those in industry may prefer to call it an evolution, to keep it within existing regulation. I would argue that it is both. Although the technology builds on earlier ones, synthetic biology and its design of new systems and organisms presents novel dilemmas. New kinds of products, from rubber-producing microbes to bacterial computers, are prototypes for a different twenty-first century design, breaking our existing relationships with the things we consume. These designs may be unlike any we have previously known.

Biology is being remodeled into a design discipline in the name of progress, but progress and evolution follow different rules. Progress in technology is forward-looking, toward a future state of perfection. It also has a single, fixed-point perspective: that of the human. We even like to imagine ourselves as products of progress. Consider the linear improvement in the (incorrect) classic trope of human evolution, man striding off the page into the future, away from those hairy apes. Evolution, however, responds to context, not intention. Evolution connects all living things; as much as we impose our design on them, living machines, such as fuel-producing bacteria, are more loyal to evolution than human aspirations.

Nevertheless, technological progress and evolution can align. Darwin noted that "selection by humans should be understood within the context of natural selection."[18] Domesticated dogs bred for diverse human needs are still subject to the rules of natural selection. We humans are similarly co-evolving with our environment and technology and tools as described in chapter 1, further weakening the notion of the nature/culture divide. We may have got up off all fours and walked, but as long as we exist, we continue to evolve, too. As such, any products of synthetic biology will be intimately bound up in our own nature.

Nature is a human construct, and so too is the tree of life, the organizational tool we use to make sense of biology's diversity. The tree itself is always changing; its taxonomies are regularly reorganized and debated according to prevailing scientific understanding. Shifting from Linnaeus' two kingdoms in 1735 to Woese and colleagues' three domains in 1990, some experts even argue that the tree is "dead" and that life in all its varieties is better represented as a fuzzy ball. Certainly, the tree's simplicity masks nature's many complexities: agency, life, death, reproduction, combination, symbiosis, self-assembly, diversity, noise, context, emergent properties, and interaction with other living things. Biology is, ultimately, focused on survival. Such complexities are at odds with engineering ideals of control and simplicity.

As living things become design objects, we will have to consider the strategies design has developed to build its own successful role in consumerism: like function, form, desire, uniformity, obsolescence, and aesthetics. Questions that design has happily ignored become essential to consider, from life spans to a product's relationship with nature itself. Synthetic biologists propose technical design features—watermarks for identification, kill switches for self-destruction, or special guards to prevent horizontal gene transfer—to address the marriage of living things with designed products, examined further in chapter 6. If these new features are successfully integrated into biology, will it differ from the "natural" biology that already exists? Can we perceive living machines as either natural or unnatural, or do they demand a new category?

Synthetic biologists take a variety of approaches to make use of biology's diversity, defining design in different ways as they refactor, mix, digitize, and simplify it. The protocell—a biochemical machine assembled from scratch (the "bottom-up" approach)—is designed, perhaps more clearly than any other synthetic biological organism. But engineered bacteria modified from the "top down" are a more complicated prospect. Designed genetic circuitry is a mix of novel or redesigned DNA originally "copied" and "pasted" from other existing organisms. Once inserted into a naturally occurring biological chassis, the modified bacteria may vary only very slightly in terms of percentage change from wild types, but human design dominates the cell's function from our perspective. Self-assembling and self-reproducing, its progeny may not be crafted by human hands or human machines. But once the cell performs its designed function, the whole is labeled "designed"; a living machine is made. The redesign of the DNA code itself marks another approach. Jason Chin's lab at the University of Cambridge is one of several around the world seeking to invent a novel, parallel biology by developing an alternative code to DNA for biology to "run" on. Proponents of these "orthogonal" systems suggest that they may be easier to subject to human intention and to prevent from interacting undesirably with nature. "Orthogonal" systems may be biological, but they are products of human design.

Are these types of synthetic organisms any different from the life forms they once were or draw on? If they do diverge, where do we classify them within the tree of life? We may have to insert an extra branch into the tree to categorize them: a *Synthetic Kingdom* for designed and modified organisms that don't fit elsewhere (figure 3.5). The *Synthetic Kingdom* is an organizing device that mirrors synthetic biology's ideology, systematizing a new nature fashioned by engineering logic and its rationalization of the complexity of living systems.

When I first designed this extra branch, I saw it conceptually akin to an engineering solution to an engineering problem. It was intended as a tool to spark debate over our understanding of bioengineered organisms. It has proved useful: Scientists often comment to me that it is attached in the wrong place. "It might be better placed coming out of a branch, not at the root," or, "How about it as a separate tree, or a cloud, or as networks of spaghetti," they say. Having such discussions about a fiction is illuminating: To me, it illustrates how inviting a suspension of disbelief helps us to imagine a different world view. That reasoned discussions prompted by a fiction can usefully address an issue is rewarding; the resulting iterations informed by these conversations help to raise new questions (figure 3.6).

Whether the branch should be smaller, differently placed, or more spaghetti-like, the *Synthetic Kingdom* itself has been viewed as veering between the critical and the celebratory. Have I have given synthetic biology a kingdom of its own, effectively validating it and enforcing the separation between nature and culture for future products of synthetic biology? I see it differently: The *Synthetic Kingdom* puts our designs back into the complexity of nature, lessening the distinction between "our things" and "our selves." Acknowledging this connection between nature and what we design may allow us to design "better."

