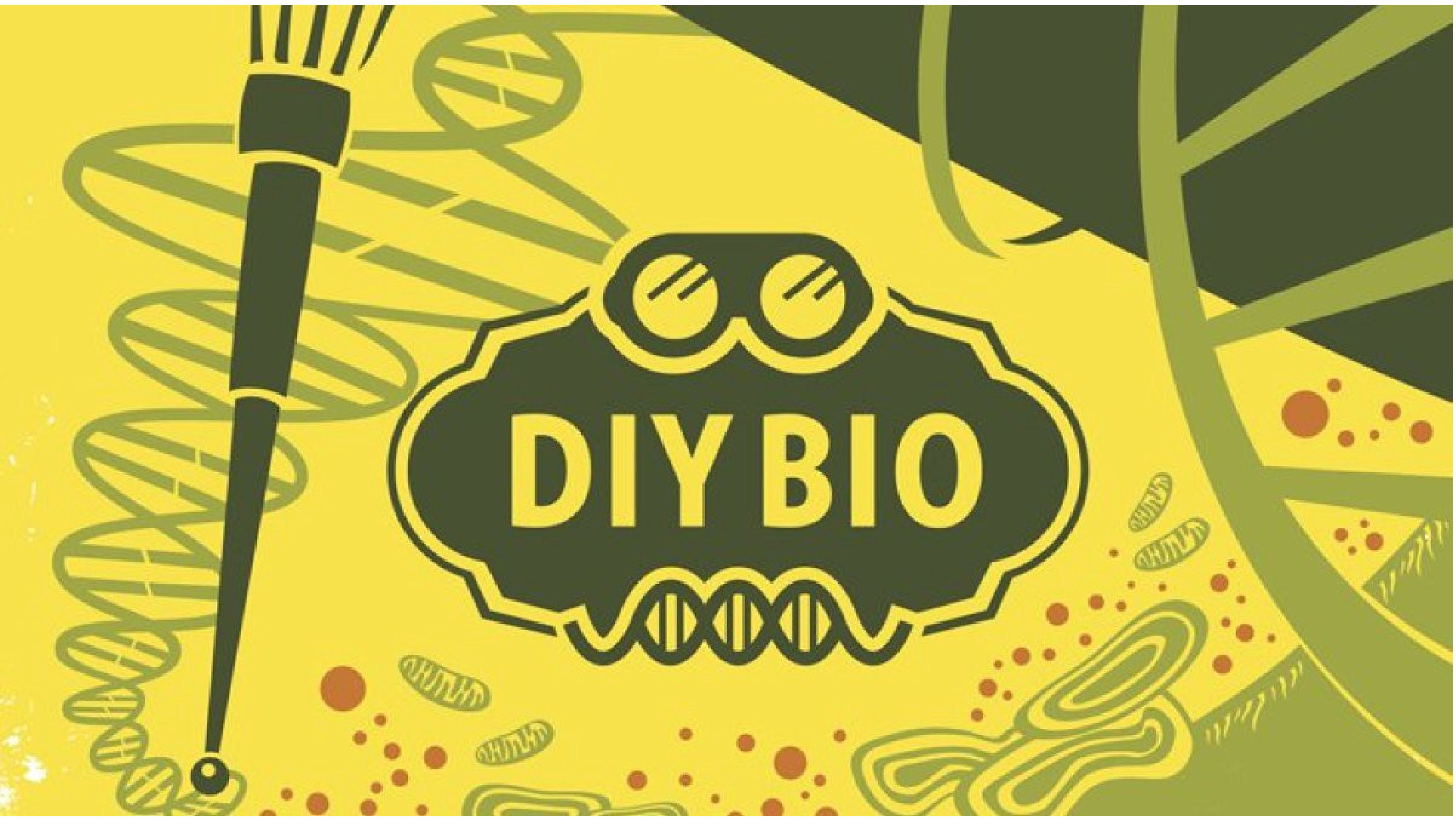


A Guide to DIYbio (updated 2019)

Almost Everything You Need to Know About "Biohacking" (with links)

A long time ago at Thought For Food, I mentioned to Christine Gould that I should eventually write a post about biohacking, rounding up all of the facts that I could about how to get started teaching yourself the basic tenets of synthetic biology, setting up a laboratory space, starting a biotech business, common events, and resources you need to get started.

This is a primer with as much information as I could find on different aspects of the biohacking community. If you have additional information, please comment below and I will continue to update this guide with additional details. I am merely a single voice in a diverse community (and definitely have a US-centric bias), and merely a collector not an expert, so I welcome any input in the comments. Feel free to share this guide if you find it useful.

A Background to "Biohacking"

Since the discovery of DNA in 1953, biology has become more and more accessible to the layperson. Biohacking is the overarching practice of creating and using tools, methods or exploits to modify and/or measure biology for the distinct purpose of changing existing systems to suit a novel purpose (normally to improve upon the human condition).

This generic definition contains many types of biohacking. Here are some examples:

Quantified Self (QS): This group tracks human biological functions through devices.

