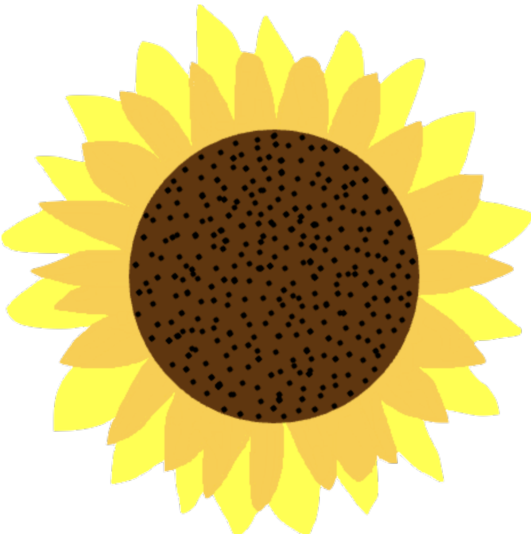
Synbio25

a man thinks about building biology



Keoni Gandall

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Preface

Synbio25 is a series of essays about the next 25 years of synthetic biology, commemorating my 25th year on this planet, in the 25th year of the 21st century.

The future, and what we believe about it, isn't just a technical challenge or a policy debate; it's a collision of grand ideas, personal emotions, and cold incentives. We too often treat ideas as amorphous, independent entities, unconnected to the human experience that created them. I'm the opposite of a dispassionate observer — I'm a passionate participant, playing in this field right now! Synbio25 is a work of love, talking about the future I care about.

To me, there is one core problem in all of biotechnology: the vast majority of experiments are done with human hands, manually. Think about that for a second. It is like if a scholar's hand had to write out every book. It is like if we are mining bitcoin on abacuses. We have leveraged great computational power to get better predictivity, but our fundamental productivity is still on the basis of human hands doing biology. We will never accelerate until we learn how to run biology experiments not using human hands but using our tools — our robots and our software.

I think of all technology in terms of power. Who controls it. Who profits from it. The shift from human hands to tools can both be a change of liberation, allowing anyone to participate in biotechnology without having to learn all the manual tools and muck around in a lab for years. Or, alternatively, it can be a change of monopolization, as the ones who own those tools seek maximize profit at the expense of the common good. The frontier ahead of us is in tension: between powerful institutions with entrenched interests versus the productive forces of new ideas, between safety but stagnancy versus innovation but risk, between optimistic idealism versus brutal and unforgiving economic reality.

Our current efforts to commoditize intelligence are laudable, but in biology, without the ability for those artifical intelligences to run experiments, we will always be constrained by the amount of data that can be produced by human hands. In contrast, our ability to create intelligence accelerates us towards automated systems. As history has shown, every technological leap like this one leads to the destruction of the old and the creation of the new. The humble laborers of today will become the industrial giants of tomorrow. And giants of today will be pulled down, kicking and screaming, replaced by a new generation that understands the shifts ahead. And the new generation, invigorated by young blood, open the door to new, ruthless, monopolistic corporations. At the same time, they may create the tools necessary for anyone to participate in the bioeconomy of the future. Maybe not dystopia, maybe not utopia, but an equilibrium that is different from what we see today, opening the opportunity for new and different values associated with biotechnology.

As the crazy technoprimitivist man once quipped: "you can't make rapid, drastic changes in the technology and the economy of a society without causing rapid changes in all other aspects of the society as well, and that such rapid changes inevitably break down traditional values." Perhaps this is quite alarming, as our technology lets us question what is human. Should we modify the natural world? Should we genetically engineer humans? What do we want our new values to be, and what will they ultimately become? What the hell is our endgame with modifying life? Is it Good?

In this field, some want to tear down institutions. Some want to fortify them. Some want to save the world. Some want to get rich. Me? I just want to keep the game going. I want to see biotech flourish — not because I have some grand ideological stance, but because it's fun as hell. I've been screwed by monopolies. I've built my own home labs. I've labored in academia and I've founded startups. Through it all, I've had a grand ol' time. You'll probably have different incentives, and that is ok. So long as you're doing things, we're on the same side.

You have fucking agency. Use it.

Godspeed to All Humanity,

Keoni Gandall

SECTION 1: THE TECHNO-BIOINDUSTRIAL ECONOMIC MACHINE

"For what shall it profit a man, if he shall gain the whole world, and lose his own soul?" — Mark 8:36

Chapter 1: Introduction

Biology belongs to all. We stand at the precipice of harnessing the most powerful technology ever developed — inherited by Provenance and Providence, created not by design or decree, but by the glory of our ancestors immemorial.

The indelible truth is that any power, truly held, may enable malevolence; but it is likewise easily forgotten that risk and innovation are inseparable. The stable artifice granted to us by the institutions in power is mere pretense for their own security. Biotechnological advancement that helps all has been and will be hampered for our "safety" by elites who do not share our problems, grievances, or optimistic hopefulness.

Yet hope placed in mere well-wishers for human flourishing will prove equally hollow. Delivering today's tools to the people is insufficient: these instruments were for institutional laboratories designed for last century's paradigm, and cannot be effectively used by those without extensive training or capital. Governmental resources and five-year roadmaps are similarly futile — those who craft such plans stand removed from the underlying currents of technological advancement. If they truly understood how futures are made, they would be creating technology, not merely pontificating about its hypothetical emergence.

The future rests with you — those still striving, struggling, and surviving at the bench or before screens. Your days aren't filled with grant writing and administrative meetings; you intimately know both the problems and possible solutions. While institutional power remains centralized, the vital knowledge — the understanding of what truly matters — is distributed in the minds and hands of all who labor. The technological frontier calls not to those who've claimed its settled territories, but to you who work at its wild edges, where innovation hasn't yet been captured by monopoly.

In the future, I see that as technology advances, the ability to do biotechnology will increasingly become centralized. Capitalists will eat the means of production for breakfast, sipping a rosy glass of robots tinted with optimism, a spoonful of AI, a hefty serving of shareholder value, and a detestable side of labor displacement for working-class people. This will follow a fairly predictable pattern:

- Centralized labs will manage physical resources far more efficiently due to having more experiments pass through their systems.

- A massive market exists for outsourcing experiments — if you can do them better, faster, and cheaper. Nobody has yet been able to do that.

- Labs that break through the technical challenges will unlock huge biological economies of scale, reinforcing their dominance in the market, but also reinforcing all their other experiments, as experiments often lead into each other.
- Resistance will be fierce: existing workflows are human-centric and manual. People will lose their jobs if we switch to robots. But in the long run, those who adapt to robots will win.

- Biological variability and reproducibility issues will make interoperability between centralized labs nearly impossible — locking users into a single platform and creating natural monopolies

- The reward: economic explosion, a strong market position — or monopolistic exploitation (same difference) — until new challengers arise.

We exist at a local maximum where nobody has figured out how to build a good centralized lab (that actually, you know, serves people's needs). It is hard to escape: I don't blame our predecessors for failing to. On the other hand, it is pure absurdity that the most advanced technology ever uncovered is physically done by people holding plungers. We're mining bitcoin on abacuses. Insanity. We can do so much better. The machines and intelligence are finally here to do it. We can ESCAPE.

Neither God nor the Invisible Hand nor the Leviathan nor the Ivory Tower will determine what lies ahead. It is up to you to envision, to create, to shape the trajectory of our collective future. And then it falls to you — you who stand at the workbench today — to drag, kicking, the great chain of human endeavor toward its truest path.

