

# Citizen Science Quarterly



Volume I



**Welcome to CSQ.**

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Citizen Science Quarterly  
Volume 01

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# Letter from the Editor

Howdy all,

As your editor, It is my great honor to welcome you to the first of many issues of Citizen Science Quarterly. For my debut editorial, I didn't have a clue what to write, other than how very ironic it is that I am an editor of a magazine.

So I'll start with what scientists do best, ask questions. Why is the magazine called Citizen Science Quarterly? Why not a synonymous name like Garage or Amateur science? And why try to include all fields, would it not be more productive for a biologist to start a DIYbio Quarterly?

I went with Citizen Science over any other name because it didn't have the same limiting connotations. A lot of the commonly used words like amateur, garage or DIY don't accurately portray what is happening or what the Citizen Science movement is about. The quality of a lot of the work being done has blurred the line between amateur and professional. Comparing people meeting in a garage to the properly formed non-profit corporations that a lot of hackerspaces are today (some even with 501(c)3 status) doesn't seem quite accurate. Especially when your "garage" has more lab and design capabilities than all but a few universities. It might be time we stop referring to the science being done outside of labs with all these media friendly descriptors and just call it what it is, Science.

If no descriptors are needed then what's the purpose of adding Citizen to the title. Aren't scientists citizens of countries too? Well yes. But I'm not talking about the "a country gave me a passport therefore I'm a citizen" type of citizenship. I'm talking about citizens in the romantic sense of the word. I could probably write an entire thesis on the difference between citizens and members of population, but for this editorial lets just skip ahead to where I claim citizen to mean someone

who takes an active role in the growth and well being of their community. Which is why we called it Citizen Science Quarterly as our goal is to grow the scientific community until it contains an entire planet of actively engaging scientists.

Now the last thing I wanted to touch on was why cover all fields of science in this magazine? Quite simply, its because very few scientific problems now a days require a single expertise and a cross fertilization of expertise is always a good thing. The most obvious example that I have for you is my own personal area of study, bioinformatics, which sits right in the middle of biology and computer science. With bioinformatics bridging the gap between fields it has allowed for the accumulation of more biological data then we can hypothesize about. Not to mention the development of computer science, to be able to process and store that data in organized but speedy manner.

Hopefully this little editorial of mine has answered a few of the questions you may have had about the magazine. Of course, if it didn't and you are still a stir with questions, my email is listed below and I welcome anyone to contact me for anything pertaining to the magazine at any time.

*Cheers and Happy Reading,*

**Jacob Shiach**  
**Editor-in-Chief**

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# It's a Fab Fab World

**Andrew Hessel**  
Co-Chair, Bioinformatics  
and Biotechnology  
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**A**t Singularity University, on the NASA Ames research campus in California, we have an innovation lab that is sponsored by Autodesk, a design and visualization software company. People use the lab's computers and software to design new objects very precisely, and to render them with photo-realistic quality. The resulting digital files can then be sent to a 3D printer. We have several of these, including a professional Stratasys unit and some DIY-cool MakerBots. In a few hours, they have something they can hold in their hands.

With these tools, any idea can be made into reality in just a few hours.

While it's nice to have these tools at our fingertips, this technology, called digital fabrication, is available to almost anyone through companies like Shapeways and Ponoko, which offer access to these printers and other tools online. These services are leading a revolution in personal-scale manufacturing by allowing designers, materials suppliers, printer manufacturers and customers to work together and make a growing array of products.

Most machines can print only one type of material at a time, usually plastic or metal. They're complicated and expensive devices, ranging in size from a microwave to a fridge, and they're packed with electronics and wiring. Yet they are unbelievably cool machines, and addictive. They're radically changing the way things are being design, developed, and manufactured. Prototypes can be made and tested rapidly. Customization is easy, too, because each unit starts as a digital file and is made on demand.

For example, Scott Summit, of Bespoke Innovations in San Francisco, is using these tools to reimagine the world of prosthetics. He uses digital fabrication to make unique replacements that are not only perfect copies of the remaining limb, but incorporate exquisite personal artistic expressions as well.

"Fab" technology is still pretty new, but it is improving exponentially, as is often the case for digital technologies. Everything related to the field is growing – from the diversity of the outputs, to the industries starting to use them, to the sophistication of the printers. One company, Organovo, has

already replaced plastic with living cells, and is using the machines to print blood vessels, and perhaps soon, complete organs, like lungs or kidneys.

Extrapolating this curve, it is clear that digital manufacturing will bring changes in manufacturing and distribution of many goods. And while it's not yet possible to fab something as common as a cell phone with a single device, chances are good we will eventually get there.

Looking further out, some foresee the day we have machines so sophisticated that they are able to make more fully-functional fab machines, creating limitless manufacturing ability, leading to an age of abundance. All that would be needed is raw materials (possibly any matter, since all things are made of the same atomic stuff), some energy, and the digital instructions to make the good. Ask them when these universal fab machines will be reality, though, and the estimates range widely, typically between twenty and forty years.

I'm a biologist, though, and I have a slightly different perspective on fab technology. What I perceive is that universal fabricators already exist, and indeed have existed for some time. They're not just under our noses, they make our noses. They're called cells.

Living cells make a vast array of compounds, and can also make all the structural components required to make more cells. They do this biochemistry with common compounds found in nature, like carbon and nitrogen, and with a wide range of energy sources, the most basic being sunlight. The digital instructions that control cells are all written in genetic code, usually but not always DNA.

Nature has been making and tinkering with bio-fabs for over 4 billion years. Some are simple, stand-alone machines, like bacteria. Others are fantastically complicated networks consisting of trillions of interconnected fabricators. Our planet is literally teeming with them, in all shapes and sizes. They are so prolific that they compete

with each other for material resources and energy, even going so far as to feed on each other or their remains. Their genetic programs produce many different shapes and sizes and behaviors. Look deeper, at the kernel of their genetic programs, though, and we find just three core functions:

- Find energy and raw materials
- Avoid predation and death
- Reproduce

We humans are, not surprisingly, a special case. We are the first of nature's bio-fabs that are able to make non-biological tools and to write our own design programs. This is the essence of technology. It's hard work but it's made us the most effective builders on the planet. With our technology, we have dominion over every other organism, and even other people if they aren't as adept at technology as we are.

In May of 2010, we reached a significant milestone, with Craig Venter and his research team using technology to make the first human-programmed cell, a bacterium. Biology begets technology which begets biology. We've come full circle.

What this practically means is that limitless manufacturing ability is already at hand. And it can be harnessed to address human needs simply by becoming more adept at writing and executing DNA code and/or organizing cells into structures that are useful. Systems and synthetic biology empowers us in the first task, and a detailed knowledge of developmental pathways, or how to 3D print cells, the second. Combined, these allow us take control over life's core functions and add a fourth attribute: usefulness to humanity.

The manufacturing processes we use today are undeniably useful. We've literally transformed our societies and our planet with them. The downsides are that they require a substantial amount of human effort to build and maintain, they consume large amounts of energy,

and they produce waste products that can be quite toxic to living creatures, including us, and the environments that they live in. In the long term, they're not sustainable.

In the city, where living things are marginalized, it's easy to forget about life. But hike into the countryside, dive in the ocean, or browse the growing number of DNA and biological databases, and one is quickly reminded that this a living world, and that life is not just abundant, but also amazingly robust and diverse. If we can become adept at making synthetic genomes and synthetic organisms, there's a good chance we can increasingly use them to manufacture the things we need for our modern, technological lifestyles, and to integrate living things back into the urban environment.

Bio-fabrication offers tantalizing improvements, a path to making products and structures and other useful things using natural compounds and the cheap and plentiful energy of sunlight or sugar. Waste products would be biocompatible, and obsolete or broken devices easily recycled through composting or digestion. And important from an economic and cultural perspective, direct human effort would be minimal because the cellular bio-fabs would do most of the work. Effectively, our role would be to design and build useful cellular systems, and to be good caretakers of the living things we create, not so different than farmers or ranchers.

When I look to the future, I see things like bio-designed shoes made of cells and other natural compounds, as durable and comfortable as one you might be wearing, only not manufactured in a faraway factory, but grown in all shapes and sizes in a nearby field. I see homes that are 3D printed from cellular materials that, after deposition, knit together to form bone or bamboo-like composites. Or better yet, grown from special seeds. And as our 3D printers become capable of working with living and non-living materials at the same time, things like submarines that are part dolphin,

and airplanes that are part bird. Such hybrid manufacturing would combine the best man-made technology with the elegance of what nature has created seamlessly.

There's a lot that has to happen before we can realize even these simple examples. For one thing, we have to train a new generation of makers that see biology as part of the engineering repertoire. This is already happening with the International Genetically Engineered Machines program created by MIT, and the mushrooming DIYbio and citizen science movement. For another, we need better tools, including design software that facilitates the making of living things, complete with metabolic and developmental libraries, plus any safety or regulatory parameters. Autodesk is already exploring how their software could enable this.

But the key thing may be a global understanding that biology is a technology, and perhaps the most important technology at hand for sustaining our species and our planet, and shed our fears of using it more broadly to serve our needs.

After all, using technology is what we humans do best.



**Andrew Hessel** is also one of the founders of a cooperative based Biotech startup called *Pink Army*, whose goal is to develop cures one person at a time.



Steven Miron, M.D.

O P E N

W I D E

a case for open source medicine

Part 01

*All that may come to my knowledge in the exercise of my profession or in daily commerce with men, which ought not to be spread abroad, I will keep secret and will never reveal. – Hippocratic Oath*

**M**edicine is full of secrets. I should know, since I am a doctor. While some philosophers will argue that there is no such thing as “good” and “bad”, our own personal system of values with which we interpret the world usually classifies everything in it relative to those two concepts. Even secrets. It sounds fairly simple, right? Good and bad are complete opposites, so the thing under consideration is either one or the other.

But medicine deals with human beings; and humanity, with all the social interactions that come with it, is a complex system. Almost everyone would agree that keeping a patient’s medical history secret is a good thing. But what happens if that married patient has a sexually transmitted disease because he has been sleeping around, and telling his wife about it would potentially destroy his marriage? Suddenly the simple secret becomes a complicated burden. Ethics committees would like you to think that there

is only one correct answer, and lawyers know that there is only one answer that will keep you out of court. But to actually be thrust into the middle of such a situation is not a pleasant task at all. You learn that something can be both good and bad at the same time.

And then there are other secrets in medicine. Secrets that leak out, from time to time, and suddenly aren’t so secret anymore. Like the secret that modern medicine for all its remarkable achievements at prolonging life, or at least quality of life, is still plagued with false assumptions, charlatans and snake-oil salesmen. That sometimes your doctor is doing what he was trained to do, but this method or this drug or this procedure was the fashion at the time of training, or was the favorite of a tutor, or simply “because everyone else is doing it”.

There have been a lot of interesting revelations lately in the popular press, about back surgeries that offer results that are no better than

physiotherapy, about drugs that don't do nearly as well as the pharmaceutical companies claim they should, about stents and bypass surgery being no better than treatment with pills. Yet this is nothing new.

As far back as the 1970's Archie Cochrane started taking a long, hard look at the practice of medicine and basically asked the question "Is what we are doing as effective as we think it is?". This is a vital question in a science such as medicine. The scientific method is not only about answering the question and designing experiments; there comes the day when your data actually has to support your claims. The status of science is the only reason we doctors are allowed to literally take people's lives into our hands and do things to people that no homeopath or chiropractor is allowed to do. When we speak, we are supposed to be supported and guided by absolute, verifiable, reproducible truth.

But then someone like Cochrane comes along and begins to turn medicine on its head, by showing that some of the things we have been doing as "standard procedure" actually have no additional benefit compared to not doing them at all. Which brings us to the next step – if it has no benefit, then why bother doing it? After all, most patients aren't coming to visit us as a social outing. Most of them realize that medicine has limitations but they want a combination of the most effective treatment, the cheapest cost, and the minimum intervention.

So why do these bad little secrets creep into what is apparently a solid, peer reviewed and highly regulated profession? The answer is simple. Medicine is a vast field that embraces many disciplines from physics and biochemistry to statistics and sociology, passing briefly through traditional medical fields like anatomy, physiology and pathology. Not only that but it is growing at a geometric, if not exponential, rate. Many things I learned at medical school are now obsolete. Even non physicians are aware of this change if they

follow the constant "Aspirin is good/aspirin is evil" debate that has been in the news for the past 20 years. Even basic CPR has been changed, again. So imagine what is happening to immunology or oncology. There is no way someone can keep up.