Physiological Biohackers: These are people that change the physical parameters of their environment. They eat differently, change sleep patterns, modify their water and oxygen intake, and try novel exercise regimes. Sometimes this is behavioral, sometimes this is with the aid of a device.

Grinders: Grinders are body modification experts. They implant, change, swap out and undergo surgical procedures to improve upon their existing biology.

DIYbio/synthetic biology: DIYbiologists modify DNA. They work with a variety of different organisms.

For simplicity's sake, we're going to focus on groups and individuals that edit DNA — one of the most powerful tools in the biohacking arsenal.

"Oh geez Rick, I think this DNA is coiled the wrong way!"

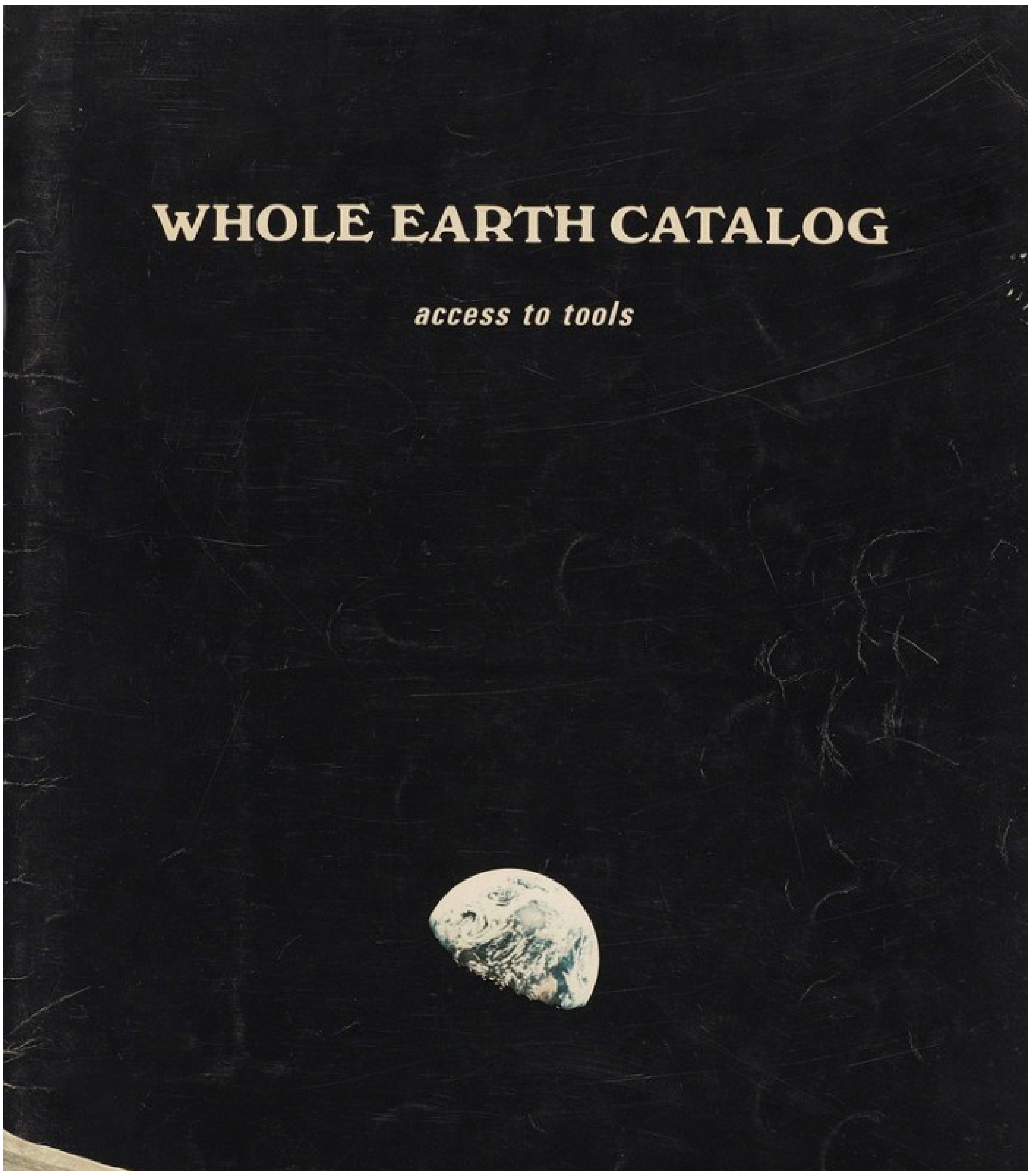
In the late 1970s, Scientists at Genentech and City of Hope inserted synthetic genes carrying the genetic code for human insulin, along with the necessary control mechanism, into an E. coli bacterial strain which is a laboratory derivative of a common bacteria found in the human intestine. Once inside the bacteria, the genes were "switched-on" by the bacteria to translate the code into either "A" or "B" protein chains found in insulin. The separate chains were then joined to construct complete insulin molecules. This kicked off the synthetic biology revolution.

