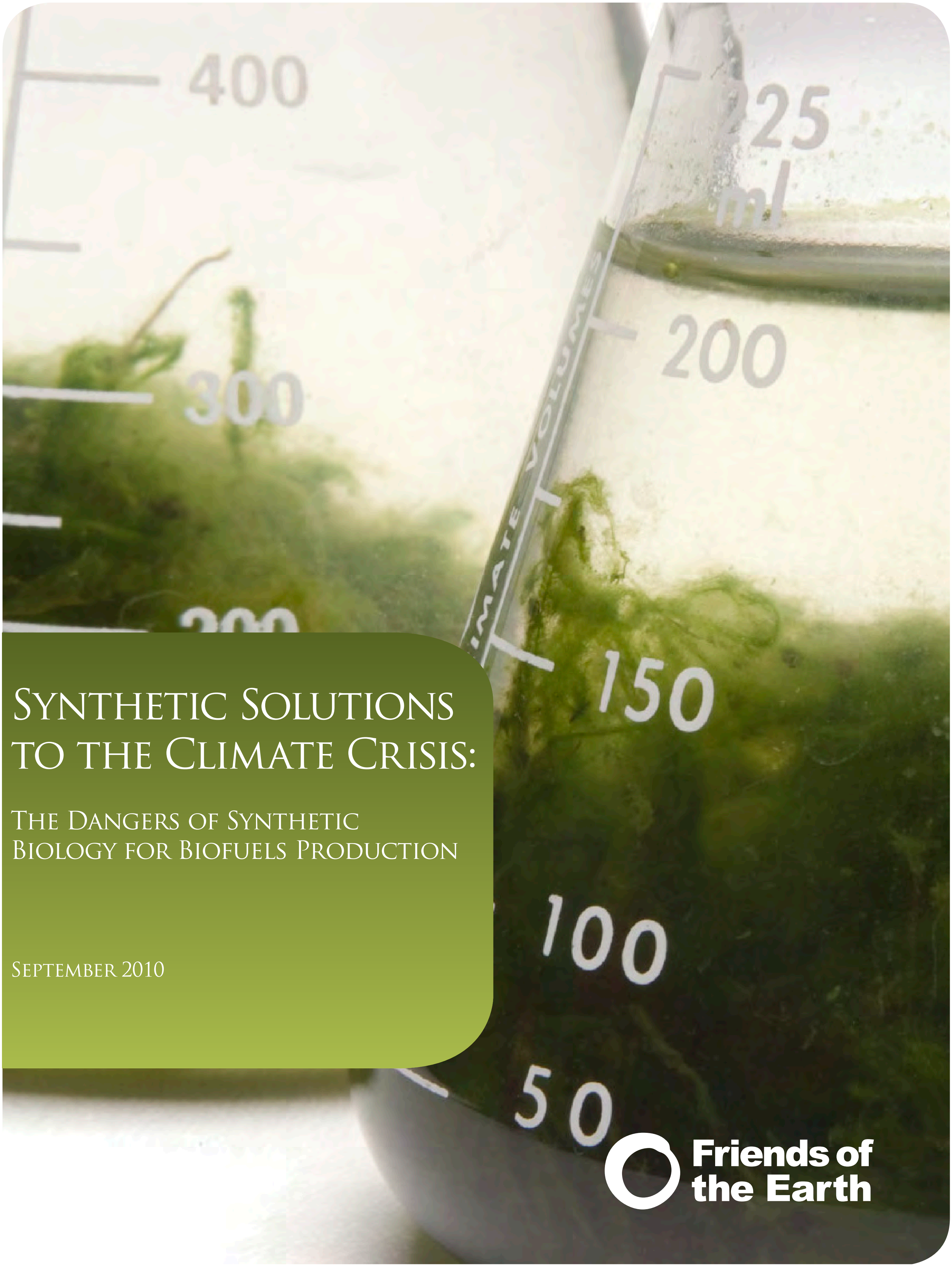


Synthetic Solutions to the Climate Crisis:

The Dangers of Synthetic Biology for Biofuels Production

September 2010

Friends of the Earth

Executive Summary

Biotechnology is portrayed as a panacea for climate change and other societal ills. However the claims that genetically engineered plants and microbes can sequester more carbon in the soil and produce more fuels when processed than conventional methods have yet to be proven. In the wake of these unfulfilled promises emerges a more extreme form of genetic engineering, also touted as the solution to the climate crisis – synthetic biology.

Genetic engineering involves inserting genes from one species into another but the goal of synthetic biology is to create life forms from scratch using synthetic, computer-generated DNA or in some cases without the use of DNA entirely.

Synthetic biology is not a sustainable solution to the climate crisis and has the potential to create an entirely new set of problems. Genetic contamination – where the genetic makeup of a man-made organism effectively roots out or destroys an indigenous species in the natural environment – is a serious threat to biodiversity, the environment, and public health. This happened when genetically engineered crops like corn were introduced in the U.S. in the early 1990s and contaminated entire strains. Synthetic biology exacerbates this problem since no one knows how organisms with synthetic DNA will act in the open environment. They could die immediately – or they could find a niche and devastate ecosystems as other invasive species have done.

In spite of this threat, commercial applications for producing biofuels through synthetic biology are under way. Brand new forms of algae, yeast, and other organisms are being designed with synthetic DNA to produce fuels or to more efficiently break down existing land-based crops to be fermented into fuels.

This research is backed primarily by the oil industry. Additionally, the federal government provides these corporations with hundreds of millions in taxpayer money to research and patent organisms for fuel and then sell that fuel back to the public. Oil companies have already destroyed the environment and should not be rewarded for putting profits ahead of protecting human health and the environment.

The only way to safeguard against possible environmental disaster is to place an immediate moratorium on the release and commercial use of all synthetic organisms into the environment and conduct full environmental and social impact statements on all synthetic biology research. Dangerous and unproven synthetic biology projects have diverted investments away from safe and clean technologies like wind and solar, and energy efficiency. A moratorium would revive research and development of these renewable energy sources, end dependence on fossil fuels and safeguard the environment and all those that depend on it.

Introduction

Scientists have been manipulating the genetic code since the early 1970s when they began genetically engineering bacteria, plants, and animals.[1] Over the years genes have been inserted into crops to make them resistant to certain herbicides or to produce toxins in their cells that kill insects;[2] fish and rabbits are injected with genes from jellyfish and coral to make them glow for purely aesthetic purposes.[3]

Since then, biotechnology has been portrayed as a panacea for climate change and other societal ills. The Biotechnology Industry Organization (BIO), the industry's largest trade group, declares that these technologies are fueling,[4] feeding[5] and healing the world.[6] Monsanto, a biotech giant, claims that its genetically engineered seeds will produce drought resistant crops and sequester carbon.[7] The industry also says that that genetically engineered plants produce more ethanol,[8] or other fuels,[9] when processed. By injecting DNA from one organism with a desired trait—say drought resistance—into another plant, scientists can tweak naturally existing plants, yeasts, algae, and bacteria to make "better"[10] ones. But "better" more often refers to the profits they can bring in once patented rather than the benefits to people or the planet. Already a handful of corporations have benefited from biotechnology at the expense of the environment, the climate, and public health.[11]

GloFish® has added a fluorescent protein gene to zebrafish like this one.

The field of genetic modification is growing in complexity. Previously, genetic engineering involved taking a short segment of DNA from one organism and inserting it into another organism to engineer a new, genetically modified creature. Scientists are now able to manipulate genetic material like never before due to advances in genetic engineering, DNA sequencing, nanotechnology, and robotics. Combining these technologies, some scientists are attempting to create life from scratch or re-design existing life. The proponents of this more complex genetic engineering call it "synthetic biology." Its supporters claim that synthetic biology will be the source of the new "green" and "renewable" fuel supply.[12] The science behind synthetic biology and how it is used to produce biofuels will be reviewed in Section 1.

Section 2 will discuss the dangers synthetic biology poses to our environment and public health, as well as risks to national security.

Section 3 addresses the hype around synthetic biology and the false belief that fuels created through synthetic biology will save the planet from climate change. Proponents of synthetic biology are banking on the appeal of a 'green' techno-fix to win over the public, in spite of the very serious risks involved.[13]

Section 4 critiques this false notion that biofuels produced through synthetic biology are a solution to the climate and energy crisis. It's unlikely that synthetic organisms will be able to produce the amount of fuel and energy needed to become competitive with other sources of energy without seriously harming the environment and public health, and perpetuating inequality around the world.

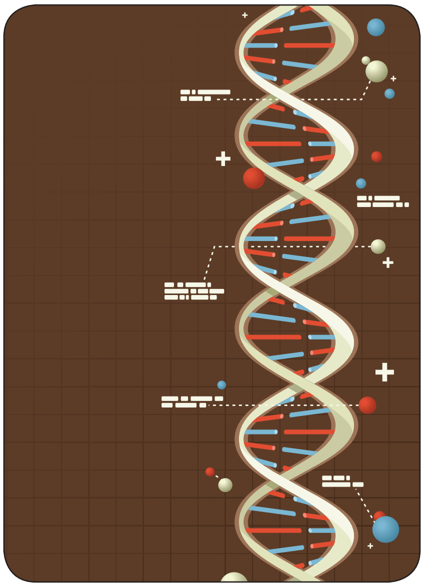
Section 5 will show the oil industry and agribusiness' connections to the synthetic biology field. With the support of oil giants, such as Exxon Mobile and BP, synthetic biology startup companies have started producing fourth generation biofuels from man-made organisms. The patenting procedure for synthetic life forms and how companies can manipulate the system to control the fuel supply will then be discussed.

Amyris Biotechnologies is one such company. It's producing biofuels and medicines with synthetic yeast, and is a prime example of how synthetic biologists use their connections with Big Oil and the government to promote unproven and unregulated products. The harms caused by Amyris' biofuels production efforts in Brazil will be highlighted in Section 6.

Next, Section 7 will highlight the other major funder of synthetic biology research – the U.S. government. With the help of federal contracts, grants, and friends in high places, synthetic biology companies have been able to receive significant amounts of public funding to start their operations and patent their organisms. These companies are also being supported by U.S. biofuels policies that are promoting new and alternative sources of biofuels.

Section 8 reveals how synthetic biologists hope to thwart any attempts at oversight and lays out the argument for precaution.

The report concludes with policy recommendations to regulate synthetic biology in Section 9 and why such regulations are necessary to protect the environment and public health from the unique dangers posed by synthetic organisms.



The use of genetic engineering has grown at an incredible rate in agriculture production, the medical field, and more recently to produce biofuels.

1. The Science of Synthetic Biology

A Brief History of Genetics:

To better understand the new dangers posed by synthetic biology, it is important to briefly cover major advances in genetics and our understanding of how genes function. The father of genetics is Gregor Mendel, a German monk, who in 1865 discovered that traits are inheritable through experiments with pea plants. It wasn't until the 1900s that the importance of this discovery was fully recognized. In the 1920s it was believed that genes constitute the basis of life and evolution and those nucleic acids were a major component of chromosomes. Alfred Hershey and Martha Chase proved in 1952 that genes, in fact, were the carriers of genetic information.[14]

In 1953 James Watson and Francis Crick made the historic discovery that DNA was formed by a double-strand helix of nucleotides.[15] Until this time, scientists did not know how DNA was composed or constructed. This knowledge opened up the door to the idea that we could re-construct DNA. Only twenty years after the structure of DNA was discovered, the first genetically engineered organism, a form of *E. coli*, was created in a process known as genetic recombination. Recombinant DNA led to the birth of the first genetic engineering company in 1977, Genentech, who started making drugs with this new technology.[16]

Since that time, the use of genetic engineering has grown at an incredible rate in agriculture production, the medical field, and more recently to produce biofuels.

Recombinant DNA, better known as genetic engineering, has previously relied on taking genes from one organism and inserting it into a new organism. The combinations of genes were limited to DNA that could be found in nature. The discovery of DNA synthesis has changed that and now DNA and genes can be created from scratch without needing to find them in nature. This emerging field is known broadly as synthetic biology.

Defining Synthetic Biology:

Synthetic biology is "the design and construction of new biological parts, devices and systems that do not exist in the natural world and also the redesign of existing biological systems to perform specific tasks."[17]

Instead of inserting genes from one species into another, what is considered genetic engineering, synthetic biology aims to create life from scratch with synthetic DNA or without the use of DNA entirely. DNA is synthesized on a computer and "printed" out, which can then be shipped anywhere in the world through the mail. While the range of practices referred to as "synthetic biology" varies, they all involve taking genetic engineering to a new extreme.[18]

Approaches to Synthetic Biology:

There are several approaches to creating synthetic life forms currently being used, each of which is working on a different scale. At the most basic level is the production of synthetic DNA through the arrangement of nucleotide bases: adenine, thymine, cytosine, and guanine—represented by the letters A, T, C, and G. Once a DNA sequence has been uploaded or typed into a computer, it can be "printed" out onto a sheet of glass from bottles of A, T, C, and G.