Since we are human, we try to hang on to a rock when we are in danger of being swept away by the storm of change. This rock can be a stubborn refusal to keep up with the changes – which is dangerous. Or, because doctors are usually reasonably intelligent people, the rock becomes our own judgment and critical thinking. We read about new things, and then we choose to believe them or not. If a new study "sounds good and logical" we accept it, and if it "sounds badly designed or illogical" we reject it. And suddenly medicine has stopped being a science and instead has turned into a belief.

Compound this with two facts: all medical research is profit driven, either by a university seeking grant money, a corporation seeking a return on investment, or an individual seeking recognition or patents; and some studies are completely false, even peer reviewed ones. Now you have a recipe for disaster. Because suddenly someone is out to convince the doctor with prescribing power, that this new machine or this new medication works. All they have to do is convince him and present an idea that "sounds right and makes sense". Well salesmen are pretty good at that. It is their job, after all

In the next issue we will look at the current state of medical equipment and how the "open source" concept could benefit everyone, including the manufacturers.

**Steven Miron, MD** is a licensed practitioner with many years experience operating a private practice. However, nothing he says in this magazine should be construed as medical advice and you should always talk to your personal doctor before making medical decisions.

# Magwan Flan

*Mark Facey*

These gelatinous terrors stalk the scalding canyons of the sun-scorched planet known as "Tsvini II". Rarely ever seen in groups, they survive by feeding upon less threatening surface mollusca and subterranean jellies. Their barbed tendrils snake into rock crevices to hook and pull out any possible prey.

Propelled by a mass of boney legs beneath its skirt, they are relatively fast in short distances. though rarely ever expelling too much energy you can sometimes see them sprint away from danger when in a tight spot.



# Sugar Shot to Space

Photo by Eric Kilby

*Richard Nakka, Director, Sugar Shot to Space*

[sugarshot.org](http://sugarshot.org)

A rather intriguing question was posted in an e-mail discussion forum devoted to sugar propellants. One of the contributors innocently asked "Would it be possible to launch a sugar-propelled rocket into Space?" This query set into motion a flurry of activity which sought to answer this question, at least from a theoretical perspective. A number of experienced amateur rocketeers pondered the question in depth, ran computer simulations, and concluded that it might be possible, but barely. Due to the low performance of sugar propellant, which has a "specific impulse" of about one half that of professional rocket propellants, the goal of reaching Space was shown to be very challenging. A conventional single stage rocket would not be capable, at least not one that would boost a decent sized payload. A two stage rocket would be needed. The key advantage to a two stage, versus single stage vehicle, is that of efficiency. A single stage rocket would propel a vehicle to a very high velocity in the lower, densest part of the atmosphere, losing a lot of energy due to aerodynamic drag. With a two stage approach, a vehicle can coast following the first burn, and soar to an altitude beyond much of the densest air before firing the second stage. An alternative suggestion was then submitted for discussion. Why not a single stage rocket that

would behave as a two stage rocket? Deemed a "dual-phase" rocket, two serial propellant charges would be separated by a common bulkhead, and share a common nozzle. Following burnout of the first charge (or phase), the bulkhead would be breached, allowing the two chambers to act as one. The second charge would then fire with the motor behaving in conventional manner. Simpler than dealing with the complexities of staging, at least in theory. And so out of this innocuous discussion, the Sugar Shot to Space project was borne, with a mandate to demonstrate that theory and reality could be merged. Amateur rocketeers with a passion for sugar propellant and a commitment to accomplish something on the edge of feasibility could pull this one off.

That was over five years ago. Over the course of ensuing time, there arose many unexpected challenges, technical as well as organizational, restrained by the limitations of being an all-volunteer, minimum budget project, delving into a little known technology. It turns out that dual-phase rocket operation is simple in theory, but more than a tad challenging to engineer a workable solution. We learned the hard way that we knew even less about sugar propellant than we thought we knew. For example, we were aware that sugar propellant is

brittle, but how brittle, and how would that play out in a large scale rocket motor? Brittleness can be a bad thing, resulting in sudden, unexpected and potentially catastrophic fracture under certain conditions. Fully understanding those conditions in order to mitigate the risk stipulates a great deal of unglamorous effort. And despite a passion for the goal of reaching Space (a dream nearly every amateur rocketeer shares), many volunteers were simply over-constrained with regard to available spare time, as many have full time jobs and a life

issue, made all the more complicated by the first, was eventually resolved through the development of a lightweight ablative material that lined the motor chamber, and served to effectively insulate it from the torrent of hot, highly pressurized and speedy exhaust gases seeking its escape to greater entropy through the chamber and out the nozzle.

What challenges associated with the use of sugar propellant lie ahead for the Sugar Shot to Space team as we graduate toward the next project, the two-thirds scale "Double Sugar Shot"?

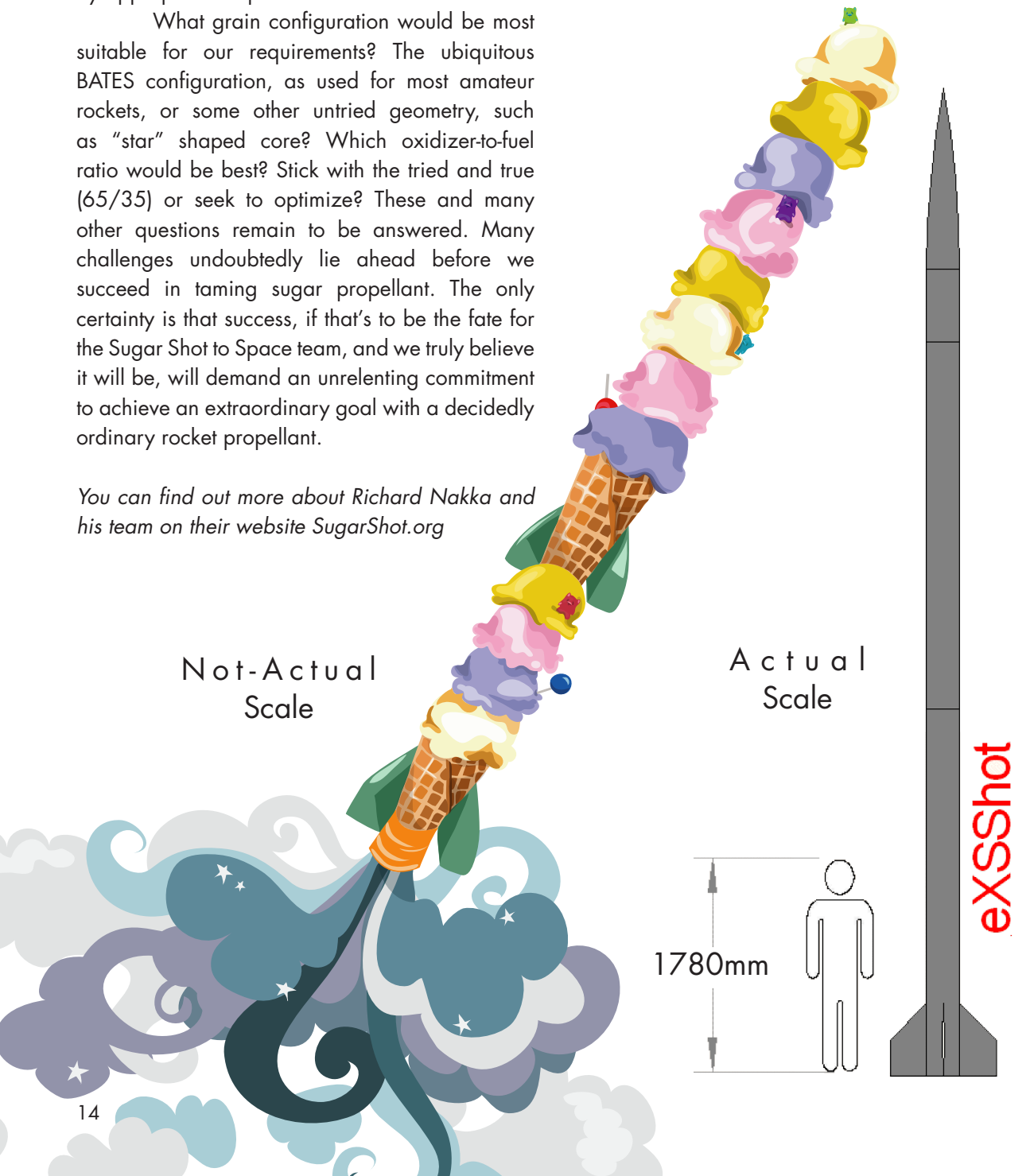
outside rocketry. Realizing that the approach taken to reaching Space "in one giant leap" was fraught with many hurdles that would likely lead to a disappointing end, the project was eventually reborn as a "program". Instead of trying to reach Space in a single attempt, the new tactic was to apply an incremental "Apollo" style approach, moving forward cautiously step by step. Three key projects were identified for the program: one-third scale, two-thirds scale and then the full-scale "Space" rocket. Tackled this way we could learn as we progressed, developing scalable hardware and methods. In hindsight, this appears to have been wise change of course. As things unfolded, the one-third scale "Mini Sugar Shot", required several static test firings before a successful firing was achieved. The difficulties were mainly a consequence of the very demanding "mass fraction" requirement needed to reach Space on a low performance fuel, and secondly due to the unexpectedly severe thermal loading the rocket chamber experienced during the second phase burn. The first of these, which demands that most of the liftoff mass (at least 80%) must be propellant, asserts that the lightest of materials be used. Gone by the wayside was the inherent comfort of using beefy metal motor casings. Only lightweight composite materials could fit the bill. The second

We've learned that brittleness of sugar propellant can lead to a catastrophic result. Encouraged by experiments that indicate that storage method, such as deep freezing, can inhibit formation of brittleness; this negative trait can hopefully be tamed. We've learned through our Mini Sugar Shot experience that we've gotten a pretty good handle on casting sugar propellant. One-third scale propellant "grains" of about a kilogram each (totaling twelve for each motor firing), and of high quality, were consistently produced. Will that same casting technology allow us to cast the much larger grains while maintaining similar and consistent quality? The need for consistency is imperative to scaled-up design approach of a rocket motor, as the burning characteristics and other traits affecting the "internal ballistics" are directly affected. The sheer quantity of propellant needed for Double Sugar Shot, 90 kg for each firing, leads to an unprecedented challenge of safe and efficient mass production. What ever method we develop should be scalable to the full-sized, appropriately named "Extreme Sugar Shot", which has a projected motor capacity of 450 kg. That's a lot of sugar propellant. Other questions come to light when considering mass production of propellant, such as "what happens if sugar propellant is accidentally ignited"?

Controlled experiments were performed to gain a better understanding of this critical aspect of sugar propellant usage. Turns out that the risks and consequences associated with such a mishap can likely be mitigated by intelligent design of propellant handling and casting apparatus, and by appropriate response to such an event.

What grain configuration would be most suitable for our requirements? The ubiquitous BATES configuration, as used for most amateur rockets, or some other untried geometry, such as "star" shaped core? Which oxidizer-to-fuel ratio would be best? Stick with the tried and true (65/35) or seek to optimize? These and many other questions remain to be answered. Many challenges undoubtedly lie ahead before we succeed in taming sugar propellant. The only certainty is that success, if that's to be the fate for the Sugar Shot to Space team, and we truly believe it will be, will demand an unrelenting commitment to achieve an extraordinary goal with a decidedly ordinary rocket propellant.

*You can find out more about Richard Nakka and his team on their website [SugarShot.org](http://SugarShot.org)*





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DIYbio

# How To Culture

Cathal Garvey

# Pure Yeast

**Y**ou've read the title, and you're still reading. You like DIYbio, you're interested in getting started in something fun! Well, there's no time like the present. Let's get you started in microbiology, the DIY way.

Microbiology is a central part of culture across the globe. We culture Yeasts, Bacteria, even Algae as a matter of tradition in virtually every corner of the Earth. This may be for bread-making, producing alcoholic drinks, producing cheese and yogurt, or for kefir, kombucha or natto. All of these are both easy and rewarding to learn to make (although the quality will strongly depend on your skill, as ever).

For DIYbio, we have different needs than the culinary fermenter. It's far easier to work with isolated species and strain, and it's easier to make sure observations without genetic oddities getting involved. So, we need to isolate a pure culture of yeast to get started.