As early as 1990, these discoveries were trickling out of labs into kitchens. With the explosion of financing due to the completion of the Human Genome Project, many biotech companies were formed to begin creating new medicines but most eventually went out-of-business due to lack of control over biological systems. The stage was set for the synthetic biology revolution.

In the mid-2000s, the Biobricks Foundation was founded to build the Registry of Standard Biological Parts. In the same time period, the International Genetically Engineered Machine (iGEM) competition was started. iGEM is a yearly contest of university teams to develop novel organisms. With iGEM's teams creating new Biobricks, the spread of education and shared protocols through OpenWetWare, and better standardization through SBOL, a small but strong movement of bioengineers began to conduct genetic engineering at home.

After the financial downturn in 2008, many labs went bust, leading to large amounts of equipment coming available for cheap. Coupled with high rates of unemployment for PhDs (also known as the "post-docalypse"), this was the perfect storm for disgruntled academics and industry researchers to leave their old labs and set off on their own.

Buoyed with the example set by community makerspaces, these intrepid founders began chatting online, eventually starting the first of many DIYbio laboratories in 2010 to practice and spread access to genetic engineering outside of "normal" environments.



History of Biohacking / DIY Ethos

"Do-it-yourself" gained mainstream acceptance as a term in the late 1960s, early 1970s. It is a movement dedicated to the empowering idea that anyone is able to perform tasks that used to the completely in the realm of experts and professionals. Being an autodidact and training yourself in a complex subject such as biotechnology or rocket science is a continuation of the same philosophy governing the DIY ethos.

The DIY movement supported in part by magazines like the Whole Earth Catalog and eventually extended by the internet. Nowadays you can find instructables, YouTube tutorials, or free classes online for practically everything.

But ***why*** is it so important to unlock knowledge in this way?

For as long as we've been conscious beings, humans have modified themselves and the world around them. Ranging from clothing to agriculture, humankind continually utilizes technology to improve upon our current state. Biohacking and the engineering of DNA is merely a tool in our technological repertoire, an interface upon which we can extend our current capabilities. In essence, it is the original tool through which life changes the world. By learning how to use this tool, you gain more control over the world around you.

To learn how to work with DNA outside of "normal" environments like universities and industry is still considered odd. It is the aim of many involved in this community to spread access to the tools of genetic engineering so that it becomes normal. There was a biopunk manifesto that was written years ago, and a draft code of conduct formulated by participants in the 2011 North American DIYbio Congress and agreed in July 2011:

Draft DIYbio Code of Ethics from North American Congress

OPEN ACCESS
Promote citizen science and decentralized access to biotechnology.

TRANSPARENCY
Emphasize transparency, the sharing of ideas, knowledge and data.

EDUCATION
Engage the public about biology, biotechnology and their possibilities.

SAFETY
Adopt safe practices.

ENVIRONMENT
Respect the environment.

PEACEFUL PURPOSES
Biotechnology should only be used for peaceful purposes.

TINKERING
Tinkering with biology leads to insight; insight leads to innovation.

The cost of reading/writing DNA has dropped precipitously in the past few years, engineering DNA is getting standardized/easier, and the availability of hardware/software has gotten to the point where working with DNA is accessible to nearly anyone located in developed countries.

We will eventually live in a time where we view DNA literacy in the same way we view learning coding — a worthwhile skill that's easy to learn and opens up all sorts of opportunities. Now that you've got the basic premise and principles, let's move on to practical applications.