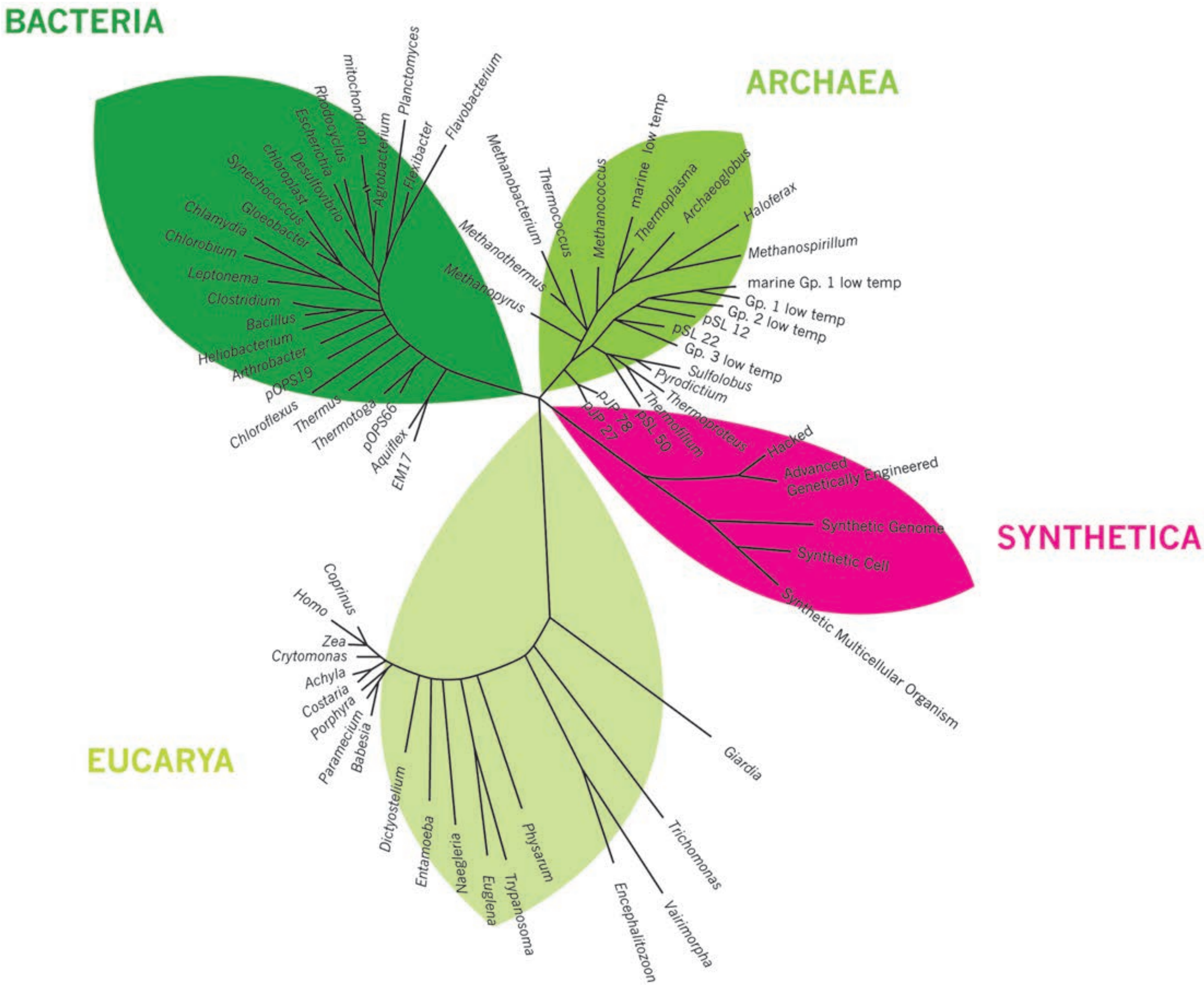
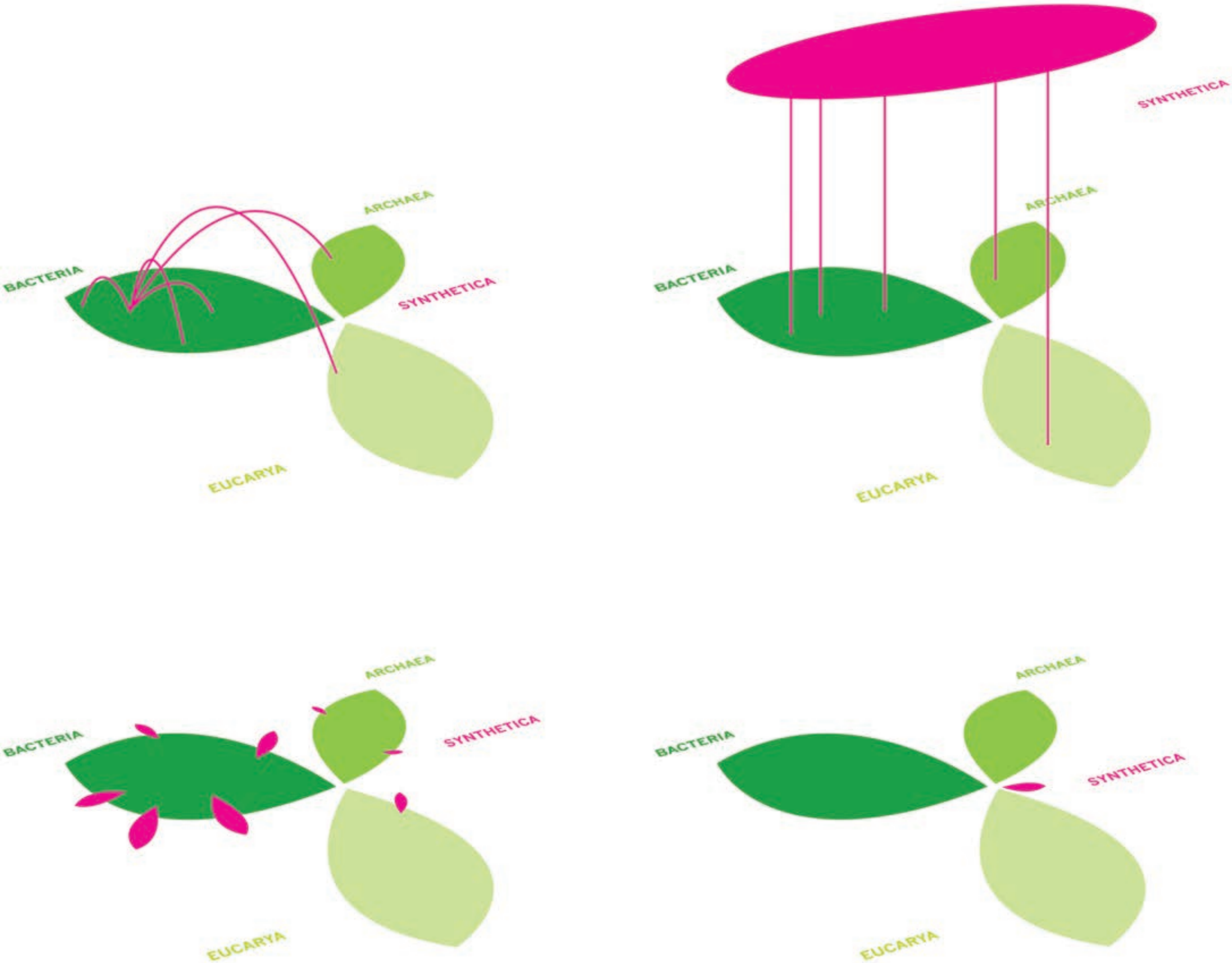