The first paradox of the life sciences is that in order to study life, you generally must learn how to obliterate life completely, and prevent it from returning without your say-so. In other words, you

must learn the art of sterile culture and "aseptic technique". The tools of the trade are:

1. The Pressure Cooker, used to sterilise equipment, containers, broths and agar by cooking them at 120C for at least 20 minutes.
2. The Oven, which can be used to sterilise heat-resistant equipment or glassware by dry heat, though the timing varies by temperature, and the temperature you can use varies by material.
3. Alcohol(s), such as ethanol ("drinking" alcohol) or isopropanol (rubbing alcohol) at 70% or higher, can be sprayed on surfaces to kill live bacteria, although spores may survive.
4. Bleach is effective at sterilising surfaces and equipment, though concentration is important and it can corrode many materials including many common metals. Take care also to avoid mixing bleach with other chemicals, as the results are seldom pleasant!
5. HEPA Filtration: Many household air purifiers sport effective HEPA filters, which filter air of microbes and spores, reducing the risk of contamination massively. Working in the airflow of a good HEPA can provide a sterile space without



much effort (though it may be costly!)

6. Burners: Bunsen burners are used everywhere for microbiology: They provide a space around the flame that is pretty sterile, and can be used for sterilising metal items like inoculating loops and blades in a jiffy. A camping cooker-burner may suffice instead of a bunsen, provided the flame is blue, tall and steady.

You won't need all of these things to attempt yeast culturing, but the more boxes you tick the better. HEPA filters are available from gadget shops, office supply stores, homeware and electrical suppliers, and the internet. Bunsen Burners can be had from many good homebrewing sites. Pressure Cookers, also known in the US as canners, are best bought large if possible, and are a microbiologist's best friend for routine sterilisation.

Spraying or wiping with 70% alcohol is a great way to mass sterilise surfaces for work. Rubbing alcohol is generally easier to find at higher concentrations from chemists or veterinary suppliers, and is about as safe to use for lab-work as ethanol (but don't drink it). It's volatile, pungent stuff though, so if you're using alcohol, try to do so in a gently ventilated room and don't spray alcohol if there's a flame anywhere in the room. Wait for alcohol to dry completely before lighting any flames or bunsens, if you're using them.

Besides your equipment needs, you'll also need ingredients to make the broth and agar you'll be using to grow Yeast, and you'll need the Yeast itself! All of these things can be conveniently found in almost any supermarket, so this shouldn't be a big problem.

Here's a hint: All we're doing below is preparing a "mash" that might be familiar to homebrewers worldwide, but rather than brewing a fine ale for its own sake, we're just after the yeasts themselves. They'll grow on something as simple as Malt Extract and Water, with added agar to make solid dishes where needed.

### Project Bill of Materials for Isolating and Culturing Yeast

- Chlorine/Chloramine free water, i.e. cheap bottled water
- Malt Extract, either powdered or as a syrup
- Table Salt, without preservatives or iodine. Not essential.
- Agar (AKA "Agar-Agar") or Carrageenan or Gelatin
- Any Source of Yeast: Bakers/Brewers Yeast, certain dried nutritional yeasts.
- Pressure Cooker or Canner
- Either a Bunsen Burner, Tall Camping Flame, or HEPA air purifier
- Toothpicks
- Optionally: Inoculating Loop (See sidebar)
- Aluminium foil
- Pyrex or Polypropylene containers or canning jars
- Petri Dishes, or Ramekin dishes

### Stage One: Preparing Sterile Equipment and Media

1. Put your petri dishes or ramekins in the pressure cooker, covering the latter if you use them with snugly formed lids made of aluminium foil. Wrap a few batches of toothpicks, five or ten per batch, in tinfoil and put those in too. If you have a big pressure cooker, wait to prepare your broth and sterilise everything together. Otherwise, run all your equipment through the cooker first to get it all ready.

### Making an Inoculating Loop from Stiff Wire

To think some sources will try to charge you for these. To make an inoculating loop, take a length of somewhat stiff, heat-resistant wire such as nichrome, bend the midpoint around a thick nail or pencil end, and then twist the nail or pencil until most of the wire is braided. Affix the loose ends to a handle of sorts, perhaps by driving a bolt or screw through the end of a piece of dowelling until it grips the wire. You could also just hold the wire if you feel lazy, but not too close to the end when you run it through the flame!

Inoculating loops are handy because a small loop like this tends to hold a little film of liquid when immersed and removed. This film will easily carry more than enough microbes from a broth to a new home. Running the loop through a flame until it is briefly red-hot and then letting it cool near the bunsen/camper flame will sterilise it for repeated use. You can use a loop like this to "streak" agar plates, spreading cells out to make isolation of colonies from single cells possible in a flash.

2. Prepare your broth and agar by completely dissolving 50g liquid malt extract in 500ml of water. Pour 200mls of this into another container and add 2g-4g agar powder or flakes.

3. Carefully microwave the broth-and-agar until it begins to simmer, then mix by swirling (not shaking) to try and dissolve as much agar as you can. Pop it back into the microwave for a few quick blasts of heat, but be careful! Agar really, really likes to boil over suddenly and make a big mess.

4. Pour your remaining, non-agar broth into a few canning jars or pyrex/polypropylene containers to a few centimeters in depth. Each jar will be used to culture a selected strain of yeast, and there's little point in going overboard. If you have test tubes with lids, you could pour 5mls into

each and use those.

5. Once you have dissolved all or most of your agar, leave it cool until it won't shatter glass, about 45C, and carefully and slowly pour it into a polypropylene or pyrex container or canning jar. You'll sterilise the agar as a batch and pour it after sterilising, before it sets.

6. Put all your broth samples and your agar into the pressure cooker, and sterilise them fully. For 200mls (the largest sample in this case), you probably won't need longer than 15-20 minutes of sterilisation temperatures.

7. While the sterilisation is taking place, sterilise a working space using either dilute bleach or disinfectant (follow the instructions for surface cleaning), or 70% rubbing/isopropyl alcohol. Take care to use a surface you don't care too much about; these chemicals can take their toll. Leave bleach or disinfectant sit for a minute before wiping away with a fresh disposable kitchen towel (wear gloves!). Leave alcohol for about 10 seconds before wiping away.

8. You have two options for creating a sterile working environment:

a. If using a bunsen or camper flame: Once any residual alcohol is long evaporated, put your clean bunsen or camping flame on the surface and light it, so that it burns at a medium level with a blue flame. Take some time to get used to the controls, and test the heat of the flame by passing your inoculating loop, if available, through the flame. The flame is at a decent level when it can bring the loop to a red glow in less than five seconds. The hottest part of a blue gas flame is just above the "inner" flame. Turn your flame down to maintain a zone of hot sterile air, but don't waste gas while you await the sterile broths and such to cool. As long as you work within 5-10cms of a strongly burning bunsen or camper flame (which must be blue!), you should

be able to maintain sterility.

b. If using a HEPA air purifier: Use alcohol in advance, if available, to clean the outlet of the purifier. Alternatively, run it on maximum speed with ozone/ioniser turned on if that feature exists, and leave it running for an hour beforehand to clear the outlet. Arrange your air purifier so that it blows a steady stream of freshly purified air down on your working area, but not too strongly. Ozone isn't good for your lungs, so turn that feature off when you're working near the purifier. As long as you work under the flowing sterile air, your samples should remain sterile.

9. When the broths and equipment are all cool and sterile (remember to seal them immediately upon opening the cooker, or alternatively wait until they are entirely cool to prevent contracting hot air from pulling nonsterile air into your fresh broth), remove them from the cooker into your sterile working area.

10. Wait for the agar to reach a temperature which is uncomfortably hot, but not too hot to handle constantly. This is the time to pour, before it begins to gel. Carefully open your sterile petri dishes or ramekins in the sterile area, and pour just enough molten agar inside to cover the base of the dish before putting the lid back on. Place the poured plates out of the way while they cool and solidify.

11. When your plates are solid and hopefully still sterile, they are ready to use. The broths, provided their lids were still covering the jars or containers when the cooker was opened and were sealed immediately, should be entirely sterile also. You're ready to move onto the culturing stage.

### **Acquainting yourself with your Pressure Cooker**

Depending on the design you may have to do things differently, but most medium-scale pressure cookers are of the "Bayonet" fitting type, where the metal lid locks by rotation into molded wings at the lip of the cooker. A rubber gasket inside the lid rim maintains pressure inside, while excess pressure escapes through a nozzle at the lid. A metal weight is placed on the nozzle to build and maintain pressure, but only after steam has pushed all the air out of the vessel during the pre-heating stage. Do some reading and look up youtube demonstrations until you are comfortable using your cooker, but here's a rundown:

1. Make sure there are at least 4cms of water at the base of your pressure cooker, with everything to be sterilised held above the water by a mesh. Leave any containers inside with their lids resting on top but unscrewed. Closed containers may break!
2. Fit the gasket inside the lid securely, and fit the lid onto the vessel, locking it into place.
3. Gently heat the whole vessel over a cooker until steam begins to emerge from the lid. Your cooker may have a handle pressure interlock, wait for this to engage fully, locking the pressure cooker closed.
4. Wait until the nozzle stops sputtering and steam is emerging constantly with fair upward force. Beware of steam burns from the nozzle! Leave it for 15 or 20 seconds to allow air to be pushed out, then carefully fit the weight on the nozzle
5. Lower the heat so that the water inside is simmering or gently boiling, and listen/watch carefully to ensure it remains at a gently boil or simmer for the remainder of the task.
6. Wait for the pressure to build until

### Acquainting yourself with your Pressure Cooker (continued)

the weight starts to emit steam; this means the pressure inside is at maximum, and the temperature should be at or around 120C. Monitor the cooker so that the weight isn't flying everywhere, a steady boil is all you need.

7. Once full pressure and heat are reached, start the clock! After 20 minutes most loads will be sterilised effectively. If you have any large vessels of liquid or gel, you might want to up the ante a bit and sterilise for 25 or 30 minutes.

8. Once the timer is done, turn off the heat and then leave the pressure cooker alone! Let it cool at its own pace, until the interlock audibly disengages and the heat goes below 100C. If you're in a hurry, you can try to cool things rapidly at this stage, but it's best to just leave the cooker alone and open it in or close to a sterile environment.

### Stage Two: Culturing Mixed Yeast and Isolating Single Colonies

In this stage, you'll wake up a mixed culture of yeast from dried stocks (whatever you found in the shop or in the baking cupboard at home!), and you'll "streak" the mixed culture out on your prepared nutrient agar, to isolate single colonies composed of the progeny of one single cell.

1. Working in a sterile area (sprayed down, dried, and with a bunsen/burner/HEPA keeping it sterile), loosen the lid on one of your prepared broths, which should be room temperature (21C) or warmer, and add a small measure of yeast. If you'd like to be more rigorous, you could prepare two stock broths here with more and less yeast. The amount of yeast needed varies by the amount of broth you've poured out, and you can always dilute them if there are too many.

2. Close and swirl this broth to suspend the yeast cells and allow them to rehydrate. Place the container somewhere warm for a while, and keep an eye on it. Wait for signs of froth forming on the top, indicating that the yeast have begun to metabolise and ferment the broth.

3. Take the broth back to your sterile area, and open it within your sterile working area. Open a petri dish or ramekin in the sterile area, and using a sterile toothpick or sterilised inoculating loop, transfer a droplet of the suspended live yeasts to one side of the agar, spreading it slightly.

4. Use a fresh toothpick or a freshly sterilised inoculating loop (remember to let it cool!), and draw a single swipe of cells from this first zone into a still-sterile zone of the agar, zig-zagging a little to let more cells leave the loop or pick.

5. Repeat the above, dragging from the second zone to a third, and a fourth. In each step, you are dragging fewer and fewer cells from the populated zone to a new, clear zone. Eventually you'll be dragging so few cells that you'll end up with single cells separated by millimeters or centimeters on the agar surface. These cells will grow wherever they land, forming a colony that you can isolate, composed of genetically similar cells.

6. When you are finished streaking as many plates as you feel necessary, close all your plates and seal them if possible with cling film before putting them upside-down somewhere warm but not hot (25C to 28C). Because yeast can live with or without oxygen, it's ok to seal them like this to help prevent contamination. They are placed upside-down to prevent water from condensing or sweating onto the surface of the plate, which can displace or spread cells around and mess things up.

7. Leave the cells to grow for 8-12 hours, before checking for colony growth. If you don't have glass petri dishes, you may have to check your dishes in a sterile area. If you see isolated, neatly circular colonies of yeast growing out and

away from the main body of growth, you're in luck! If you're seeing many colonies of all different shapes, colours and sizes, especially those not matching the area you first inoculated (which should be overrun with mixed and overlapping yeast), take care to avoid them when isolating your colonies for further study. They may have come in with the mixed yeast, or they might be airborne contaminants, or they might be a sign that your agar or glass wasn't sterilised well enough.