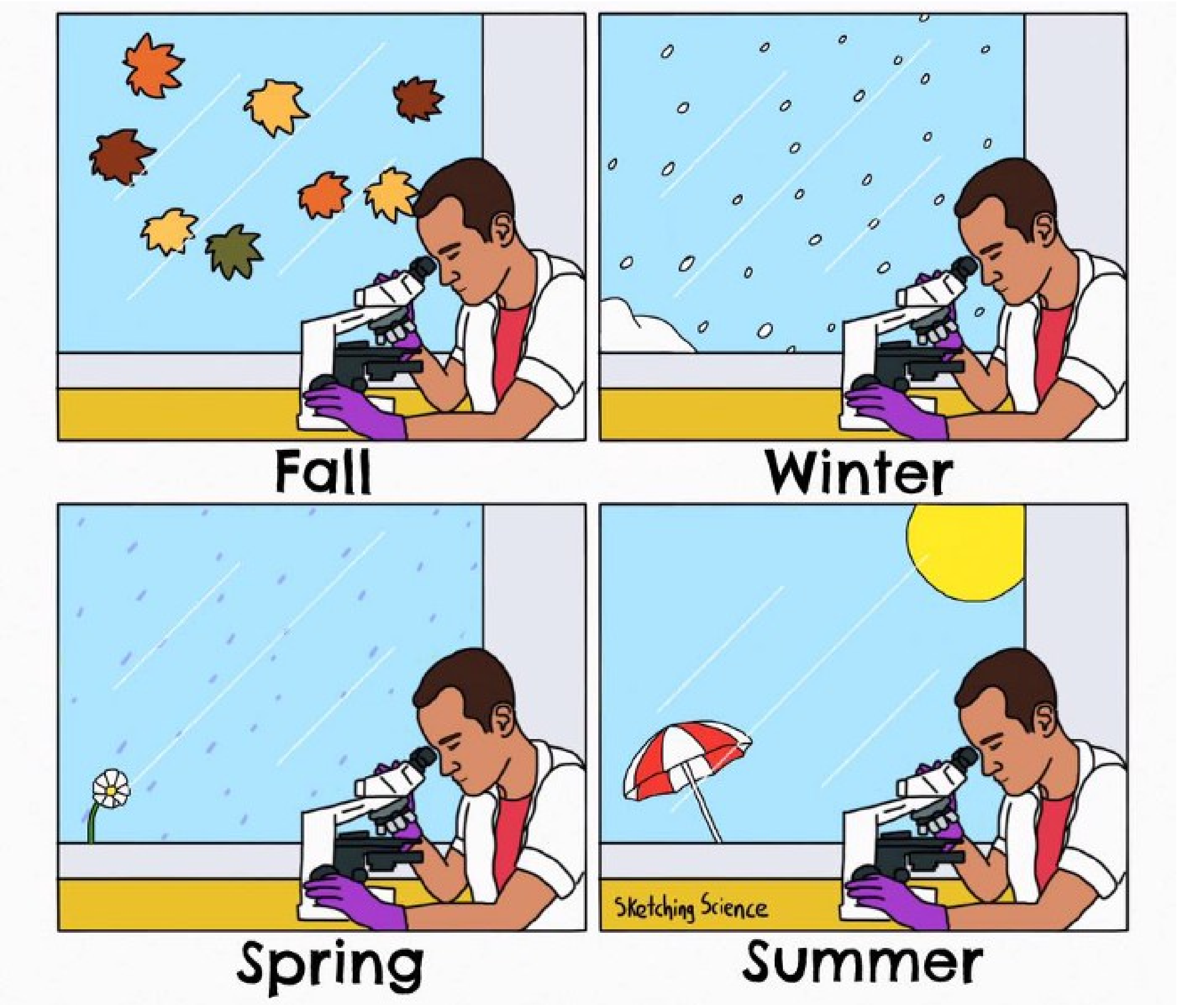
What can I do with DIYbio/synthetic biology?

You can make new foods, materials, clothes, colors, medicine… virtually anything that currently exists in the world can be made with the tools you learn through DIYbio. As George Church, a prominent figure in synthetic biology said:

He's like the synthetic biology Santa

Sounds great right? Well, biology is hard as hell to get anything to work. One of the core things you need to know before you start is that **failure is good**. A failed experiment teaches you something. Make sure to be ready for constant contamination, PCR problems, and more when conducting your initial experiments. Just like anything worthwhile, it will take a long time to master these skills. Be consistent, write it down, and keep trying.

It's absolutely important to build a solid basis of fundamentals before swinging for the fences. You're not going to be able to engineer a Sequoia before you figure out how to use a scale. Start slow and ramp up to where you're attempting things at the bleeding edge.



Inspiration

Just because something is hard, doesn't mean it's impossible. Some companies that started out of DIYbio labs include: Spira, Hyasynth, OpenTrons, Bento Bio, Chai, Microsynbiotix, Pili, Kilobaser, Algiknit, BluePha, Nyoka, and more.

Some prominent projects that started out of DIYbio labs include: Real Vegan Cheese, Open Insulin, Metafluidics, and more. Check out an ever-evolving list here.

Some prominent DIYbio university labs are: Fernan Federici, David Kong, Drew Endy, Andrew Pelling.

I've always posited that art asks questions that science tries to answer. The bioartists that explore the boundaries of the possible with biotech are absolutely brilliant and create masterpieces that poke at what it means to be human. The following are ever-evolving collections of some notable works of bioart: WeMake$$$NotArt, Vice, LaBiotech, and of course on Twitter.

Education: How to Learn DIYbio

So now that you've gotten some inspiration, let's dive deep into some of the best resources to learn how to properly engineer organisms.

Locations

The very best thing you can do when starting to learn a new topic is to find a community of people with shared interests. There's been an explosion of spaces that now offer seminars, workshops, classes and tools for synthetic biology. See if one is located in your city. Some of the first DIYbio labs in the

US are also the most prominent, including: Counter Culture Labs, Biocurious, Genspace, and BUGSS.

Events

Another way to get a sense of the community is to attend one of the events. This is a great way to find other like-minded individuals and potentially a mentor to guide your work.

Biosummit: The annual gathering of DIYbio community organizers held in Boston at MIT, founded by the wonderful David Kong.

Gap Summit: A community of 100 young leaders in biotechnology that meet each year at different locations all over the world to solve major problems in medicine.

Biohack the Planet: Started by Josiah Zayner, this conference is held in Oakland at Counter Culture Labs and focuses on individual biohackers.

Synbiobeta: The premier synthetic biology business conference, started by John Cumbers and hosted in the Bay Area.