Figure 3.5

The *Synthetic Kingdom*, my proposal for a new branch of the tree of life to accommodate our ì new natureî (2009).



The modernist designers of the twentieth century argued that in terms of beauty, form followed function. For synthetic biology, the matter and meaning of designed things converges.[19] Our greatest challenge may be to acknowledge that the design rules for biology are unlike those for any other material. Human intention may not be enough to overcome evolution. Synthetic biology's designs on nature require us to adapt our understanding of design, the natural world, and life itself. With the prospect of change comes the opportunity to improve our thinking.

Machines for Living and Living Machines

Twentieth-century modernism advocated that the world could be improved through design. Modernist architect Le Corbusier saw the house as a "Machine for Living," a place where human efficiency could be enhanced through technological and functional design of the built environment. For Le Corbusier, humans were standardized parts in a rationalized urban system (figure 3.7). Modernism eschewed diversity, individuality, context, and bottom-up self-organization, prioritizing the architect's top-down control. Later, after these one-size-fits-all solutions were replicated around the world, it became apparent that the glass and concrete monoliths of the International Style did not solve all societies' problems. Cities from Africa to North America are still dealing with these insertions, as approaches to design shifted with the deconstructive backlash of the postmodern era.

Synthetic biology arguably follows these original modernist design cues. The J. Craig Venter Institute's synthetic life form, supposedly the first self-replicating species on Earth whose "parent is a computer," is widely described as a "living machine" (figure 3.8).[20] Corbusier and Venter's works are both objects described in the language of intentional design and control that celebrate the rational engineering paradigm and the merits of top-down design. While synthetic biologists may know less about the inner workings of the biological materials they use than did the engineers of Le Corbusier's concrete machines, both groups conceptualize design as separate from environmental or social context and arguably, the diversity and complexity of reality.

Forty years ago, biologist James F. Danielli, known for his work on synthesizing the first artificial cell from different components of an amoeba, highlighted this issue of a division between a technology and the societal factors surrounding it. Asked by *New Scientist* magazine in 1971 to share his predictions for synthesizing biology, Danielli outlined what was then just an imagined field of synthetic biology. His remarks remain curiously prescient, as does his concern for the ethical and social implications of such work.[21] Ending with a sober reflection, he described the societal burden of scientific progress:

> "But I agree that there are all sorts of borderline regions where things aren't so obvious. The trouble is that although vast sums of money are spent in science and technology in developing the research, only trivial amounts are spent on trying to predict the results of the work on society: as soon as something becomes available it is applied, without any study of what it might do to mankind." He looked wistfully out of his hotel window, the first trace of pessimism revealed. "If only we would spend at least as much money on studying the consequences of new technical discoveries as we spend on making them."[22]

Figure 3.6

New iterations of the *Synthetic Kingdom*, drawn after discussions with experts. From top left: the kingdom as a spaghetti network, and a ì floatingî kingdom. From bottom left: small weeds on the existing branches, and a more ì realistically sizedî kingdom (2010ñ2011).

Figure 3.7

The architect Le Corbusier pointing from on high at a model of his proposal for the ideal city, *La Ville Radieuse*, which was intended to place man in a well-ordered environment (1930). Courtesy of Fondation Le Corbusier and Artistsí Rights Society.