Let's build the future, you crazy fuckers.

Chapter 2: Centralization is Coming

Everyone deserves the ability to build beautiful things with biology. The gifts of Provenance and Providence given to us by Nature belong not to one person, nor a group of people, nor a corporation or a government, but to all people. Yet as we stand at this frontier where the very nature of what it means to be human — familial lineages, disease, and possibly even death — can be altered and changed, we face a fundamental tension between raw technological necessity and lofty democratic ideals.

Right now, most experimentation is done, ad hoc, in labs scattered across the nation, a community primed for "disruption" — after all, synthetic biology is heading towards a future of centralization. Specifically, I mean the physical doing of synthetic biology experiments: while ideas can be distributed throughout the land, execution efficiency just scales too well. This is not merely a trend, but a technological inevitability; centralized industrial might — the assembly line, the datacenter — is simply more effective in deploying labor and capital than decentralized efforts when it comes to the management of atoms. We see this from the silicon fabs to the mega-farms to the industrial gigafactories. We will not only decouple DNA design from synthesis, but experimental design from execution; and in the near future intention from experimental design using AI. We will not consider the downsides of centralization: there are many, but ultimately they will be largely irrelevant because the benefits will outweigh the costs. Instead, we will focus on what we can do.

Centralized lab infrastructure can spur greater innovation at the edges, provided it's accessible. The challenge lies not in whether centralization will come, but in how we harness its power while preserving the democratic spirit of innovation. While the process of experimentation (i.e., moving molecules around) will become more and more centralized and effective, intentionality around what to do with that efficiency should ideally become more decentralized. There is so much value on those edges, where people's imagination lies, where it is untrodden by established forces. We can look to the software industry for a model: while AWS is massive, the software running on top of AWS is much, much more valuable. By allowing people to interact with centralized primitives (which must run on atoms), massive value for the world is created.

Imagine if we had a similar process in biology to that we have in software: experiments written as code, reliably executed, in a fashion that is both economically more efficient than running them yourself, and more shareable, and faster. Imagine how much we could learn. Imagine how many diseases we could cure. As we have an abundance of capability, we should have an abundance of views and perspectives and opinions on what to do with this biotechnological experimental capacity.

But while corporations obviously want more customers, they will weigh the economic costs of doing so. In particular, any regulation in the name of "safety" or "biosecurity" produces an invisible and insidious chilling effect. Nobody can truly quantify it, but there is evidence in the form of innovative technology companies arising from American and European cultures. Regulation has saved lives — there's no question about that. But like all centralized power structures, it accrues its own inertia, its own self-interest, and at some point, we must ask: when does protection become stagnation? How much progress has been lost because of well-meaning gatekeepers who fear risk more than they value discovery?

In these cultures, the cost of economic exchange with the powerless is high, because any interaction incurs risk. Where the rigorous, and mostly correct, vetting by the parasitic lawyers denies access to the up-and-coming in the name of safety is where innovation and long-term prospects will suffer the most.

The economic costs associated with regulation are not divided equally. While as a society we suffer, quarterly profits of individual corporations actually benefit. Regulations do not harm the largest corporations — they not only have a hand in crafting them, but compliance will also hamper the ability for newer competitors to take hold in the marketplace.

Look no further than the centralization process by the largest pharmaceutical corporations. One may argue that the governmental regulations are a requirement for the People, but one must acknowledge that this comes concomitantly with the exact undesirable side effects listed above. Pfizer (1849), Johnson and Johnson (1886), Merck (1827), and Roche (1896) all were founded in the 1800s, while Novartis was created through a merger of two companies, Ciba-Geigy (1857,1859) and Sandoz Laboratories (~1886). These corporations have monopolized biotechnological power in pharma for over 100 years.

It is important to note that unlike monopolistic technology corporations, which largely keep power through network effects and superior technology, the mechanism that biotechnology corporations keep power is explicitly government instituted: through the patent and through rigorous regulation. In 2024, the pharma lobby was nearly three times larger than the oil lobby (293.7 million vs 109.77 million). Out of every technology industry, biology is the one most in bed with the government — it is the one most likely to monopolize power not through superior products, but through manipulative government meddling.

While they have maintained power for generations, the innovative prowess of these companies has decreased. The cost of new drugs has increased exponentially, doubling approximately every 9 years. This is called Eroom's Law, a somewhat tongue-in-cheek play on Moore's law, which states that computing doubles every ~2 years (Eroom is Moore backwards). Nowadays, most of the blockbuster drugs are developed not by Big Pharma, but by smaller companies and academic spinouts.

Our risk intolerance has real effects that affect real people. Pharmaceutical companies are a relatively smaller part of a larger problem in our society. The ballooning of the administrative class feeds itself: as you need more bureaucrats to deal with the regulators, these bureaucrats argue for more regulation. Well meaning individuals, aiming to make things safer, compound and destroy the functioning of the system from within. Approximately 25% of US healthcare costs are spent on administrative tasks, only 18% are spent on prescription drugs. How much of that 18% is on administrative tasks all the way down?

An over-scrupulous bioethics and biosecurity panopticon, zealously guarding power will be represented as mere cautious, careful, and calculated protection of the people from the people themselves; a stagnant and inevitably decaying institution propped up at the expense of the public good, while masquerading as public benefit. It is insufficient to only lobby our government representatives, or play the game that the most powerful will win at. Instead, I hope we can go arm-in-arm with our fellow citizens and vent our frustrations at the deeply unfair and inequitable systems that we all are players in, not of. To give attentive consideration to the fact that the incentives of the systems we create will govern themselves, and that if we only incentivize safety, we will be granted nothing more than a continuation of the status quo.

Centralization is coming. But without bottom-up support to organizations willing to subvert the status quo, to say: "No, we accept that this is a risky endeavor and wish to continue anyway", those with power will be the only ones benefiting. If there is an existential risk to organizations willing to innovate for the public good (for example, in selling to individuals), we will only have ourselves to hold accountable when nothing good happens. We deserve to be citizens, not subjects, participating in the bioeconomy. But with that power comes great responsibility, the responsibility to actually do something about the problems you see in the world.

In the context of synthetic biology, this means the centralized labs need to be willing to run experiments that current generations would consider risky — whether it be experiments run by individuals rather than institutions, or production of experimental selfadministered gene therapies. We need power to subvert current power structures: only by holding that means of production can we ensure that the existing means of production are not aimed against our interests.

Optimistic philosophy is no match for uncaring economics. Centralized labs will have the incentives to capture the market and sell to those that they can profit from the most. Any institution, regardless of their initial optimistic outlook, will inevitably be drawn to make returns. They must. But you, as an individual, are different. You can convince your fellow citizens that, maybe, we should risk it a little bit more. You can choose to support institutions whose incentives are aligned with long term equitable power distribution. Most important of all, you can choose where you align your labor, the most valuable thing of all. So realize that centralization is coming, and that it doesn't give a shit about your values — but also realize that those institutions can only subsist and innovate on your consenting labors.

Chapter 3: Too much Tacit Knowledge

A major practical challenge to the centralization of physical aspects of synthetic biology experimentation is the fact that synthetic biologists have failed to abstract away variation between labs — in people, equipment, location, environmental conditions — and this variance is reflected in the biology that operates within them. This isn't a problem, it is the problem of synthetic biology. Until we break the necessity of learning the particulars of our execution environment, we can't (effectively) share ways of doing things. Right now, it should be natural and expected to have a reproducibility crisis. The requirement for tacit knowledge (implicit, unwritten knowledge) for every single experiment extends so far that it has become an invisible requirement for biotechnology.