SBX.0: International conference on synthetic biology organized by Drew Endy.

iGEM Jamboree: International competition for synthetic biology, teams compete from all over the world to build organisms and solve problems.

Biohackathon/Biohackathons: These are varied all across the world and involve short design sprints to quickly come up with a proof of concept to solve a synthetic biology problem.

BDYHAX: Conference for body modification/implant specialists held in Austin, Texas.

Biodesign Challenge: International competition for bioartists held in NYC started by Daniel Grushkin.

Biofabricate: Annual conference on biomaterials held in NYC.

HOPE: Hackers on Planet Earth — conference focused on open source, DIY hacking. They always have a DIYbio village.

DEFCON: A premier conference for biohackers, they always tend to have a biohacking village.

GOSH: Gathering for Open Science Hardware, focused on enabling access to low-cost equipment for community science.

TECHNOx: A LATAM-focused synthetic biology competition.

New Harvest: A conference focused on cellular agriculture research and businesses, founded by Isha Datar.

BBKOpenScience: Organized by BioOk, this event is held in Spain.

Biofabbing: An annual conference in Geneva hosted by Hackuarium and the Hackteria Network.

Some quick tips on how to get into conferences if they're on a topic you're interested in: volunteer, tell them you're a member of the press and write up a quick recap piece, befriend someone going (oftentimes there are no-shows and you may be able to take someone's place), or worse-case scenario just walk in and explain why you're so interested in the first place.

Classes

Now that you've found a community, it's time to start training. Luckily enough, there are plenty of classes available online to begin learning about synthetic biology. I've arranged these in order of beginner to advanced.

Synthetic Biology 1: A beginner's course taught by the hilarious Jake Wintermute.

Biohack Academy: A class started by Waag Society in Amsterdam, this class takes you through the basics of building all of the essential lab equipment you'll need to start and growing your first organisms.

Bioengineering 101: Taught by Josiah Zayner, this covers how to get started from no experience whatsoever in genetic engineering.

Principles of Synthetic Biology: EdX course taught through MIT. Gives you a good understanding and grounding of synthetic biology.

HTGAA: How to Grow Almost Anything is a spinoff of How to Make Almost Anything, a course started by Neil Gershenfeld, creator of the Fab Foundation. This class is advanced and focuses on the cutting-edge in biotech.

If you're really serious about DIYbio and synthetic biology, go to school for it! The following universities are world-renowned for their programs in synthetic biology: MIT, Stanford, UC Berkeley, Imperial, Harvard, and many more across the world (don't get insulted if I didn't mention your school!). Google bioengineering, synthetic biology, genetic engineering or systems biology programs to find one that best fits you. If you're looking local, the best thing to do is locate any university that won gold in iGEM and contact the faculty mentor.

Guides

Boolean Biotech: An all-around great guide to learn how to make a workflow using a cloud laboratory like Transcriptic. In addition, this blog is fantastic to follow if you're interested in computational biology.

Primer for Synthetic Biology: Great overview of the basics by Scott Mohr.

Essential Biohackers Guide: Created by the SynTechBio Network in Latin America, this is an amazing resource for starting a lab.

The ODIN Kits: Relatively easy to work with, these kits allow you to get hands-on experience with DIYbio.

AminoLabs: Hands-on learning meant to be an entire all-inclusive package for learning genetic engineering techniques through easy-to-follow directions.

Biotech in a Box: Virginia Tech loans out kits for educators to teach kids how to engineer biology.

Carolina Scientific: General all-purpose science education kits.

Read Papers

One of the big things you'll discover in the DIYbio community is that everyone reads papers. That's the main source of new knowledge.

Google Scholar: An indispensable resource to find the papers you need.

Sci-Hub: The best way to get a paper that's behind a paywall. It seems sketchy but it's a wonderful way to unlock knowledge.

LibGen: A method to torrent PDFs of textbooks so you don't have to pay 100s of dollars.

ResearchGate: A social network of scientists publishing and discussing papers.

Semantic Scholar: Another good way to search/filter through papers.

NCBI: Great place to find research tools and datasets.

When reading a paper, there's a few things to keep in mind. I've come up with a simple process to "de-bone" a paper quickly to get all the meat out of it:

1. Check the # of citations, the date of publication, whether you recognize the author's name, the university of origin and the journal. All of these

things are a quick gut-check to see if anything seems amiss or if it's bad/old research.

2. If nothing smells funny, read the keywords and abstract to get a sense if it answers the question/project you're working on. I like starting with literature reviews of the topic first to get a good grasp of the entire state-of-the-art in the field.
3. If you find good evidence that the paper has some information you're looking for, skip all the way to the conclusion and read that.
4. Next, read through the discussion section, highlighting any lingering questions and future experiments the author might perform. This is so you can keep an eye out for these questions in other papers you read.
5. Go through the methods/materials section, noting down the proper reagents, papers cited and protocols. This is the bread and butter of what you'll practice in the lab so be sure to understand the steps. Science is like a recipe and this section teaches you how to bake the proverbial cake.
6. If you know the topic well-enough, skip the introduction.
7. Finally, seek out any additional papers to read in the references. This is why starting with literature reviews are best because they are a gold mine of scientific findings and the references page is like a choose-your-own adventure book of scientific knowledge.