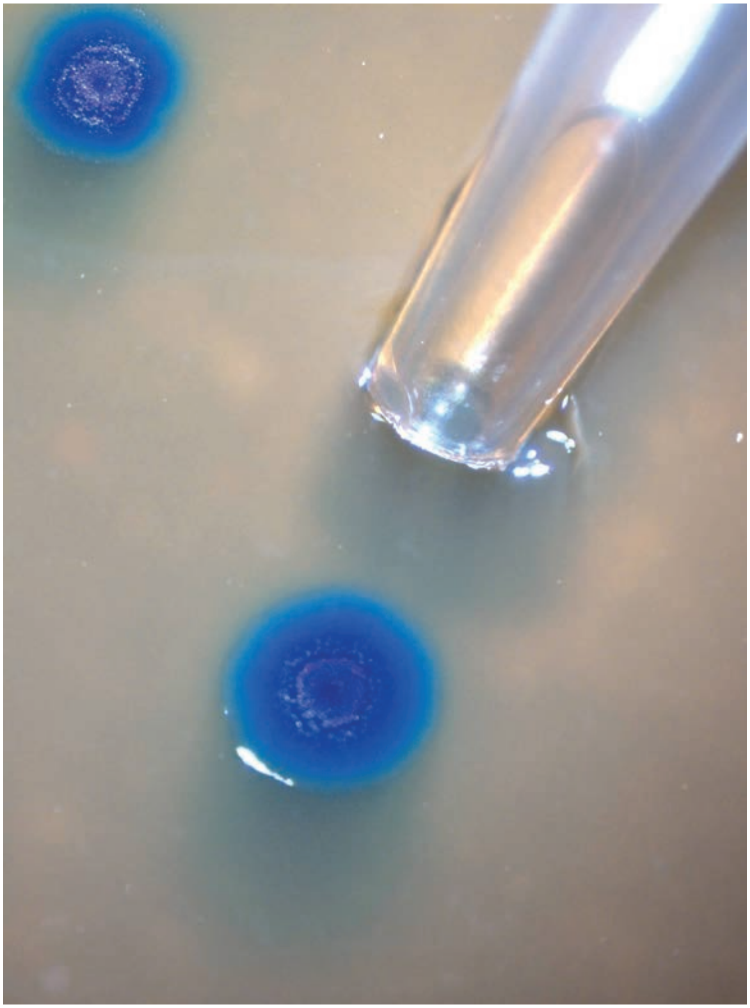


Figure 3.8

Top-down biological design. The J. Craig Venter Instituteís 2010 synthetic *Mycoplasma mycoides*, more commonly known as ìSynthia,î the first self-replicating synthetic bacterial cell, with a pipette tip for scale. Courtesy of J. Craig Venter Institute.

What might be the consequences of technical discoveries that Danielli alludes to? Modernism was seen as the panacea for a rapidly urbanizing world, yet we now know that some of its most lauded theories for improving urban life had quite the opposite effect once built. And while living standards may have improved immeasurably for a proportion of the world's population, industrialization's success has brought with it unintended consequences that we now know have significant impact on the planet and our longer-term prospects. The unexpected outcomes of biotechnology need careful consideration, too. What is at stake, culturally, environmentally, and ethically as the materials of design come to life?

Appropriately, synthetic biology has been flooded with social scientists, bioethicists, and policy and risk experts, examining the potential promise and peril and evaluating whether the field raises novel issues. Investigation tends to focus on the same concerns: bioerror (the "right" technology going wrong, whether through design or user error, or the material deviating from human intention), bioterror (the "wrong" people using the "right" technology), and ownership (the technology lost in intellectual property thickets or monopolized). A fourth, potentially irresolvable category is the moral issue around designing life, or "playing God." In 2010, the U.S. Presidential Commission for the Study of Bioethical Issues deliberated on these issues and announced that effectively synthetic biology is no different in terms of risk and reward compared with previous technologies.[23] Their verdict: we should proceed, with caution. The underlying assumption is that all technology is good and vital for human progress.

Although Danielli's fantasy of a designed biology and the likelihood of a "synthetic future" may have become increasingly real, it is certainly not yet reality. But future products of the technology—and speculation on their impact—tend to be discussed in the many reports as if this is a fully realized technology. The scenarios that fuel the discussions swing between two poles of promise and peril, which Drew Endy wryly refers to as "the half-pipe of doom."

Many of the promises originate from within synthetic biology, its supporters constructing a one-size-fits-all utopia, marked by conflicting visions. Synthetic biologists describe a disruptive, sustainable technology that won't disrupt existing infrastructure, for example pumping out "green" jet fuel so that we can carry on as we are. Bacteria that will make materials and chemicals will be designed so that they survive only within the security of an industrial fermenter, yet the same species are also touted as potential powerful field technologies that will be safe to let loose to clean up toxic pollution. Synthetic organisms will work symbiotically with natural systems, nitrogen-fixing to improve crop production, but will not alter the ecosystem, thanks to kill switches. Open-source ideals will empower the developing world, but the technology is still being ring-fenced by first-world patent regimes to encourage investment. Friendly FBI agents liaise with do-it-yourself amateur biologists, assessing whether their work could ever present a potential risk, simultaneously raising the profile of "Do-It-Yourself" biology (DIYbio) while monitoring its activities.

These concepts are ultimately manifested in the twin spectre of the "dual-use dilemma," which describes a useful technology that can also be used to cause great harm (like an airplane or hammer). And synthetic biology certainly could well be both: the U.S. Defense Advanced Research Projects Agency (DARPA) is developing foundational technologies for manufacture called "Living Foundries" and "green" explosives, while the U.S. Defense Threat Reduction Agency (DTRA) sponsors the field's major conference series and wants to find ways to combat biological threat.

Building promise—and with it, hype—may be necessary for a new field of science to attract funding. But where do the dystopian extremes come from, if not just the active critics of the technology and DARPA/DTRA's involvement? If science sells utopias, the dialogue is set up in such a way that bioethicists called in to comment are often positioned toward the role of technological gatekeeper. They are asked to supply the "voice of reason," speculating on the potential impact of the technology, and in doing so may even invoke images of catastrophe to counter the utopian scenarios. Yet the arguments driving both sides are all too often made in the abstract and the extreme, plucked from a far-off future where the imagined technology is conclusively sophisticated. These are essentially tales of science fiction, and they lead to debate structured around world-saving green living or world-destroying tales of pandemic.