The first synthetic gene was created in 1970 with 207 nucleotides.[19] DNA synthesis has evolved greatly since the 1970s and can now be done relatively cheaply and quickly by gene synthesis companies that are popping up across the globe. Customized DNA strands can be purchased online and delivered through the mail for just $0.40 a base pair—compared to $10-$20 per base pair just ten years ago.[20] These base pairs can then be arranged into genes that, through RNA (ribonucleic acid), code for desired proteins.[1]

Proteins are built out of the twenty known amino acids. Codons, a serious of three chemical bases, determine which amino acid will

1 *To see a map of synthetic DNA companies, government laboratories, research institutions, and universities conducting synthetic biology research and policy centers examining issues surrounding synthetic biology, please visit: http://www.synbioproject.org/library/inventories/map/*

be produced in a given cell. Much of the synthetic biology research is occurring at the codon level, since it is through codons that scientists can chose among "biological instructions" for the desired trait expression. Some synthetic biologists are even creating new artificial amino acids (outside the twenty found in nature) by combining codons in ways never done before[21] or even trying to create life without DNA entirely.[22]

Dr. Clyde Hutchinson, Chair of the scientific advisory board of Synthetic Genomics, and Professor Emeritus of Microbiology and Immunology at the University of North Carolina at Chapel Hill.

Drew Endy, formerly of Massachusetts Institute of Technology and currently at Stanford University, founded the BioBricks Foundation. The Foundation is a registry of standard DNA sequences that code for certain functions.[23] For example, DNA "parts" can be created that make an organism glow. One could request this "biobrick," put it into an organism they want to engineer, and in theory the organism should then be able to glow. These open-source "bricks" (often compared to toy "Lego" bricks) can be used by researchers across the world to construct new genes and DNA sequences.

Craig Venter of Synthetic Genomics and the J. Craig Venter Institute created another approach. His research team produced an organism with the minimum number of genes needed to survive. One could then add any DNA sequence to this "minimal genome" and produce fuel for cars, medicine, or any other synthetic product.

In May 2010 Synthetic Genomics announced that it had made the world's first organism with a completely synthetic genome. "This was the first self-replicating species that we've had on the planet whose parent is a computer,"[24] according to Venter. The announcement was also the first time the majority of the public and policymakers had heard of synthetic biology or considered the field's risks and benefits.

Another approach attempts to create life forms without DNA, like the field of "xenobiology," which combines nucleic acids in ways never done before in nature. Naturally, the four nucleic acids (A, T, C, and G), are linked together by the backbone of DNA – a sugar group (2-deoxyribose) and phosphate. Xenobiologists hope to combine the nucleotide bases to different sugars in the backbones, to create things such as threose nucleic acid (TNA), hexose nucleic acid (HNA), and glycol nucleic acid (GNA) – all of which never existed before in nature.[25] The hope is that these organisms will not be able to cross-breed with naturally occurring organisms, eliminating some risks of genetic engineering, but xenobiology carries its own risks, such as invasive species with novel genetic constructs, that have yet to be assessed.

Others hope to build life up from scratch by creating a "protocell." To do this, researchers are combining inanimate chemicals and arranging them in such a way that they hope will eventually lead to the creation of synthetic life. Some hope these protocells will provide insight into the origin of life and may lead to the creating of new organisms that don't even need a DNA-like structure to survive and multiply.[26] This protcell approach is the closest in theory to creating "life from scratch" of all approaches to synthetic biology.

Synthetic Biology for Biofuels Production:

Synthetic biology is being used in two different processes for biofuels production: first is using synthetic enzymes to break down biomass into sugars for fuel, and second is creating microbes that produce fuel directly.

Enzymes, which are proteins that catalyze reactions, are being engineered into microbes that can break down biomass much quicker than traditional methods. Synthetic DNA that codes for these enzymes is inserted into microbes that then produce these synthetic enzymes. These enzymes can now be tailored towards specific types of biomass, such as woodchips or corn stalks, and increase the rate at which they are broken down into sugars that can then be fermented into ethanol or other types of fuels. Examples of how synthetic enzymes are being used to break down biomass will be discussed in section 5 and even further in section 6 when Amyris Biotechnologies' efforts to use yeast with synthetic enzymes to break down Brazilian sugarcane are discussed.

The second approach being used to produce biofuels is through creating organisms, largely algae, that produce biofuels directly. Synthetic algae or other microbes do not necessarily require biomass to produce fuel, unlike organisms with synthetic enzymes, and instead can produce lipids that are processed into fuels from sunlight, water, and fertilizers. Synthetic biologists hope to change the organisms 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.[27] These microbes would become "living chemical factories"[28] that can be engineered to pump out almost any type of fuel or industrial chemical.

The Evolution of Understanding Genetics - A Precautionary Tale:

Scientists have learned an incredible amount about genetics since Watson and Crick first discovered the DNA double-helix in 1953. And while it's now possible to construct synthetic DNA, engineering organisms out of synthetic DNA strands is unchartered territory.

It was thought that with the Human Genome Project we would find a one-to-one correlation between genes and traits. We now know this to be a grossly inaccurate belief. Some believed they would find hundreds of thousands of genes, but in reality humans have somewhere between 20,000-35,000 protein-coding genes,[29] which is not much more than that of a nematode or roundworm. It was even discovered in 2009 that corn plants have more than double the number of genes humans do.[30]

Genes, sections of our DNA that actually code for proteins, only make up around 2 percent of our genome. Until recently, scientists believed the other 98 percent was simply "junk DNA." But scientists are learning that the "junk" is actually quite important and likely regulates gene expression. Scientists are also learning that

"If the society that powered this technology collapses in some way, we would go extinct pretty quickly."

- Drew Endy, founder, International Genetically Engineered Machine (iGEM)

inheritable changes in DNA can be caused by environmental and other factors, in the emerging field of epigenetics.[31]

Understanding of genetics is evolving rapidly and has disproved many previously held beliefs and assumptions. What remains to be seen is how synthetic organisms will affect the environment and whether scientific understanding of the role of DNA will precede its application in industry. Precaution would lead us to further study the still-unknown role genetics plays in the creation and development of organisms before creating novel life forms with synthetic DNA.

2. The Dangers of Synthetic Biology

Synthetic biology alters the genetic material responsible for creating every living thing on Earth. Challenging and attempting to improve upon the original design of life ignores the evolutionary balance of the natural world. All life is interconnected, and these new forms of man-made life will undoubtedly interact with the Earth's natural ecosystems. As the scientific field of ecology has shown, altering just one part of an ecosystem can affect all the living beings within it. While ecosystems are always in flux, organisms tend to have a set place in the food chain with certain prey and predators. Synthetic organisms may lack the predators that normally keep populations in check.

Drew Endy, a leader in the field of synthetic biology, recognizes the danger this new technology poses. Scientists are now able to create synthetic organisms that produce biofuels and medicine and unfettered. Synthetic biologists claim that they might one day develop to methods to create new crop species and livestock, designer children and made-to-order pets.[32] "We are talking about things that have never been done before. If the society that powered this technology collapses in some way, we would go extinct pretty quickly." Endy continues, "You wouldn't have a chance to revert back to the farm or the pre-farm. We would just be gone."[33] These are strong words of warning from the same person who promotes "Do-it-Yourself" synthetic biology in people's basements[34] and helped create iGEM – the International Genetically Engineered Machine competition[35] – which encourages undergraduate students to build novel biological systems with "BioBricks."[2]

Environmental Risks:

Whether a synthetic organism is released unintentionally from a lab or intentionally into the environment, the threat to our ecosystem is the same. Since the widespread use of genetically engineered

2 *While not all work from the DIYbio and iGEM community falls under the umbrella of synthetic biology, much of the work is indeed synthetic biology. iGEM encourages students to design their own BbioBricks," or standard DNA parts that can be synthesized and engineered into organisms anywhere around the world. DIYbio hopes to spread the tools of biology and bioengineering to anyone who is interested, and much of this work does occur in people's basements or garages.*

(GE) crops, we have seen that GE plants have the ability to share genes across species,[36] evolve and mutate over time[37], and drastically affect entire ecosystems.[38] GE crops generally use genes that have been in the environment, but some of these new synthetic biology creations are using DNA that are human-made and not found in nature. While other types of pollution such as synthetic chemicals break down over time and do not breed, synthetic biological creations are designed to self-replicate and once released into the environment they would be impossible to stop and could wipe out entire species. This type of pollution, known as genetic pollution, can be devastating since it cannot be cleaned up. Once it has escaped, it can never be removed from the environment.

A drawing from Aurora Algae™ showing the scale that open-air operations will be working at within a year or two.

Dr. Allison Snow, an ecologist at Ohio State University, explained at the Presidential Commission for the Study of Bioethical Issues meeting in 2010 what this scenario might actually look like: "As a hypothetical example of a worst case scenario, a newly engineered type of high-yielding blue-green algae (cyanobacteria) could be grown in thousands of acres of outdoor ponds for biofuels. Algae grown in open ponds will be engineered to be very hardy and they could be more competitive than native strains. The new type of engineered algae might spread to natural habitats—to lakes, rivers, and estuaries, where it might flourish and displace other species. In some cases, this could result in algal blooms that suffocate fish and release toxic chemicals into the environment. So it would be a bad decision to go ahead with this kind of application."[39]

This leads to another major concern - the effect synthetic organisms will have on the ecosystem when they are created to survive outside the lab. Many hope synthetic organisms could be used to break down environmental pollutants such as oil spills.[40] As a report written by Michael Rodemeyer for the Wilson Center's Synthetic Biology Project highlights, "synthetic organisms intended for non-contained use will be specifically engineered to survive and function in the environment into which they are being released. As a result, they are more likely to be fit for survival and competition in the natural environment than organisms intended solely for contained use, making the risk of reproduction, spread, and evolution more probable."[41]

Experts in the field agree that there is no way to contain synthetic or genetically engineered organisms—particularly algae. According to Lissa Morganthaler-Jones, CEO and co-founder of Livefuels Inc., a small number of genetically engineered algae have already leaked from the lab into the environment. "They have been carried out on skin, on hair and all sorts of other ways, like being blown on a breeze out the air conditioning system," she said.[42] Isaac Berzin, founder of GreenFuel Technologies Corp., the first algae-to-biofuels company, believes that a leak hasn't happened yet but that it is inevitable. "Of course it's going to leak, because people make mistakes," said Berzin.[43]

Synthetic biologists like to talk about designing in a "kill-

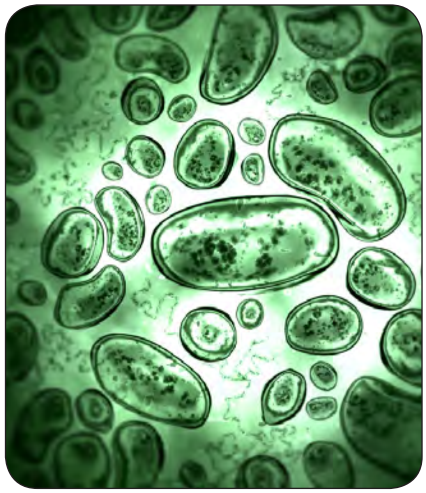
The fact that we can't predict the novel risks created by synthetic biology is why we need strong regulations from the beginning.

switch" or "suicide genes," that could be used to stop any organisms from getting out of control if they are released into the environment. Craig Venter has described how his team of researchers "will be able to engineer synthetic bacterial cells so they cannot live outside of the lab or other production environments. This is done, for example, by ensuring that these organisms have built in dependencies for certain nutrients without which they cannot survive. They can also be engineered with so called 'suicide genes' that kick in to prevent the organism from living outside of the lab or the environment in which they were grown."[44] Other examples include algae designed without swimming flagella or an inability to absorb the low levels of carbon dioxide found in seawater.[45]