The best process that I've found to synthesize the information found in the papers you read is to write your own literature review on the topic of choice. This is a good guide on what to do next to start designing your experiment.

Media

For some reason, the majority of people in the biohacker community communicate 1-on-1 via Facebook. We all hate it but it works. I've listed some of the most active resources below.

FB Groups: iGEM, DIYbio, Biosummit, Biohacking + Genetic Design Network, Biohack Academy, BiohackSyd, DIYbio Mexico, Amateur Microscopy, SyntechBio, Biohackers Global, BiohubIL, and more.

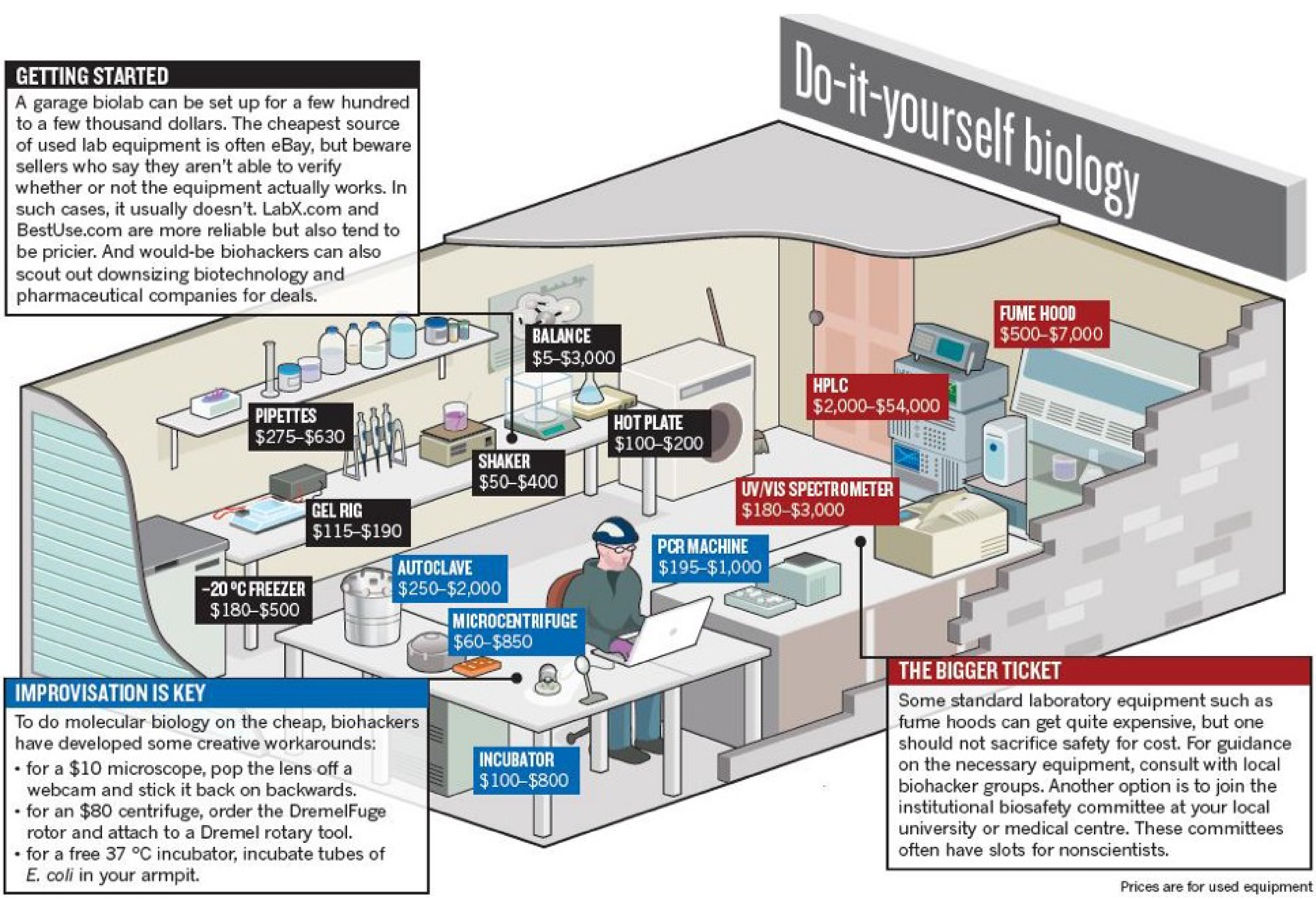
YouTube Channels: The Thought Emporium, David Ishee, Waag Wetlab, iBiology, Synbio1, Peter Bickerton, The ODIN, DIYSect, GaudiLabs, NurdRage, Bunsen Burns, Ken Killeen, IndieBio, IsInstantLife, NileRed, Alex Dainis, Backyard Scientist, ThoiSoi, Cody's Lab, Applied Science, Biologik Labs, Backyard Brains, The Action Lab, Open Science School, Intro to Systems Biology, and more.