8. Taking a wrapped bundle of sterile toothpicks in your sterile working area, pick up a sample of cells from the middle of a nice, circular, isolated colony and dab the tip of this toothpick with the cells atop it into sterile broth in another container. This will inoculate the broth with your isolated yeast strain. You can isolate several different strains from the same plate. Odds are they're all pretty similar or identical if it's a commercial brand of yeast, but you may as well treat them as different strains when you can't be sure. Label them all to your liking!

9. These broths, you can seal again and place somewhere warm. As yeast grow in your broth and multiply, they'll turn the fairly clear sterilised broth into cloudy (turbid) broth. The degree of cloudiness relates to the amount of cells present, but if you let them overgrow they may start to die off, clearing the broth again and leaving a fine deposit on the base of the container. They'll grow quickly somewhere warm, and not so well at room temperature or below. At 4C, things slow to a crawl. At these slower growth rates though, the chances of the culture being overtaken by a bacterium are increased, because the yeast will be less able to compete.

10. If you want to keep culturing and re-isolating from this yeast for practise, it's a great way to learn the habits of microbiology. You'll find they rapidly become second nature. If you'd like to experiment with ways of safely storing your yeasts for long-term uses, you could try the protocol in the "Freezing with Beads and Glycerol" sidebar.

### Freezing with Beads and Glycerol

Glycerol can be had either pure or at moderately high concentrations (about 30%) from some pharmacies as a balm for itchy or tickly throats, or as a food additive in some supermarkets. It's harmless stuff, but it has uses in storing bacteria and yeasts because it inhibits the formation of deadly ice crystals.

To raise the odds of keeping cells long-term, you can use tiny toroidal beads as a way to reduce ice formation still further. Because ice forms straight crystals, a tightly curved surface inhibits the formation of long, branching crystals pretty well.

To freeze-stock your cells: either grow them to a really high number in broth or scrape them from an agar plate with a sterile tool, so you have loads of cells. Mix them with fresh broth and pre-sterilised glycerol at the highest concentration you can find to attain as close to 40% glycerol, 60% cells in broth as you can attain.

Mix the resulting liquid into a little pre-sterilised container containing the smallest smoothly curved plastic beads you can find, and seal and mix vigorously by shaking. Then decant off as much liquid as you can, so that most beads are wet with a film of cells but are not immersed in it. Pop these in the freezer toward the back where the temperature doesn't fluctuate as much. Rapid freezing helps to inhibit ice crystallisation.

When you need cells from this stock, quickly remove just one bead in your sterile workspace before putting them immediately back in the freezer, then use that bead to inoculate a sample of broth. With luck, the curved bead and glycerol will have protected the live yeast from ice, and you'll revive your culture for another day's DIYbio! Be sure to make another fresh stock whenever you get a chance.



# The Light Bulb PCR Machine

*Russell Durrett*

This clever device shatters the cost of current thermal cyclers and increases the accessibility of this integral piece of bioware. For less than \$50, it could be yours.

Citizen Scientists have already begun to empower themselves and others by making biology more accessible. The first wave of change, it seems, is coming in the form of cleverly-built hardware – PCR machines, incubators and centrifuges made from materials one normally wouldn't think to employ.

A few weeks ago I struck on a 2002 publication by Brian Blais describing a working PCR machine he built using a light bulb as its heating element.

Ingenius.

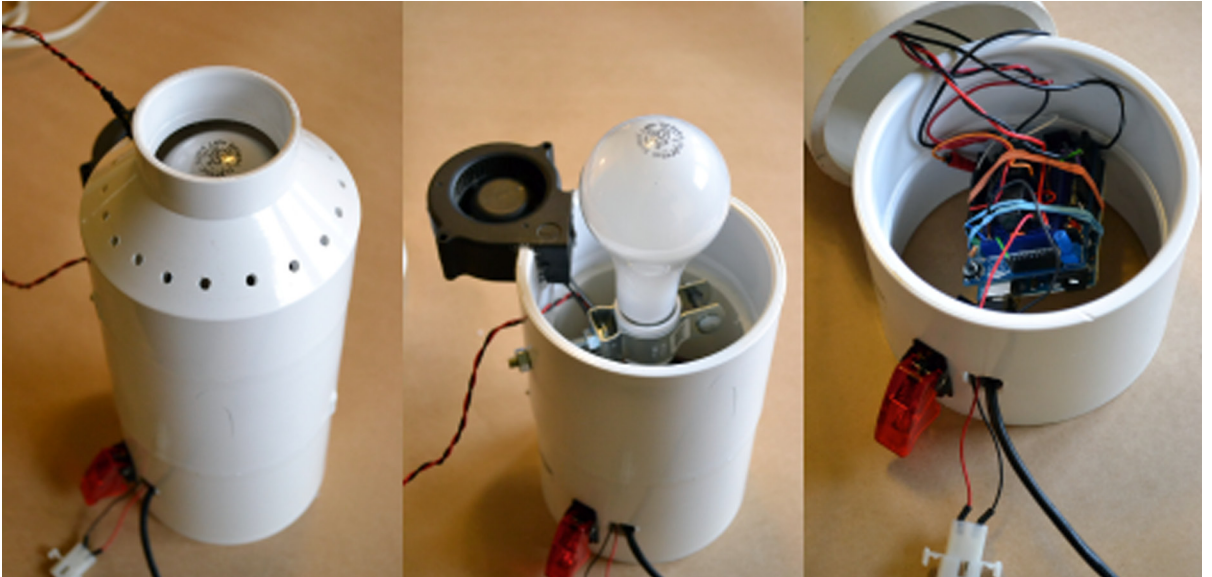
Since then, it seems there has been no further development in this potentially revolutionary type of machine - so I decided to build one myself. I had almost no prior electrical experience, but I was willing to learn. If I was able to build this machine in less than a week, then you can too (and it will probably blow this one out of the

water).

Using only Home Depot and Radio Shack products accessible to anyone, I built this PCR machine for less than \$20. This prototype requires a \$30 Arduino Uno to operate (which was already available), but the control system in future models can be scaled down to a much simpler circuit, an LCD screen and a few buttons.

I decided to use 4" PVC pipe and couplings for the enclosure because of the range of attachments available. The machine consists of three layers: the top is a 3" to 4" adapter with holes to house the PCR tubes, the middle is a coupling that holds the fan and light bulb in place and the bottom is a coupling that shelters the arduino and a safety switch. The 110V AC is wired with a simple two-wire connector.

The arduino monitors the temperature by using a thermistor, basically a resistor that lowers



the resistance the hotter it gets. The thermistor is wired in-line with a 5V potential and an analog input pin of the Arduino. The hotter the thermistor gets, the higher the potential flows to the input pin.

During a run, the thermistor is placed inside one of the tube holes. For more accurate readings in the future, the thermistor can be submerged in water and mineral oil inside a PCR tube.

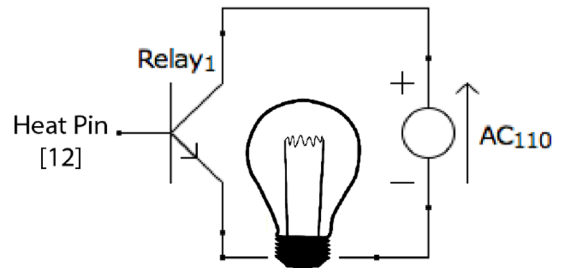
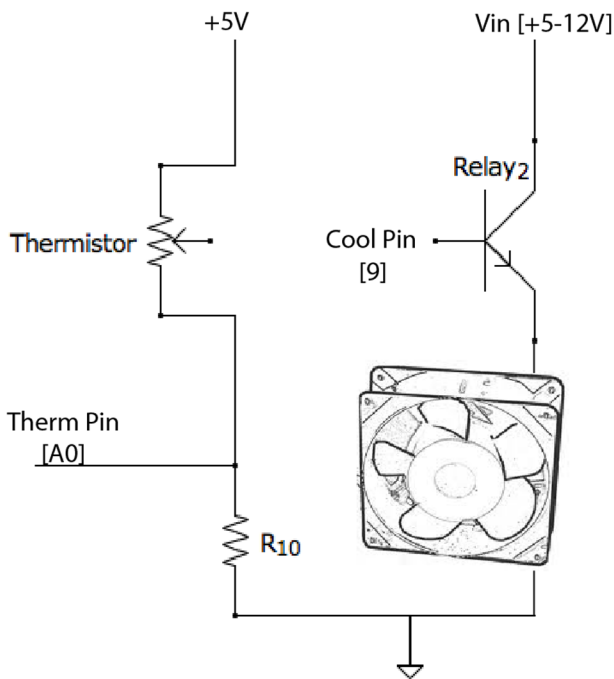
The thermistor can be substituted for a more consistent IC temperature sensor, such as the LM335, in future models.

The schematic for the machine is extremely simple - due to the Arduino's simple interface requirements, many hardware components can easily be subbed for software programming.

5V relays are used to control the fan and light bulb. These relays can be switched on and off using the native output of the Arduino - no amplification required.

The entire control module could fit onto the arduino using a prototyping shield called the makershield. I programmed the arduino to control the relays and sense the temperature through the thermistor, then wrote a code to allow the machine



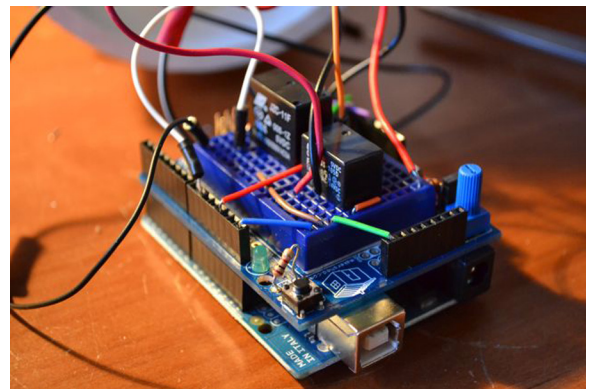


to cycle through the three designated temperatures for the PCR reaction.

The machine cycles quickly - a standard 1KB run takes less than 2 1/2 hours to complete. I am in the process of testing the machine using PCR reagents, but given Mr. Blais's success in the 2002 model I am confident it will work.

Instead of buying a thermal cycler for your lab, I encourage you to go out and build your own machine! This entire system took about \$50 (+ a computer to program it) and less than 5 manhours to construct.

My arduino code and more details about the machine to help get you started are available at [russelldurrett.com](http://russelldurrett.com).

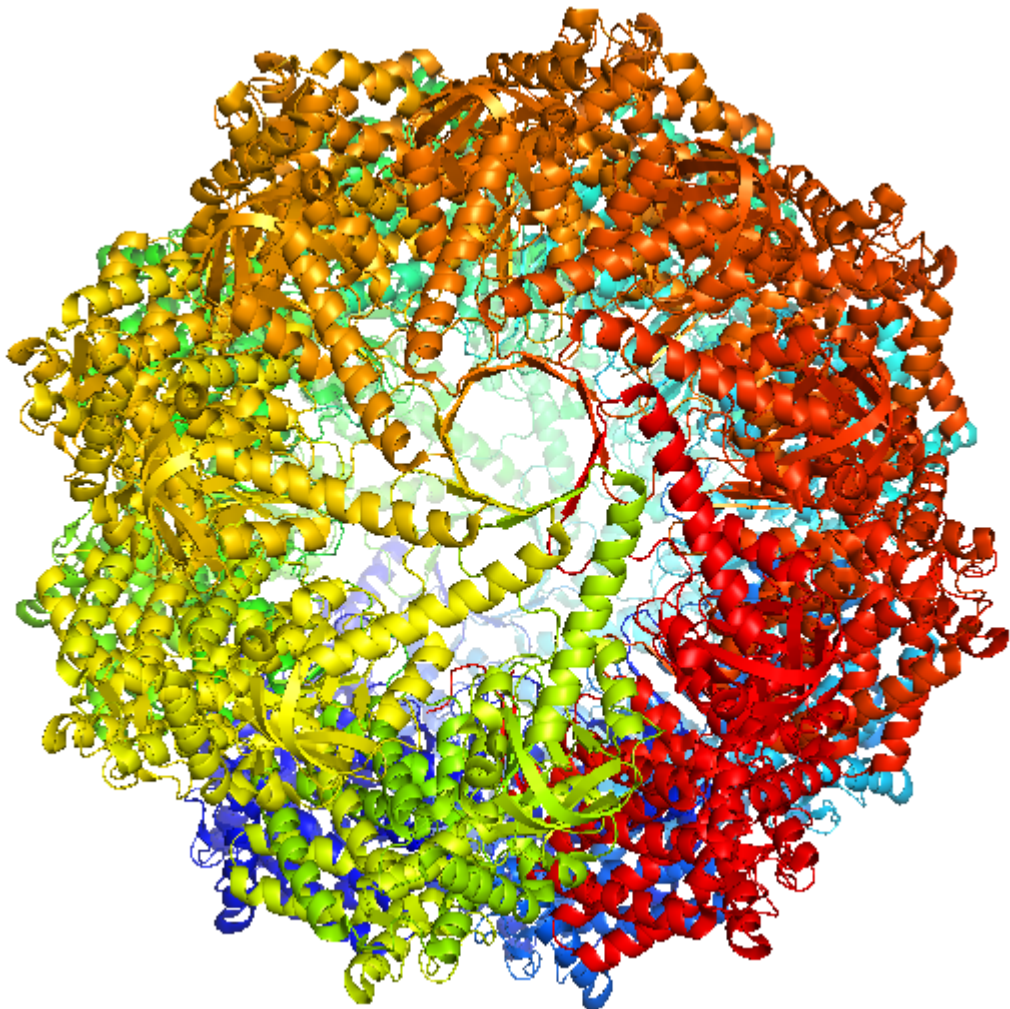


*Russell Durrett is a Research Specialist in Bioinformatics and Genetic Engineering in the Mason lab at Weill-Cornell Medical College and is a cofounder of GenSpace NYC, the world's first community biology lab. You can reach him at [Russell@Genspace.org](mailto:Russell@Genspace.org)*



# PyMol

visualizing molecules



To get 3D representations of a wide range of molecules similar to the chaperonin above, download a copy of PyMol. Open *Plugin* > *PDB Loader*, enter in the PDB ID # of your chosen molecule and press Enter. If you don't know your molecule's PDB ID# , you can do a quick search on [pdb.org](http://pdb.org) to find out.