Unfortunately, ecology has shown that one cannot just engineer safety into synthetic organisms. Even if the novel organisms are domesticated and seem innocuous, argues Dr. Snow, "mutations or unexpected properties might allow them to multiply in some environments. Physical or biological confinement (which could be based on engineered suicide genes or chemical dependencies) may not work forever or in all cases because mutations, human error, or unexpected events might allow [genetically engineered organisms] GEOs to escape and reproduce." Dr. Snow continues, "It would take only a few survivors to propagate and spread if biological confinement breaks down. The potential for rapid evolutionary change is especially high in microbes. Some will die out but others may thrive and evolve. GEOs that can exchange genes with related lineages or other species could evolve even faster—allowing synthetic genes to persist in hybrid descendants. So, we cannot assume that all domesticated or supposedly 'suicidal' GEOs are unable to persist in the environment."[46] Issac Berzin agrees: "You know where you start… but you don't know where you are ending. Algae adapt to their environment. Once you release it into the environment, guess what? They change. They get used to the worst toxins known to man… We live on a small planet, so it doesn't matter if disaster comes from Africa or China or New York. We are all going to be affected when it happens."[47]

Once a synthetic organism enters the environment, either through intentional or unintentional release, the ways in which these organisms will interact with the natural environment is unpredictable, potentially devastating, and permanent. A synthetic organism designed for a specific task, such as eating up oil from oil spills in the ocean, could interact with naturally occurring organisms and adversely harm the environment. The synthetic organism could displace existing organisms or interfere with the existing ecosystem. Once it found an ecological niche in which to survive, it would be difficult if not impossible to eradicate.[48]

The fact that we can't predict the novel risks created by synthetic biology is why we need strong regulations from the beginning. According to a 2006 report from the *New Atlantic*, synthetic organisms "will lack a clear genetic pedigree and could have 'emergent properties' arising from the complex interactions of its constituent genes…Accordingly, the risks attending the accidental release of such an organism from the laboratory would be extremely difficult to assess in advance, including the possible spread into new ecological niches and the evolution of novel and potentially harmful characteristics."[49] It is the uncertainty of risk that must prompt us to establish strong regulations from the beginning to ensure these fears are not realized. As Dr. Snow has highlighted, what makes assessing risk even more difficult is that most of the information from private industry is kept under lock and key as proprietary information.[50]



There is a real danger that the technology could be used to make deadly viruses and other biological weapons.

Public Health and National Security Concerns:

Beyond concerns that synthetic biology could wreak havoc on Earth's biodiversity, there is a real danger that the technology could be used to make deadly viruses and other biological weapons. In 2002, researchers at the State University of New York at StonyBrook recreated the polio virus (which took generations to eradicate) from mail-ordered DNA sequences.[51] In 2005, the U.S. Armed Forces Institute of Pathology recreated the 1918 Spanish Influenza, which killed between 20-50 million people worldwide, to "help them better understand — and develop defenses against — the threat of a future worldwide epidemic from bird flu."[52] What would happen if these deadly viruses – which proved to work in a lab – were created with ill intention and released or unintentionally leaked from a lab?

As a 2006 *Washington Post* article on bioterrorism highlighted, it is possible and completely legal for a person to produce the 1918 influenza virus or the Ebola virus genomes. It is also legal for someone to provide kits, detailed procedures, and any other needed materials to reconstitute the full viral DNA genome, and they could advertise and sell these viruses as well.[53] In fact, in June 2006 a journalist for *The Guardian* had synthetic DNA fragments for the *Variola major* virus that causes smallpox sent to his house from a commercial gene synthesis company to show how easily it could be done. As the ETC group highlights, the genome map of the *Variola major* is available on the internet in several public databases and the ability to purchase and combine synthetic DNA gets easier every day.[54] It was also discovered through a 2005 *New Scientist* investigation that only five of twelve DNA synthesis companies checked their orders systematically to ensure that they were not synthesizing and selling DNA that could be used to assemble the genome of a dangerous pathogen.[55] Concerns also exist of creating brand new viruses or toxins by combining DNA from different pathogenic organisms in novel ways.[56]

The U.S. Pentagon is even looking into the potential of synthetic biology to be used as a weapon. The U.S. military invested $6 million in 2010 in research to create synthetic organisms that could live forever or be turned off with a "kill switch"[57]—a security measure that would in theory kill the organisms in case of an emergency or if they got out of control. One potential military use of this technology would be to create bacteria that eat all living plant matter and food in an enemy's territory. President Obama's 2010 budget provided $20 million to the Defense Advanced Research Projects Agency (DARPA), a research arm of the Pentagon, for synthetic biology research.[58]

Naturally born microbes like the 1918 influenza virus and HIV are devastating enough, and there's no telling how devastating an engineered microbe could be. But it is feasible that an engineered organism, without natural predators, could cause widespread virulent disease, destroy the world's basic crops, or lead to the emergence of a new super-species. Synthetic biology creates a unique problem in that it is impossible to predict these risks. We can predict that a synthetic organism with a trait that makes it more competitive will out-compete its natural counterpart, as is seen with other invasive species.

3. The Hype Around Synthetic Biology as our Climate Solution

> *"Synthetic biology…has the potential to reduce our dependence on oil and to address climate change. Research is underway to develop microbes that would produce oil, giving us a renewable fuel that could be used interchangeably with gasoline without creating more global warming pollution. Research could also lead to oil-eating microbes, an application that, as the Gulf spill unfortunately demonstrates, would be extremely useful."*[59] *– Representative Henry Waxman (D-CA)*

The above quote sounds like the CEO of a synthetic biology start-up company talking to venture capitalists but in fact it is the opening statement by the chair of the House of Representatives Committee on Energy and Commerce during its first hearing on the implications of synthetic biology.

At that same hearing, Dr. Jay Keasling of the University of California at Berkeley, the Lawrence Berkeley National Laboratory, and Amyris Biotechnologies stated: "Through advances in synthetic biology, we can engineer…industrial microorganisms to produce biofuels that will work within our existing transportation infrastructure…these new, advanced biofuels reduce the production of greenhouse gases, as they are derived from plants that use sunlight and atmospheric carbon dioxide to grow. These biofuels will reduce our dependence on foreign oil and could rejuvenate U.S. agriculture."[60] Section 6 discusses Amyris' biofuels production efforts, proving they are far from carbon neutral and will only exacerbate strains on agricultural production.

Aristides Patrinos, president of Synthetic Genomics and a former member of President George W. Bush's team at the Department of Energy states that synthetic biology is the "holy grail" of energy production: "Advances in genomics and specifically synthetic genomics are the real 'game-changers' that can help us reach the goal [of removing 100 billion tons of carbon from the world's economy this century] …Our first goal is to put our vast knowledge and experience in the field of synthetic genomics to work in helping to solve the energy crisis…But one of the ultimate and disruptive technological goals of our synthetic genomics research is the use of carbon dioxide as a feedstock for the production of biofuels and biochemicals. Imagine that: carbon dioxide as a feedstock. This would be the 'holy grail' of bioenergy production: the transformation of a fossil fuel into a renewable resource."[61] This quote is the 'holy grail' of hyperbole and shows just how much hype surrounds synthetic biology without much thought to its repercussions.

In 2007, many of the world's top synthetic biologists met in Ilulissat, Greenland for the Kavli Futures Symposium on synthetic biology and nanotechnology. The outcome of this meeting was the "Ilulissat Statement" which said, among other things, that "the early 21st century is a time of tremendous promise and tremendous peril. We face daunting problems of climate change, energy, health, and water resources. Synthetic biology offers solutions to these issues**:** microorganisms that convert plant matter to fuels or that synthesize new drugs or target and destroy rogue cells in the body…Fifty years from now, synthetic biology will be as pervasive and transformative as is electronics today."[62] Steven Chu, current U.S. Secretary of Energy signed this statement while he was still director of the Lawrence Berkeley National Laboratory. Other signatories include Freeman Dyson, Drew Endy, Jay Keasling, and John Glass from the J. Craig Venter Institute, the leaders in the growing field of synthetic biology.

The world's largest oil, agricultural, and pharmaceutical companies are already pouring hundreds of millions of dollars into synthetic biology research.

Many scientists and engineers use synthetic biology to reengineer the processing, refining, and growing of biological material for use as transportation fuel (biofuels) and electricity (biomass). Their goal is to maximize the production of biofuels from an acre of land in order to reduce global warming emissions and oil consumption.

The world's largest oil, agricultural, and pharmaceutical companies are already pouring hundreds of millions of dollars into synthetic biology research at their own companies, at smaller start-up corporations, and at universities. Many small, privately held firms are doing the same thing. In the United States, more than 15 companies and many top university biology departments are starting major synthetic biology programs to develop synthetic organisms that produce biofuels. Even the U.S. government is funding major synthetic biology projects for biofuels production and Secretary of Energy Chu has a background in synthetic biology.

These promises are unfortunately illusory and in reality the only thing green about synthetic biology is the color of the algae being used and the $4.5 billion dollars the industry stands to make over the next few years.[63]

4. Synthetic Biofuels – A Synthetic Solution

The New Bio-Economy and the Threat to Socio-Economic Justice:

Even with so much hype, researchers have been unable to produce biofuels at the rate necessary to compete with traditional sources of energy. Synthetic biologists believe that the next generation of biofuels will overcome this barrier and be more efficient and sustainable than the previous generations of biofuels. They claim synthetic biology can free up land and other resources so fuels are not competing with food crops.

Unfortunately, this is far from true. Biofuels created through synthetic biology will create what ETC Group calls the "sugar economy" or the "bioeconomy:"

> [Synthetic biology] enthusiasts envision a post-petroleum era in which industrial production is fueled by sugars extracted from biological feedstocks (biomass). The biotech industry's bioeconomy vision includes a network of biorefineries, where extracted plant sugars are fermented in vats filled with genetically engineered – and one day, fully synthetic – microbes. The microbes function as "living chemical factories," converting sugars into high-value molecules – the building blocks for fuels, energy, plastic, chemicals, and more. Theoretically, any product made from petrochemicals could also be made from sugar using this biological manufacturing approach.[64]

If microbes can be genetically engineered and synthetically built to break down any type of biomass, than any source of biomass becomes a commodity that can be turned into fuel. As ETC Group asks, "Will *all* plant matter become a potential feedstock? Who decides what qualifies as agricultural waste or residue? *Whose* land will grow the feedstocks?"[65]

A 2008 issue of *Nature* argues that synthetic biology "might be tailored to *marginal lands* where the soil wouldn't support food crops"[66] (emphasis added) while ignoring the fact that these lands are often the source of livelihood for small-scale farmers, pastoralists, women, and indigenous peoples.[67] Steven Chu, before he became the U.S. Secretary of Energy, argued that there was "quite a bit" of arable land available for rain-fed energy crops and that Sub-Saharan African and Latin America could benefit from growing biomass for fuel.[68] Again, Chu fails to realize that these "marginal lands" are actually used to grow food for local communities and assumes they would rather grow fuel crops for wealthy nations. *The Economist* even suggested that "there's plenty of biomass to go around" and that "the world's hitherto impoverished tropics may find themselves in the middle of an unexpected and welcome industrial revolution."[69] In other words, poor nations should shift their economies to produce fuels for rich nations, exacerbating land grabbing efforts[70], deepening their dependence on the Global North, and limiting their ability to create self-sustaining local economies.

Synthetic biology enthusiasts work under the false assumption that there will be an endless supply of biomass and land to fuel their biofuels revolution. Even the U.S. Department of Energy, a major funder of synthetic biology research, has said "almost all of the arable land on Earth would need to be covered with the fastest-growing known energy crops, such as switchgrass, to produce the amount of energy currently consumed from fossil fuels annually."[71] There is a limit to how much biomass can be sustainably produced on the planet. Can even the most productive synthetic organisms produce enough fuel to meet the world's energy needs or will the world be led down an unpromising path with no real solution?

Deforestation in Brazil will only worsen as synthetic organisms are used to break down biomass for fuels.

The Real Environmental Impacts of Synthetic Biology:

Even algae, which synthetic biology cheerleaders claim are the solution to our fuel crisis since they do not require land-based biomass to produce fuels, are not as promising as they seem. Synthetic Genomics, which created the first synthetic cell, has specifically claimed that it would use the same technology to develop an algal species that efficiently converts atmospheric carbon dioxide into hydrocarbon fuel, supposedly addressing both the climate crisis and peak oil concerns in one fell swoop. Yet, contrary to the impression put forth by these researchers in the press, algae, synthetic or otherwise, require much more than just carbon dioxide to grow - they also require water, nutrients for fertilizer and also sunlight – and consequently they need land or open ocean. This cannot be done in a vat without also consuming vast quantities of sugar.