Instagram: Biohack Info, Sebastian Cocioba (also check out his FB), Kristin Weissenberger, Alkymi, Bioquisitive, AminoBio, Little Pink Maker, iGEM, Logan Thrasher Collins, Anna Dumitriu, Cellul-air, Pili, Gingko Bioworks, Nature Synthetic, Next Nature, and more.

News Websites: DIYbio.org, Synbio Project, Bitesize Bio, DIYbio, Protocol Online, OpenWetWare, Wired, The Scientist, Nature, Quanta, BioRxiv, Synberc, Addgene, PLOS, Synbiobeta, Biocoder, SingularityHub, NeoLife, LaBiotech, GEN, Biopharma Dive, Science Daily, Fierce Biotech, Biospace, Endpoints, Stat, and more.

Podcasts: DIYscience, DIYbio.fm, Talking Biotech, NatureBiotech, The Bio Report, Digital Biotech, Biofocus, a16z, Bioflash, The Readout, Talking Biotech, Genemods (one of my favorites).

Books: Biobuilder, Synthetic Biology, Biopunk, Regenesis, Biostrategy, Synthetic Aesthetics, Synthetic, A Crack in Creation, Life at the Speed of Light, Synthetic Biology: A Lab Manual, Biology is Technology, Zero to Genetic Engineering Hero, Gene Machine, Biodesign, Bioart, Evolving Ourselves, Genentech, Dancing Naked in the Mind Field, Illustrated Guide to Home Biology Experiments, Dan Gibson's Textbook, Christina Smolke's Textbook, Gigi Gronvall's Bioethics Textbook, Jay Keasling's Textbook, Genomes, and plenty more.



Equipment

So you've got inspired, found a community, read some papers and started figuring out a specific experiment to practice. What if you don't have the proper equipment? Well, lucky for you the biohacking community has been building low-cost DIY equipment for years now, or scavenging plasmids from strange places, and there are a plethora of resources available for the scrappy scientist. WARNING: be careful with some items and putting together your own equipment — there is the potential for minimal danger in doing so.

DIY Equipment

iGEM Catalog of Parts: Great resource for project ideas and plasmid parts.

Reddit, Meetup, Hackaday, Instructables: All good places to find guides / instructions on how to build equipment. Makerspaces are a good place for hardware and power tools to put together your own labware.

Hackteria: Wonderful resource for everything laboratory hardware.

The Odin: Sells a starter package for a DIYbio lab.

OpenWetWare: Good DIY equipment guides on how to build your own stuff.

Thingiverse: Free 3-d printing files for DIYbio lab equipment.

GaudiLabs: Great repository of equipment (related to hackteria).

Biohack Academy: Open source collection and course on how to build your own laboratory equipment.

Scintia: A source of affordable lab equipment in LATAM.

Open-source Lab: Great collection of open source lab equipment.

CitiSci: A blog that takes you through the steps of building equipment.

Always check at your local hardware store, makerspace or with other biohackers to see if there's easy ways to get equipment. Use your local community as a resource and your lab will be built in no time at all.

Buying Equipment

Some equipment just isn't worth trying to build. If you start with trash, you often end up with trash. Auction sites, university surplus and eBay can yield some amazing finds. I've built a fully-equipped analytical chemistry lab (estimated equipment value ~$500,000+) for less than $12,000. Even kitting out your own home lab can be done with ~$1,000.

MinIon: $1000 gene sequencer that plugs into your USB port.

OpenTrons: $4000 open source pipetting robot.

BentoBio: Affordable and effective portable lab

GovDeals: Government auction site. You can make some great finds here.

LabX: Used equipment website. A bit pricier but anything from here works.

BioSurplus: Same as LabX.

eBay: Every biohacker's go-to website for buying anything you need for your lab.

Bio-world: Great place to get reagents for cheap and they don't require a business address.

AliExpress / Alibaba: It might take awhile to get to you, but if you need a lot of something or want a piece of equipment for cheap, this is your best bet.

New England Biolabs: Great place to get reagents.

Always check with your local university — they all have surplus warehouses. The best way to get free equipment is to befriend the people there, talk to other biohackers, and keep an eye out for deals where/when labs go out of business. Also if you don't absolutely need a piece of equipment, see if you can borrow or collaborate with another lab (that's an easy way to make friends).

Funding Your Project

Launching a career in DIYbio is a daunting task. It's challenging to support yourself at the very beginning — most DIYbiologists teach, lead workshops, or have other jobs to pay their science habit. These are a few methods that seem to work:

Experiment: Science experiment crowdfunding. I've used the website a few times for projects and I'm amazed by the research done by the community.

Patreon: Great way to support individual creators. Some of the best in the DIYbio community use Patreon.

Kickstarter/Indiegogo: If you have a product you're looking to produce, there's no better place to go than a crowdfunding website. Plenty of DIYbio projects have gotten their start this way ranging from Glowing Plant to ProPCR.