In other words, it is a programming environment with zero libraries where all compilation is done by hand, and there is no formal specification for the code, and every single CPU works differently. To become more like modern software engineering, one of the most scalable information-based technologies we have, we require a few things:

- CPUs that work (a fully-automated lab)
- a formal specification for protocols (standardization of tacit knowledge),
- a compiler (abstraction on top of any given fully-automated lab),
- an environment with libraries (bottom-up adoption).

In practice, this looks like formalizing protocols as code — because code is exactly how humans have figured out how to communicate and abstract machine operations. Lots of people know this. But they lose the magic of what made it work in the world of computers. The magic of lower-level languages in code is that you can make something, quickly, that just works, and then build on top of it. The magic of higher-level languages in code is that you can take a bunch of libraries written by a variety of different people, then run it on almost any machine, and it just works! Magical.

That means you can't just have protocols as code that work on a single machine or architecture or lab. You can't just have protocols as code in a way where people don't actually share code to build on each other. You lose the magic. It's not just about having an API to your fully automated lab. It's about creating the experience around those APIs that just lets people do awesome things easily.

The magic is writing a protocol, pulling a ton of dependencies — GoldenGate cloning, yeast transformation, plate reading — and instantly being able to execute that protocol locally or on an automated cluster elsewhere. Simplicity in use, sharable at the core, in a way that cannot be taken away by a single provider. Magical!

Here is the secret to the magic that the ones who don't work at the bench do not fully comprehend: these ideas are completely worthless without ruthless implementation from the bottom up. You will never get there if you only implement so-called "valuable protocols", like drug screens. They're too idiosyncratic and one-off. No, rather you need to build implementations that every single biologist would want to use, and can use, for their own small projects and experiments. You need a million eyes finding the bugs to make reliable and worthy implementations. At first, this means implementing commodified and everyday workflows, which inherently makes for bad business and boring papers. But some founders and investors need to make the first step, to put up the activation energy, to produce massive value later.

As a concrete example of tacit knowledge inflating costs: right now, you can commercially purchase clonal synthetic DNA for $125 per kbp. The price, for the same amount of synthesis from the same company, but in the format of oligo pools, costs $1.5 per kbp. The difference, if you do not know, is that oligo pools are large collections of short, mutation-prone DNAs all mixed together, while clonal synthetic DNA is long, sequence-perfect strands of a certain sequence. The arbitrage is purely within DNA assembly and sequence validation — which I have shown in my own lab only costs about $6 per kbp. The most infuriating thing is that I did not believe I would hit those unit economics — surely those big labs must have a hidden cost that I have not discovered — but I was wrong. But it took me almost 2 years with extreme specialization and extensive know-how in the field. And as it stands, I can't even really share my improvements.

The real barrier to reaping these cost reductions in most biotech workflows isn't the raw materials; it's the reliance on tacit, specialized knowledge and the ability to keep trying to reduce costs. If we systematically handle tacit knowledge and build environments so that protocols aren't idiosyncratic "black boxes", we can encode this knowledge (and knowledge of all other aspects of biological production) into code. We commodify esoteric specialization into concrete, importable implementations. By applying this towards every single foundational biological protocol, I hope we can exponentially decrease the cost of doing any biology research.

This commodification will be difficult because it requires moving protocols from human hands to robots, where the real difficulty lies not in the re-description, but in the differences in how debugging is done. Lowering prices will require heavy batching, which opens an economic opportunity for companies, both in margin and in moat building.

The logical outcome of this commodification of protocols is that required overhead for new companies is dramatically lowered, increasing the variation in interesting companies we can see. In the long term, these factors will shift biology towards being understood as much more of a black box, to the dismay of scientists and to the delight of pragmatists.

Chapter 4: Bitter Biologists Battle Bioautomation

People who are trained in biology underestimate what robots can accomplish. The conceptual battlefield here plays out in the (truthful) pointing out that there are biological protocols that we simply cannot use robots for. Some protocols for washing mammalian cells really do require precise pipetting that robots are incapable of. Without these, the protocols cannot be run. On the other hand, this should be blatantly obvious: the protocols themselves were designed to be run by humans. A tweaked and hacked protocol could be run on robots, but there is a lot of testing that has to be done to validate that.

Importantly, these problems are not with the robots: they are with the biological methods and software that run on top of that hardware. Most biological processes become automatable and economical at scale when redesigned from the ground up for automation — but redesign from the ground up for automation is often extremely difficult.

The truth is that debugging protocols on robotic systems is fundamentally different from how you debug traditionally. Biologists move invisible liquids between tubes and pray it works — and if it doesn't, maybe they'll make a hypothesis for what didn't work and test that variable. It is an artisanal way of troubleshooting, which works well for the constraints of biology right now, but works terribly once you start working with robots.

I brutally learned this lesson while I was building my DNA assembly pipeline. For months, I ran around testing out different hypotheses on why my cloning reactions weren't reliable. It was extremely frustrating — every variable I tested would impact others in unknown ways. I spent months of my life doing, frankly, stupid troubleshooting.

In essence, I was investigating this opaque, emergent entity which was my protocol. I floundered when depending on the past of "I thought this worked!". What changed was my decision to make the invisible visible, at every step. I sequenced every single intermediate product in my entire pipeline — which was both physically and computationally taxing — but I got real, ground-truth answers. I figured out, immediately, what went wrong (it was competent cells). This is almost never done when cloning by hand — sequencing is too expensive if you're only running a couple samples, and the software takes a lot of work. But the minute you scale to robots in a centralized system, the calculation changes, and you open up a different way to troubleshoot. The key is that with humans, you debug assumptions, but with robots, you debug states.

If you write a protocol (and debugging is part of this writing) for a robot like you would a human, you're in for trouble. It takes a fundamental cultural shift in how you think about debugging, and nobody writes about this kind of stuff, so you literally have to fuck around and find out. More importantly, nobody I've met thinks about the meta of building these systems: that is, rather than focusing on the debugging of your particular protocol, focusing on the debugging of any protocol. General automation for synthetic biology, rather than specific automation, should be the goal — but no one is incentivized to do this at the current time.

Why don't people think about it? In a traditional biotechnological race for IP, by the time you are large enough where your internal operations would benefit from leveraging general automation, you have too much institutional momentum to make the reforms necessary. Think of how many people whose jobs you'd have to fundamentally change. People might lose their jobs! Better to just go build the next drug. Every incentive right now is to get your specific protocol working. So it might take a lot of fucking around for that specific protocol, but you eventually find out.

Frankly, retraining the whole field to think about debugging in this new way is hard. What if instead of focusing on the pedagogy of humans, we focus on the pedagogy of AI systems (which will likely be writing most of the code anyway)? Why train a million biologists to debug like robots when you could train one robot to debug like a million biologists? With enough data — from logs of failures, to human-refined solutions to problems, to successful recovery — our systems can learn to debug biological protocols better than 95% of individuals could ever hope to.

To escape the local maximum we are stuck at right now, we will have to rewrite nearly every important biology protocol and verify they work in an automated system, which will take a massive amount of troubleshooting. These protocols will look fundamentally different than how they would look if you were executing them by hand. It'll be hard, but worth it — a fantastic opportunity for the enterprising spirit.