*Adam Griffith, Jeffrey Warren, & Sara Wylie*

# From Grassroots Mapping → to a Public Laboratory

In late April 2010, the Deepwater Horizon oil rig exploded and sank, initiating what has been cited as one of the worst environmental disasters in US history. In the weeks and months that followed, a variety of activists, researchers, community organizers, and technologists from the Grassroots Mapping community and the Louisiana Bucket Brigade joined forces to spearhead a citizen effort to map the oil spills effects.

Using basic tools such as cheap digital cameras, kites, balloons, and tanks of helium, we set out to produce high resolution aerial maps of endangered and oil-affected sites. With the cooperation and extensive support of interested Gulf Coast residents, not least a number of fishing captains, we led over 30 trips in the first two months of the spill to map coastal areas. While not attempting to produce imagery of the entire

Aerial image of Bayou St. Denis  
taken by Cesar Harada and  
Tico Aran





coastline, which stretches several thousand miles from Louisiana to Florida, our teams focused on acquiring high resolution imagery of specific sites with the goal of producing 'before and after' maps. Increasingly large areas of the Gulf of Mexico were being closed to fishing, and with their livelihoods at risk, many in the fishing industry were eager to participate in the documentation of the spill.

The need for such a citizen-led effort is evidenced by the media blackout in the months following the explosion of DWH. While NOAA, USGS, and other government agencies have collected a great deal of high quality data, much of it remains to be released to the public in any meaningful way. More than 30,000 samples of water, tissue, tar balls, and sediment have been collected and analyzed by various government agencies, but public access to that data is limited and confusing. Additionally, the role of BP in the data collection process has been the source of both fear and speculation, prompting



Photo by Adam Griffith



Photo by Adam Griffith

Karolien Debusschere from Louisiana's Oil Spill Coordinator's Office to make public assurances that BP would be involved only after the data was collected and analyzed.

Transparency of these processes is hindered by the sheer size of the endeavour, but such transparency and legibility are exactly what the public needs in order to file claims. Our initiative invites members of affected communities to collect, interpret and discuss data themselves. Its beauty is in its simplicity: photographic data is accessible and it invites interpretation without requiring specific expertise. It also provides rich coverage of a large area – often lacking in data gathering approaches which require repeated point sampling – and empowers locals to perform on-demand monitoring of oiled sites, instead of waiting for NOAA overflights or updated satellite sweeps.

The basics of aerial balloon photography are surprisingly straightforward – a digital camera

inside a protective housing is tied to the string of a kite or balloon and lofted to between 500-4500 feet. The mappers travel along the desired path, on foot or by boat, and the camera, whose trigger is held down by a rubber band, captures a photo every second or so.

Upon recovery, and after returning home, the photos are uploaded and stitched together into a map – most by Stewart Long of GonzoEarth.com, but increasingly with an easy-to-use online stitching program at <http://cartagen.org/maps>.

Originally developed to produce low-cost geographic data for land tenure negotiations in Lima, Peru, these techniques have been refined and improved through dozens of trips to coastal areas in the Gulf of Mexico. More than a hundred volunteers have been involved in capturing tens of thousands of aerial photos of the spill, and further tests have allowed us to image several square kilometers per day with a team of just a handful of mappers.

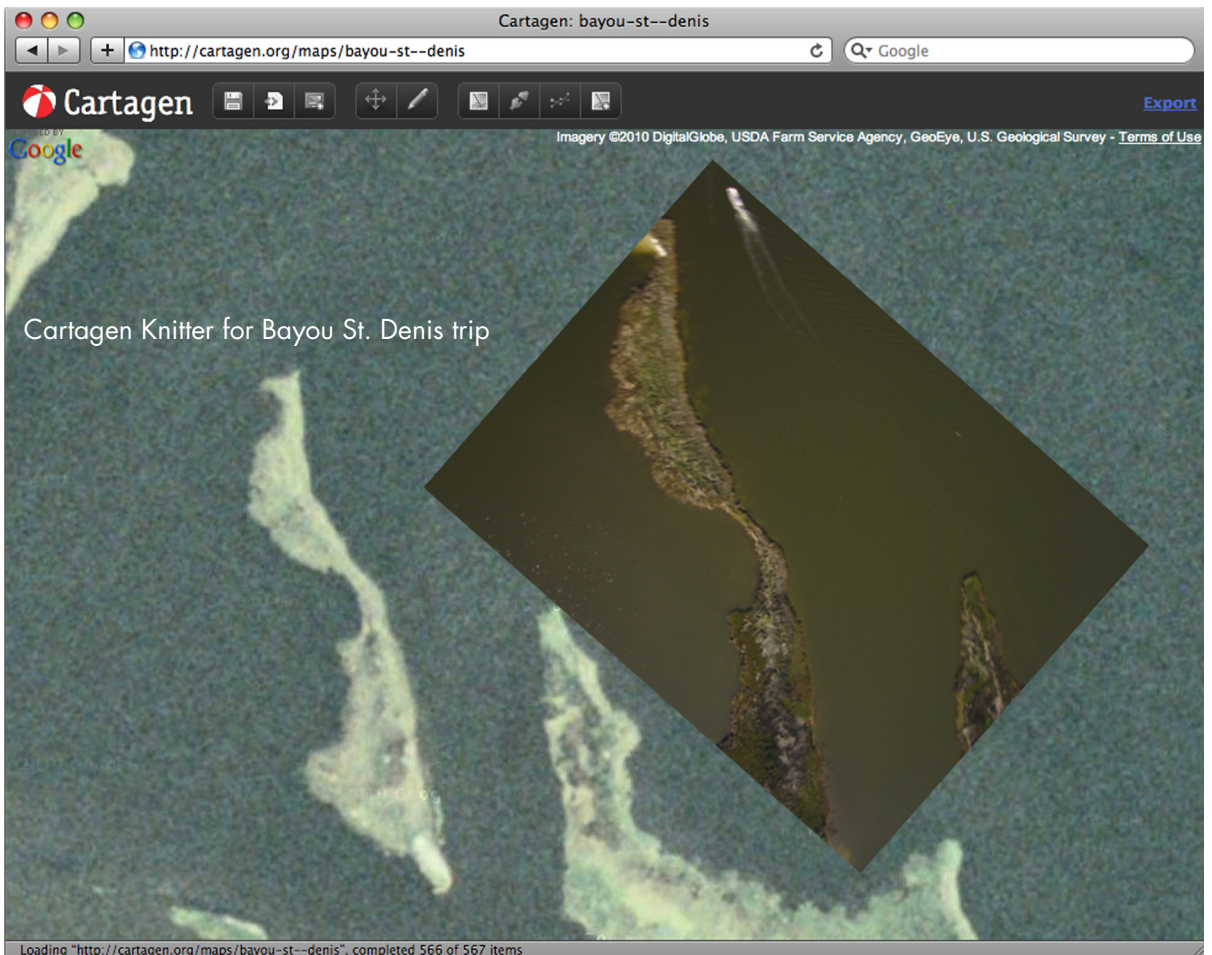
Perhaps even more impressive is the detail we have captured in these maps. Unlike satellites or airplanes, our balloons fly low enough that clouds never obscure our imagery and the sound of engines need not scare away wildlife. Schools of fish, coral reefs, and miles of boom are not unusual in our imagery. Some maps achieve up to 3 centimeters per pixel of resolution – almost a hundred times that of the daily satellite scans by NASA’s MODIS sensor, and a good ten times that of typical Google Maps imagery. Individual birds can be counted and their species identified by comparison with ground-based imagery. Our hope is that our growing archive provides a wealth of data for future ecologists and adds valuable detail to any analysis of the spills effects – scientific, economic, or legal.

### A broader participatory science initiative

Based on the success of this example of citizen science and public action, we have begun a more extensive initiative called PLOTS: Public Laboratory for Open Technology and Science. Founded by a group of engineers, activists, social scientists, hackers, and scientists, we are working together to generate cheap, easy to use tools for community based environmental investigation and data gathering.

Amongst the principles we hope to expand upon are:

- low cost
- data legibility (including a preference for maps and other rich visual means of representation)



- ease of use/low barrier to entry
- public participation
- high quality, environmentally and socially relevant data
- creative reuse of consumer technology
- open source and user modifiable design



Closeup image of birds, coral

It is in this spirit that we have begun developing more advanced tools, such as the capability to perform aerial infrared imaging for analysis of vegetation (NDVI), hyperspectral scanning using Flip cameras with simple DIY spectrometers, and thermal imaging cameras for assessing heat loss from buildings. These technologies, developed in collaboration with local communities, are the centerpiece of a participatory science initiative which includes public workshops, online documentation, and lots of field testing in sites such as the Gowanus Canal cleanup in New York and mountaintop removal mining sites in West Virginia.

### Science 'by citizens' or 'of citizens'?

Citizen science is a name which is often used by scientists asking the public to submit

reports on phenomena such as has been used in Audubon societies for years. This has seen a revival in recent years through the practice of 'crowdsourcing,' which typically attempts to draw upon populations to submit data points – emphasizing consistency over richer and more engaged means of building on local expertise. We see this (along with the recent craze for data visualization) as part of a larger trend towards an 'analytic' basis for government – a trend described over ten years ago by Partha Chatterjee in an article for Economic and Political Weekly, who voiced similar concerns while discussing the differences between the concept of citizens and that of populations:

*"This regime secures legitimacy not by the participation of citizens in matters of state but by claiming to provide for the well being of the population. Its mode of reasoning is not deliberative openness but rather an instrumental notion of costs and benefits. Its apparatus is not the republican assembly but an elaborate network of surveillance through which information is collected on every aspect of the life of the population that is to be looked after."*

Crowdsourcing, like much centralized information gathering, runs the risk of instrumentalizing or commoditizing its participants so that they are merely members of a population which can be measured and managed. This process can turn participants into data points – in that they are denied participation in the process of data collection and analysis. Without such involvement, participation in its conclusions, and therefore its outcomes, becomes impossible. For example, the collection of health surveys by experts who recognize a pattern could produce significantly different results from that of a community which recognizes shared symptoms through communal discussion. Still, our hope is not to further polarize this, but to renegotiate a



collaborative and mutually beneficial relationship between stakeholders and experts. Our emphasis on public workshops and collaborations stems from our alternative definition of citizen science – as a process of involving a broader public in making data collection instruments, in order to gather, interpret, and publish independent information.

### **A growing gap between experts and the public**

Historically, the field sciences have been seriously underdeveloped. With the development of experimental sciences over the course of the 20th century, the laboratory took pride of place as the center for knowledge making. Unfortunately, historical research shows that laboratory based science has actually been harmful to the study of toxic chemicals in our environments (see Christopher Seller’s *Hazards of the Job*). Despite the scientific ideals of transparency and peer-review, with the specialization of science into innumerable branches, the number of qualified experts who are capable of understanding, interpreting and speaking for the results of experiments has dwindled to a select few. Sociologically, this has resulted in an increasing division between laymen and experts.