In order for Synthetic Genomics or their partners, such as Exxon, to scale up algal biofuels production to make a dent in the fuel supply, the process would likely exert a massive drain on both water and on fertilizers. Both fresh water and fertilizer (especially phosphate-based fertilizers) are in short supply,[72] both are already prioritized for agricultural food production and both require a large amount of energy either to produce (in the case of fertilizers) or to pump to arid sunlight-rich regions (in the case of water). In a recent lifecycle assessment of algal biofuels published in the journal *Environmental Science and Technology* researchers concluded that algae production consumes more water and energy than other biofuels sources like corn, canola, and switchgrass, and also has higher greenhouse gas emissions.[73] "Given what we know about algae production pilot projects over the past 10 to 15 years, we've found that algae's environmental footprint is larger than other terrestrial crops," said Andres Clarens, an assistant professor in University of Virginia's Civil and Environmental Department and lead author on the paper.[74]

Moreover scaling-up this technology in the least energy-intensive manner will likely need large open ponds sited in deserts, *"Can massive quantities of biomass be harvested sustainably without degrading soils, destroying biodiversity, increasing food insecurity and displacing marginalized peoples?"*

- ETC Group

displacing desert ecosystems. Indeed the federally appointed Invasive Species Advisory Committee has recently warned that non-native algal species employed for such biofuels production could prove ecologically harmful and is currently preparing a more complete report on the matter.[75] A similar plant owned by Sapphire Energy is already under construction in New Mexico that will take up 300 square acres of algal ponds for biofuels production.

Algae are arguably one of the most important organisms on the planet due to their special role in nature. Algae exist in almost every environment and produce upwards of 50 percent of all the oxygen in the air. They are the basis of many food chains and new species of algae are still being discovered.[76] While genetically engineered plants are problematic in their own right, synthetic biology raises the bar for the level of harms that can be caused. As the CEO of Livefuels Inc. said, "With [genetically engineered] corn, you can expect one crop a year, but with algae, you could get one crop a day"[77] Since algae reproduce almost daily. In other words, a single corn stalk could only reproduce with the limited number of seeds on its cobs in one given year whereas algae numbers double daily. This poses a brand new risk and makes the chance of an environmental crisis all the more likely. Al Darzins, a molecular biologist and principal group manager in bioenergy at the National Renewable Energy Laboratory has said that he is "absolutely convinced that if you're going to be using genetically modified algae in the future -- growing out in an open pond -- that before that happens on a very large scale there has to be some sort of risk assessment on what's going to happen to the potential ecology."[78]

The social and environmental questions this technology raises were best asked by the ETC Group:

> Advocates of synthetic biology and the bio-based sugar economy assume that unlimited supplies of cellulosic biomass will be available. But can massive quantities of biomass be harvested sustainably without eroding/degrading soils, destroying biodiversity, increasing food insecurity and displacing marginalized peoples? Can synthetic microbes work predictably? Can they be safely contained and controlled? No one knows the answers to these questions, but that's not curbing corporate enthusiasm. In the current social and economic context, the global grab for next generation cellulosic feedstocks threatens to repeat the mistakes of first-generation agrofuels on a more massive scale.[79]

Most synthetic biology projects described in this report are still in their early research phases. The industry already has at least one product in the marketplace (Du Pont's 'Sorona' bioplastic), and another recently cleared for market entry in 2011 (Amyris Biotechnology's 'No Compromise' biofuels) as well as several dozen near to market applications. Amyris' artemisinin will likely be the first medical application, as discussed in section 6 – but it will be tested on poor Africans – raising serious ethical and socio-economic issues of its own.

It is too early to know how productive synthetic bioproducts can be in producing biofuels or if they can actually work on a large scale. We do know that they will require an incredible amount of land, water, and fertilizer for either biomass or algal production – all of which are in short supply and are needed for agricultural food production.

Large investments in synthetic biology could prevent us (or distract us) from examining the root causes of climate change and the energy crisis: over-consumption and a dependence on dirty fuels. The same time and money could be invested in the development of truly sustainable forms of energy, such as wind and solar, as well as energy efficiency. We know we must put a price on carbon, make homes and cars more efficient, drive less and buy less, and stop subsidizing dirty forms of energy[80] - such as oil, coal, corn ethanol, and now biofuels made from synthetic biology.

Instead we are trying to force living organisms to produce fuels that fit our failing dirty system. Is it really easier to build novel life forms from synthetic DNA with unknown consequences on the environment and human health than fund sustainable solutions that we know can work? Or do we simply want to come up with a quick techno-fix that allows us to over-consume dirty fuels without changing our lifestyles in the slightest? Real-world sustainable solutions already exist; we must build the political will to actually rebuild our energy economy in a sustainable and just way.

5. Big Oil Plus Big Bio Equals Big Profits

One of the largest funders of synthetic biology research is the oil industry. As natural stocks of oil become depleted, these companies have begun to fund and create joint partnerships with biotechnology corporations to produce biofuels through synthetic microbes.

The following is a list of synthetic biology corporations and the research they are conducting on biofuels production, organized by research type. This list is a sample and not comprehensive, since deals are now being announced on a regular basis. Their links to Big Oil, corporate agribusiness and other dirty corporations are highlighted.

Synthetic Enzymes to Break Down Biomass for Fuel:

Amyris Biotechnologies is working with **BP,**[81] **Shell,**[82] and French oil company **Total**[83] to use its synthetic yeast to produce enzymes to break down sugarcane into fuels. Amyris is opening a plant in Brazil so it can have easy access to cheap sugarcane (see case study on Amyris in section 6 for more information on the company). The former director of BP's domestic fuel production is now in charge of Amyris.[84]

BP created a joint venture with **Verenium,** a Massachussetts-based biotechnology company, to provide $45 million[85] for cellulosic ethanol production through the use of Verenium's synthetic enzymes. Verenium also received $500,000 from agriculture biotechnology powerhouse **Syngenta** for tailoring its DirectEvolution™ technology to break down Syngetna's genetically engineered crops for biofuels.[86]

Agriculture for food or fuel?

Cellulosic ethanol company **Mascoma** has partnered with **General Motors**[87], **Marathon Oil**[88], and **Royal Nedalco**[89], a Netherlands-based ethanol corporation, to engineer yeast and bacteria with enzymes to break down cellulose for ethanol production. Their process of "consolidated bioprocessing" combines the digestion and fermentation process into one step with the help of these synthetic organisms.

General Motors has also invested an undisclosed amount to Illinois-based **Coskata,** which uses synthetic bacteria and gasification technology in a patented process to turn anything from wood to old tires into pure ethanol, a process that would supposedly "leap-frog cellulosic production."[90]

Genencor, a division of Danisco, has entered into joint ventures with two agribusinesses, **Cargill** and **DuPont,** to create synthetic enzymes. For the grain processing giant Cargill, Genencor's technology will be used to break down corn into ethanol, corn syrup, and other projects in a deal that is worth around $70 million.[91] Genencor and Dupont created a venture named *DuPont Danisco Cellulosic Ethanol LLC*, a $140 million initial investment to turn non-food sources such as corn stover and sugar cane bagasse into ethanol with the use of Genencor's patented enzyme technology.[92] DuPont owns Pioneer Hi-Bred, a leading genetically engineered seed company.

Royal Dutch Shell has partnered with Canadian cellulosic ethanol company **Iogen**[93] to create cellulosic ethanol with the use of synthetic enzymes to break down plant fibers.

Codexis, a leader in the development of the synthetic biology industry, received $60 million from **Shell** in 2009 alone - almost double the amount it received the year before, for enzyme creation.[94] Codex also receives major funding from **Chevron**.[95]

Synthetic Microbes to Directly Produce Fuel:

Synthetic Genomics, J. Craig Venter's company, plans on using its basic, stripped-down form of a simple bacterium to create an organism that might be able to take carbon out of the atmosphere, produce hydrogen fuel or methane, or as feedstock for other fuels. In 2007 Synthetic Genomics entered into a long-term partnership with **BP** to use synthetic biology to develop new biological conversion processes for petroleum. BP also made an equity investment in Synthetic Genomics.[96] The company received $600 million from **Exxon Mobil** over five years to develop biofuels from synthetic algae.[97] The algae would produce oil that closely resembles naturally-occurring petroleum, which can can enter Exxon's processing facilities without any changes of equipment or further processing.

LS9 was founded by George Church, a professor of Genetics at Harvard University and a leader in the field of synthetic biology. The California-based biotechnology company has re-engineered microbes to produce hydrocarbons that are similar to those found in petroleum, possibly creating a new source of crude oil. In 2009, LS9 finished raising $25 million in venture capital with help from **Chevron**.[98]

Solazyme, an algal energy firm based in San Francisco, uses genetically engineered marine algae to turn biomass into biodiesel through its patented process. [99] Solazyme entered into an agreement of an undisclosed amount with **Chevron**.[100]

Gevo, which produces biobutanol, received an undisclosed amount from **Virgin Fuels** in 2007 to develop butanol and isobutanol from biomass for airplanes.[101] This fuel would be used in Virgin Group's airline company, which prides itself as being the first airline to fly with biofuels.[102]

Corporate Money to Universities:

Corporate money has even spilled over into public research institutions. In one particularly controversial research agreement, **BP** invested $500 million in the **University of California Berkeley** to develop fuels through synthetic biology.[103] UC Berkeley is leading the initiative with the Lawrence Berkeley National Laboratory (LBNL) and the University of Illinois at Urbana-Champaign, to develop microbes that break down different feedstocks into a number of biofuels including biodiesel, butanol, and hydrogen. BP also invested an undisclosed amount into **Arizona State University** to develop biodiesel-producing bacterium.[104]

UC Irvine has also seen private money flow in to fund synthetic biology research for biofuels. **CODA Genomics** (which has since been renamed **Verdenzyme**) provided $1,670,000 in funding to engineer yeast with synthetic DNA that can turn switchgrass, hemp, corn, wood, and other natural materials into ethanol.[105]

While these investments are small compared with the profits Big Oil is bringing in, which top $40 billion a year,[106] it is a significant source of funding for the start-up synthetic biology corporations running the projects and the only thing keeping some of them operational. These investments have less to do with a dedication to sustainable energy production and more to do with bottom-line profits. The oil industry recognizes that alternative energy sources are gaining traction as the U.S. looks for alternatives to foreign oil. [107] Investments in synthetic biology are a strategic move by oil companies to control the future of fuel.

Eyebrows should be raised when the funders of alternative energy "solutions" to climate change are the same corporations who have polluted our climate and environment through emissions and oil spills for decades. These are the same corporations that are simultaneously funding climate skeptics whose only goal is to convince the public and policymakers that climate change is not even happening.[108] One must question if these companies are dedicated to truly transforming our energy sector or if they are just trying to placate policymakers through investments in "clean" technologies and own any future fuel that may come into use through patent protections.[3]

Investments in synthetic biology by Big Oil corporations are nothing short of a way to own and control a potential future fuel supply.

Exxon, the world's largest and wealthiest publicly traded oil company, is notorious for not funding alternative energy sources. It therefore came as a surprise to many that their first major investment into alternative fuels went to synthetic biology research in 2009 – $600 million to Synthetic Genomics (only around 1 percent of Exxon's $44.22 billion profits from that year). Synthetic algae-based fuel was appealing to Exxon since fuels from algae can be designed to have similar molecular structures to petroleum products and therefore can be used in their existing processing infrastructure. Exxon and Synthetic Genomics also hope to create algae that can absorb large amounts of carbon dioxide in an attempt to offset other "dirty" energy sources. This move by Exxon is nothing short of green-washing their dirty reputation. It is short-sighted to create new and unpredictable life forms that fit with our current infrastructure instead of investing in a new, clean, and sustainable infrastructure.

The development of biofuels through synthetic biology is dependent on cooperation and funding from Big Oil. As Venter has stated in regards to developing a biofuels sector, "These changes can't take place without a leader in the fuel industry."[109] By investing in synthetic biology, oil and agriculture corporations are betting against the development of a truly clean energy supply and infrastructure.

Patents on Life & the Control of a Future Fuel Supply:

Investments in synthetic biology by Big Oil corporations are nothing short of a way to own and control a potential future fuel supply. What is more frightening about the current corporate rush to fund synthetic biology is that unlike oil or natural gas, these organisms are *alive* – and will be owned by the Exxons and the BPs of the world.