Chapter 5: Batching for Economic Efficiency

Biology does not need to be expensive. We're simply bad at organizing labor and utilizing our material inputs: we don't need any new biological technology to drop costs by 10x to 100x for most biology experiments, we just need to use what we have more effectively. This redefines the problem from a biological question — what new enzymes or novel processes can we build to lower costs — to a logistics question — how do we batch experiments well, how do we run existing well-trodden experiments effectively, and how do we scale economically?

We can do this through batching people's experiments together, so even 1 experiment can benefit from scale. In order to scale, there are two interconnected challenges: dropping labor costs and dropping material costs. Labor is a function of how effectively we can keep the robots running. Material costs are a function of how well we can utilize that labor to get closer to raw-biology, having the system produce its own enzymes and strains.

Robots, in biotechnology, are shamefully underutilized. Go visit some biology labs — academic, industrial, or startup — and you are sure to see robots just sitting there, doing nothing, collecting dust. They're booted up for when an experiment really calls for them, but spend most of the time just sitting there like some industrial themed-decoration. Information wants to be free and tools want to be used! Those eye-wateringly expensive robots deserve to be used more than they are.

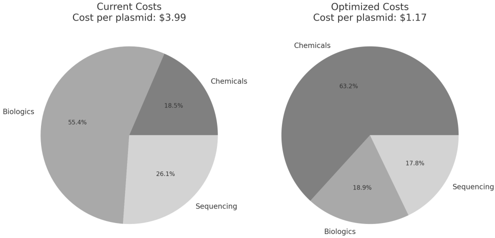
The benefit of aggregating many experiments together in a centralized facility is that we can keep robots busy. Even if you just want to run 1 protocol, there may be 95 others who want to run that 1 protocol as well — together, you can fill 1 robot's workspace optimally. A centralized system lets you do this among many protocols — otherwise, you'd need to ship samples between labs, which is just too much. While the final step, testing your particular hypothesis, might still require customized attention and dedicated robot time, the heavy lifting — strain prep, validation, etc — can be batched and automated.

The key, then, is to pull these robots towards projects and protocols that are closer and closer to the raw material side of biology, so that you can build everything else on top of those. For example, PCR enzyme, polymerase, is very widely used, but rather expensive if you buy proprietary enzymes. On the other hand, you can produce it for yourself very cheaply. If you utilize your robots to produce enzymes, you can then use this enzyme in all other experiments, dropping the costs of those experiments as well. The reason is quite simple: without a middleman, your costs approach chemical + energy + labor costs. A billion years of evolution made this, relative to other industries, very inexpensive. You just need to start from the bottom and move up.

To illustrate my point, here are real data points from my DNA assembly system I've been building over the last 2 years. It assembles oligo pools into clonal plasmids. In my efforts to create a system like the one I describe here, I chose to start with DNA assembly because I felt it was the lowest level of all — but the . I've already dropped the cost by ~10x through clever use of material, but now am hitting the limits of traditional optimization. I've broken down the material costs to 3 different sections: Chemicals, biologics, and sequencing (a separate category because it is a fundamental operation that we can't reproduce from fundamentals). The below table is for the cloning of 96 plasmids:

Chemicals	Plasticware	$38.34	10%
	Beads	$25.52	7%
	Bacterial Media	~$2.00	0%
	Other (qubit reagent, ethanol, etc)	~$5.00	1%
Biologics	Enzymes	$78.65	21%
	Competent cells	$133.33	35%
Sequencing	Nanopore Flongle flow cell + library prep	$100 (two DNA builds for 1 flow cell)	26%
		$382.84 (materials only)	

With optimization — producing enzymes and competent cells in-house and using maximum-sized sequencing flow cells — these costs drop dramatically. Biologics costs decrease by at least 10x (achievable even by bulk sourcing enzymes from China or using commercial competent cell preparation kits). Sequencing costs drop even more significantly — 100x the sequencing quantity only costs 10x more (we will assume only a 5x drop in cost for sequencing). With these optimizations, the cost per plasmid could theoretically decrease from $3.99 to about $1.17, with raw chemical inputs becoming the dominant cost factor (63.2% of the total, up from 18.5%).



Every process, every experiment, every protocol is like this, and it builds from the bottom up. By making the basic processes efficient, we can make every experiment on top more efficient as well. You cannot hit these efficiencies without carefully batching each experiment: if you want to enable 1 protocol to be run quickly and cheaply, you need a centralized system that is running it often, batching with many other people's protocols.

I am excited about this, not only because I'm a logistics nerd, but because of what it enables. If people can remotely run experiments without their own equipment, they can spend time thinking about wacky new experiments rather than acquiring a protein gel-box. They don't have to learn the intricacies of manually executing the lead up to their experiment — no more cloning, strain transformation, strain verification. They think something up, and then they run it for cheap, and then get real data back.

By lowering the overhead needed to get started building new things, more people will build new things. Rather than cowardly hide from the leviathan of corporate venture investment — which let's be honest, leveraging their greed will be necessary — we should grab hold of the harness and lead the building these execution systems for the benefit of all who want to build. I want more people to build wonderful, wacky, wild creations. And I see no better way than lowering the cost of doing that — while making sure the corporations don't seize the means of production for themselves, and the regulators don't ban creativity and originality in our fascinating and nascent field.

Chapter 6: The Bitter Lesson of Synthetic Biology

Let's say we have centralized facilities capable of running any experiment you can dream of, remotely, without your involvement. Let's use it for something awesome!

The hardest problem shifts from the physical implementation of an experiment (ie, the actual by-hand process of experimentation) to the theoretical design of the experiment. For 40 years, we've thought about how to move biology to an engineering discipline, and unfortunately, we have thus far largely failed.

The theory behind the original synthetic biology manifestos was that we could build biological systems up from their component genetic parts, and recombine them in a modular fashion. We, largely, could not — or at least not in a way we could predict what they'd actually do. The biggest and most bitter lesson that can be learned from the last 20 years of synthetic biology is that full context creates far more useful knowledge than individually controlled or simulated cases.

Biological systems are all interconnected — every change can affect everything else — and so the idea of modularity just doesn't really work. We can't really predict what biological systems will do from first principles, and this is alarmingly unsatisfactory for many biologists.

In fields like software engineering the entire stack is designed so you can have abstractions and interfacing, where each abstraction or interface is sufficiently small such that a human can understand them. These stacks are then built on top of each other. This is the same for most fields of human endeavor from mechanical engineering to VLSI to civil engineering. But biology is different: no abstraction really exists between components, and everything interacts with each other.

There is one field where "everything interacting with everything" is actually embraced: AI. AI is one field where full context (with LLM systems) seems to lead to more intelligent decision making. AI systems can be remarkably simple (fewer than 5000 lines of code for implementing LLMs), yet leverage a massive amount of data and computation to get good results. Biological systems, likewise, can operate over remarkably simple ingredients: bacteria can be grown with a basic chemical slurry and an incubator — yet with billions of dollars and decades of research we still don't understand them fully. It could be that full context, with all those seemingly irrelevant details, could be required for simulating sufficiently complex systems like intelligence or biology.

In this way, AI systems naturally mirror biological systems. We roughly understand how they work from first principles (linear algebra or molecules, respectively), but once you put them together we really don't know how the emergent properties of intelligence or life arise. This black box is frustrating! But we might be able to leverage this property: we may be able to effectively simulate biological systems — not through first principle understanding of the components, but through massive data collection with the full context of our modifications.