The environmental science toxicology began with the experiences of laymen – in worker health studies performed without experts. In industrializing Chicago, Alice Hamilton’s progressive era social activism made the link between lead exposure and worker illnesses. However, in the fraught battles between labor and

capital that defined American industrialization, environmental sciences soon moved from the workplace into the laboratory, where scientists distanced themselves from the tradition of surveying worker health and close documentation of environmental conditions. Within the laboratory, factory conditions were instead simulated in gas chambers, where genetically standardized mice were exposed in increments to various level of potential toxins. These mice were then analyzed for illnesses that repeatedly appeared in these limited populations. However, as historian of science Michelle Murphy points out in her book *Sick Building Syndrome*, these mice were hardly a good representation of genetically diverse human populations, which are not exposed to single chemicals but mixtures, in various doses over their lifetimes. The biggest problems arose when data from these studies was used to set threshold levels of chemicals to which workers might be ‘safely’ exposed. Protocols were then developed to test factories, offices, schools, industrial sites, and spills such as that of the Deepwater Horizon for those threshold levels – anything lower was declared safe.

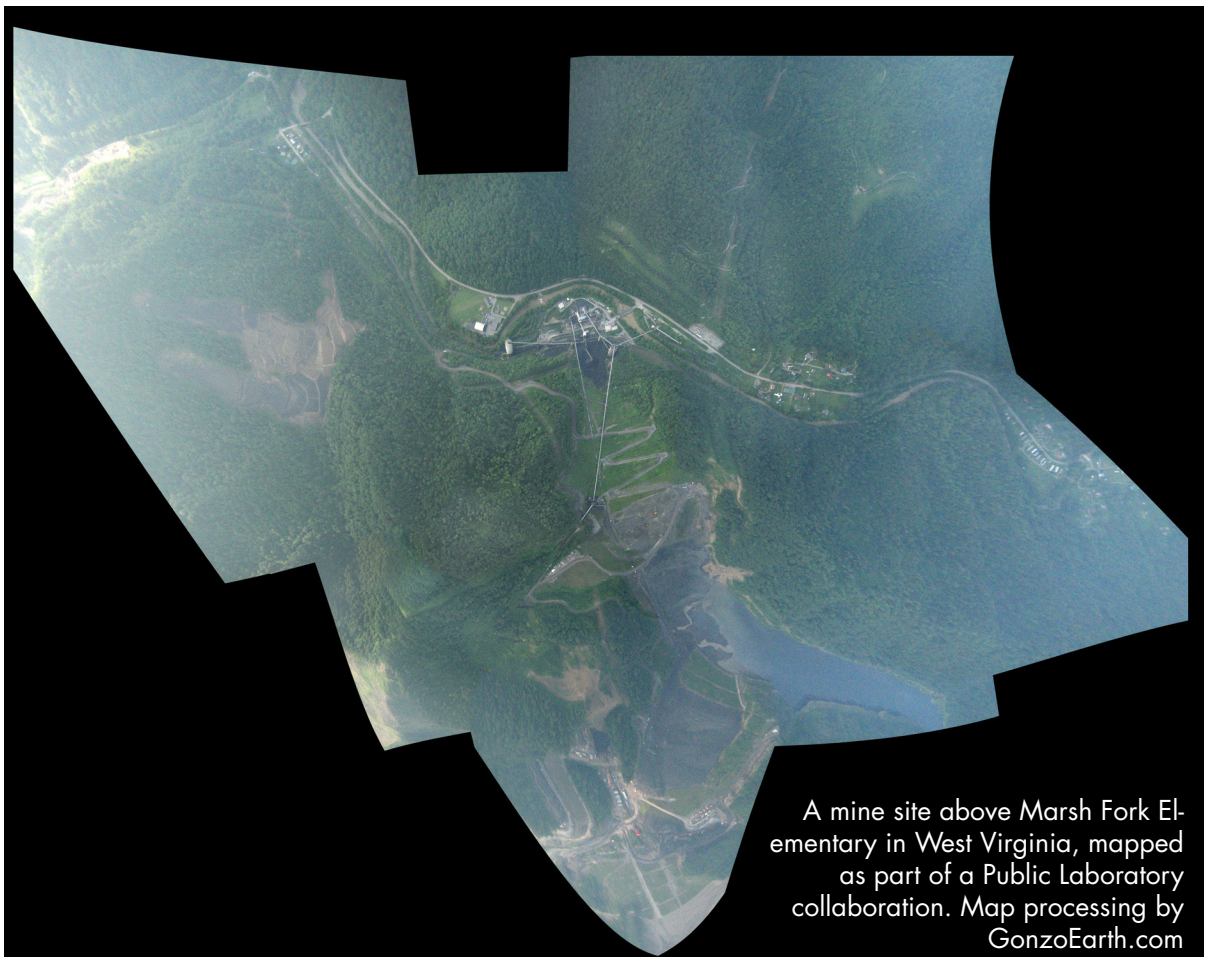
Environmental justice movements such as that in Love Canal, NY, reemerged in the United States using many of the same methods of those developed by Hamilton: community maps and surveys which illustrated patterns of health problems. Still, such data is met with stiff critique in legal battles with industries and within the scientific establishment. Most of us have grown

up in society of information consumption, rather than production. Indeed, when individuals and communities do produce information about their own conditions and experiences, that information is invariably dismissed as anecdotal and therefore unscientific. Michelle Murphy argues that we have generated “regimes of imperceptibility” around environmental health problems: not only do we lack the scientific tools, social or legal frameworks to make them perceptible, but our current approaches actively make them scientifically and legally imperceptible. Despite this, we continue to experience the effects of such problems, participating as we are in a global experimental system produced by our fossil fuel and petrochemical based industrialization. What is the long term impact of carrying a body burden

of 200-700 synthetic chemicals? How should society respond to the dramatic and diverse effects of climate change in a grassroots manner? How do we as citizens measure, make visible and begin to remediate a crisis on the scale of the DWH event? PLOTS suggests that the solution to such large scale issues comes not through simply refining the scientific establishment or demanding a pleasant fiction of scientific certainty or wholly unbiased data, but by involving ourselves in the production of knowledge and empowering ourselves to investigate, document and collaboratively analyze our own experiences so that we may act collectively to remedy environmental health problems.

#### **A participatory science**

PLOTS asks: How can we diversify,



A mine site above Marsh Fork Elementary in West Virginia, mapped as part of a Public Laboratory collaboration. Map processing by GonzoEarth.com



Spectrometry workshop in Lima, Peru  
December 2010  
Photo by Nadya Peek



support, sustain and aggregate community-led information gathering to transform the way local geographic communities investigate environmental issues? PLOTS answers: we work in collaboration with local groups to generate citizen science tools that are responsive and adaptable to local needs and constraints. We are already developing and testing new DIY tools. Our first set includes a thermal imaging camera for detecting heat leaks from buildings for only \$200 (compared to a typical \$5,000 for an off-the-shelf version), a toxin hunting tool adapted from the Roomba vacuum cleaner, and an inexpensive portable spectrometer for analyzing environmental contaminants adapted from a digital camera.

Our tools are already being published and shared online, as well as in face-to-face workshops in communities we are working with along the Gulf Coast, in West Virginia, Wisconsin, New York, and Colorado. We are developing an online space at [PublicLaboratory.org](http://PublicLaboratory.org) to allow us to scale up our outreach and documentation efforts and generate communication and collaboration between regional groups. Communities will soon be able to analyze and visualize their data, publish their results, and share new data gathering and measurement techniques. Many of our tools already include an online component –

for example, users of our spectrometry tool upload their spectrometer data to an online analysis site, now under development (<http://spectrofred.unterbahn.com>). All our tools and analysis software are open source – as is the data we publish.

*PLOTS' core research team combines expertise in digital media, programming, anthropology, citizen science, biology, geology, geography, art and design. Our interdisciplinary group integrates lay and expert initiatives in social and scientific fields into lasting research and data gathering collaborations. Communities affected by the problems of climate change, contamination, environmental justice, and corporate responsibility are often key innovators in solving these problems; we look forward to continuing and expanding our community-led efforts with new DIY research tools, data collection and analysis in the coming months.*

# Liquid Nitrogen Generator

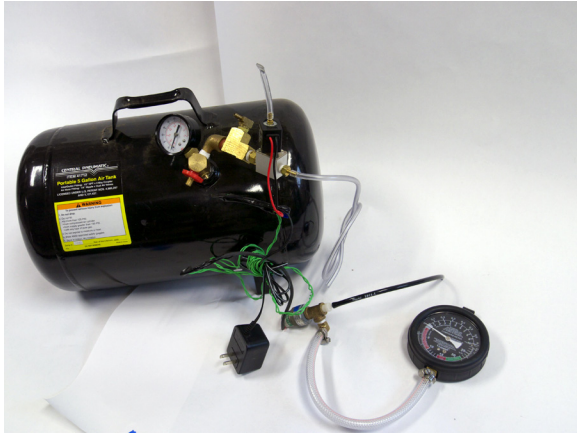
Ben Krasnow

I have always been intrigued by science demonstrations using liquid nitrogen, and often made trips to a local welding supply store with my stainless steel vacuum flask to purchase liquid nitrogen and satisfy my cryogenic craving at home. After a few fill-ups, I wondered about the possibility of making liquid nitrogen on demand. Some companies have already produced self-contained liquid nitrogen generators that are designed for small laboratories ( [HYPERLINK "http://www.elan2.com/"](http://www.elan2.com/) <http://www.elan2.com/>). The Elan2 would be ideal for home experimenters, but the cost is over \$10,000, so I decided to build a similar device with less total output, lower purity, and at much lower cost. The device that I built cost less than \$500 and produces 1 liter of liquid nitrogen per day.

Nearly all large-scale liquid nitrogen is made by compressing, cooling, and expanding air. This process removes heat from the air and can be repeated until the air liquefies. The condensing gasses are then separated using fractional distillation. This process cannot be easily scaled down because it relies on maintaining a complex, large distillation column to separate nitrogen from the other gasses in air. To avoid using a distillation column, one could use a nitrogen separation device to strip out the nitrogen from air at room temperature. Then, the room temperature nitrogen can be liquefied via the standard compression and expansion method. This is likely the process used in the Elan2 generator. However, it still requires

the use of a very high pressure compressor and heat exchanger, extensive insulation and many other custom parts.

Another approach to producing small-scale liquid nitrogen is to use a self-contained cryocooler, which is a specialized refrigeration device that is designed to pump heat across a high temperature differential. In many cases, the devices are specifically designed for small-scale use and designed for spot-cooling in electronics. The benefit of using a cryocooler is that the device requires almost no maintenance and can liquefy gasses at atmospheric pressure. A compressor would not even be necessary in a gas liquefier using a cryocooler, but is helpful for removing water from the air and isolating nitrogen from air's other component gasses. There are a few different basic types of cryocooler, but this article will highlight free-piston Stirling cycle cryocoolers. These devices are built with an internal piston that is driven by an electrical coil – a linear motor. The piston expands a working fluid (usually helium) in the device while a separate displacing piston moves the fluid to the tip. The piston then reverses direction, compressing the fluid as the displacing piston forces the fluid toward a heat-rejection area of the device. This process is repeated so that the working fluid is constantly being expanded at the tip, and compressed at the heat-rejection area. This causes heat to be pumped from the tip to the rejection area. The rejection area is cooled with atmospheric air, or other fluids that exchange heat



Nitrogen storage tank with tank pressure gauge, electronic control valve, gas pressure sensor with attached AC power adapter and dewar pressure gauge.

with the environment.

Stirling cryocoolers are not relatively common devices, but they are used for RF filters that contain superconducting components. Such RF filters with their integrated cryocoolers can be found on eBay for under \$300. One particular unit is the Superfilter built by Superconductor Technologies Inc. It contains a cryocooler that is rated at 140 watts of input power, and is extensively documented here ( [HYPERLINK "http://books.google.com/books?id=POLgG5mma6lC&pg=PA75"](http://books.google.com/books?id=POLgG5mma6lC&pg=PA75) <http://books.google.com/books?id=POLgG5mma6lC&pg=PA75>).