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3 *Companies should be applauded if they begin to embrace sustainable sources of fuel. But Big Oil continues to argue climate change is not even real – contrary to decades of strong scientific evidence - and they continue to fight for lax or non-existent regulations of oil production, whether it is oil from the ground or algae. It is clear that their interest lie in profit and not protecting the environment or public health. We need companies committed to sustainable energy production, not corporations who may abandon a promising technology to support a dangerous technology—such as synthetic biology—because it could make them a quick profit.*

In 1980, the Supreme Court ruled in *Diamond v. Chakrabarty* that genetically engineered life forms could be patented. While the case was referring to more traditional genetic engineering, the court's ruling extends to the products of synthetic biology: "…the patentee has produced a new bacterium with markedly different characteristics from any found in nature and one having the potential for significant utility. His discovery is not nature's handiwork, but his own: accordingly it is patentable subject matter."[110]

As the ETC Group highlights in its comprehensive report *Extreme Genetic Engineering*, patents have already been granted on many of the processes and products involved in synthetic biology, including patents on: methods for building synthetic DNA, synthetic genes and DNA sequences, synthetic pathways, synthetic proteins and amino acids, and novel nucleotides that replace the letters of DNA. [111]

In 2007, the J. Craig Venter Institute applied for a frighteningly broad patent of its "minimal bacterial genome" called *Mycoplasma laboratorium.* This organism was an attempt to create life with the minimum number of genes by cutting out as many DNA sequences as possible without removing its ability to reproduce or survive. U.S. patent number 20070122826 describes creation of the first-ever, entirely synthetic living organism – a novel bacterium whose entire genetic information is constructed from synthesized DNA. This patent claims exclusive monopoly on: the genes in the minimal bacterial genome, the entire organism made from these genes, a digital version of the organism's genome, any version of that organism that could make fuels such as ethanol or hydrogen, any method of producing those fuels that uses the organism, the process of testing a gene's function by inserting other genes into the synthetic organism, and a set of non-essential genes. [112]

While this patent was denied, the claim shows the extent to which synthetic biologists are testing the limits in the battle to control the fundamental building blocks of life and actual living organisms. The patenting of living organisms is an issue worthy of its own report, but it is important to note here since it is through patents that these corporations hope to control the production, processing, and distribution of fuels. Also of concern, as mentioned in section 2, is the potential for a synthetic and patented organism to escape into the environment. First, much of the information on these organisms is being kept secret as proprietary so proper risk assessments cannot be conducted beforehand. Second, once the synthetic organisms escape researchers might not be able to study them to develop clean-up mechanisms since this may violate the patent – as is seen in researchers' inability to study the full risks of genetically engineered crops.[113]

6. Case Study: Amyris

Background on Amyris:

Amyris Biotechnologies was founded in 2003 by Jay Keasling. Dr. Keasling serves as the Deputy Laboratory Director of the Lawrence Berkeley National Laboratory, the Chief Executive Officer of the U.S. Department of Energy's (DOE) Joint BioEnergy Institute and a professor of chemical and bioengineering at the University of California Berkeley. A leader in the emerging field of synthetic biology, Keasling first gained notoriety for his production of arteminisic acid – a precursor to the important anti-malarial medicine arteminisin – through the creation of *E. coli* with synthetic DNA. Unlike traditional genetic engineering that often transfers one or two genes, this process transfers at least 14 genes into the bacteria, [114] one of which was synthetic amorphadiene syntase.[115]

While the desire to produce affordable anti-malarial drugs is laudable, it is important to note that thousands of farmers throughout Africa and Asia depend on the natural production of arteminisin.

With the help of $43 million from the Bill and Melinda Gates Foundation, a non-profit partnership was established between Amyris, the Gates Foundation, and the Institute for OneWorld Health to scale-up and eventually commercialize synthetic arteminisin production.[116] Arteminisic acid is traditionally found in the sweet wormwood plant, *Artemisia annua*, but natural production levels are low and cannot currently meet current world demand.

While the desire to produce affordable anti-malarial drugs is laudable, it is important to note that thousands of farmers throughout Africa and Asia depend on the natural production of arteminisin.[117] Instead of promoting the growth of these markets, which would bring a sustainable source of income to thousands of the world's poor, the Gates Foundation has instead decided to fund an American corporation, in a sense ignoring innovative approaches to sweet wormwood production that empower the world's poor and are already being utilized. For example, Anamed (Action for Natural Medicine) is promoting sustainable artiminisin production with "artemisia starter-kits" that include seeds and instructions on how to plant, harvest, and use the plant to create an anti-malarial tea in places where other medicine is unavailable.[118] The Anamed Artemisia Programme includes more than 1,000 people in more than 75 countries.

As the above story exemplifies, there are often low-cost, low-tech solutions to many of the problems being addressed by synthetic biology without the risks of social upheaval and environmental degradation. Amyris' biofuels production will have similar socio-economic effects that will lead to environmental degradation and disempowerment of local communities.

Since Amyris would not make money from its non-profit arteminisin endeavor they had to look for a new application of their technology. Keasling had been involved in energy production research for some time at the Joint BioEnergy Institute and is close to Steven Chu, the U.S. Secretary of Energy who was his predecessor at the

Lawrence Berkeley National Laboratory, so biofuels production was a logical source of profit for Amyris.

Amyris is using similar synthetic biology methods to create biofuels as they did for anti-malarial medication. This technology is based on the creation of synthetic pathways that lead to the production of isoprenoids – molecules used in a wide variety of energy, pharmaceutical, and chemical applications. Using yeast with synthetic DNA, Amyris claims they are able to convert plant-based feedstocks into 50,000 different isoprenoids. The image to the right, from Amyris, shows how this process is being used for fuel production.

Instead of creating alcohols such as ethanol, which cannot be used in pipes or other infrastructures since it is too corrosive, their yeasts are able to turn sugar into combustible hydrocarbons that resemble diesel fuel, gasoline, and jet fuel and can therefore be used in traditional engines.

Biofuels Production in Brazil:

Amyris' feedstock of choice is sugarcane. To guarantee a long-term supply, Amyris started creating partnerships in the world's largest sugarcane producing country – Brazil. They also opened a fully-owned subsidiary, Amyris Brazil, in Campinas, São Paulo, near Brazil's cane processing industry.

In 2008, Amyris and Crystalsev, of Brazil's largest ethanol distributors and marketers, created a joint venture "Amyris-Crystalsev." This venture named Brazil's former Minister of Agriculture Roberto Rodrigues to its Strategic Advisory Board. In December of 2009 the company bought a 40 percent stake in Sao Martinho Group's (one of the largest sugar and ethanol producers in Brazil) Boa Vista mill to process sugar cane. A few days later they announced deals with Bunge, an international food conglomerate who processes and trades sugarcane in Brazil, Cosan Guarani, a subsidiary of the French sugar corporation Tereos and Brazilian-based Açúcar Guarani, which cultivates and processes sugarcane. Amyris has also partnered with Brazilian sugarcane company Canavialis, which was bought by Monsanto in 2008,[120] to produce jet fuels for the U.S. Department of Defense from sugarcane grown in Alabama.[121,122]

These agreements would allow Amyris to build "bolt-on" facilities attached to their current ethanol plants to produce Amyris' fuels. According to Amyris' filing for Initial Public Offering with the U.S. Securities and Exchange Commission, they "expect these arrangements to provide [them] with access to over ten million tons of sugarcane crush capacity annually, which [they] intend to expand over time with these and other mills."[123] Amyris also licensed its propriety technology to Santa Elisa, the second largest ethanol producer in the country.

To scale-up their fuel production capabilities Amyris received

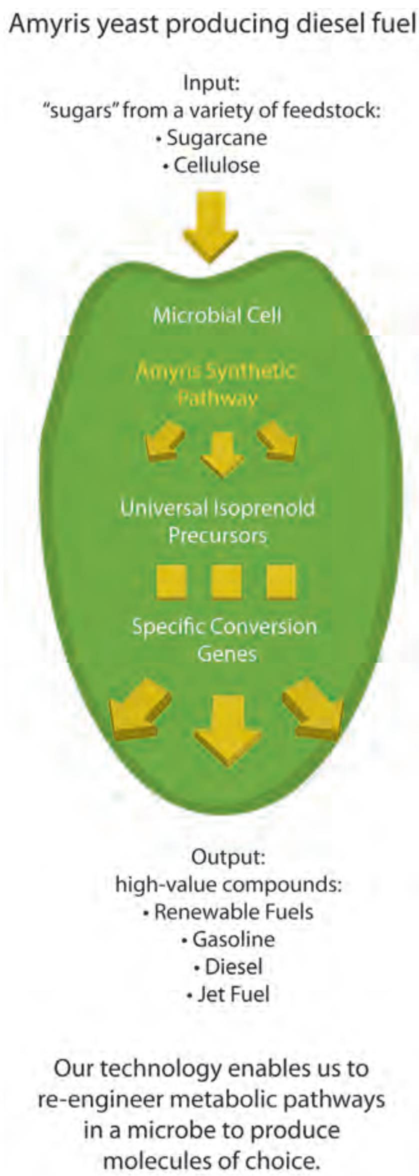


Image Courtesy of Amyris Biotechnologies[119] help from experts in the field. They hired the former President of U.S. Fuel Operations for BP, John Melo, as their Chief Executive Officer. Ralph Alexander – formerly the CEO of BP's Gas, Power and Renewables and Solar segment and a member of the BP executive group – was brought on board as the Chair of Amyris' Board of Directors. BP also gave $500 million to UC Berkeley and the Lawrence Berkeley National Lab to develop biofuels through synthetic biology[124] – both with ties to Jay Keasling and his biotech start-up.

Sugarcane production for biofuels is accelerating deforestation, water contamination, and increasing atmospheric pollution.

The Problem:

Amyris claims that their product will be "a perfect renewable fuel" that can reduce "lifecycle [greenhouse gas] emissions of 80 percent or more compared to petroleum fuels."[125] While it is unclear where Amyris gets its calculations from, it is known that most studies on the environmental impact of biofuels do not take into account the mode of production for the feedstocks and it is likely that Amyris did not look into the emissions from industrial sugarcane production. As *Time Magazine* has noted in reviews of general biofuels impacts, "it is as if these scientists image that biofuels are cultivated in parking lots."[126] But unfortunately sugarcane cannot be grown in parking lots and requires nutrient-rich soils and large amounts of land and water to be grown.

What we do know is that sugarcane production in Brazil is far from sustainable and the recent increase in demand for biofuels is accelerating deforestation, soil degradation, water contamination, destruction of native vegetation, and increasing atmospheric pollution from sugar cane fires – particularly in the Cerrado. The Cerrado (a savannah) is home to nearly 160,000 species of plants and animals, many of which are endangered. According to a 2008 report by Maria Luisa Mendonça, nearly 22,000 square kilometers of savannah are cleared every year. Estimates claim that over half of the region has already been devastated, and at this rate it will be completely destroyed by the year 2030.[127]

Despite this fact, the Brazilian government has targeted the Cerrado as a location for new biofuels plants – including the Boa Vista Mill that Amyris partially owns. Due to the Cerrado's flatness, soil quality, and access to water, it is an ideal location for sugar cane production[128] and is the only region the government allows sugarcane to even be planted. The Brazilian Institute of Geography and Statistics has shown that in 2007, sugarcane production occupied about 5.8 million hectares of the Cerrado.[129]

To plant sugarcane, all native plants and trees must be uprooted, affecting not just the environment but local communities. As one report from the Society, Population, and Nature Institute (ISPN) has noted, deforestation for sugarcane production "directly harms rural populations who survive off the biodiversity of the Cerrado. The other terminal consequence is that small food farmers leave their lands, having been lured into temporary employment in the sugarcane fields. This will diminish the food production in the area, which only serves to aggravate the migration to urban slums."[130]

Brazil's monoculture sugarcane production has other environmental impacts outside of land-use changes. Eighty percent of Brazil's sugarcane crops are set on fire to reduce cane straw, making manual harvesting and transportation easier. Smoke from these fires has been shown to harm nearby communities and native animals.[131] Sugarcane plantations require an incredible amount of water and often divert local rivers away from communities and farmers growing food. They have also led to increased use of fertilizers and pesticides.[132] The sugar plantation industry also has a dark history of slave labor and worker exploitation that it has yet to eliminate.[133]

The Cerrado, the center of Brazil's industrial sugarcane industry.

Amyris will need an incredible amount of sugarcane to compete against oil, gas, and ethanol production. Amyris' pilot project in California produced 2.4 million gallons of fuel at annual capacity. They plan to make 200 million gallons of synthetic biofuels a year by 2011. The needed feedstock to produce at this capacity does not grow on parking lots but rather on priceless land that is home to diverse life. Further, the spread of sugarcane production is pushing other forms of agriculture deeper into previously forested lands such as the Amazon. While the direct emissions from Amyris' fuel might be less than burning traditional fossil fuels, when we take these other environmental effects into account the picture begins to look much less green.