Certainly, it is not just government agencies and bioethicists considering the potential hazards of new biotechnologies. Speculating on the societal impact of new and imagined technology, often inspired by scientific discourse, science fiction novelists and screenwriters have long examined biological futures, often played out to catastrophic end. These include early classics like Mary Shelley's *Frankenstein* of 1818 or the monstrous animal hybrids of H.G. Wells's 1896 *The Island of Dr. Moreau*. By the 1950s, the decade of Watson and Crick's discovery of the structure of DNA, the implications of man-made biological life forms already anticipated the same themes of bioerror, bioterror, and ownership that still dominate policy and risk inquiry today. John Wyndham's intentionally designed, oil-producing, man-killing plants in *The Day of the Triffids* remain an evocative exemplar of bioterror.[24] Pohl and Kornbluth wrote of an overpopulated future in *The Space Merchants*,[25] where states exist only to support commercial enterprise, outlining the risks of a patented, technologized nature. Farm laborers tend monstrous protein blobs or work on vertical algae plantations in jungle skyscrapers. John Christopher's *The Death of Grass* depicts a natural virus decimating the world's major food crops.[26] Collapsing civilizations lie in its wake, echoing modern fears of pandemic caused by escaped or released synthetic organisms. Battling a stray, man-eating goo was Steve McQueen's leading-man debut in 1958; *The Blob* long presages Drexlerian concerns of self-replicating nanotech gray goo or synthetic biological green goo. With 60 years of scientific development behind us, we are still afraid of the same things.

Contemporary bio-fictions still unravel into spine-chilling dystopias, describing our world recolonized by nature, ruined by biology out of human control. Writer on landscape and nature Robert Macfarlane wonders if the underlying reason is a misanthropic slide back toward nature that helps us feel better about our postindustrial role in "ruining the world."[27] Nature will win again, eventually. These bio-apocalypses are often "cosy catastrophes," an accusation leveled at tales like Wyndham's where heroes survive unchanged in a world purged to a more natural state, simply shed of excess people.[28] Is this logic symptomatic of our entrenched view of humanity and its culture emancipated from the wilds? Nature is our enemy, constantly threatening us with both its nonliving and biological threats. The overuse of well-meaning, human-"invented" antibiotics triggers natural superbugs to kill us. Hubris over human intention and loss of control is easier to deal with than the unknown agency of the nature that we presume to master. These are the horrors that we transfer onto synthetic biology.

So how do we design for a world we want when that possible world doesn't yet exist, even in our imaginations? One of the difficulties for the development of policy and governance of synthetic biology is how to build a flexible and adaptive system that reflects current practice in the field but can also accommodate future developments. The balancing act between the safety of the "precautionary principle" often advocated by critics of the technology—treating something as dangerous until it can be proved harmless, which we may never be able to do—and desire for progress, is complicated.

As Danielli argued, we should be considering not only how or what we might design for this potential future, but what its effects might be. In 1990, the Human Genome Project, the multinational effort to sequence an entire human genome for the first time, invited examination of the societal issues that such knowledge of humanity might expose. The Ethical, Legal, Social Implications (ELSI) initiative was part of its remit. This work was placed downstream of technological development, implicitly stating that societal and environmental implications *follow* scientific development, rather than be part of it.

Vision may drive progress, and speculation can be useful. But viewing societal impact as an add-on is an error. I've heard synthetic biologists sigh, "If only they understood, they would want it!"—declaiming public misapprehension of genetic modification. But science and society are not distinct entities; scientists are part of society. The break between science and society mirrors the dichotomy between nature and culture, the psychological emancipation that stops us seeing our technology in the context of the ecosystem. Both are equally problematic as synthetic biologists attempt to design biology.

Working to improve the ELSI model, social scientists have experimented with moving the societal research "upstream" in synthetic biology, to earlier stages of the research process. While design too easily avoids responsibility for what it makes, these exemplary attempts within synthetic biology to include social considerations have been well meaning, but have on occasion become fraught.[29]

Despite these efforts, swinging speculations still dominate; the dystopias are shrugged off as "unbelievable," constructing a sense of inevitability to the direction of technological developments. As we rock between salvation and apocalypse, it is the more probable middle ground that proves harder to grasp. These are the closer-to-hand, incremental advances offered by synthetic biology that need analyzing now, which are less remarkable, as is the everyday life they represent. What will a world infused with biotechnology look, smell, or feel like? How will we have to change our behaviors and interactions and lifestyles? How do we protect ourselves from the corporate monopolization of living matter or make democratic decisions about appropriate levels of risk to the environment? It is the unexpected that often emerges from new technologies, rather than the neatly sign-posted paths of government plans. And there may be more than bioerror, bioterror, and intellectual property at stake.

While synthetic biology promises a better future through design, we should be wary as always to presume that there is one definition of "better," a one-size-fits-all future. Synthetic biologists' desire for standardization—whether minimal organisms or a universal biological "chassis"—threatens to standardize out the diversity and complexity of living things. A chassis may be "better" for maximal production of biofuel, but we should not assume that it means it is "better" for biology. If synthetic biology intends to design nature, its practitioners need to be fluent in the social and environmental issues embedded in their work: nature and culture, science and society are all interconnected. We need to design for multiplicity. But how do we design this bigger picture?