While this is in the early stages of development, we already have evidence or preliminary evidence in two places where this works fairly well: protein folding and transcriptomic simulation. But we have yet to collect sufficient data to characterize interesting properties in other areas. The unfortunate chore, the most bitter lesson of synthetic biology, is that the true way to fully understand a cell is not to rigorously study each component. Rather, it is to design systems that collect an absurd quantity of good quality data about both the entire cell and each component interacting with each other, that can be compared and trained upon.

Once efficient centralized capacities are established and robust execution of protocols as code is realized, we will unlock this fundamentally different way to look at and engineer biology — and it'll actually work. The most valuable biologists will be like GPU programmers, creating AI algorithms, except that they are programming remote biology labs, creating data to be swallowed by AI. Rather than biological insight and intuition, insight and intuition to the data creation and usage process will become much, much more valuable. This will be a different skillset from what most are trained for in biology, and most large institutions will be completely unaware when this comes to pass. Your training in biology may become useless; your training in computer science may become a saving grace. At that moment, massive value can be captured, and it will be there for you to grab for yourself.

SECTION 2: BLOOD OF THE MACHINE: PEOPLE

”I am moved by fancies that are curled, Around these images, and cling: the notion of some infinitely gentle, Infinitely suffering thing.” — T. S. Eliot, Preludes

Chapter 7: Holocene Explosion

Holocene Extinction be damned! I want to see just the opposite: I want to see the Holocene Explosion! An explosion of new, novel life forms the likes we haven't seen since the Cambrian! The failure of Colossal (well, among many) is that they haven't gone far enough: I don't want to just see mammoths, I want to see new creatures we haven't even imagined. I want there to be dragons, in an entirely literal sense. I advocate that we should literally make dragons. We may be lowering biodiversity at a rate never seen before in the history of Earth, but we can also do the opposite: create biodiversity at a rate never before seen either.

On the other hand, it can be seen as a bit excessive to revive mammoths when there are plenty of species going extinct right now. Preservation of biodiversity is likely more effective than making new biodiversity before we get much better at genetic modification. And before we have greater control over introduced biological organisms, we risk further ecological damage.

Still, I want to put in your mind the positive idea that biodiversity, inherently, is moldable by human beings. We will be able to make new life soon enough. We can create Jurassic Park. Will we be so preoccupied with whether or not we could, we didn't stop to think if we should?

I've stopped and thought about it. We should.

In particular, I think we are gripped with the clearly and demonstrably false perception that we don't have control over biology — and the ironic and self-defeating idea that as we get, by definition, better at controlling biology that we will not be able to control it. We made wolves into chihuahuas almost by accident. We've extinct viruses. Most mammalian biomass is directly controlled by humans — with 15x more mammal biomass being our food than there are wild mammal biomass in total. Even the worst pandemic in anyone's memory killed fewer than 1/1000th of us, and we were able to get a vaccine out in record time — and with advances in technology, we'll be able to get one out even faster.

If we look at our media, on the other hand, almost all sci-fi and fantasy have fantastic elements of new, interesting, unique biological life, hiding in forests or in the ocean. We see these and are met with wonder: but suddenly, when we propose that *let's go make those*, it is taboo, or stupid, or arrogant? Why can't we imagine a more beautiful world, then go make it?

Rather than arrogance, I think this is simply acknowledging that we are a power like the world has never seen. With great power comes great responsibility: and is it our responsibility to simply keep the world as a static jar, like a terrarium we are too afraid to touch? Or do we have a responsibility to make the world an even more vibrant, interesting place?

I believe we should build beautiful things with biology. I believe we can do that responsibly. We don't lack power; we only lack imagination.

Chapter 8: Moral Failure of Genetic Hesitation

Humans have been, and will be, genetically modified. The Blessings of Liberty extend to them, to us, and to our shared, intertwined Posterity. The pattern of nucleotides within us does not determine our Humanity. Whether or not the hands and hammer of man have refined your encoding does not make you more or less human.

Modern medicine has removed much selective pressure from the human race. However, under the assumption that there are more deleterious mutations than benign mutations, we should expect to see a gradual increase in genetic diseases among ourselves. In Nature, those mutated humans would be selected out of the population, but the family of Humanity is above Nature. We can, and should, choose to repair our genomes as we see fit. Any argument against human genetic modification has the implicit concession that those people's sacrifice of their own happy lives is worthwhile for abstract ideals. To not modify humans is sadistic and selfish.

While you may be able to make laws against human genetic modification in your nation, it is inevitable that many people will choose to free their children of genetic diseases or give them advantages in life, even if it requires traveling to a different nation. And so, if your primary concern is that a privileged class of people will first have access to this technology, instead of banning it, you should make your nation the very best place for it — which will decrease the cost locally and let more people access it.

And eventually, this will open Pandora's box

— widespread modification of human children for any other purpose — cosmetic, intellectual, or muscular. Maybe even modifications to make sure your lineage has a huge dick. While it may seem silly in abstract, things like that carve at the core of people's self worth.

Germline modification raises obvious moral questions because the unborn cannot consent, which breaks apart our liberal ethical models of the world which emphasize consent. In truth, the unborn can't consent to anything, even being born. Even in cultures that believe in reincarnation, you don't get to decide where you are born and to who. Consent cannot be had here. The liberal perspective of harm reduction (such that deleterious mutational fixing should be allowed, but other traits should not) will naturally trend towards being more accepting of modifications, since being ugly will cause more psychological harm than being gorgeous/handsome, and who doesn't want their kid to have the best life possible? The conservative perspective is inherently at odds with itself: there is a simultaneous emphasis on the sanctity of humans and the benefit of the kin group — and I think the kin group is going to win here, like it almost always does.

Parents make countless decisions for their children. In fact, this is pretty much how we define childhood — the fact that you *can't consent yet*. A child can't choose to be raised religiously, or to take or not take certain medical interventions. As a society, many of us even choose to force genetic self-modification onto children (through antibody evolution in response to vaccination). Our moral frameworks already accommodate non-consensual but well-intentioned parental decisions — the only reason genetic modification is different is because it is new. And someday it will not be new.

Yes, we cannot fully predict the outcomes of some genetic changes. We're slowly getting better, but this is a danger. But so is just letting your child be randomly mutated — there are tens of completely random genetic mutations every generation. We don't know the effects of those, but somehow we find *completely random* mutations more palpable as a society than *specific* mutations with some theoretical backing that they may be beneficial.

It is seen as morally righteous to change the world in a way that betters mankind and the future generations. To me, then, it is a moral failure of our institutions to restrict human genetic modification to the degree that they have. But their deaths — the anguish of children, men, and women whose cancer could have been stopped at the source — will be invisible to the well-meaning bioethicist bureaucrat. They'll be patted on the back and paid with taxpayer dollars to hold the door closed on what could be.

Chapter 9: Transhumanists vs the System

I have argued that we ought to actively add biodiversity back to the environment and that it is immoral to not genetically modify humans. It may come as a surprise, then, that I don't care much for the so-called transhumanism I see around me. I think the core of what doesn't pass my vibe check is that transhumanists often think that increasing human abilities could someday make us "post-human", or that increasing our own abilities is anything but what humans do naturally, literally all the time. It's nonsensical, but what brings me from apathy to caring is seeing the concept that individual human abilities are what brings us towards the future.

In our day, some of our greatest abilities come from the fact that most of humanity has a device that can, theoretically, communicate with any other device on the planet. We have information at our fingerprints like no human before has ever had. We have artifical intelligence that augment our capabilities. Shit, we have reading glasses! Those enhance abilities!