The chart on the next page highlights Amryis' close ties to Big Oil, the U.S. government, and Brazilian sugarcane and ethanol producers. Similar webs would be drawn for most synthetic biology corporations and the following is provided as way of example.

7. Public Money for Private Profit: Federal Support for Synthetic Biology

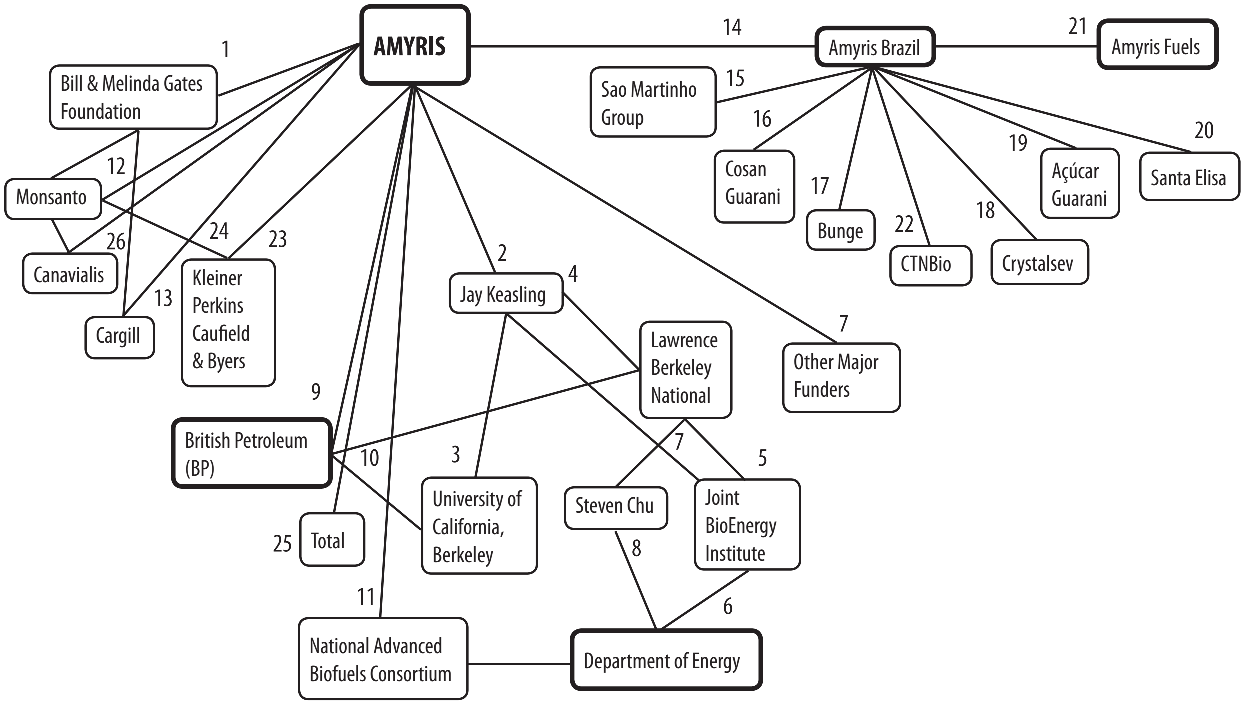
The Revolving Door:

The federal government, particularly the Department of Energy (DOE), has been one of synthetic biology's biggest supporters. This comes as no surprise since the revolving door between industry and government has been swinging smoothly.

Aristides Patrinos was the associate director of the U.S. Department of Energy's Office of Biological and Environmental Research under President George W. Bush. He oversaw both the Human Genome Project and the Genomes to Life program, the latter of which supports synthetic biology research for biofuels and other technological fixes, such as carbon sequestration.[134] Patrinos left the Bush administration in 2006 to become president of Craig Venter's emerging company Synthetic Genomics.

Secretary Steven Chu has been a leading proponent of synthetic biology. As head of the Lawrence Berkeley Lab, Secretary Chu advocated for using synthetic biology to create brand new organisms based on the microbes normally found in the guts of termites to

AMRYIS' LINKS TO BIG OIL, THE U.S. GOVERNMENT, AND BRAZILIAN SUGARCANE AND ETHANOL PRODUCERS



1. The Bill & Melinda Gates Foundation provided $43 million to create Amyris for their production of synthetic anti-malarial medicine.
2. Dr. Jay Keasling founded Amyris Biotechnologies in 2003 with funding from the Gates Foundation.
3. Keasling is a Professor of Chemical Engineering and Bioengineering at the University of California, Berkeley.
4. Keasling is the Director of the Lawrence Berkeley National Laboratory, a Department of Energy lab conducting synthetic biology research run by UC Berkeley.
5. Keasling is also the chief executive officer of the Joint BioEnergy Institute, a partnership including the Lawrence Berkeley National Laboratory, who aims to produce next-generation biofuels.
6. JBI is one of the Department of Energy's three new Bioenergy Research Centers.
7. Steven Chu is the former director of the Lawrence Berkeley National Laboratory where he used synthetic biology to produce ethanol.
8. Steven Chu is the current U.S. Secretary of Energy under President Obama. DOE is one of the largest funders of synthetic biology research, over $305 million in 2009 and a similar amount is expected to be spent in 2010.
9. John Melo, CEO of Amyris, was formerly the President of U.S. Fuels Operations for British Petroleum (BP). Ralph Alexander, Director of Amyris' Board of Directors, is Chief Executive Officer of Innovene, BP's former $20bn olefins and derivatives subsidiary and was also Chief Executive Officer of BP's Gas, Power and Renewables and Solar segment and was a member of the BP group executive committee.
10. BP gave $500 million to UC Berkeley and the Lawrence Berkeley National Lab to develop biofuels through synthetic biology.
11. Amyris is a partner in the National Advanced Biofuels Consortium, which received $33.8 million from the Department of Energy in 2009.
12. Carole Piwnica, a member of Amyris' Board of Directors, also sits on Monsanto's advisory board.
13. Peter Boynton, Chief Commercial Officer of Amyris, worked for Cargill for 18 years.
14. Amyris Brazil is a subsidiary of Amyris strategically located in Campinas, São Paulo, near Brazil's cane processing industry. This company was created with the intent to scale-up Amyris' technology leading towards full-scale commercialization.
15. Amyris recently bought a 40% stakeholder in Sao Martinho Group's (one of the largest sugar and ethanol producers in Brazil) Boa Vista mill to process sugar cane.
16. Cosan Guarani is a Brazilian sugar processor (subsidiary of French sugar corporation Tereos) which recently joined a partnership with Amyris.
17. Bunge, an international food conglomerate who processes and trades sugarcane in Brazil, recently joined a partnership with Amyris.
18. Amyris and Crystalsev, of Brazil's largest ethanol distributors and marketers, have created a joint venture "Amyris-Crystalsev." Fernando Reinach, on Amyris' board, serves as an advisor to this venture.
19. Açúcar Guarani cultivates and processes sugarcane. They also entered into partnership with Amyris along with Cosan Guarani, Bunge, and Crystalsev at the end of 2009.
20. Amyris has licensed its technology to Santa Elisa, the second largest ethanol producer in Brazil.
21. Amyris' Chicago-based subsidiary that distributes ethanol.
22. CTNBio, the Brazilian Federal Science and Technology Department, approved Amyris Brazil's request for the release of genetically modified yeast for commercial production to produce farnesene in early 2010. Luciana di Ciero, formerly with the University of Sao Paulo is now Amyris Brazil's Regulatory & Institutional Relationships manager. She has been a strong promoter of biotechnology.
23. Venture firms Kleiner Perkins and Khosla Ventures each owned 15.4 percent before the IPO, TPG Biotechnology Partners II, L.P owns 12.1 percent, Advanced Equities Financial Corp owns 6.4 percent. Other investors includ DAG Ventures, and Cornelio Brennand - a Brazilian real estate and energy group.
24. John Doerr, a partner at Kleiner Perkins Caufield & Byers, is a former design engineer for Monsanto.
25. In June 2010, Amyris announced that it has formed a partnership with major international oil and gas company Total (based in France) to work jointly on R&D of synthetic pathways for organisms to produce fuels.
26. Amyris has partnered with Brazilian sugarcane company Canavialis, which was bought by Monsanto in 2008, to produce jet fuels for the U.S. Department of Defence from sugarcane grown in Alabama.

Amyris Biotechnologies has officially filed to raise $100 million in an IPO. The company, which will go public under the symbol AMRS, already raised a total of $244 million in funding and plans to start producing its synthetic organism-based biofuel at commercial scale in 2011.

produce ethanol from cellulose.[135,4]

In Secretary Chu's first year in charge of the Department of Energy (DOE), the Department spent more than $305 million on synthetic biology research and a similar amount is expected to be spent in 2010.[136] Most of this research funded by the DOE is done out of the Joint Bioenergy Institute (JBEI), a six-institution partnership led by Lawrence Berkeley National Laboratory.[137] A report from the Synthetic Biology Project out of the Wilson Center has shown that the U.S. government has spent more than $430 million on synthetic biology research since 2005. Only 4 percent of this has been used to research the ethical, legal, and social implications of synthetic biology.[138] The report did not show the amount of funding going to assess environmental risks, most likely since no funding is being put towards this purpose.

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Federal Grants to Synthetic Biology Companies:

Major programs funded by the federal government are highlighted below as examples of the types of projects under development. This list is not meant to be comprehensive:

Sapphire Energy has received $50 million from DOE and a loan guarantee for $54.5 million from the U.S. Department of Agriculture (USDA) to build a pilot plant in New Mexico for the production of algal fuel. While they will be using natural algae initially, their use of biotechnology and synthetic biology is no secret.[139] Sapphire has on staff the former CEO of **Monsanto** and a former executive of **BP**.[140]

Novozymes has received $29.3 million from DOE for a number of projects to develop synthetic enzymes.[141] The *Cellic® CTec2* enzymes break down cellulose from different feedstock types (including corn cobs and stalks, wheat straw, sugarcane, and woodchips) into sugars that are fermented into ethanol.

In 2003, DOE provided **Genencor** (a division of Danisco USA) $17 million through its National Renewable Energy Laboratory (NREL) to use synthetic enzymes for biofuels production[142]

Boston-based **Mascoma** received $26 million from DOE in 2008 for the development of cellulosic ethanol from woodchips through the use of "propriety microorganisms and enzymes."[143]

In 2008, DOE announced $33.8 million in funding to go to four synthetic biology projects focused on enzyme production over four year. Besides Novozymes (mentioned above), three other companies received funding for similar work: **DSM Innovation Center Inc.** is using its proprietary fungal systems to develop new approaches to improve enzymes for the conversion of pre-treated cellulosic biomass into sugars for fermentation into cellulosic ethanol. **Genencor**

4 These synthetic organisms could theoretically take termites' ability to break down wood (as they are so famous for doing in people's houses) and turn it into energy. This raises the question as to what would happen to all of the trees and wood in the environment, our houses, and buildings across the world if these organisms were to leak out of the laboratory.

plans to reduce the enzyme-dose level required for biomass conversion to sugar by improving the specific performance of a fungal-based enzyme. **Verenium Corporation**'s project will use their synthetic enzymes to produce a more cost-effective enzyme solution for biomass saccharification that would supposedly lead to more economic cellulosic ethanol production.[144]

The Danforth Plant Science Center of Missouri was the recipient of $15 million in 2009[145] and $44 million in 2010 (as the leader of The National Alliance for Advanced Biofuels and Bioproducts)[146] from the DOE for its research into algae-based biofuels. Danforth, through its Center for Advanced Biofuels Systems and the National Alliance For Advanced Biofuels and Bio-Product (NAABB), hope to develop new strains of algae that can produce biofuels more efficiently and affordably than their natural counterparts. The Danforth Center is closely linked to the biotech giant Monsanto, so much so that Tom Philpott of *Grist Magazine* referred to it as "essentially that company's NGO research and PR arm."[147] Much of its start-up funds were provided by the Monsanto Fund, and the president and CEO of Monsanto sits on the Danforth Center's Board of Directors.[148]

The former director of Danforth, Roger Beachy, was appointed by President Obama to run the USDA's newly-formed National Institute for Food and Agriculture (NIFA) in 2009. NIFA provides over $400 million in agriculture research across the country per year. One of NIFA's main priorities is the development of next-generation biofuels through the use of biotechnology. NIFA's 2009 budget for biofuels and bio-based products was around $2.5 million[149] and is expected to expand in 2010.[150] Of that funding, a significant amount was given to synthetic biology research.