New Models for Biological Design

Design's engagement with our experience of the everyday means that it is a familiar language we can all effortlessly connect with. Working for industry, the designer's social responsibility has ultimately been economic. Design indeed can mean making beautiful "designed" things, but as Museum of Modern Art (MoMA) Senior Design Curator Paola Antonelli argues, design should be about making things meaningful.[30] "Designers stand between revolutions and everyday life," she asserts.[31] Rather than looking to existing design practice, it is emerging approaches in art and design that can provide useful models for a "better" biological design. Art and more experimental design practice can tease out problems, questions, and ideas not addressed by other disciplines, finding ways to express what we cannot yet put into words, including our fears. These new perspectives may help us negotiate the complex relationships between the living things that will be designed and the people they will be designed for, to help us think in more concrete terms about how a synthetic biological future might change us as individuals in particular, rather than the world in general.

At the fringes of design, revolutions in practice have existed since the Modernist era, as designers seek new definitions for their work, questioning embedded attitudes around design. This search for meaning reveals a desire to take more responsibility for design's role in contemporary culture, broadening its potential beyond the economic. This experimental design is where "innovation, functionality, aesthetics and a deep knowledge of the human condition combine to create outstanding artifacts."[32] Although this kind of design may still be concerned with function and utility, its interest in imperfection, rather than uniformity, is more aligned with art. Architects Jean-Gilles Décosterd and Philippe Rahm take this approach with their investigations into "physiological architectures." Décosterd & Rahm's ephemeral built spaces are not defined by their physical limits, but by their inhabitant's physiological response to stimulation. By manipulating light levels or the air's chemical composition, they challenge our conventional understanding of architecture as a physical structure, redefining it as the relationship between our body's biochemistry and the space we inhabit (figure 3.9). As design borrows and even blends into art (and scientific) practice, it can be used to investigate not only new functional potential but also philosophical and aesthetic issues raised by new materials and experiences.

Designers are increasingly realizing the societal impact in using design as a medium to trigger debate and discussion. British designers Anthony Dunne and Fiona Raby have been instrumental in developing "critical design" or "design for debate." Their *a/b* manifesto describes this shifting role of designer

Figure 3.9

DÈcosterd & Rahmís *Diurnisme* (2007) installation makes ì night during the continuous artificial day of modernity.î The installation at the MusÈe National díArt Moderne, Centre Pompidou, uses bright orange–yellow light with wavelengths above 570 nanometers, which are perceived by the bodyís clock as ì trueî night.

from problem-solver to philosophical sense-maker (figure 3.10). Designers can become "problem finders," Dunne and Raby suggest, identifying glitches in the system. Antonelli proposes that by asking, "What is this about and can we do something about it?" designers can go further, becoming "problem makers." By seeking out questions, we can reveal new perspectives on the world; as problem makers, we can challenge existing systems and design ways we might change them.

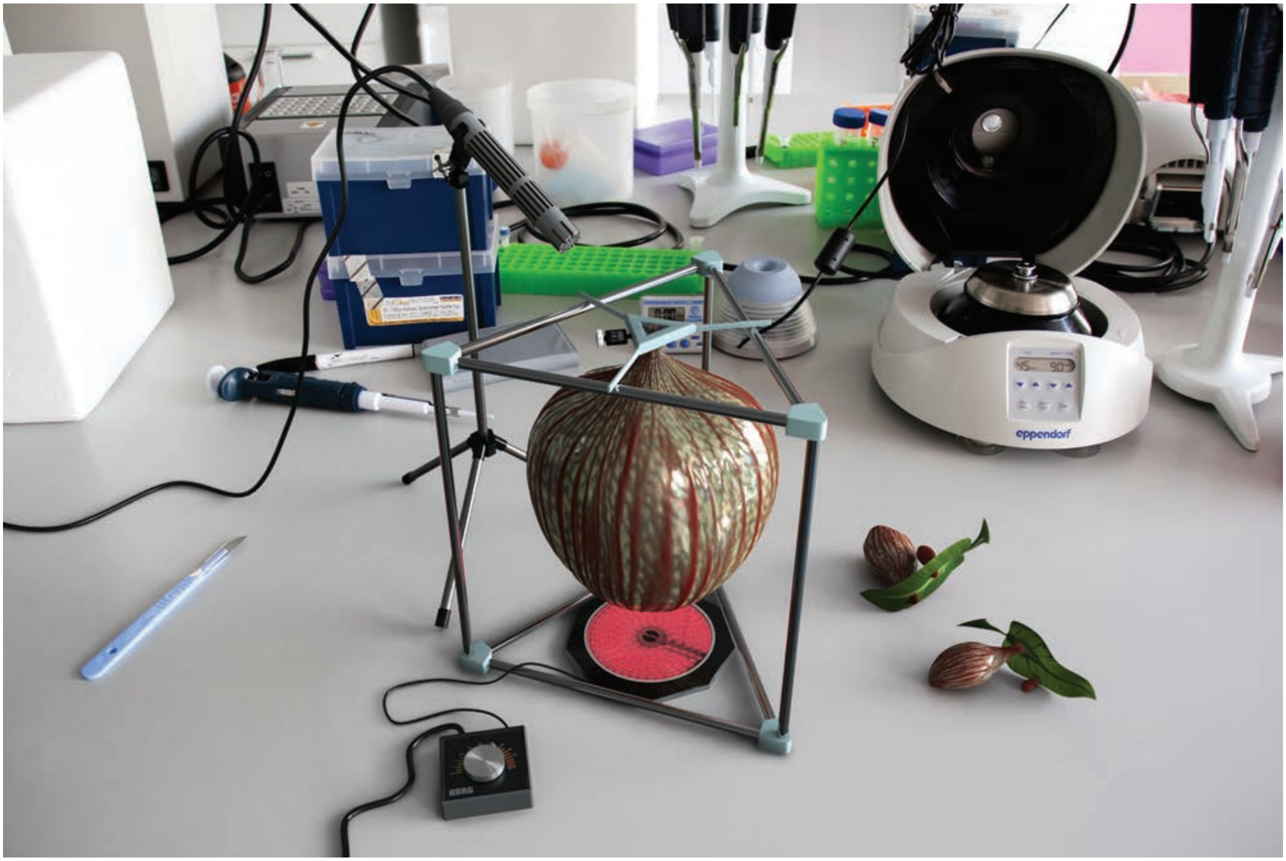
These attitudes can cross into synthetic biology's design discourse. While Dunne & Raby "design for designers" to stimulate new modes of practice, designing for synthetic biologists may well be similarly useful.[33] Moving away from designing goods to consume, to designing ideas and questions, designers have a potential role upstream in science, where new technologies are made. This "design without commerce" holds with Bruno Latour's notion