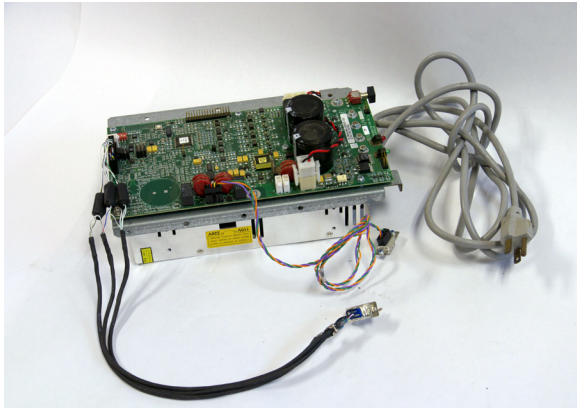
I purchased the Superfilter on eBay and extracted the cryocooler. In order to test the device, I attached a small heatsink to the cooler's cold tip, placed the tip into a household vacuum flask, and powered up the unit. After 30 minutes, I took the cryocooler out of the flask, and noticed a small amount of liquid air had collected at the bottom. Inspired by this success, I continued construction of a more complete liquid nitrogen generator. I already owned a 30-liter dewar (large vacuum flask) and fabricated an acrylic plate that would seal the top of the dewar while the cryocooler was also mounted to the plate with its heatsink hanging down into the neck of the flask. I also removed the cryocooler's finned heatsink on its

heat rejection area and replaced it with a liquid-cooling manifold. Liquid cooling lowered the heat rejection area temperature more effectively than forced air cooling, and this ultimately lead to higher system efficiency.

The liquid nitrogen generator has two basic sections, the dewar with cryocooler, and the air processing equipment that creates dry nitrogen from atmospheric air. The dry nitrogen is fed into the dewar at just above atmospheric pressure where the cryocooler chills the nitrogen until it liquefies and drips off the heatsink. Surprisingly, most of project's time budget was spent designing and building the equipment to produce dry nitrogen from air. There are some companies who make dry nitrogen supply devices, but even small units are meant for much higher throughput than what is needed by this liquid nitrogen generator. Each liter of liquid nitrogen requires about 700



Air processing unit with two aluminum desiccator chambers, two small black coalescing filters, two beige carbon filters, nitrogen separation membrane at lower right, and a flow meter with needle valve.



Cryocooler control board mounted on top of a 27VDC switching power supply. The two DB9 connectors are a serial port for firmware control/update and a connection for the system's three temperature sensors.

liters of room temperature nitrogen gas. 700 liters per day is only 0.5 l/min, a very modest flow rate. One popular, but unnecessary use for relatively low-purity nitrogen is filling car tires. I tried to purchase such a machine, but the cost and flow rate were much higher than anticipated. Instead, I found a very small nitrogen separation membrane on eBay. It's original use was unknown. The separation membrane is the actual component inside commercial nitrogen generators that perform gas separation. The membrane is formed into a large bundle of hundreds of 2mm dia tubes. Air is fed under high pressure into one end of the bundle. The tube walls are semi-permeable and allow oxygen, water vapor, carbon dioxide and other "fast" gasses to permeate relatively quickly. Nitrogen and heavier gasses do not permeate as quickly, so the concentration of nitrogen is much higher at the exit end of the tubes than it is at the input end. Higher purities of nitrogen can be achieved by restricting the flow rate through the tubes, thus allowing plenty of time for the unwanted gasses to permeate the tube walls and leave the system. The resulting nitrogen will contain trace amounts of argon and even smaller amounts of other noble gasses.

I also built a dessicator from aluminum cylinders filled with silica gel and plumbed this

into to the system before the air reaches the separation membrane. These units are available commercially, and the one that I built is not particularly specialized. Separation membranes also exist for removing water, and this would be an improvement over silica gel dessicators, which require the gel to be dehydrated in an oven after it becomes saturated with water.

The liquid nitrogen generator has proved to be a reliable, but fairly slow method to produce small quantities of liquid nitrogen at home. The initial cool-down of the dewar takes about 12-18 hours, after which liquid nitrogen is produced at a net rate of 1 liter per day. The generator uses about 300 to 400 watts of electricity (includes the water chiller, which cycles on and off), so the energy cost for producing one liter of liquid nitrogen is about 8.5 KWh, or \$1.10. This is substantially less expensive than having a thermos filled at a local welding supply store.



System overview showing a window air conditioner converted into a liquid cooler with liquid cooling lines running to the cryocooler which is mounted atop a Linde dewar. The additional refrigeration compressor mounted on top of the air conditioner unit compresses atmospheric air for liquid nitrogen production.

## Liquid nitrogen experiments:

### Make Ice Cream

Mix a standard ice cream recipe in a large bowl.

4 cups half-and-half

½ cup heavy cream

¾ cup white sugar

2 teaspoons vanilla extract

pinch of salt

Add liquid nitrogen slowly while stirring the mixture. As the nitrogen boils, it will help froth the ice cream as it freezes the mixture very quickly. The rapid freezing produces small crystals and a fine texture in the ice cream.

### Freeze a balloon

Inflate a standard latex balloon with air, then submerge in liquid nitrogen. The balloon will deflate dramatically as the internal gasses contract and even condense. After removing it from the nitrogen, it will reinflate as it warms. This process can be repeated many times.

### Perform magnetic levitation on a superconductor

Certain high-temperature superconductors can be used at the boiling point of liquid nitrogen – 77 K. Once the material is cooled, it will exhibit “magnetic mirroring”, so that a permanent magnet can be levitated above the superconductor as its magnetic field is reflected. The best type of magnets for this are small (5mm dia or less, by 2mm long) neodymium-iron-boron magnets.

### Make liquid oxygen

A variety of common gasses such as oxygen can be liquefied by passing them through a copper tube submerged in liquid nitrogen. Liquid oxygen can accelerate the combustion of common objects by creating a localized pure-oxygen environment.

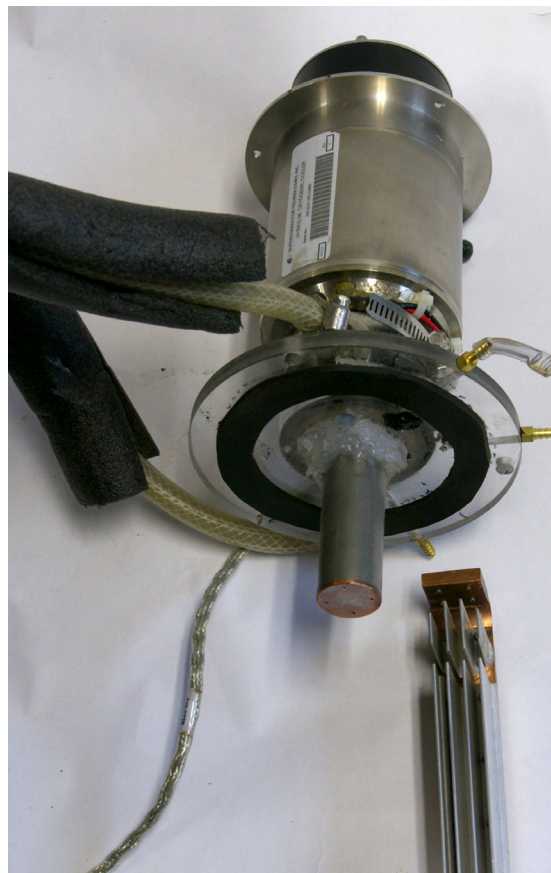
### Ping-pong ball spinner

Use a needle to puncture a ping-pong ball, then bend the needle to make the hole somewhat tangential to the ball. Repeat this on the other side of the ball with the hole “facing” the

opposite direction as the first like a rotary garden sprinkler. Submerge the ball in liquid nitrogen for about 30 seconds, then remove it and place on a large flat surface. The ball will begin spinning as the captive nitrogen boils and streams out through the holes.

### Effect on semiconductors

Connect various LEDs to a 9V battery with an appropriate current limiting resistor, eg 1Kohm. Submerge the LED in liquid nitrogen and note its color and brightness. As the semi-conductor cools, the band gap changes, causing a color shift. Some have also suggested the color shift comes from the spacing of the crystal lattice changing due to the very cold temperatures. Different LEDs will show varying degrees of color shift, so try a few from different manufacturers.



The Stirling-cycle cryocooler with custom heatsink and acrylic dewar-mounting plate. The mounting plate has a rubber gasket that forms a seal with the neck of the dewar.

# Molecular Gastronomy

Thomas Scheckter

**M**olecular gastronomy is the logical result of merging food, physics and chemistry. While not the most common style of cooking, the results can be very impressive or disgustingly bland – or both. The problem is that it is all too often seen as some exclusive cult – limited to Michelin star fame. Fortunately this is not true for the amateur molecular gastronomer.

The more important obstacle is understanding what to do with food, something many chefs struggle with, using flashy food to compensate for lack of cooking skill. Looking at restaurants, it seems the three most common uses of molecular gastronomy are foams, “caviar” and sous-vide. Foams are used to create a light touch of a flavour for your food. Making foam can be done with



Chocolate ice cream with fresh Turkish coffee foam



Clockwise from top: Turkish coffee powder, sugar and soy lecithin

gelatine, however, an emulsifier can be simpler to use. Fortunately soy lecithin (non G.E. varieties are commonly available, cheaply, at health food stores) is a very useful emulsifier (something which keeps two things together), and perfect for foams. "Caviar" are small spheres, varying from the size of a pea to a walnut, surrounded by a gelatine like film with liquid inside; they are both a symbol of molecular gastronomy and already a cliché. Finally, sous-vide is a form of cooking food in a vacuum sealed bag in warm water for very long periods of time to preserve the flavours and constitution of food. Beginning with molecular gastronomy can be intimidating, and so to start, a foam is useful, simple and cheap, unlike "caviar" and sous-vide. Below is a recipe for Turkish coffee foam, a nice addition to many desserts, which can also be frozen for a light coffee sorbet.

#### **Ingredients:**

1 tablespoon Turkish coffee powder (less if you don't like strong coffee.)  
1 to 2 tablespoons sugar (more if you don't like bitter coffee.)  
1 teaspoon lecithin granules (easily available at health stores)  
175ml water  
80ml milk

#### **Method:**

You can either make Turkish coffee properly if you have a cezve or you can use a pot. Either way, you will need to sieve the coffee before use to remove the dregs.

To make Turkish coffee in a pot, simply put your coffee powder, sugar and half a cup of water in a pot, and while stirring, heat until the coffee starts to boil on medium to high heat.

Preparing soy lecithin can be difficult. Depending on what you use (there is lecithin for restaurants available that is easier to deal with) your lecithin may need some encouragement to dissolve into 50ml water, which can be done by placing it in a microwave on medium or low power for two minutes. If you do this, strain the excess lecithin that did not dissolve and keep the solution.

Mixing the milk, lecithin solution and coffee into a dish with a large surface area, and taking a stick blender so that the blade is half in the solution, and half in the air, blend on medium-low speed. Bubbles and foam will quickly form. An open dish is useful because good contact with air is necessary for foaming well.

Scoop off the foam and you are done. You should get a cup or two of foam, but there will be excess fluid, which you can drain off or blend to make more foam. The foam will last for a good half hour, but any longer may be pushing it. If you want you can freeze it for a light coffee sorbet.

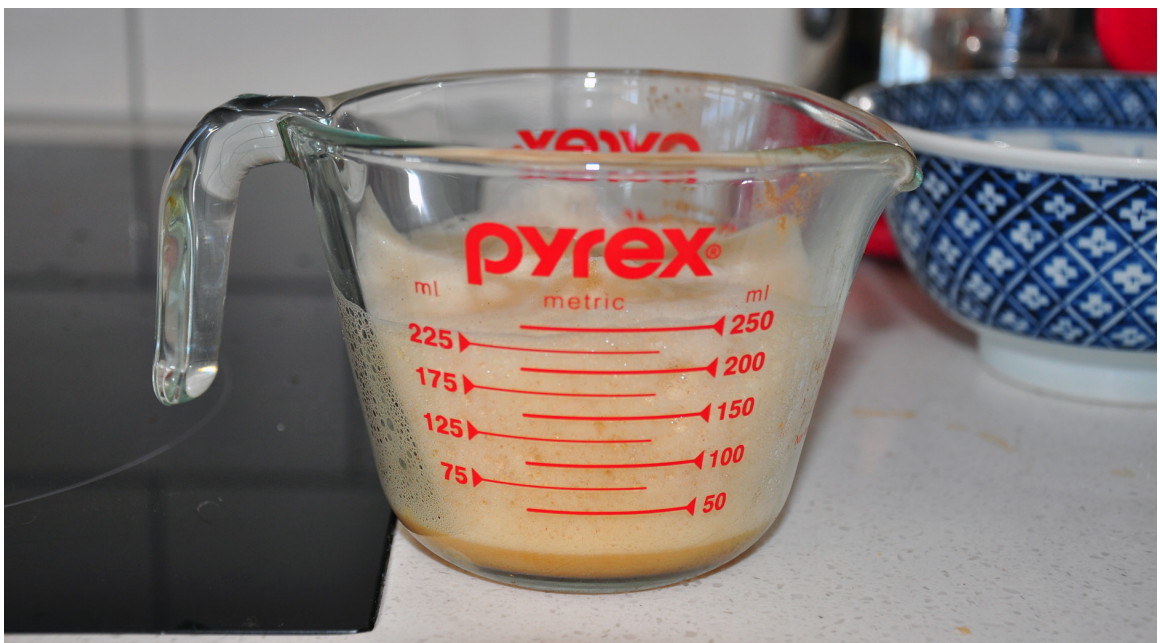
The trick is to get the right amount of lecithin, which binds the air bubbles to the coffee



Above: Boiling the coffee

by forming a thin sphere around the air bubbles, keeping the foam stable, rather than gelling in the bubbles, making the foam more solid, as with gelatine. Your mileage may vary and so it is important to experiment! Try some other drinks – cola and tea come to mind, but it is your experiment. Serve with ice cream or milkshakes for a little something extra. For more information, see [khyos.org](http://khyos.org) or watch some of Heston Blumenthal's television shows. Think about how you could use some of the techniques, and try them out. You'll be surprised.