Kuehnle Agrosystems received $350,000 to create three synthetic forms of algae that can be used for biofuels production and other commercial uses. **Allopartis Biotechnologies** received $80,000 from NIFA for the development and modification of proteins to break down biomass.[151]

The USDA had also provided synthetic biology funding through NIFA's predecessor, the Cooperative State Research, Education, and Extension Service (CSREES). In 2009, USDA gave $1.8 million to **Gevo** for the development of synthetic yeast that can turn cellulosic-derived sugars into isobutanol, a second generation biofuels/bio-based product that can be used for fuel or plastics.

Outside of its synthetic biology research for eternal organisms that was discussed earlier, the Department of Defense (DOD) has also been investing in synthetic biofuels development. In 2009, the DOD provided $8.5 million to **Solazyme** for the production of over 200,000 gallons of algae-based jet fuels, specifically for the F-76 Navy ships.[152] Solazyme's synthetically engineered algae are grown in the dark and fed sugars from cellulose.

Amyris Biotechnologies has partnered with Brazilian sugarcane company **Canavialis**, which was bought by **Monsanto** in 2008,[153] to produce jet fuels for DOD from sugarcane grown in Alabama.[154,155]

The above list is just a sample of the hundreds of millions of dollars of public money that is going to private interests to help develop the field of synthetic biology. These synthetic organisms are almost always patented. Since such significant funding is being provided by taxpayers, the public has the right to demand a strong regulatory framework to protect the environment and human health from this new technology.

It should also be noted that funding projects that were highlighted are specifically for synthetic biology research. The U.S. government has also been a major source of funding for more "traditional" genetic engineering research. According to the Union of Concerned Scientists, "in the 11-year period of 1992 to 2002, the USDA spent approximately $1.8 billion on biotechnology research,"[156] an amount that has no doubt increased since that time.

Support Through Federal Biofuels Policy:

The U.S. government is supporting synthetic biology not only directly through grants but also indirectly through federal biofuels policies, particularly biofuels tax credits and the Renewable Fuel Standard (RFS).

The U.S. has a long history of supporting the production and use of biofuels without much concern for their environmental impact. The rush to produce biofuels without considering the indirect impact is fueled by the desire to reduce the use of foreign oil, particularly in times of high oil prices or under the auspice of national security, and also to create an additional market for U.S. agricultural commodities. Unfortunately, the development of conventional biofuels in the U.S., such as corn ethanol and soy biodiesel, has resulted in widespread environmental damage in the form of increased water and air pollution from agrochemicals as well as land-use competition with food production and natural ecosystems.[157] In the last several years this has encouraged development of new forms of biofuels, ones that do not have adverse impacts. However, in an attempt to avoid these problems, other ones have arisen, including the development of synthetic organisms.

Ethanol and corn ethanol, in particular, have benefited from tax subsidies for more than 30 years which have been renewed every few years. At present, this credit is worth $0.45 per gallon blended with gasoline.[158] Biodiesel also has a separate credit worth $1.00 per gallon blended with diesel fuel.[159] And, lastly, cellulosic biofuels have their own production tax credit worth $1.01 per gallon.[160] Cellulosic biofuels is a liquid fuel produced from any lignocellulosic or hemicellulosic matter available on a renewable basis. As was discussed in section 5, organisms are being genetically engineered with synthetic enzymes to break down the cellulose into sugars which can be converted to fuel. While there are naturally occurring enzymes that are being developed for this purpose, the market is

The U.S. government is supporting synthetic biology not only directly through grants but also indirectly through federal biofuels policies, particularly biofuels tax credits and the Renewable Fuel Standard (RFS).

leaning towards synthetic ones since proponents claim they will be more efficient.

The second main policy driving biofuels production in the U.S. is the Renewable Fuel Standard, which mandates the consumption of an increasing amount of biofuels each year. Created originally in 2005, and expanded upon in 2007, the RFS mandates that a total of 36 billion gallons of biofuels be blended into fossil transportation fuels by the year 2022.[161] Of those 36 billion gallons, approximately 15 billion gallons are allotted for "conventional" biofuels, which is widely assumed will be filled by corn ethanol.

The remaining mandate is for so-called "advanced" biofuels, which includes any other form of biofuels besides that which is produced from corn starch. Of the "advanced" biofuels portion, 16 billion gallons are supposed to come from cellulosic biofuels.[162] Cellulosic biofuels in the RFS are defined include those renewable fuels derived from cellulose, hemicelluloses or lignin. The remaining portion of the "advanced" biofuels category will likely be filled with sugar ethanol and some soy biodiesel, though could also be filled with non-cellulosic next-generation biofuels, such as those produced from algae.

The RFS mandate serves as an indirect subsidy for the industry because it creates a guaranteed market for biofuels. This means that biofuels must be purchased at whatever price the industry demands irrespective of market demand. It is widely expected that cellulosic biofuels will not be able to achieve the RFS mandate levels, especially in the near term and EPA has already reduced the mandate accordingly. While the RFS does contain some minimal environmental performance standards, including protections for forests and other natural ecosystems, as well as global warming emission thresholds[5], there is no incentive to produce biofuels from naturally-occurring biomass or to reduce the use of invasive species.

Tax credits for cellulosic biofuels and the RFS mandate for "advanced" biofuels are both supporting developments in synthetic biology. Without these two policies it would be much more difficult, if not impossible, for biofuels produced from synthetic organisms or any other method to compete with other sources of energy. The government must use tax and energy policy to support safe, proven, and sustainable sources of clean energy – not dangerous and unproven technologies such as synthetic biology that threaten to do more harm than good.

8. Safety Rules Can't Keep Up

Federal regulation:

The field of synthetic biology is void of any regulation, allowing researchers to freely manipulate the basic code of life without any

5 *Biofuels produced at biofuel plants that already existed prior to 2007 will not have to comply with the emissions standards.*

oversight. Three federal agencies—the Food and Drug Administration (FDA), the Environmental Protection Agency (EPA), and the Department of Agriculture (USDA)—have refused to regulate any new form of genetically modified or synthetic organisms.

The first federal guideline that attempts to oversee the emerging field of synthetic biology came from the Department of Health and Human Services (HHS) in 2010. This guideline provides rules for screening synthetic DNA in an attempt to flag any DNA sequences that may be used to create anything a biological weapon or any other dangerous virus or toxin. Unfortunately, following the guidelines is entirely voluntary for DNA synthesis companies[163] whose profits are derived from selling more – not less – of their product. It is entirely possible for a bad actor to purchase synthetic DNA and build a potentially deadly virus under the current rules. The Recombinant DNA Advisory Committee (RAC) of HHS has also decided to review some synthetic biology research but will not look at projects using synthetic DNA of 100 oglionucleotides or less. This decision was made at the request of the synthetic biology and biotechnology industries since it is at this level – 100 base pairs of DNA or less - that much of the synthetic biology research is currently being conducted. Decisions of oversight should be based on potential risk of harm not convenience for the industry.

Decisions of oversight should be based on potential risk of harm not convenience for the industry.

HHS's soft voluntary screening process is far from adequate. There are no industrial safeguards in place to protect lab workers from infection or contamination from synthetic biology products, nor are there any protocols to prevent the release of synthetic biology products into the environment. A recent case of a Pfizer worker who says she has been intermittently paralyzed by a genetically engineered virus she was working on shows that these dangers are real and serious.[164] Anyone can order online manufactured pieces of DNA, and build a synthetic organism in their basement, since there are no regulations on the rapidly growing market of manufactured DNA. Used DNA synthesizing machines can be purchased online through auction sites for as little as $1,000. As a May 2010 *New York Times* headline expressed, our "safety rules can't keep up with [the] biotech industry."[165]

Self regulation:

Proponents of synthetic biology are framing this technology in two very different lights to different audiences. To corporate investors and venture capitalists synthetic biology is being portrayed as a new, emerging, and exciting technology that is manipulating life in ways never even imagined before. When discussing regulations, on the other hand, they change face and portray synthetic biology as nothing more than a simple extension of current genetic engineering technology that should not be placed under any different or stronger regulations. Synthetic biologists should not be allowed to have it both ways.

Scientists working on "traditional" genetic engineering technologies hoped to preempt any government regulations by drafting the *Asilomar Declaration of 1975*. This declaration was a short-lived moratorium on some of their work but was hailed as a prime example of industry self-regulation. As we have seen in the years since, genetic engineering technology has moved forward at a rapid pace without any real self-regulation and barely any government oversight.[166]

Synthetic biologists have made several unsuccessful "Asilomar-type" attempts at self-regulation. In 2006, Stephen Maurer of the Information Technology and Homeland Security Project at UC Berkeley's Goldman School of Public Policy proposed a list of self-governance guidelines based on interviews of those working in the field. These guidelines included a boycott of gene synthesis companies that do not screen orders for dangerous pathogens, the development of software that could check if genetic sequences could be used to create dangerous pathogens, and a hotline for synthetic biologists to call if they had ethical concerns about their work.[167] These soft, voluntary attempts at self-regulation did not convince the strongest supporters of synthetic biology that they would have any effect. At a public event to discuss these regulations, Drew Endy said "I don't think [these proposals] will have a significant impact on the misuse of this technology."[168]

The second annual synthetic biology conference, SynBio 2.0, in May 2006 was being portrayed as "Asilomar 2.0," the meeting where synthetic biologists came together and wrote a set of self-regulations that would protect the environment and help perpetuate the field. Unfortunately, civil society was blocked from attending this conference to share the views of communities that will be most impacted by this technology. In response 38 civil society organizations,[169] including Friends of the Earth, the International Center for Technology Assessment and ETC Group, drafted an open letter to the conference attendees dismissing the proposals for self-governance as severely inadequate. Sue Mayer, director of GeneWatch, said "Scientists creating new life-forms cannot be allowed to act as judge and jury. The implications are too serious to be left to well-meaning but self-interested scientists. Public debate and policing is needed."[170]Asilomar 2.0 failed to produce any results. Synthetic biologists were too concerned about hurting the gene synthesis, synthetic biology efforts, and their own personal progress to agree on even weak attempts at self-regulation.

The J. Craig Venter Institute and MIT also attempted to draft self-regulations the following year in their report "Synthetic Genomics: Options for Governance."[171] This document was limited in scope to biosecurity and biosafety, focused solely on U.S. governance, and failed to consult civil society. One of the report's main criteria for effective governance was whether a regulation would "minimize costs and burdens to government and industry."[172] This is not a goal for regulation but rather an argument for no oversight. Protecting the environment and human health should be the main priority when regulating any technology. In the end, the report's recommendations were more soft approaches such as monitoring and controlling gene synthesis firms and DNA synthesizers, educating synthetic biology practitioners and strengthening Institutional Biosafety Committees (IBCs).

It is clear that self-regulation will not work since the industry is more interested in promoting the quick growth of synthetic biology. Even so, attempts of self-regulation by the synthetic biology community have failed, largely due to their inability to agree on even the weakest of rules. The best way to ensure that synthetic biology efforts do not cause unintended environmental or public health harms is for the federal government to establish strong precautionary regulations before this technology develops too far.

Synthetic Biology is Not Our Only Option:

Many proponents threaten that if regulations are established, it will lead to devastating results. As Jay Keasling of Amyris once said, "If we choose to regulate the industry, we have to be willing to pay the price for that, which means there won't be cheap anti-malarial drugs developed and there won't be potential biofuels developed or other drugs for diseases and cleaning up the environment and all the things that come from this area."[173] Keasling does not mention that any medicines would still require FDA approval – a form of regulation under which the pharmaceutical industry has still been able to thrive.

Instead of turning to biofuels to save the environment, investments can be made in clean energy technologies and updating the energy grid.

Arguments like Keasling's create a false dichotomy between sustainable fuels and environmental degradation; between life-saving medicine and wide-spread disease. While the potential benefits of synthetic biology, such as anti-malarial medicine, could better society the choice is not that simple. Malaria could be prevented by helping communities around the world escape poverty so they can afford bug nets and build up water infrastructure so mosquitoes do not have still water on which to lay and hatch eggs. Moreover, many of the areas with the worst malaria are areas still in the midst of civil war where millions of people are forced into swamps to survive and then go to refugee camps where mosquitoes hop from person to person and spread malaria. While synthetic artemisinin may be a tool in the fight against malaria, it is not the only available tool and would not eradicate the root causes of malaria and poverty. And like most malarial drugs, it will become less effective over time.