(a)	(b)
affirmative	critical
problem solving	problem finding
design as process	design as medium
provides answers	asks questions
in the service of industry	in the service of society
for how the world is	for how the world could be
science fiction	social fiction
futures	parallel worlds
fictional functions	functional fictions
change the world to suit us	change us to suit the world
narratives of production	narratives of consumption
anti–art	applied art
research for design	research through design
applications	implications
design for production	design for debate
fun	satire
concept design	conceptual design
consumer	citizen
user	person
training	education
makes us buy	makes us think
innovation	provocation
ergonomics	rhetoric

Figure 3.10
Dunne & Rabyís *a/b: a changing understanding of design*, a manifesto for new thinking about design (2009).

of an object-oriented democracy, making, as design historian David Crowley suggests, "a forum where science and its objects are put under scrutiny."[34]

Despite calling for change, Antonelli believes designers should remain generalists: "Designers should keep on doing what they do best, which is to address… the sensible, human and beautiful production of things in the world."[35] Decades ago, Buckminster Fuller anticipated a "comprehensive designer." For him, "The specialist in comprehensive design is an emerging synthesis of artist, inventor, mechanic, objective economist and evolutionary strategist."[36] This might still ring true. Future designers may need to understand biology, but they also need to know the world it operates in. Artist, computer scientist, engineer, and experimental designer Natalie Jerimijenko works in this space, unfazed by changes in scale or material between the lab, the studio, the community, and the ecosystem. Her *One Trees: An Information Environment* design research project appropriates the tree as a biosensor. In 2003, 1,000 genetically identical cloned specimens were planted throughout the San Francisco Bay Area as a network of environmental biosensors and long-term record-makers.[37]



But synthetic biologists—designers of biology—and designers are not one and the same. The designer's flexibility to adapt to different roles and act as a go-between for experts and nonexperts offers a complementary set of skills to the knowledge of biology's complexity required of the synthetic biologist. An emerging role for the designer is a form of social critic. Here, the designer acts as a mediator between science and public interest and its social desires, addressing the fact that science is "concerned with what is, not with what ought or ought not to be" further down the line.[38] This sounds a little like the public intellectual, a role in decline. "Intellectuals in different guises play a crucial role in initiating dialogue and engaging the curiosity and passion of the public," sociologist Frank Furedi writes.[39] While this can manifest as public engagement with science, more interestingly, it can face the other way, as scientific engagement with the public, or better, work to eliminate the divisions between the two. This has been the direction of an evolving critical design, as some of its practitioners—many taught by Dunne & Raby (including myself)—develop a type of applied, speculative bioethics. Researching science and engaging in discussion with scientists, these designers speculate on future interactions with biotechnology by designing tangible objects, developing new visual metaphorical languages in the process.

One such project is David Benque's *Acoustic Botany*, which challenges synthetic biology's promise to design for our needs (figure 3.11). Instead, he wonders what it would be like if it were designed to feed our most irrational desires, like many other consumer products today. Designing in dialogue with scientists, he imagined a *Genetically Engineered Sound Garden*, designed purely for aesthetic pleasure. In his fiction, varietals are engineered to produce different sounds, some even relying on symbiotic relationships with insects to "pluck" their fibers or with modified agrobacteria, producing air for the instruments.

Some philosophers of science suggest that science uses models as useful fictions to explore the world.[40] The model helps to test a hypothesis. If wrong, the hypothesis (and the model) can be rejected, and science continues with this knowledge noted. Useful fictions could quite literally help us explore possible worlds: Robert Macfarlane asks whether, instead of nostalgically looking backward to a nature untainted by human hubris as described in the previous section, can we design our fictions as "constructive ruins" that help us better imagine our own present and choose more wisely between our own available futures? [41] These "complicatedly forward-looking ruins" could help us feel crisis in our guts before we progress. Testing these fictions by experiencing them, we examine our personal responses, socially politically, ethically, and culturally. Combining these two very different concepts of the fiction, from philosophy of science and literature, could help us to imagine how we could think about applications and implications holistically from the outset.

Figure 3.11

Lab Testing Rig **from designer David Benqueís** ***Acoustic Botany*** **(2010), a design fiction about plants engineered to produce sound. Factors like tension and temperature are modulated to fine tune the sound. Benque asks if we might engineer biology for reasons of pleasure, not just need. Courtesy of David Benque.**

Useful "design fictions" or "speculative fictions," such as Benque's *Acoustic Botany*, model potential worlds. They are not intended to be predictive, the preserve of futurists who imagine what technologies might come next; rather they test and explore the everyday interactions of much nearer possible futures. They aim to confront complex societal issues by imagining unrecognized things or situations, critically commenting on—or triggering for debate—behavior and fears through our reactions to objects and our use or misuse of them.