But those abilities do not derive from the individual, although they help the individual; they derive from the systems around us that we built. The great supply chains or internet or AI are all enabled by the creation of systems which are larger than the individual that the individual interacts with. And there comes my critique: if you want to progress humanity, the role of the individual is not to make the individual have more abilities (though this may be a natural consequence), the role of the individual is to manipulate, play, and hack the systems surrounding them to improve them, to create them, or to destroy them.

When I look out into the world, of how I interact with the systems I live with on our tiny pale blue dot, I am struck with a sense of wonder in not just what they do for me or what I do for them, but our synergistic relationship. How our sum is greater than our parts. How our humanity is infused into the systems that we built. When I think about the United States, for example, I see both a massively bloated, bureaucratic machine, and a passion project of a few great men from 1787. How all these systems around us, in many ways, are passion projects of our ancestors.

What is our relationship to these systems we find around us? To me, we're more than simply parts of system. We are the agents that drive them forward, that give them direction. We, in this way, through our agency, are the deeply animalistic drive of the techno-industrial machine, we are the emotions inside the great systems which surround us all.

We're not the gears; we're the blood, we're the anima, we're the soul of the machine! We are the greedy, short sighted bastards at the wheel, except instead of convincing the body to get wasted and text your ex, it convinces the machine to focus on short term quarterly gains. We are the irrational actors which drive the real world forward towards... towards whatever!

We're the chaotic entropy in the machine that it subsists on. In this way, the concept of transhumanism — the concept that we can individually enhance our abilities — is rather boring to me. We already do that with iPhones and ChatGPT and web browsers. But we don't celebrate enough the fact that humanity is what shakes shit up! Not the boring bureaucratic bumblefucks (which collectively act in a way that is hardly distinguishable from robots), but people who DO things. Our ability to manipulate the great systems around us, to me, is one of the defining characteristics of what make us human. We have agency! We can do things! You can do things!

We are in this supernal Sisyphusian situation where we build and participate in systems that do not care about us and that will forget about us. And thus, I imagine Sisyphus, as a vicarious incarnation of myself, as more than happy — but smiling and scheming. What improbable obstacles do we place in the way of our boulders falling down the mountain? What great fun can we make, can we choose to make, in the knobs and levers of the systems which surround us? Twist the dumb knobs! Pull the damn lever! Smash the button! It's big and red and menacing and why not press it! Maybe for you, it'll be technological interfaces with AI. Maybe for me it'll be biology and robotics. Maybe for someone else it'll be local elections, for someone else green energy, for someone else financial markets, for someone else rationalist collectives.

To me, there is something deeply unsettling with the individualistic intellectual masturbation done by so-called "transhumanists" when there are so many interesting external systems that are just sitting there, waiting to be played with. Injecting yourself with CRISPR is fun, but how about DIY lobbying the national government to change policy around self experimentation? Or shifting the technologically-elite Overton window with a poorly obfuscated manifesto, arguing for accelerating synthetic biology, in order to shift the localized cultural zeitgeist?

In essence, a focus on the individual's abilities is not nearly as important to me as a focus on the individual's abilities to muck with the systems that surround them. I want empowerment in the fully holy yet horrific meaning. Power over self, yes, but also power over the systems around you — which in truth, is real power. And if there is anything to take away from these essays, it is that I want you to take hold of the chains, the great web of systems surrounding you, and *pull.*

Chapter 10: Trickle Down Abundance

There is an elitist conception in technology that as we make things more abundant, life improves. They constantly point towards the industrial revolution as the time when every metric of human life improved. I am unconvinced of this viewpoint. They speak of abundance: but they speak of *their abundance*. While us technologists have become fabulously, generationally wealthy off of our technology, how has the other 90% of our society fared?

When I ask "whose bioeconomy", I ask specifically because it doesn't belong to the common man. It belongs to the fucking elites. It probably belongs to *you*, if you are this far through esoteric essays on a particular technological niche. And I can see why most people don't trust us: our new technologies almost always make us massively wealthy and dubiously improve the lives of normal people.

Take a moment of empathy for the anti-GMO or anti-oil protestor. We promise efficiency through genetically modified organisms — lower costs for the farmer right? Except that this competitive pressure forces, in a commodified market, all to use organisms owned by a single corporation. And in the case of RoundUp, leads to massive amounts of chemical runoff. Or the anti-oil protestor, who sees the oil wash up on their pristine beach, and for what? They don't own shares of Exxon-Mobil. They just see the wealthy becoming wealthier, while damaging our common goods.

Or, more viscerally, let's talk about the elephant in the room, COVID. Millions were essentially forced to get vaccinated, and they were lied to: vaccines can have side effects (albeit very rarely), and there was a concerted effort from government forces to censor information related to this. Our children lost years of socialization due to shutdowns. Nearly 1/3 of small businesses closed during COVID — for many, their own American Dream dying with them. Meanwhile, pharma posted record profits. We, biotechnologists, posted record profits.

There was a time when improving abundance really did trickle down to the rest of the population, during a time when you needed people to expand businesses. But a shift happened as we developed better technology: now a very small number of people can run a much larger business. AI will only exacerbate this inequality, as now even intelligence is becoming commodified.

People aren't stupid. They're suffering. They can see our success does not include them. People can see that technology that promised to make lives better... didn't, and they see the decimation of the society around them. Technologists quest for creative destruction: But the creation is for us, and the destruction is for them. We watch others starve in the land of milk and honey, and don't realize it's not just that we don't have UBI, but rather its the foundational economic precepts which allow our society to function.

Perhaps it is easily forgotten that our initial American success, the open frontier, was built off the complete decimation of many peoples. We have no more frontier, no more people to plunder, and no more wars to reset the march of progress, and yet, we fearlessly march on, promising that, no, this march will be different.

A common refrain in the techbro community is a refutation based on the failure of the Malthusian theory of population growth — the theory that population growth is exponential, but resources are finite, and thus living standards will eventually reduce, triggering a population decline. Right after he made this prediction, the industrial revolution started, and our technology abundance matched the exponential population growth.

Unfortunately, Malthus was wrong because he assumed that we couldn't change Nature. Turns out that was relatively easy. But our modern struggles are not against Nature — they are against ourselves. Population decline isn't happening because we ran out of food, it is happening because our youth is, economically speaking in relative terms, fucked.

Henry George, arguably one of the sparks of the Progressive Era, gave a biting critique of this blissful ignorance in his book "Progress and Poverty" published in 1879. Nearly 150 years later, and what have we learned?

"In the United States it is clear that squalor and misery, and the vices and crimes that spring from them, everywhere increase as the village grows to the city, and the march of development brings the advantages of the improved methods of production and exchange. It is in the older and richer sections of the Union that pauperism and distress among the working classes are becoming most painfully apparent. If there is less deep poverty in San Francisco than in New York, is it not because San Francisco is yet behind New York in all that both cities are striving for? When San Francisco reaches the point where New York now is, who can doubt that there will also be ragged and barefooted children on her streets?"

But surely, you can keep comfortable in the knowledge that if somehow, if just for better governance, or less governance, or different governance, or any variation of anarchist-to-authoritarian, left-to-right politics, all this foundational suffering could be fixed. It becomes a lot less comfortable if every march of progress outside the frontier inevitably levies itself — heaped and fattened — upon normal, powerless people. Whether it be communist or capitalist, whether it be Victorian England or ancient Rome, do you think this is different? Perhaps, it is that a stable, growing human society is incapable of fixing these inequities: those with power inevitably turn to rent-seeking rather than labor, regardless of that society's socioeconomic system. I am not saying that we cannot craft policies which help the median — we surely should — but I am pointing out that any closing of the frontier inevitably brings upon efficiency and poverty, not due to capitalism or real estate, but due to the inherent rent-seeking of the powerful.