Below: One cup of foam, ready for use





# A Review of DIYbio Suppliers

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For those of us doing molecular genetics in a home based lab there is a serious need to find sources of reagents, equipment and enzymes. Some smaller suppliers are amenable to sending chemicals/reagents and enzymes to home residences, while most of the larger suppliers (Fisher, NEB, Invitrogen, etc.) are not. Having had several years of experience in trying to source supplies necessary to build a functioning home-based lab I am covering here some of the suppliers I have found most useful in stocking a lab from home. As equipment (glassware, gel boxes, incubators, consumables such as pipette tips and petri dishes, etc.) are not too hard to find via ebay (or some of the sites listed in Table 1), I am focusing this short review on a few of companies from which one can obtain the reagents necessary for basic molecular genetics (cloning, sequencing, classical genetics). A few caveats to my review below; 1) this is not comprehensive since those suppliers I find useful might not be so for a lab with a different focus; 2) I am assuming one has some money to spend; 3) all of these companies are based in the US, as I am; I have no idea if they ship elsewhere or if the regulatory situation in a given country outside the US allows these

purchases. I make no attempt on my own to source most chemicals from common household products or to play DIY chemistry/alchemy, many of those who do have made some really useful contributions to the DIYbio google group and their efforts can be found there. A good, comprehensive summary of household/grocery/gardening products that can be used is found here: ([http://blog.makezine.com/science\\_room/general/setting\\_up\\_a\\_home\\_science\\_lab3/](http://blog.makezine.com/science_room/general/setting_up_a_home_science_lab3/)). I would especially recommend the boric acid buffers for agarose gels as a very cheap and effective alternative to TAE/TBE buffers for anyone with money constraints.



**Chemsavers, Inc.** ([www.chemsavers.com](http://www.chemsavers.com)) primarily offers high quality reagent grade chemicals. Thousands of chemicals in varying grades are available, what is in stock does vary over time so occasionally you may not find what you are looking for. They ship very quickly, usually 1-2 days from the time of order and accept PayPal or Visa. One can order chemicals that some consider potentially hazardous, but in these cases you will have to fill out an "Intended Use Form" stating that you are going to use the chemical in question for research purchases. This is sensible, since they only sell these in small quantities. There is not much one can do with 50 g of ammonium nitrate except use it in media or solutions a few grams at a time as it is intended for.

**Boston BioProducts, Inc.** ([www.bostonbioproducts.com](http://www.bostonbioproducts.com)) offers mainly pre-made buffers, reagents, DNA markers, and plasmid prep kits for molecular biology. They do not have an extensive collection of individual chemicals. It is a little expensive, but if there is a buffer for which you are missing an individual component and may not want to spring for the cost of buying a 50 g quantity of something when you simply need 100 mg for a stock that might last years, this is useful (agarose gel running buffer with bromphenol blue and xylene cyanol, for instance). They also sell some basic antibiotics such as ampicillin and kanamycin and x-gal and IPTG for blue/white selection in E. coli. Very fast delivery to residential addresses, 1-2 days again, credit cards. They usually offer some free samples of buffers and solutions and if you order enough they might start giving you a box of chocolates at Christmas or New Years.

**Sunrise Science Products, Inc.** ([www.sunrisescience.com](http://www.sunrisescience.com)) is geared towards yeast molecular genetics. A really good supplier for amino acids and supplements for defined media and a wide variety of pre-made stocks of media

and reagents used in yeast molecular genetics. Also tryptone, yeast extract, various sugar sources for making your own E. coli and S. cerevisiae media recipes. They also have a small selection of DNA/RNA prep kits. Their stuff is pretty expensive, and shipping is usually high; they accept credit cards and PayPal.

**Sibgene L.L.C.** ([www.sibgene.com](http://www.sibgene.com)) offers, among other things, PCR reagents, including Taq and dNTPs. Their Taq is comparable to that available at NEB or Promega at a significantly cheaper cost; a review of costs I posted a while ago to DIYbio google group has been posted at Openwetware (<http://openwetware.org/wiki/DIYbio/FAQ/Equipment>, search "Taq") and I routinely use their Taq. Quality dNTPs for PCR are quite hard to find, especially delivered to the home. I have not tried theirs specifically, but unless you have an academic source this would be a good bet. It's always nice to get a quick delivery of Taq under the doormat.

**ScienceLab.com** ([www.sciencelab.com](http://www.sciencelab.com)) At the other end of the spectrum, here is an example of what to watch out for when ordering online. They purport to offer chemicals and lab supplies but rarely deliver. I have twice ordered from them and both times been given a runaround about items being backordered. They do take your money very quickly though. When inquiring about the status of an order you will get a response as follows from [brande@science.lab.com](mailto:brande@science.lab.com): "We wanted to let you know the item you ordered is on back order with the manufacturer. Back-ordered products usually arrive within 2-3 weeks; however, many times we get the product in much earlier and in rare instances it may take longer. We assure you that once your product arrives to our warehouse we will expedite it to you." Do not ever expect this item to arrive or to get a refund. Just google "ScienceLab.com reviews" to get a hint at their problems or go to

(<http://sciencelabdotcom.blogspot.com>), a blog entirely devoted to this apparent scam. I got my credit card replaced after the second, and last, time I ordered just as a precaution.

**Restriction Enzymes** A glaring omission from the sites mentioned above and below is a discussion of how to get restriction enzymes delivered to residences. Sibgene, and a couple others, sell a small selection of DNA modification enzymes in addition to Taq for home delivery, but this is a limited selection. Most primary vendors such as NEB ([www.neb.com](http://www.neb.com)) and Invitrogen do not make home deliveries. I have gotten around this as I have, until recently, worked at a University

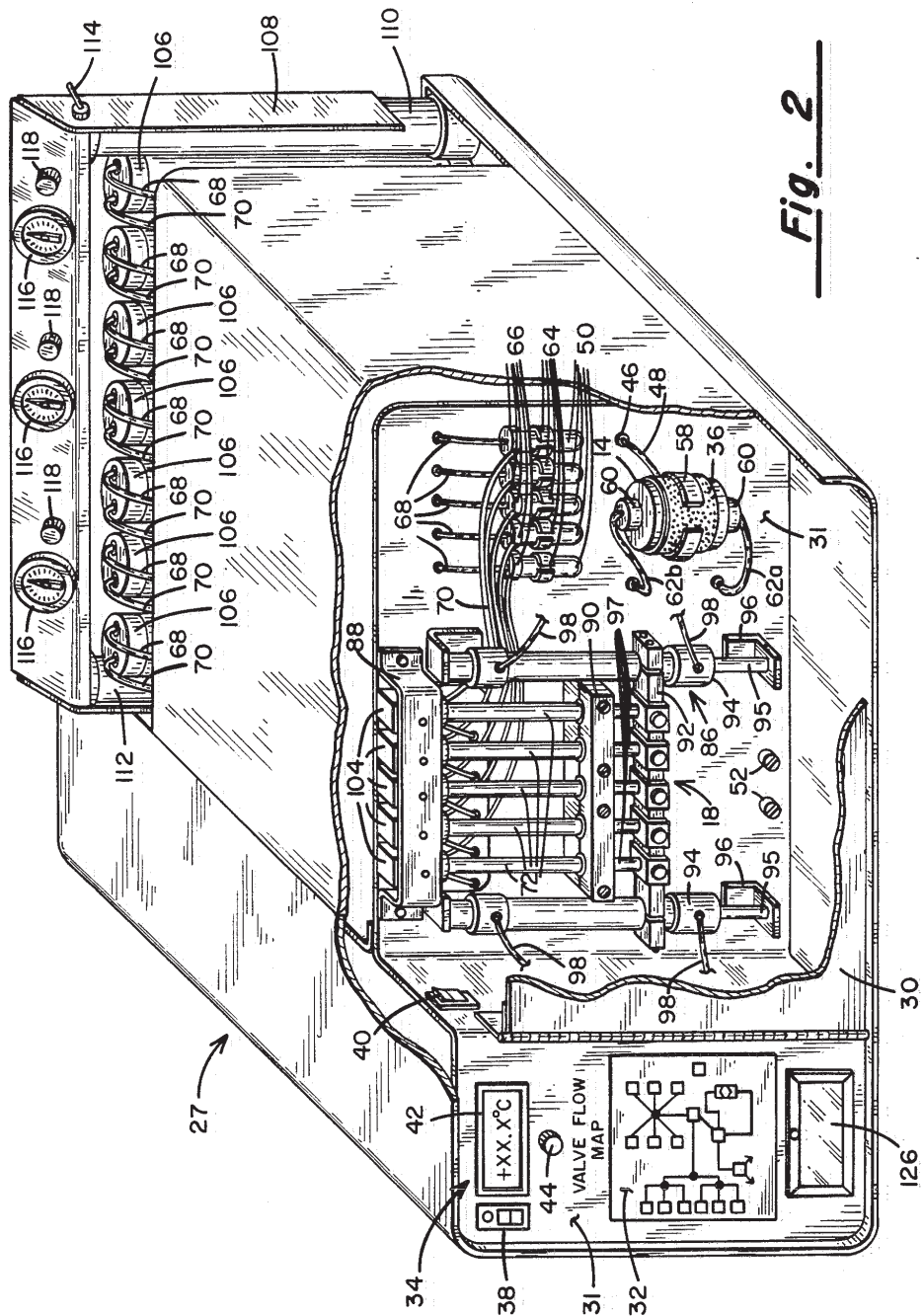
where even if you are in a building that has no wet labs, you can get delivery of enzymes from NEB without a University account and with at least a Business Visa (I have not tried a personal Visa). While NEB and Promega do this, Invitrogen is simply beyond hope. I would suspect that at least NEB would deliver to any place of business since they are probably keying on local zoning or ZIP codes for acceptable delivery addresses. I have not tried this, it would definitely be worth attempting. I have recently found that Promega ([www.promega.com](http://www.promega.com)) will deliver restriction enzymes to residential addresses, with a personal Visa. The shipping on this is quite high though, so order a lot at once if you try this.

## Other Companies that do Residential Delivery

Company	Website	Focus
Daigger	<a href="http://www.daigger.com">http://www.daigger.com</a>	Lab Equipment, Supplies
Cole Palmer	<a href="http://www.colepalmer.com">http://www.colepalmer.com</a>	Lab Equipment, Consumables
Scientific Equipment of Houston	<a href="http://www.agile-fx.com/servlet/storefront">http://www.agile-fx.com/servlet/storefront</a>	Lab Equipment
Carolina Biological Supply	<a href="http://www.carolina.com">http://www.carolina.com</a>	Consumables (Will not deliver chemicals to residences)
LabX	<a href="http://www.labx.com">http://www.labx.com</a>	Chemicals, Consumables, Equipment
Bel-Art	<a href="http://www.belart.com">http://www.belart.com</a>	Lab Equipment, Supplies
Reptile Supply Co.	<a href="https://www.reptilesupply.com/login.php">https://www.reptilesupply.com/login.php</a>	Incubators
Operon	<a href="http://www.operon.com">http://www.operon.com</a>	Primers
IDT	<a href="http://www.idt.com">http://www.idt.com</a>	Primers (Higher Shopping)

# Guess the Patent.

Send guesses to [guess@citizensciencequarterly.com](mailto:guess@citizensciencequarterly.com)  
Correct guesses will be entered in a drawing for a prize.



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