Useful fictions in science may be built on the proposition, "as if . . .,"[42] but this work often sits in the realm of "what if . . .," the eponymous title of a series of exhibitions curated by Dunne & Raby, showcasing the work of their students (including myself) in this vein.[43]

The *Microbial Kitchen*, a "Philips Design Probe," is a design fiction with the gloss of corporate design language and is intended to test, not predict, how we might live with biotechnology in our homes (figure 3.12).[44]

But produced and researched within a corporate setting, its designers may well influence the way that future biotechnologies are developed. Scientists admit to being inspired by science fiction on occasion. This may be due to the authors' thorough research into current science and its likely trajectory, rather than their stories actually influencing research directions. But as I have learned through my own experiments collaborating with synthetic biologists: in imagining the future, you may make it more likely. Useful fictions can unintentionally become embedded in the language of the field, even shaping it. These are the well-informed ideas that straddle a delicate boundary, so well rendered in the accessible consumer language of design, they become difficult to identify as fictions.

If they look too real, speculative fictions risk losing their critical edge. Issues that the designer wants to be debated simply become acceptable, the power of "what if . . ." deflated as the audience is desensitized to something previously quite unfamiliar. Rather than testing possible worlds, the fiction becomes a kind of sophisticated endorsement of a now-more-probable future. An example of this in a collaborative project of my own, *E. chromi*, described in chapter 6. Finding ways to design and test futures without prioritizing them and preventing other outcomes is important for designers or artists working with scientists in this way.

"Bio art" works differently to investigate biotechnology's impact. Bio art is an emerging branch of contemporary art "that manipulates the processes of life" as bio artist Eduardo Kac explains. It uses biological materials or organisms, as well as biotechnology's tools and processes, often toward "unusual or subversive" means.[45] Bio art is a way to initiate discourse over science and often brings scientists and artists to work together. But many bio artists are unhappy with their work with living materials being co-opted as a descriptor of technologies and a tool for public engagement. One solution for these artists is to work with scientists, but separate their work conceptually to avoid diminishing their role as provocateurs. As Oron Catts, of the Tissue Culture & Art Project and SymbioticA (and Synthetic Aesthetics resident) explains, in this disciplinary integrity and avoidance of making "useful" things lies the ability to create shock to create discourse. Yet both Kac's infamous green fluorescent *GFP Bunny* from 2000 or Tissue Culture & Art's *Semi-Living Steak*—a slab of ironically titled "victimless meat" grown, fried, and eaten in a gallery in 2003, described in chapter 2—have over time encountered the strange frontier where provocation becomes absorbed into and even part of scientific progress. "Victimless meat" has become a stock phrase in media reports on the burgeoning industry of lab-grown burgers.

Figure 3.12

Bio-digester Kitchen Island **concept from the Philips Design Probe, *Microbial Home*. Courtesy of Philips Design.**

This awkward line shows how neither art nor design is immune from instrumentalization by the science it works to critique. These examples also demonstrate how important it is to continue to interrogate the cutting edge. It is through the *Semi-Living Steak* project, not the recurrent media hype about a future of plentiful lab-grown meat, that we are reminded that victimless meat is no such thing, fed as it is on fetal calf blood products, and we are obliged to consider the strange "semi-living" status of tissue culture.

Synthetic biology not only presents problems that need to be solved but also presents dilemmas. Designers and artists can work as "provocateurs," seeking out and testing these predicaments. Working within science rather than separate from it is a way to ensure such investigations are informed by scientific developments and that they are considered by the scientific community, removing the imagined divide between science and society. The different models of contemporary design and art practice described here illustrate ways that designers and artists are working to challenge the accepted boundaries of their own disciplines. These approaches could inspire new, more collaborative practices between synthetic biology and social science, art, and design that help to open up the discussion of what could or ought to be, not just what is, questioning the assumptions held.

As part III documents, the Synthetic Aesthetics residencies have followed this route in their collaborations. Some of the projects suggest a synthesis of approaches between synthetic biology, art, and design, hinting at "critically-engaged biological design." Where biological things were physically made, they were real, like Christina and Sissel's human cheese (chapter 17), or Oron and Hideo's circuit board digesting-algae (chapter 11), more like the "real" products of bio art than the props of critical design, avoiding the possibility of being mistaken as fictions. While these objects were real, they were functional, too, countering the anti-utilitarian ethos of bio art. Their strength is in the way that they are useful: they are provocative, challenging core assumptions embedded in the technology. These living organisms, tools, and ideas provide new insights into synthetic biology. Useful fictions as models of possible futures need not be science fiction, but can be experimental artifacts.

Synthetic biology suggests a different nature, and a different world; we need to think about what we want from this biological future. As synthetic biology attempts to design a new biology, there is an opportunity to reinvent design: If design is engaged in these technologies, it should proactively claim a role in shaping them, too. Design (and art) can bring tools for useful critique, debate, collaboration, and investigation into science, while bringing the tools of science to the expertise of others in society. For synthetic biology to be a successful future design practice, it should consider applications and implications together, a mode that emerging design practice is investigating. As a discipline, synthetic biology should include not just scientists and engineers but also artists and designers, social scientists, and risk and policy experts. This is not a public engagement process or a search for predictions; it should be a critical part of the scientific process, if we hope to design a new nature well. Here lies the opportunity to design a disruptive technology, one that might actually challenge entrenched modes of living and consumption and challenge the prevailing attitude that what we make is somehow separate from the natural world.