How many times in the Bible, or Pliny's Historia Naturalis, or Confucian texts, do authors lament about greed and avarice gripping their society? You think, after all you've seen over the last 25 years, that we have technological solutions to fix that fundamental tension in the fabric of human society? You think, with a better app, or more abundance, it will suddenly convince people that we should simply share more?

Technology is the one place where the frontier is always open, and will always be open. We have an oasis that never runs dry where our liberation is ensured. The powerful will always need us and our labor, and so we can safely watch whatever happens to the rest of society. So what makes me fucking furious is when our intelligentsia argue, without empathy, with elitist chins raised, using historically cherry-picked examples and optimistic yet unrealistic visions of the future to drive public policy. They're not ignorant. They're not dumb. They just don't fucking care what happens to the rest of society, who are obviously just radical leftists or a basket of deplorables.

I have no innocence here. I'm not asking you to change or become a luddite. I, for one, am a maniac who will never stop building technology, and this very document is a series of essays in support of technological advancement. I'm just asking you to not be blinded by your own propaganda. I build technology with the explicit intention of decreasing human participation in physically executing biology experiments. If I succeed, this will make me rich. This progress will not be good for everyone. People will lose their jobs. I only ask that if we choose to sacrifice others to the Altar of Progress, at least look at them in their god damn eyes.

SECTION 3: ME

"Live by the harmless untruths that make you brave and kind and healthy and happy." — Kurt Vonnegut, Cat's Cradle

Chapter 11: The Joy of Engineering

Where is the zest, the gusto, the joy, the love and hate and anger and lust and emotion!? I didn't learn bioengineering to make a career, I learned it because it was fun. Because I love it. Many people have other things they love — writing, dance, poetry, film — but this is what I love. And yet I look around, and people don't care. They say this is a career. They put tables in my temple. But no. Stop that. I live here.

I go out, and I see people making careers. I love going to iGEM because those damn kids haven't lost it yet. The it that made me start doing all of this. The beauty that stays, independent, from impact, and money, and my ability to pay the rent. To me, the fabric of life is like the artist's canvas, or the writer's empty pages. And I think there is beauty in painting and sewing this fabric. I don't view my life's work as valuable from a human health perspective or industrial manufacturing standpoint or any other endpoint. I view it as important because it is fun.

One special memory was when I was running my science fair back in 8th grade. I didn't have a PCR machine, but I had to run a PCR! I did, however, have a water bath and two pots on the stove, with cheap glass thermometers. My science fair was coming up, so I stayed home from school to sit in front of those pots for about an hour and half, carefully moving my tube of DNA and polymerase between each temperature every 30 seconds, watching the thermostats and tuning the burners to maintain temperature, to simulate what a machine could achieve easily. That was awesome! I wasn't paid to do it, I wasn't getting a grade. Nobody was watching me. It wasn't efficient, but the dance came from within, and through that, I felt proud of my work.

But now, now I see the structure of it all, the way academia manufactures fresh blood for the machine, fed with bright-eyed graduate students, undergraduate students, and tax-payer funded research. I see the venture capitalists calculating ROI, and the public SEC filings and the incestuous inbreeding of money to create more money, and I see the brave few who stay to pump out papers from faceless grants for impact factor.

Throughout my life, I've always been on the side of freedom, equity, and decentralization of biotechnology. Why? Because I want to see lots of other people having fun like I've had! What about societal impact, you may ask. Biosafety and national security and the climate and aging and the economy?! Noble endeavors for men and women more noble than I. Let me enable those who care about those things to do their best work. Allow me to share the joy I feel and may it bleed into their labors.

What are we missing most in the world? It's not money or resources or energy. It's people who care. It's such a limited resource everywhere you look. It's so valuable. People who really fucking care. We need you! And if you're a person who cares, don't just take the safe route. There are too many people who value other things that are already doing that. We need you, god damn it. Live risky; live for you; live against all odds. Throw caution to the wind; don't act as if you are a statistic; don't just be a statistic. You have one chance: make it count. Make it fun.

Chapter 12: I was a teenage biohacker

I was a teenage biohacker. I built and operated my own home lab, and I'm still damn proud of the things I did over a decade ago as a preteen. Biohacking promised that we could democratize and distribute the means of biological production — whether it be genetically engineering organisms, creating medicines, or learning more about ourselves — away from power structures that abuse that power into the hands of everyone. Think insulin costs, or Monsanto being Monsanto, or treatment of rare diseases. But if there is one lesson I took away from the actual doing of biohacking at the time, it is that its primary function is educational — creating fresh blood for the academic techno-bioindustrial machine. Not fighting the system, or creating a viable alternative, but fueling it.

I am no exception. I got started doing biology experiments at home and hanging out on the DIY-bio forums, but my expertise in lab work came from working at UCI in Chang Liu's lab, not my own lab. It was and is prohibitively expensive to learn while doing anything real, which is the best way to learn. I know numerous other teenage biohackers that have gone down this route — eventually, to keep doing what they want to do, they join the system.

In 2016, while in high school, I attended the first "BioHack The Planet" (BioHTP) conference, meeting many of my much older peers. I asked Josie Zayner, who was running the event and is well known for injecting CRISPR into herself onstage while drunk, and who I had argued with on the internet before, if I could give a little talk with some of my current ideas. "Sure thing kid", she said. This led me to, unknowingly, give a presentation right before Drew Endy's where I independently espoused many of our shared ideals. Drew Endy one of the original founders of synthetic biology as a field, and I had looked up to his work for years. After his talk, he approached me, excited about my ideas, and said I should work in his lab.

I was obviously very excited about this: so I applied to Stanford to work in Endy lab. Of course, I didn't get into Stanford (or 14 other colleges I applied to, my grades were terrible). So he said "that's bullshit", and I went to work in Endy's lab anyway. There, I worked for Drew in the BioBricks Foundation for 3 years, heading the FreeGenes Project, until the COVID pandemic hit. I was still a teenager when I started there — and many of my formative years were spent seeing how philosophy and storytelling worked when it hit the real world, and the implications of things like bureaucracy, idealism, and interpersonal relationships.

Biohacking quickly hits a cliff for users: after initial small experimental steps, like a GFP transformation, it becomes nearly impossible to do any more research without joining an organized biology lab. Biohacking only handles easy ways of making biotech easier to do, while not tackling the harder problems in the field that force folks like me to join the system. The problems biohacking has primarily addressed, right now, is access to educational materials, some reagents, and equipment. These are nice but insufficient. And thus, it has remained niche, and unfortunately, unimportant.

The most difficult problem behind biotechnology is that tacit knowledge underpinning experiments is too difficult to teach without real experimentation. It is like trying to teach how to play an instrument without ever touching the instrument itself — you just gotta play the instrument to really know how. But experimentation is more expensive, and it takes longer. It is possible to self-train, but it takes unrealistic dedication and resources for most. So, in biohacking, you have more dreamers than doers.