Venture Capital: If you're interested in going beyond research and starting a company around your work, there are a number of accelerator programs, grants and more focused on launching biotech businesses. You can find investors for your work at: IndieBio, RebelBio, YCbio, Ilumina, Synbicite and more.

Many DIYbio labs set up nonprofits and raise money through donations, selling lab equipment, workshops, classes and memberships. Whatever way you end up funding your project, it's going to be a challenge getting it off the ground. Some folks in the community are looking to figure out this problem to enable access to experimental science to anyone. If you have any ideas, be sure to share them with your community.

Software Tools

Design: Genome Compiler, SnapGene, Geneious, Cello, Genetic Constructor, j5, APE, OmicTools (collection), Wikigenes (collection), GenoCAD, Wikipedia list of software, ChemDraw, NEB software, Agilent Primer design, BLAST, open source bioinformatics software, and more.

Electronic Lab Notebook: OSF, Protocols.io, Benchling, SciNote, Docollab, ResearchSpace, Jupyter, OpenWetWare. Here's a full overview.

Share Papers/Literature Review: Mendeley, ReadCube, PaperPile, Zotero.

Lab Management: Quartzy, Happilabs.

Important Note: Safety + Fundamentals

Depending on where you are in the world, there are different regulations required to practice bioengineering. Be sure to adhere to local rules and regulations when starting otherwise you may be endangering both yourself, your project and your community. Since DIYbio is still in its infancy, some commonsense rules apply.

Some basics: wear gloves, dispose of biohazard waste properly, ensure you have MSDS information on-hand, keep areas well-ventilated, and wipe down surfaces with alcohol and bleach. Don't do anything that would cause you or others harm. Keep passageways clear, a fire extinguisher and eyewash station handy, store more dangerous materials in the proper places, and ensure that you have the ability to get help if needed.

Oftentimes a laboratory supply company won't deliver to an address because it's not properly registered. A good way around that impediment is by partnering with an existing DIYbio lab while you're working to get your address registered with the laboratory supplier.

In the US, figure out what biosafety level and standards you need for your lab. When starting a lab, it's important to contact your local WMD FBI agent. Ed You gave a great talk at DEFCON about biosecurity. With the FBI, someone once told me you're either a suspect or informant. When working with sensitive biological materials, it's far better to be an informant, so be sure to get in touch with your local agent.

Getting the basics down is essential. You have to pipette before you can PCR. Make sure to practice, read papers constantly and work to continuously improve. Without the fundamentals, you may miss something and waste time, energy and effort. Design your protocols properly — get off the internet and get into the lab.

Example: My Personal Workflow

When editing this round-up post, someone mentioned that I should provide a concrete example of how to go about using these resources so I decided to include my personal story of how I got started learning and how I currently use these tools in my normal day-to-day work.

I started learning by reading papers. I attempted to join an iGEM team while in high school but was rejected. Luckily, since I was a student I had easy access to papers and after I graduated, I started using Scihub. I went to school to study biomedical and chemical engineering and starting volunteering in a systems biology lab, learning the basics but never participating in writing a paper or doing experimental design. So I decided to start my own lab. Next, I audited the Principles of Synthetic Biology course, and began building equipment from Biohack Academy at my local makerspace while watching advanced lectures from HTGAA. I started my first lab in 2014, using some home-built equipment in a friend's garage space. I read Biobuilder, Synthetic Biology and began designing workshops for the community. I got a spirulina kit, a GIY kit and some basic microbiology kits from Carolina to get started practicing fundamentals. I highly recommend getting ANY low-cost kit to teach you the basics. It's also more fun if you have a couple of friends do it with you. After a few months of hosting community workshops, practicing techniques, and reading background papers on my various ideas, I started experimenting with mycelium as a replacement for ceramics, keratin bioprinting and genetically engineering spirulina.

I start each project with a thorough literature review using Zotero, Sci-hub and gDrive. Once I have a write-up, I learn whatever fundamental skills are necessary to be successful at following through or I find a mentor/expert to help me with that process. Next, I map out protocols and determine the proper budget, supplies and timeline. Finally, I actually go through with the experiment, analyze and interpret the results, and summarize my findings. I've use Snapgene for genetic design, Benchling in the past as an electronic lab notebook, and Quartzy to order supplies. I often get plasmids through Addgene, reagents through Bioworld and lab equipment off of eBay.

If I don’t have the proper resources (lack of money/equipment), I normally go back to the literature to find alternatives or ask around for help. It’s surprising what you can get if you just ask. The community is also incredibly supportive so be sure to reach out if you need help! Facebook is the normal platform where people communicate and share information so be sure to join a group.

Conclusion

That just about covers practically everything you need to get started. Be sure to check back here as I expect to go through and update this routinely as more information comes out every year and the community matures.

When I started a few years back I wish I had all this information at my fingertips and a mentor to help guide me. If you’re just starting out, be sure to reach out to someone if you need help. Good luck in your journey and let us know what you discover!