For fuel production, the choice is not just between dirty fossil fuels and products from synthetic organisms. Instead of turning to biofuels to save the environment, investments can be made in clean energy technologies and updating the energy grid so it can be connected to wind turbines, solar panels, and electric cars across the country. Investments in energy efficiency can reduce the strain on energy resources. There wouldn't be a need for synthetic bacteria to eat up oil spills if no one was using dirty oil for energy and if the corporations that contaminate the environment were held accountable. Oil created from synthetic organisms that mimics the structure of natural oil only deepens dependence on an out-dated energy infrastructure. And as a recent study has shown, biofuels from algae may not even reduce overall emissions.[174]

The risks synthetic biology pose to human health and the environment are serious since synthetic biology has the ability to create organisms that have never existed before and their complexity will only increase over time. We must establish a regulatory framework before this technology evolves too far and it is too late.

A federal moratorium on the release of synthetic organisms into the environment and on their use in commercial settings should be implemented.

The precautionary principle could guide the governance of synthetic biology to ensure that any harm caused by this technology do not outweigh any potential benefits. The fact that all the risks associated with novel living organisms are unpredictable supports the need to move forward with precaution. Researchers and corporations would be responsible for proving that none of these dangers are realized. In other words, synthetic microbes should be viewed as dangerous until proven to be safe – not the other way around.

What is needed is broad debate in society about the risks and benefits of synthetic biology and its impact on the environment, human health, human rights, security, and social justice. Conversations at the local, national, regional, and international level would ensure that all communities impacted by this technology would have input in its development – whether this is a technology that should be used, which applications are appropriate, and which are not. Since projects are being conducted across the world and organisms can travel between political borders it is important to ensure these conversations are international in scope. Only after these conversations have taken place in a fair, open, transparent, and democratic way should the real-world release and commercialization of synthetic or partially-synthetic organisms even be considered. If the risks and harms are found to be too great than this technology should not move forward.

9. Policy Recommendations

Moratorium on the Release of Synthetic Organisms

A federal moratorium on the release of synthetic organisms into the environment and on their use in commercial settings should be implemented until the impacts on the environment, biodiversity, human health, and all associated socio-economic repercussions, are examined. This moratorium should extend to "DIY-bio" research that is not affiliated with an institution or firm since there is no guarantee that research outside of professional laboratories can be contained.

Research in laboratories affiliated with an institution or firm should only be allowed to continue under strict regulations that ensure organisms do not escape into the natural environment. If this burden cannot be met, the research should be halted. At this point, synthetic biology research and products should stop at the laboratory door.

Permanent Ban on the Open-Air Use of Synthetic Organisms

A permanent ban on open-air experiments with synthetic organisms in ponds and areas not fully contained is needed to prevent the spread of organisms into the natural environment.

Environmental Impact Statements on All Federally Funded Research

Environmental Impact Statements (EIS) should be required for all synthetic biology research funded by the federal government, as required under the National Environmental Policy Act. [175] With hundreds of millions of taxpayer dollars going to private researchers to develop synthetic biology, their full environmental and societal impact should be analyzed before the research begins.

Federal Study on the Impacts of Synthetic Biology

Congress should appropriate the necessary funds to the Department of Health and Human Services, the USDA, EPA, or FDA to direct the National Academies of Science to conduct a study on the full environmental, public health, safety, and societal impacts of synthetic biology. This study should also research the ability (or inability) to contain such organisms. The last study on biological containment was conducted in 2004[176] and the section on the containment of viruses, bacteria, and other microbes was far from comprehensive.

Human Applications of Synthetic Biology must go through the Recombinant DNA Advisory Committee

All human applications of synthetic biology should be reviewed by the National Institute of Health's Recombinant DNA Advisory Committee (RAC) and the research made public. The go-to regulatory body, the FDA, does not have to disclose the results of its reviews and in the past has failed to demonstrate that it can adequately evaluate the safety of products with human applications and it should not be reviewing synthetic DNA drugs in secret. The RAC should change its policy to waive oversight for projects using synthetic oglionucleotides of 100 base pairs or less. Synthetic DNA of any length poses new risks that should be reviewed on a case-by-case basis.

Create a Federal Regulatory Body to Oversee All Synthetic Biology Research and Commercial Products

Congress should create a similar counterpart to the National Nanotechnology Initiative (NNI) to oversee developments in synthetic biology. Unlike the NNI, this body should have regulatory authority over research and should direct all federal funds that go towards synthetic biology projects to ensure that the money is used to study the environmental, public health, and socio-economic risks of this research. This organization can oversee and direct projects across the federal government and will be a central location for the public to see all projects that are being funded or are in development

Define Synthetic Biology and Any of its Chemical Products under TSCA

The Toxic Substances Control Act (TSCA) should be revised to include new language to define and regulate products created from synthetic biology. This definition should cover all synthetic organisms and products made from these organisms.

Do Not Extent Biofuels Tax Credits to Projects using Synthetic Biology

Efforts are underway to extend biofuels tax credits to algae biofuels operations. Congress should specify that if this tax parity were created it should only apply to naturally occurring algae. We do not fully understand – nor are we prepared for – the risks associated with genetically engineered and synthetic algae. Instead of promoting this unproven dangerous technology with tax credits, Congress must work to protect the environment and public health from the dangers of synthetic organisms and use the tax code to promote proven, safe technologies.

Direct the National Invasive Species Council (NISC) to Review Novel Risks from Synthetic Organisms

Executive Order 13112 created the National Invasive Species Council to ensure that federal programs and activities to prevent and control invasive species are coordinated, effective and efficient. NISC should review the novel risks posed by synthetic organisms and revise the National Invasive Species Management Plan to incorporate conclusions from the review. Organisms with synthetic DNA should be reviewed as potential invasive species, even if the DNA closely resembles that of naturally occurring organisms.

DNA Synthesis Companies Must have Mandatory Purchase Guidelines

Commercial DNA synthesis companies should be required by the Department of Health and Human Services (HHS) to screen all orders to verify that buyers are associated with recognized research institutions, and that the ordered DNA cannot be used to create select agents such as biological weapons or known viruses. All synthetic DNA orders should be stored in a database to ensure synthetic DNA can be traced back to the buyer and seller at any time.

Those Creating or Using Synthetic DNA Must be Licensed

Anyone using DNA synthesis machines, for both commercial and non-commercial use, must be registered with the Department of Health and Human Services. Those who are using synthetic DNA, for both commercial and non-commercial use, must be licensed by the Department. This should be applied even to those conducting DIY (do-it-yourself) biology experiments. If licensing and registration can be required for tattoo artists or hairdressers, it is reasonable to require those creating synthetic organisms to acquire basic education, training, and licensing.

Synthetic Biology Included in Regulation of Nanotechnologies

Synthetic biology is working on the nano-scale and should be regulated in a similar fashion as other nanotechnologies. Contrary to what supporters of synthetic biology want the public to believe, this technology is an extreme version of genetic engineering and its potential to create new life forms is unprecedented. Synthetic biology is converging with other nanotechnologies, robotics, and information technology. Any regulations should look at these emerging technologies as whole and not isolated parts.

Convention on Biological Diversity

The scientific body (the Subsidiary Body on Scientific, Technical and Technological Advice – SBSTTA 14) of the UN's Convention on Biological Diversity (CBD) recently proposed draft text that would establish an international moratorium on the release of all synthetic organisms into the environment until "there is an adequate scientific basis on which to justify such activities and due consideration of the associated risks for the environment and biodiversity, and the associated socio-economic risks, are considered." This language was proposed in May 2010 at the CBD meeting in Nairobi and waits final censuses by all parties at the October 2010 meeting in Japan.[177] If passed, there would be an international moratorium on the release of synthetic organisms. The United States should ratify the Convention on Biological Diversity, encourage the passage of this text, and vote in favor of a moratorium on the release of synthetic organisms into the environment.[6]

Conclusion

Synthetic biology for biofuels production is a false solution to our climate crisis. The risks are too great and their promises are too illusory to be a worthy investment. There is still disagreement as to what exactly fits under the wide umbrella of "synthetic biology" but what is clear is that this new and extreme form of genetic engineering will not be a sustainable solution to our problems of fuel production and consumption. Synthetic organisms require too much land, water, and chemical inputs to produce biomass feedstocks or to produce oil directly through algae to truly be a long-term answer to our energy and climate crisis.

Our understanding of genetics is still elementary. It would be more worthwhile to gain a better and more complete understanding of how genes, DNA, and epigenetics works before researchers begin creating new genomes on a computer. Our ability to synthesize

6 The Convention on Biological Diversity, an international legally binding treaty, was signed in 1992 and entered into force in 1993. The convention recognized for the first time in international law that biological diversity is "a common concern of humankind" and aims to preserve biodiversity, counter the loss of biological diversity around the world, and promote the fair and equitable use of genetic resources. The United States has signed the Convention, but it has failed to be ratified by the U.S. Senate.

DNA has far outpaced our basic understanding of what the DNA actually does. That alone should be reason to pause before moving forward.

This is not a call to halt scientific progress. Experimentation is necessary for our scientific knowledge to expand to discover methods and products that benefit people and our environment. It is through scientific inquiry that humans have been able to discover some of the most important medicines, sources of food and products that we use in our daily lives. We should be investing in proven methods of producing energy sustainably from renewable sources, such as wind and solar, while increasing energy efficiency – not a dangerous and unproven technology. Synthetic biology may prove to be a useful tool in learning more about genetics and how life works. This research has promise but must remain in the laboratory.

What is needed is precaution. Craig Venter's announcement that he created the world's first organism with a fully synthetic genome was a wakeup call to the public and policymakers. It was undeniably a scientific feat, but it also shows the potential power in this emerging technology. It was also the first time many people had even heard of synthetic biology or that synthetic DNA even existed. We must step back to review all the environmental, economic, social, and public health implications of this research. Only then, if the benefits outweigh the risks and researchers and corporations have proved that this technology will not damage the environment or public health, should we move forward with any research. The burden of proof lies with those promoting this technology, not on the public. Synthetic biology should be treated as dangerous until proven safe, not the other way around.

BP's Deepwater Horizon oil spill disaster could be the worst environmental disaster in America's history. It is worth noting in this report for two reasons. First, many had longingly wished that we could use synthetic algae in the Gulf of Mexico to eat the spilling oil,[178] including those from the industry[179] and our own government.[180] If this were actually done, we would have intentionally released genetically engineered algae with synthetic DNA into the Gulf which would have easily made their way into the Atlantic Ocean. It would be absolutely impossible to recall these algae if something went wrong and they would have permanently contaminated our oceans with a potentially invasive species.

The second reason to mention this disaster is the fact that the Department of the Interior waved BP's Environmental Impact Statement for the Deepwater Horizon rig since the chances of a massive oil spill were "unlikely."[181] Proponents of synthetic biology argue repeatedly that the chances of synthetic organisms escaping and harming people or the environment is "unlikely" and so any regulation will just hamper scientific progress and the forthcoming "clean and green" revolution in fuel production. If the BP oil disaster has taught us anything it is that we must use precaution when we are dealing with new and potentially harmful technologies – whether it is deep-sea drilling or creating synthetic organisms.

The answer to our climate crisis does not lie in handing over our energy future to the same bad actors in the oil, biotechnology, and agribusiness sector that have repeatedly damaged and contaminated our environment while walking away with record profits and while fighting any attempt to protect the public through appropriate regulations. We cannot reward these corporations' total disregard for the wellbeing of people, communities, and the environment in which we live with government contracts and patents on organisms that spit out petroleum.

Thankfully, we know how to end our climate crisis and produce fuels sustainably. The answer lies in clean renewable technologies such as wind, solar, and energy efficiency. If we were to dedicate our public research and development funding to these three things we would be well on our way to bringing the climate back under control and forging a sustainable energy future. This would also be a more just future since people's water, air, and food would not be poisoned by dirty fuels and genetically engineered organisms.

We know how to end our climate crisis and produce fuels sustainably. The answer lies in clean renewable technologies such as wind, solar, and energy efficiency.

Far too often we have been presented with quick technological fixes to our problems only to discover they do not live up to their hype. Even worse, these techno-fixes usually produce a whole new set of problems that are often worse than the original problems they set out to solve. It is time that we invested in tried and true sustainable solutions to our climate crisis. We must use this opportunity to press for strong regulation of synthetic biology while demanding investments in long-term sustainable and renewable sources of energy.

The longer we delay investing in sustainable solutions to our climate crisis, including renewable energy such as wind and solar, and energy efficiency, the worse off we will be. Synthetic biology is a dangerous and expensive distraction from these real solutions. The public should demand proper regulation of synthetic biology. Genetically engineered crops have failed to feed the world or cool the climate but have led to increases in pesticide use, lose of biodiversity and risks to public health. We must not be duped into thinking extreme genetic engineering will be a safer bet.

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