I remember the good ol' days in high school: I had an old thinkpad I threw linux on and a cracked version of SnapGene, and would spend recess designing plasmids and experiments rather than, oh, talking to friends. I still have my old folders of experiments I wanted to execute! Hundreds of genetic designs itching to be played with. Nearly none of them actually got built or tested. I was completely bottlenecked by my ability to build and test the genetic designs in the real world. But I had the vision! And I know that others in my position reach the same frustrations. I could read the papers, I could write the code, I could design the DNA. But I did not have the resources or time or skill to execute the experiments.

On the positive side, the fundamental issue of executing experiments plagues both the commercial side of synthetic biology as well as the hacking side. As the technologies develop to abstract away experimentation and lower the cost of building and testing DNA, biohacking will become more and more accessible as a technology that anyone could start playing with. Interests are aligned with the invisible hand and I believe it'll just take time.

Back then, some of my ideas were pretty stupid. I wanted to make bioluminescent zebrafish and genetically modified carnivorous plants. I made phages to target recoded E.coli, because the inventors said no phages that targeted their fancy new recoded strain. I encoded the RickRoll as a protein into a fruit fly gene drive (but did not transform it), because I thought it would be funny when scientists in the future inevitably found it. Shenanigans! Stupid shit, because it was fun. And in the future, we will see an explosion of variance in the types of things people can just do that would be completely impossible in our current biotechnology incentive structure.

As a society, I think it is of utmost importance that we acknowledge that somebody is gonna make a dumb rickroll-fly. Somebody is gonna inject themselves with stupid stuff. Somebody is gonna try to sell snake oil. And more importantly, that might be ok. Sometimes, that snake oil isn't actually snake oil — it's a novel treatment. Sometimes, that self-injection is meaningful bodily autonomy that can help not only that person but others in their position. Sometimes teenagers will do stupid shit because teenagers do stupid shit and they learn from their stupid shit. Our goal is to minimize the harm to society, but at the end of the day, we stand to lose much by decreasing the variance in what people can do. In what people have the ability to do.

When COVID hit, how many lives could have been saved if we just let people take an unknown vaccine? How much faster would we have gotten data on efficiency? If we simply accepted that people have the bodily autonomy and decision making capability to take that risk, how many people could we have saved? Sons and daughters, mothers and fathers, grandparents and relatives that didn't have to die. How many graves didn't need to be filled? We can argue about Antivaxxers, but I want to see the opposite — the Roguevaxxers! When we look at all the tragic chronic illnesses out there — who are we to say, once we have the capabilities, that they ought not to take a risk? ANY risk?

Biohacking is the rejection of the narrative that they, the authority figures of our society, know best. The extremely alarming and to some, naive, perspective that as a society we ought to embrace dangerously optimistic endeavors that benefit us all. And someday, it'll actually work. What will we do?

I don't advocate for an apathetic government and society in regards to biotechnology. As Alexander Hamilton said in the first Federalist Paper during the establishment of the United States Constitution: "it will be equally forgotten that the vigor of government is essential to the security of liberty; that, in the contemplation of a sound and well-informed judgment, their interest can never be separated; and that a dangerous ambition more often lurks behind the specious mask of zeal for the rights of the people than under the forbidden appearance of zeal for the firmness and efficiency of government". I take a radically different perspective from many others, that as a society we should **encourage** more variance in biotechnology. The genius of our republican democracy is that every person gets some level of agency in governmental affairs, electing certain individuals that get even more agency. In a similar way, I want everyone to have agency in biotechnology; while many won't go beyond simple DNA transformations, I want them to be able to get there, and I want the brave, crazy souls who want more to be able to go further. We should, therefore, put active protections in place that allow people to experiment. We must remind ourselves that beautiful and elegant and useful ideas are not opposed to, but perhaps concomitant with ugly, stupid, useless ideas.

I can't wait to see the stupid and beautiful and genius and ugly things people come up with. I hope that we can handle these with grace. I dream of the day that a teenage Keoni is limited by his imagination, not his hammer, hands, and wallet. I believe there is a way that we can regulate biohacking without smothering it in the cradle. I imagine a future where we consider not only the effects of doing something, but the effects of not doing it as well.

I was a teenage biohacker. But I grew up. I grew up seeing how much we could improve, how much better we could be. I grew up watching my heroes mellow with age, and my peers fail to achieve anything at all outside of the system. I grew up seeing the alternative path I loved be wrought with failure and irrelevance. But more importantly, I grew up seeing how we can fix it. I can only hope that I, too, do not mellow with age. Brave faces, everyone: the future is ours.

Chapter 13: Beauty in the March

I build technology. And sometimes, late at night, I feel very conflicted about my place in our world. Capitalism is getting eaten alive by Technology, acting to centralize economic power. Inequality is rising, our mental health is deteriorating, and our society is becoming polarized. The technoindustrial machine has made us into cogs, made us into a species of transactions. Science killed God, and technology that promised to bring us together tore us apart. We were promised leisure as production increased and we were lied to. I sometimes have to question — where is our march of progress bringing us?

In November 2019, on a complete whim, I took a trip to the redwood forests in Humboldt. I decided I wanted to go at about 2pm on Friday, and by 3pm, I was out of the lab, driving 6 hours from Stanford up to Eureka. That night I stayed at an Airbnb on the Samoa Peninsula with an outdoor shower — and good god, I've never felt celestial wonder like I did under that elysian sky. The next day I drove to the redwood forests and took a short hike on The Miners' Ridge and James Irvine Loop. I remember the late orange sun shining through the redwoods and the sweat on my brow and the cool ocean breeze and the ferns swaying among the lonely trunks. Most of the old growth redwoods were cut down by people looking for lumber — reasonable people, like you and me — in the shameful name of progress. Only 5% of the old growth redwood forest remains. Our industrial world took a look at the natural world and *absolutely decimated* it.

That night, I stayed in an Airbnb down in Ferndale. It was my host's first time hosting someone. She was a lovely lady — that next morning, she cooked me delicious toast with some locally produced jam while her children tended the rabbits and chickens and ducks in the backyard. During that breakfast she explained to me how the house was made many years ago in Victorian style out of pure redwood and how grateful she was to finally own a home for her family, that she could raise her children in. I saw in her eyes a woman who truly cherished what she had. Cherished a home built out the beautiful redwoods the loggers shamelessly cut down.

And within this, I am struck by the symmetry, not contrast, in every sense possible — of my ability to cynically rationalize the structure of progress, history, and society versus my emotions appreciating the beauty in things around me. Or equally so, the opposite: to optimistically show data of how the world is improving versus the lived realities of the people of this nation and the negativity gripping the world.

I can see beauty in sun beams through forest leaves, beauty in intricate quilted patterns on the heavy blanket I slept with on the couch, beauty connecting with the people around me who had nothing in common with me. Or, I can see disaster in the apocalyptic nature of our climate crisis, the rising housing prices and stagnation of the common man's wages, or how much vitriolic hatred has infested our public discourse. Or, I can see how much technology improves our lives, and how much better things are getting. I can see how bad things were, how much better they are now, and how much better we can make them. I can be hopeful; I can be despairing.

I could be optimistic in my rationalization and pessimistic in my stories, or I could choose to be pessimistic in my rationalization but see the sunshine in my life, or any other combination. Where I choose data and where I choose emotion is arbitrary. It's not on the basis of what is actually true — because both are equally true from different perspectives — it is on the basis of the ways I choose to experience the world and the situations I put myself in. Just maybe, I can be both a critic and lover of the future.

At the end of the day, I want to build technology because I think technology is beautiful. Anything more is rationalization. Although, in the end, is there a difference?